MINERALOGICAL MAGAZINE, JUNE 1976, VOL. 40, PP. 627–36

Genthelvite and the helvine group

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SUMMARY. A plot of seventy-five new analyses of members of the helvine group and fifty-seven analyses from the literature indicates complete miscibility between the Fe and Zn members (danalite and helvine) and between the Fe and Mn members (danalite and genthelvite). The new analyses include essentially pure helvine and genthelvite (for both of which X-ray data are presented) and the nearest approach to pure danalite (86 at. % Fe). Two new localities for genthelvite, the rarest member, are reported.

IN the helvine group, $R_4Be_3(SiO_4)_3S$ (R = Mn, Fe^{2+}, Zn), the member with Mn preponderant, helvine, is commoner than the Fe^{2+} member, danalite, and the Zn member, genthelvite, is by far the rarest; only twelve analyses of genthelvite were found in the literature (six being incomplete analyses), and the largest and finest crystals described had not been analysed.

A helvine-group mineral from Mt. St. Hilaire, Quebec, Canada, examined in 1973 was found to have a particularly small unit cell, suggesting that it might be zinc-rich; it has indeed proved to be genthelvite, a new occurrence. Moreover, X-ray and optical study of material from Rhode Island, discovered in abundance in 1964–8 and then assigned to danalite (but with an anomalously high density), indicated that it too might be zinc-rich; this too has proved to be a new genthelvite occurrence. This suggested a comprehensive study of the group.

Genthelvite was discovered in 1872 at Western Cheyenne Canyon, El Paso County, Colorado, and was analysed and described by Genth (1892) as a zinc-rich variety of danalite (Table I, no. 3). Glass *et al.* (1944) re-examined Genth's material; as it has zinc as the predominant cation they considered it deserved species status and named it in honour of Frederick A. Genth. A second genthelvite crystal from Colorado, then the largest known, was described, without analysis, by Glass and Adams (1953), and an exceptionally well-developed crystal from the same locality by Scott (1957). Eskova (1957) described an emerald-green genthelvite (all others are red, tan, yellow, or pale green) with a very high manganese content from the Lovozero alkali massif (Table I, no. 8). Further occurrences have been described by: von Knorring and Dyson (1959) in the Younger Granite of Jos, Nigeria (Table I, no. 7); Kingsbury (1961) from the Treburland mine, Altarnun, Cornwall (no. 12); Vasilev (1961) in a microcline-perthite pegmatite from an unnamed locality in the Kola peninsula (no. 11); Oftedal and Saebo (1963), from Låven (no. 4), Brevik (no. 2, yellow tetrahedra up to 2 mm), and Lågendalen (no. 1, colourless to light-green tetrahedra up to 10 mm), all in Norway; Gurvich *et. al.* (1963) in a silicified syenite from an unnamed Russian locality (no. 6, less than 1 mm); Galetskii (1966) with cassiterite in a granite, also from an unnamed Russian locality (no. 5); Bollingberg and Petersen (1967) from the Ilímaussaq alkaline intrusions in Greenland (no. 9); and Morgan (1967) with bertrandite at Coire-an-Lochain, Cairngorm Mtns., Scotland.

Although danalite and helvine occur in a wide variety of rock types, but most frequently in tactites and skarns, genthelvite is usually found in granite pegmatites and syenite pegmatites. The Colorado occurrences were in miarolitic cavities in granite pegmatites, and the Rhode Island occurrences in quartz veins in a granite.

TABLE I. *Prior analyses of genthelvite (in order of decreasing* ZnO)

	1	2	3	4	5	6	7	8	9	10	11	12
ZnO	53·44	46·3	46·20	43·6	42·4	41·3	40·56	40·00	38·0	37·0	33·54	25·9
FeO	< 1·0	2·5	6·81	2·5	5·7	n.d.	11·73	6·70	1·2	9·9	13·71	19·8
MnO	1·0	5·1	1·22	7·66	2·5	n.d.	1·72	10·21	0·6	5·8	5·21	4·4

1. Lågendalen, Norway; Oftedal and Saebo, 1963.
2. Brevik, Norway; Oftedal and Saebo, 1963.
3. El Paso Co., Colorado; Genth, 1892; BeO 12·70, SiO_2 30·26, S 5·49, Others 0·51, Total 100·45; agrees well with new anal. 4.
4. Låven, Norway; Oftedal and Saebo, 1963.
5. U.S.S.R.; Galetskii, 1966; BeO 13·4, Others 0·09.
6. U.S.S.R.; Gurvich *et al.*, 1963; BeO 11·9.
7. Jos, Nigeria; von Knorring and Dyson, 1959; BeO 12·39, SiO_2 30·70, S 5·50, Others 0·18, Total 100·04; agrees well with new anal. 22.
8. Lovozero massif, U.S.S.R.; Eskova, 1957; BeO 12·00, SiO_2 27·35, S 5·74, Total 99·13.
9. Ilímaussaq, Greenland; Bollingberg and Petersen, 1967; SiO_2 40·00, BeO 15·0, Total 94·8 (S n.d.).
10. Cairngorm, Scotland; Morgan, 1967; BeO 14·2, SiO_2 30·80, S 5·1, Total 100·2.
11. Kola Peninsula, U.S.S.R.; Vasilev, 1961; BeO 11·71, SiO_2 32·08, S 5·49, Others 0·84, Total 99·84.
12. Treburland, Cornwall; Kingsbury, 1961.

Helvine-group minerals were among the last to form in most of the observed matrix specimens. Late crystallization is indicated by the very common association of fluorite and the frequency with which members of the group occur as discrete euhedra in vugs and as vein fillings in quartz.

The twenty-five genthelvite samples employed for the twenty-five new analyses (Table II) were obtained from the National Museum of Natural History and the Harvard Museum, and for many only scanty details are available.

Three specimens were from Mt. St. Hilaire: NMNH 127205 (Table II, anal. 2), collected by Mr. Quintin Wight in 1970 in a section of the De-Mix quarry that is in contact with the Desourdy quarry. The genthelvite is in small colourless, transparent tristetrahedra, about 1 mm in size, rounded due to stepped growth on {111}, and is associated with wurtzite crystals, also about 1 mm, and with 8-cm analcime and 5-cm astrophyllite crystals; from discussions with mineral collectors it appears that this association has not been found elsewhere in the quarry. NMNH R17909 (anal. 1) and NMNH 128397 (anal. 3), collected in the De-Mix quarry in 1973, have hopper-shaped buff-brown genthelvite tetrahedra scattered on a matrix of acmite and serandite. No epitaxial growth was observed. The exact contents of the pockets from which the specimens were collected are not known, but genthelvite of this type is frequently

TABLE II. *New analyses of genthelvite, with specific gravities and refractive indices.*

Anal.	Sample	ZnO	FeO	MnO	CaO	BeO*	SiO_2	S	Total	Sp.gr.	n_D
Theoretical		54·54	—	—	—	12·58	30·19	5·37	100·00	3·66	1·740
1	R17909	54·53	0·00	0·66	0·10	12·58	29·65	5·61	100·33	3·66	1·741
2	127205	54·43	0·00	0·95	0·08	12·58	29·66	5·61	100·51	3·66	1·743
3	128397	52·30	0·03	2·11	0·08	12·62	29·98	5·53	99·89	3·63	1·745
4	127180	47·06	6·14	1·53	0·05	12·69	29·78	5·65	100·29	3·66	1·746
5	113108	43·83	10·06	0·11	0·08	12·75	29·51	5·57	99·13	3·64	1·745
6	C-5936	33·24	13·76	6·84	0·05	12·92	30·55	5·54	100·13	3·51	1·750
7	82284	43·57	11·62	1·08	0·08	12·75	29·97	5·63	101·89	3·50	1·749
8	82284	31·39	17·48	6·06	0·08	12·94	30·55	5·67	101·34	3·50	1·750
9	H33991	32·51	17·73	3·84	0·07	12·92	30·60	5·74	100·54	3·49	1·750
10	H87365	31·29	22·60	0·64	0·08	12·95	30·49	5·58	100·84	3·50	1·750
11	93468	30·88	17·77	4·64	0·08	12·95	29·73	5·49	98·85†	3·51	1·748
12	H33981	26·55	20·76	5·40	0·07	13·02	29·90	5·61	98·51	3·45	1·752
13	H108172	42·65	9·94	1·80	0·08	12·77	29·38	5·57	99·41	3·37	1·747
14	119443	42·57	9·76	1·75	0·10	12·78	30·70	5·66	100·49	3·59	1·749
15	119443	42·50	10·33	1·78	0·07	12·78	30·27	5·74	100·57	3·59	1·752
16	119443	41·44	10·79	1·93	0·10	12·79	29·97	5·64	99·84	3·59	1·750
17	119443	42·17	10·29	1·82	0·09	12·78	30·31	5·68	100·30	3·59	1·750
18	121718	41·09	11·11	2·34	0·07	12·79	30·18	5·77	100·47	3·57	1·748
19	C-6676	34·18	10·05	10·00	0·10	12·90	30·22	5·72	100·31	3·57	1·748
20	H108232	27·92	22·16	2·34	0·04	13·00	30·41	5·60	98·69‡	3·50	1·753
21	127871	31·43	17·20	5·03	0·11	12·94	29·86	5·63	99·45§	3·48	1·752
22	113673	41·73	10·90	1·85	0·08	12·78	30·05	5·69	100·24	3·59	1·745
23	132974	25·42	17·53	9·96	0·08	13·04	31·17	5·59	100·09‖	—	1·744
24	106748	26·23	19·62	7·67	0·05	13·03	29·58	5·71	99·04	3·59	1·752
25	133023	31·84	19·05	1·91	0·08	12·94	29·68	5·55	98·28	—	—

1, 2, and 3: Mt. St. Hilaire, Quebec, Canada.
4: Western Cheyenne Canyon, Colorado (chips from the holotype specimen).
5 and 6: Cookstove Mtn., El Paso Co., Colorado.
7 to 12: Rockport, Massachusetts.
13 to 20: Cumberland, Rhode Island (details see text).
21: Staples Road, Cumberland, Rhode Island.
22: Jos, Nigeria.
23: Moat Mtn., North Conway, New Hampshire.
24: El Paso Co., Colorado.
25: Ukraine, U.S.S.R.

* Calculated (see text).
‡ Incl. Al_2O_3 0·02.
‖ Incl. Al_2O_3 0·09.
† Incl. Al_2O_3 0·05.
§ Incl. Al_2O_3 0·06.
Anal. 17 is the mean of 14, 15, 16.
All totals less O ≡ s,

found at Mt. St. Hilaire as multi-twinned crystals implanted on serandite and associated with polylithionite, natrolite, and fluorite.

Another four specimens came from the new occurrences in Rhode Island: NMNH 127871 (anal. 21) was found in a granite S. of Staples Road in Cumberland, and is associated with fluorite and quartz. NMNH 119443 (anals. 14, 15, 16, and 17), NMNH 121718 (anal. 18) and NMNH C-6676 (anal. 19) are all from 1200 ft south of the intersection of Routes 114 and 121 in Cumberland; they were collected in the 1960s from a granite that may be related to the Quincy granite; NMNH 119443 is representative of the bulk of the Rhode Island genthelvite, consisting of rough euhedral rock-locked tetrahedra in a quartz matrix, associated with fluorite, quartz, acmite, and metamict zircon. The Rhode Island genthelvite and danalite are often found coated with a black platy mineral that resembles ilmenite but is metamict, probably due to the associated zircon (which is often found with danalite and genthelvite at other localities).

NMNH 127180 (anal. 4) consists of small chips from the holotype genthelvite, no. 367.3 in the Genth collection at the University of Pennsylvania; Genth noted that it is associated with quartz and astrophyllite, but did not record the rock type. The present analysis of the holotype material is in good agreement with Genth's.

NMNH C 5936 (anal. 6) and 113108 (anal. 5) are both from Cookstove Mountain, El Paso County, Colorado; no further details are available for the former specimen, but the latter was described fully by Scott (1957). NMNH 106748 (anal. 24), also from El Paso County, was described by Glass and Adams (1953), and was the largest proven genthelvite prior to the identification of the Rhode Island material.

Danalite was orginally found at Rockport, Massachusetts (Cooke, 1866), and the holotype specimen, Harvard Museum no. H-85384, was kindly loaned for this study by Professor Frondel (Table III, anal. 34). The nineteen danalite analyses, made on seventeen specimens, also include specimens from two new localities, both in the Conway Granite, North Conway, New Hampshire: NMNH 132975 (anal. 32) from Moat Mountain, collected by Mr. Ernest Schlicter, and NMNH 128470 (anal. 33) from Government Pits, collected by Mr. Don Wyman and Mr. Leo Vaught. Decayed and corroded fragments of danalite are common at these localities, but good crystals are rarely found; the largest known is 1·5 cm in maximum dimension.

A zoned specimen (Harvard H-33976) from Iron mine, Bartlett, New Hampshire, described by Glass *et al.* (1944) consists of a core of bright-yellow helvine (Table IV, anal. 51) overgrown with red danalite (Table III, anals. 26 and 27).

The pure *helvine* (NMNH R11124; Table IV, anal. 45) from the East Moulton mine, Butte, Montana, occurs as discrete anhedral blebs in massive rhodonite, which also contains pyrite euhedra. Paragenesis at the Lexington mine, also in Butte, is similar. The helvine from Governador Valadares, Brazil, occurs as discrete euhedra in gem quality tourmalinated quartz.

Chemistry. The seventy-five new analyses (Tables II, III, and IV) were made with an ARL-EMX electron microprobe operated at 20 kV, with a sample current of 0·15 μA and beam diameter 15 μm. All data were corrected for background, fluorescence, absorption, and backscatter using the ABFAN computer program of the Geophysical Laboratory, Washington, with the Probe I program of the Smithsonian Institution. The standards used were: Springwater olivine for Mg, Fe, and Si; pyrite for S; anorthite, An_{80}, for Al; spessartine for Mn; and an analysed hornblende for Ca and Na.

As beryllium could not be determined on the probe, a percentage was calculated, assuming the ideal ratio (Mn, Fe^{2+}, Zn, Ca, Mg) : Be : : 4 : 3.

Zoning parallel to {111} and {1$\bar{1}$1} was common in the danalites studied, but much less so in the helvines and genthelvites. In many danalites, the chemical zoning is accompanied by colour zoning, manganese-rich sections being yellow and zinc-rich ones colourless, but other factors may effect a colour change; thus the Rhode Island genthelvite no. 119443 has a thin light-pink outer zone (anal. 16), a dark-red middle

TABLE III. *New analyses of danalite, with specific gravities and refractive indices*

Anal.	Sample	ZnO	FeO	MnO	CaO	BeO*	SiO_2	S	Total	Sp.gr.	n_D
Theoretical		—	51·44	—	—	13·43	32·25	5·74	100·00	—	—
26	H33975	0·89	44·27	7·37	0·07	13·42	30·76	5·41	99·49	—	1·755
27	H33976	0·48	41·70	9·05	0·12	13·43	30·51	5·70	98·19‡	—	1·755
28	H33976	2·40	30·67	18·46	0·21	13·42	30·33	5·32	98·33§	—	1·754
29	†	4·40	35·52	13·10	0·07	13·38	30·94	5·69	100·29‖	3·31	1·755
30	114868	3·84	35·32	13·30	0·11	13·39	31·66	5·75	100·57¶	3·32	1·756
31	126986	17·04	33·55	1·99	0·05	13·16	30·74	5·91	99·49	3·35	1·755
32	132975	8·49	32·86	11·12	0·07	13·31	30·92	5·72	99·65**	3·29	1·751
33	128470	9·68	32·07	10·65	0·04	13·29	30·71	5·54	99·23**	3·33	1·754
34	H85384	15·39	32·44	5·10	0·05	13·19	30·72	5·65	99·72	3·42	1·754
35	H105223	15·10	32·03	4·97	0·05	13·20	31·09	5·68	99·28	3·44	1·755
36	H85383	20·35	27·31	5·46	0·09	13·11	30·58	5·78	99·81**	3·35	1·754
37	R3399–1	25·44	24·88	4·84	0·07	13·04	30·33	5·63	101·42	3·45	1·755
38	H95105	21·14	24·37	6·95	0·08	13·11	30·60	5·65	99·08	3·37	1·750
39	C2684	22·68	24·40	3·69	0·07	13·08	30·65	5·74	97·44	3·45	1·754
40	H87365	23·93	21·59	7·32	0·07	13·07	30·48	5·71	99·32	3·45	1·754
41	H107088	1·52	30·69	22·23	0·12	13·43	30·64	5·72	101·65††	3·27	1·750
42	H34011	20·64	27·96	4·59	0·08	13·12	30·23	5·70	99·51‡‡	—	1·755
43	H104577	23·70	22·28	7·39	0·09	13·07	29·81	5·67	99·18	3·46	1·754
44	H100833	24·24	21·81	7·53	0·08	13·06	30·12	5·74	99·71	3·42	1·751

26 to 28: Iron mine, Bartlett, New Hampshire; the core of this specimen is helvine, Table IV, anal. 51.
29 and 30: Yxsjoberg, Sweden.
31: Cumberland, Rhode Island.
32: Moat Mtn., North Conway, New Hampshire.
33: Government Pits, North Conway, New Hampshire.
34 to 40: Rockport, Massachusetts.
41: Dixon, New Mexico.
42: Gloucester, Massachusetts.
43: St. Peter's Dome, El Paso Co., Colorado.
44: Cookstove Mtn., El Paso Co., Colorado.

* Calculated (see text).
† Unnumbered specimen from a private collection.
‡ Incl. Al_2O_3 0·05.
§ Incl. MgO 0·10, Al_2O_3 0·08.
‖ Incl. Al_2O_3 0·03
¶ Incl. Al_2O_3 0·06.
** Incl. Al_2O_3 0·02.
†† Incl. MgO 0·06. Al_2O_3 0·10.
‡‡ Incl. Al_2O_3 0·04.
All totals less O ≡ s.

zone (anal. 14), and an orange-red inner zone (anal. 15), but there is no significant difference in composition and the colour zoning remains unexplained.

Much of the Rockport danalite is strongly zoned, with alternating zinc-rich and iron-rich zones averaging 100 μm in thickness; the zones vary, on the average, by about 20 % of the iron component, and the outer zones are frequently zinc-rich. One particularly large (6 cm) genthelvite crystal from Rockport (NMNH 82284) has a

TABLE IV. *New analyses of helvine, with specific gravities and refractive indices*

Anal.	Sample	ZnO	FeO	MnO	CaO	BeO*	SiO_2	Al_2O_3	S	Total	Sp. gr.	n_D
Theoretical		—	—	51·12	—	13·52	32·46	—	5·78	100·00	3·20	1·728
45	R11124	0·55	0·18	52·48	—	13·52	31·06	0·30	5·51	100·85	3·20	1·736
46	R11125	0·38	0·21	52·50	0·17	13·51	31·29	0·33	5·65	101·22	—	1·735
47	127337	0·55	0·96	51·70	0·08	13·52	31·79	0·09	5·84	101·61	2·99	1·735
48	H93700	0·44	0·21	51·46	0·47	13·52	32·24	0·66	5·45	101·73	3·19	1·734
49	106012	0·24	1·46	47·67	0·60	13·51	31·90	0·71	5·17	98·68	—	1·730
50	106626	3·41	2·25	46·47	0·64	13·46	31·65	0·33	5·56	100·99	—	—
51	H33976	3·11	5·52	44·65	0·14	13·43	30·49	0·19	5·46	100·26	—	1·736
52	94081	2·12	4·26	43·08	2·00	13·46	31·60	1·34	5·41	100·57	3·19	1·730
53	R10668	2·51	3·57	42·98	2·81	13·46	31·32	1·37	5·11	100·57	3·20	1·730
54	83200	2·31	4·47	42·24	3·06	13·46	31·04	1·26	5·18	100·43	3·18	1·732
55	C2682–2	2·27	4·24	42·20	2·34	13·46	31·61	1·56	5·15	100·26	3·20	1·728
56	45634	2·89	4·55	42·17	2·24	13·45	30·86	1·26	5·06	99·95	3·00	1·731
57	13291–1	2·27	3·37	42·04	2·88	13·46	32·55	1·83	5·09	100·84	—	1·727
58	C2682–1	3·09	6·34	40·73	2·60	13·44	30·68	1·12	5·41	100·71	3·20	1·734
59	R3400	6·57	6·10	39·86	0·29	13·38	31·29	0·48	5·19	100·57	3·21	1·739
60	123702	2·34	3·44	42·83	2·64	13·46	31·68	1·61	5·19	100·60	3·02	1·727
61	R3395	2·80	4·44	42·68	2·62	13·45	31·59	1·40	5·16	101·56	—	1·730
62	127181	1·69	8·40	42·13	0·11	13·47	30·62	0·33	5·68	99·61†	3·24	1·735
63	133022	3·41	4·28	41·33	2·67	13·44	30·35	1·54	5·18	99·61	—	1·732
64	122806	5·32	7·48	38·33	0·15	13·40	32·05	0·81	5·19	100·14	—	1·737
65	R3394	8·51	7·49	37·66	0·05	13·34	30·83	0·20	5·64	100·90	3·31	1·744
66	H85358	12·77	6·78	34·33	0·11	13·27	30·21	0·05	5·54	100·29	3·35	1·742
67	128417	8·69	8·55	35·68	0·38	13·34	30·19	0·89	5·60	100·70‡	3·30	1·744
68	128417	9·45	8·02	35·49	0·09	13·33	29·96	0·31	5·61	99·61§	3·30	1·745
69	128417	7·98	10·58	34·08	0·20	13·35	30·03	0·32	5·56	99·44‖	3·30	1·747
70	128417	7·29	16·78	28·79	0·13	13·36	29·63	0·20	5·62	99·14§	3·30	1·747
71	106514	5·75	17·80	31·92	0·05	13·36	29·98	0·20	5·27	101·70	3·31	1·744
72	106514	7·13	15·47	31·52	0·05	13·35	29·62	0·18	5·38	100·01	3·31	1·746
73	H107087	6·24	18·66	28·10	0·07	13·37	30·89	0·07	5·77	100·29	3·36	1·746
74	128206	4·13	24·00	24·97	0·05	13·40	30·56	0·10	5·73	100·08	3·32	1·750
75	H87436	16·09	13·25	24·34	0·07	13·21	29·62	0·03	5·91	99·57	3·36	—

45: East Moulton mine, Butte, Montana.
46: Lexington mine, Butte, Montana.
47: Mt. St. Hilaire, Quebec.
48: Kapnik, Romania.
49: Governador Valadares, Brazil.
50: Grandview mine, Grant Co., New Mexico.
51: Iron mine, Bartlett, New Hampshire; the outer zone of this specimen is danalite, anals. 26 and 27, Table III.
52 to 59: Schwarzemberg, Germany.
60 and 61: Breitenbrunn, Germany.
62: Oashi mine, Tochigi Prefecture, Japan.
63: Långban, Sweden.
64: Moscow mine, Milford, Utah.
65: Låven, Langesund, Norway.
66: Langesund, Norway.
67 to 70: Hörtekollen, Lier, Modum, Norway.
71 to 73: Iron Mtn., New Mexico.
74: Mt. Francisco, Australia.
75: Pitkaranta, Finland.

* Calculated (see text).
† Incl. MgO 0·02.
‡ Incl. MgO 0·18.
§ Incl. MgO 0·15.
‖ Incl. MgO 0·12. All totals are less O ≡ S.

variation of 12·18 % ZnO from the inner zones to the more zinc-rich outer zones (Table II, anals. 7 and 8).

An extreme example is the Bartlett specimen H-33967 mentioned above, the yellow helvine interior having 44·65 % MnO, 5·52 % FeO, and the red danalite exterior 7·37 % MnO and 44·27 % FeO—the nearest approach to the end-member so far known.

Observations of compositional variation indicate that, in most cases where all three components are present in zoned crystals, the order of deposition is Mn–Fe–Zn.

While zoning is frequent, many localities, including Rockport, Cookstove Mountain, and Rhode Island, have produced unzoned crystals of both danalite and genthelvite; and Mt. St. Hilaire has only produced comparatively pure genthelvite and helvine.

Miscibility in the helvine group. The data compiled by Glass *et al.* (1944) and by Vlasov (1964) suggest an almost complete miscibility between helvine and danalite, but the limits of solid solution between these members and genthelvite were not well established. A plot of the present analyses together with those from the literature is presented in fig. 1. It is obvious that there is complete miscibility between the Mn and Fe members, and between the Zn and Fe members; the absence of a series of Mn–Zn mixtures is not explained, though a large number of helvines were analysed.

Cations other than Mn, Fe^{2+}, and Zn are uncommon: Fischer (1926) reported a helvine with 2·24 % MgO, but no other member of the group with appreciable MgO was encountered in this study or traced in the literature. Substitution by Al is also limited to helvine, with a maximum of 1·83 % Al_2O_3 in NMNH 13291–1, from Schwarzemberg, Germany. The most calcium-rich member is also from Schwarzemberg, NMNH 83200 with 3·06 % CaO, and no appreciable CaO was found in any other member of the group except helvines from Långban and Breitenbrunn.

Physical properties. The helvine group are all tetrahedral, $P\bar{4}3n$, and euhedral crystals have been found at most localities, the most common forms being, in decreasing order of frequency, {111}, {1$\bar{1}$1}, {112}, {011}, {001}, and {122}; there is no cleavage, but a possible weak {111} and {1$\bar{1}$1} parting, perhaps due to compositional discontinuities.

While essentially pure genthelvite is colourless to light green, most genthelvites are light yellow to beige if Mn > Fe and medium to dark red if Fe > Mn; most genthelvite is deeply coloured and transparent only in thin section.

Pure helvine is yellow, and danalite is red to reddish brown, as are most members having substantial amounts of all three cations.

No response to ultraviolet radiation was observed except in the Mt. St. Hilaire genthelvite: the colourless crystals, NMNH 127205, fluoresce bright green in both long-wave and short-wave U.V.; the beige crystals, NMNH R17909, fluoresce bright green on the outside edges in both long-wave and short-wave, but their centres, which are richest in Mn, fluoresce yellowish orange in long-wave and green in short-wave. No phosphorescence was observed.

The relation between composition, specific gravity, and refractive index found by Glass *et al.* (1944) has been confirmed, except for the specific gravity calculated for pure genthelvite (3·70); careful determinations, by flotation and by Berman balance on the pure Mt. St. Hilaire material (NMNH 127205), gave 3·66. Pure helvine (NMNH R11124) has sp. gr. 3·20, but slightly lower values may be obtained for Ca-rich specimens.

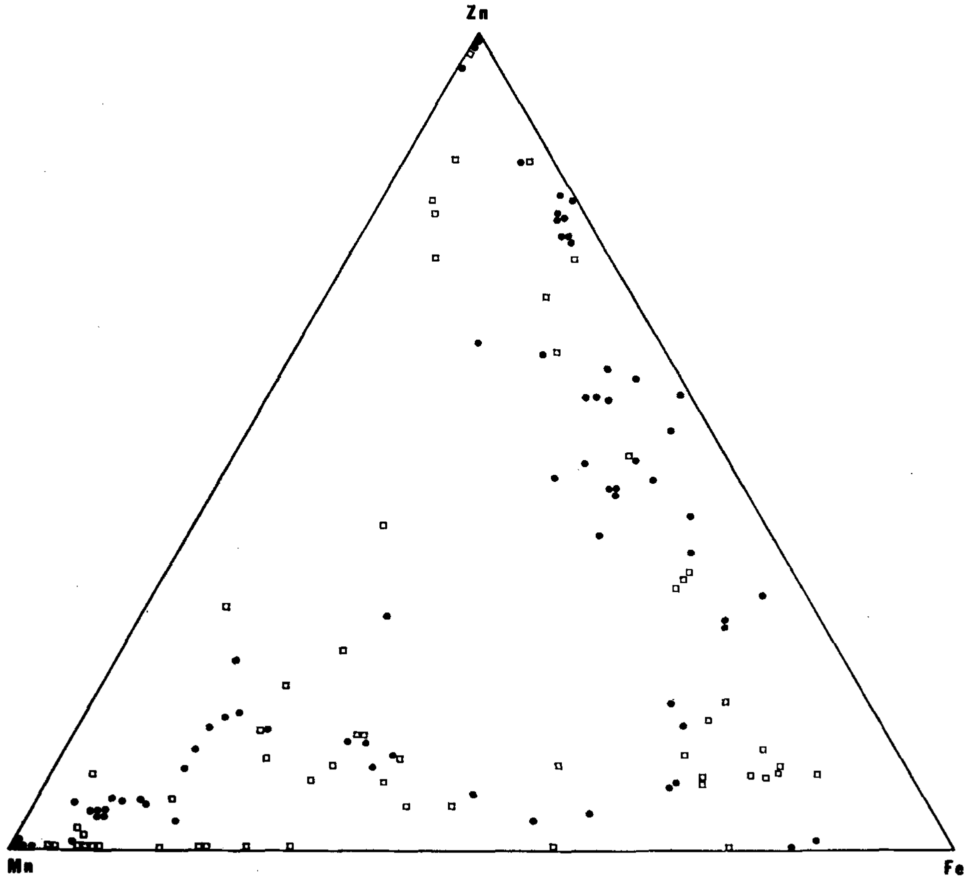

FIG. 1. Plot of Zn, Mn, Fe for analyses of the helvine group. □ from the literature; ● from this study.

The extrapolated refractive indices, 1·728 for helvine and 1·740 for genthelvite, were confirmed on the pure specimens.

Refractive indices and specific gravities for all the analysed specimens are included in Tables II, III, and IV.

X-ray data were obtained for the pure helvine and genthelvite on a Gandolfi powder camera, radius 114·59 mm, with Cu-$K\alpha$ radiation, and refined unit-cell sizes determined using the program of Appleman *et al.* (1972) (Tables V and VI). The variation in cell-size reflects the difference in ionic radii, $Mn^{2+} > Fe^{2+} > Zn^{2+}$ (Holloway and Giordano, 1972).

TABLE V. *X-ray powder data for genthelvite from Mt. St. Hilaire, Quebec*

I	d_{obs}	d_{calc}	hkl	I	d_{obs}	d_{calc}	hkl
5	5·700 Å	5·742 Å	110	50	1·435 Å	1·435 Å	440
30	4·040	4·060	200	50	1·393	1·393	530
40	3·626	3·631	210	50	1·354	1·353	442
100	3·320	3·315	211	50	1·318	1·317	611
20	2·876	2·871	220	5	1·285	1·284	620
65	2·567	2·568	310	50	1·253	1·253	541
1	2·424	2·448	311	3	1·222	1·224	622
10	2·344	2·344	222	3	1·212	1·210	542
8	2·251	2·252	320	3	1·200	1·197	631
70	2·168	2·170	321	3	1·175	1·172	444
10	2·032	2·030	400	5	1·150	1·148	550
80	1·916	1·914	330	50	1·103	1·105	721
40	1·815	1·816	420	5	1·070	1·066	730
8	1·770	1·772	421	50	1·030	1·031	651
5	1·732	1·731	332	40	0·9986	0·9995	554
65	1·657	1·657	422	8	0·9840	0·9847	820
40	1·592	1·592	510	8	0·9760	0·9776	821
4	1·507	1·508	520	8	0·9680	0·9706	653
50	1·483	1·483	521	8	0·9550	0·9570	660

Plus *c.* 20 lines to 0·7785.

TABLE VI. *X-ray powder data for helvine from Butte, Montana*

I	d_{obs}	d_{calc}	hkl	I	d_{obs}	d_{calc}	hkl
5	5·965 Å	5·864 Å	110	50	1·466 Å	1·466 Å	440
30	4·156	4·147	200	50	1·422	1·421	530
40	3·724	3·709	210	50	1·382	1·382	442
100	3·382	3·386	211	50	1·350	1·345	611
20	2·935	2·932	220	5	1·312	1·311	620
65	2·618	2·622	310	50	1·279	1·280	541
1	2·502	2·500	311	3	1·251	1·250	622
10	2·400	2·394	222	3	1·236	1·236	542
8	2·299	2·300	320	3	1·219	1·222	631
70	2·215	2·216	321	3	1·193	1·197	444
10	2·072	2·073	400	5	1·172	1·172	550
80	1·955	1·955	330	50	1·126	1·128	721
40	1·854	1·854	420	5	1·085	1·089	730
8	1·809	1·809	421	50	1·052	1·053	651
5	1·770	1·768	332	40	1·021	1·021	554
65	1·692	1·693	422	8	1·005	1·006	820
40	1·627	1·626	510	8	0·9960	0·9984	821
4	1·539	1·540	520	8	0·9911	0·9912	653
50	1·510	1·514	521	8	0·9754	0.9774	660

Plus *c.* 20 lines to 0·7767.

Unit cell measurements on a large number of the specimens analysed verify that there is a direct correlation between cell-edge and composition, though, as noted by Oftedal and Saebo (1963), it is not linear. Helvine-group minerals with a cell edge greater than 8·23 Å may safely be assigned to helvine, and those with a cell edge less than 8·14 Å to genthelvite; members with cell edges between 8·14 and 8·23 Å are usually iron-rich, but cannot be assigned to one of the three species without additional data.

Acknowledgements. The author is indebted to many persons for assistance: Miss Annette Pealey translated Eskova's paper from the Russian. Mr. Grover Moreland and Mr. Richard Johnson assisted in the preparation of samples for microprobe analysis. Dr. Dean K. Smith kindly lent some of the holotype genthelvite from the Genth collection at Pennsylvania State University. Mr. Richard Kelley generously donated the Mt. St. Hilaire helvine, and Mr. Quintin Wight supplied the pure genthelvite from Mt. St. Hilaire. Dr. Clifford Frondel permitted the author to examine and analyse the helvine group minerals in the Harvard Museum. Mr. Donald G. Wyman and Mr. Ernest Schlicter donated the specimens from North Conway. Mr. Bill Pinch kindly allowed four specimens from the Pinch Mineralogical Museum to be analysed.

The author is especially indebted to Dr. C. Wroe Wolfe, Dr. Daniel Appleman, Mr. Paul E. Desautels, and Mr. John S. White, Jr., for critical review and helpful suggestions during the course of this study, and to Dr. M. H. Hey for adjustments to the manuscript.

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[*Manuscript received 16 December 1974, revised 23 December 1975*]