

Hibonite-spinel-corundum-hematite assemblage in plagioclase-clinopyroxene pyrometamorphic rock, Hatrurim Basin, Israel: chemical composition, genesis and temperature estimation

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Supplementary data

Supplementary data

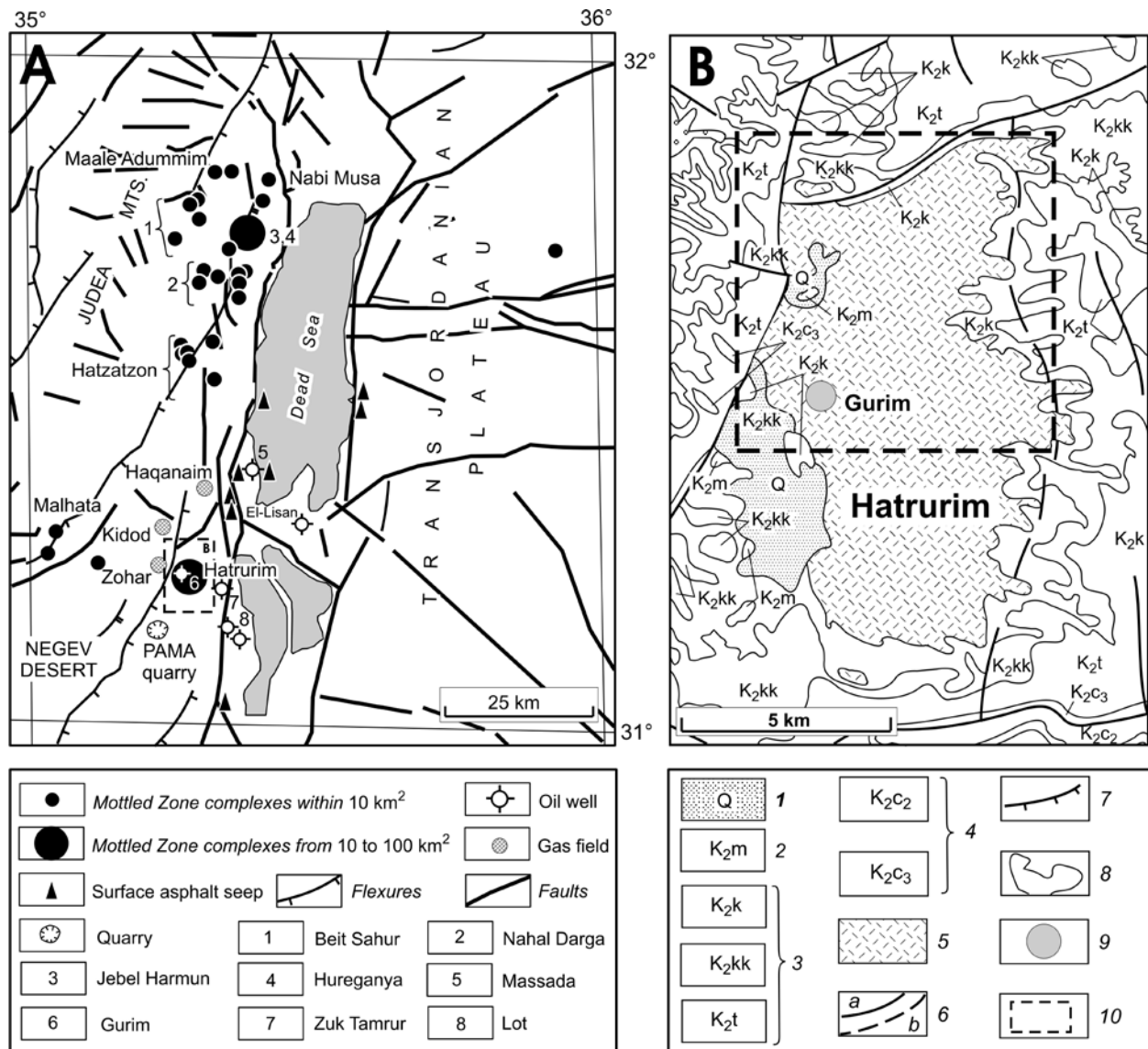


Fig. S1 A-B.

A. Generalized geology of the Dead Sea Transform area with locations of the Mottled Zone complexes, gas fields, asphalt shows, and oil wells, after (Nissenbaum and Goldberg, 1980; Gardosh et al., 1996, 2008; Hall et al., 2005; Sokol et al., 2010, 2014).

B. Generalized geological map of Hatrurim Basin. Geology simplified after the 1:200,000 Geological Map of Israel (Bentor et al., 1965; Picard and Golani, 1965; Shen et al., 1998), after (Hall et al., 2005), as well as after (Burg et al., 1991; 1999; Sokol et al., 2007, 2010).

1 – Pleistocene sand, carbonate, and clay marine sediments (Q);

2 – Maastrichtian organic-rich marine chalk (K₂m);

3 – Campanian (K₂k), Santonian (K₂kk), and Turonian (K₂t) limestone, chalk, and dolomite with chert and phosphorite intercalations;

4 – Cenomanian (K₂c₃, K₂c₂) limestone, dolomite, and chalk;

5 – Hatrurim Formation rocks;

6 – observed (a) and inferred (b) faults;

7 – folds;

8 – stratigraphic boundaries;

9 – Gurim anticline;

10 – fragment of map, shown in Fig. S1 C.

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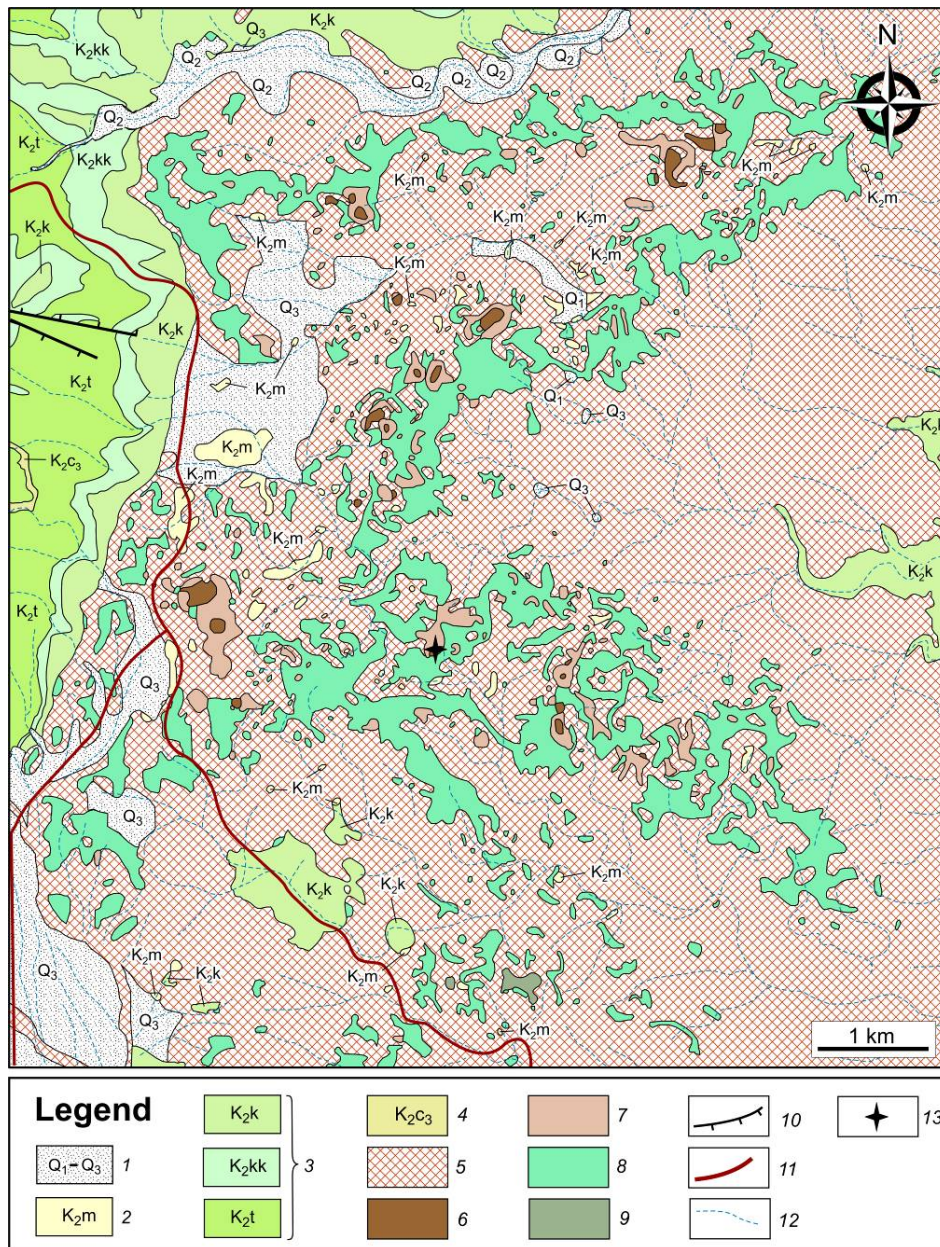


Fig. S1 C. Geological map of NW part of Hatrurim Basin, modified after the 1:50,000 Geological Map of Israel (Hirsch et al., 2010).

- 1 – Pleistocene terrace conglomerates (Q_1 , Q_2 , Q_3);
- 2 – Maastrichtian organic-rich marine chalk (K_2m);
- 3 – Campanian (K_2k), Santonian (K_2kk), and Turonian (K_2t) limestone, chalk, and dolomite with chert and phosphorite intercalations;
- 4 – Cenomanian (K_2C_3) limestone, dolomite, and chalk;
- 5 – Low-grade Hatrurim Formation rocks;
- 6 – Larnite rocks (High-grade Hatrurim Formation rocks);
- 7 – the “Olive rocks” (Hatrurim Formation);
- 8 – Spurrite marbles (Medium-grade Hatrurim Formation rocks);
- 9 – Pseudoconglomerates;
- 10 – Faults;
- 11 – Road;
- 12 – Wadi;
- 13 – Sampling site.

Hirsch, F., Burg, A., Avni, Y. (Eds.), 2010. Geological Map of Israel. Scale 1:50,000. Geol. Surv. Isr., Jerusalem, Arad sheet 15–IV.

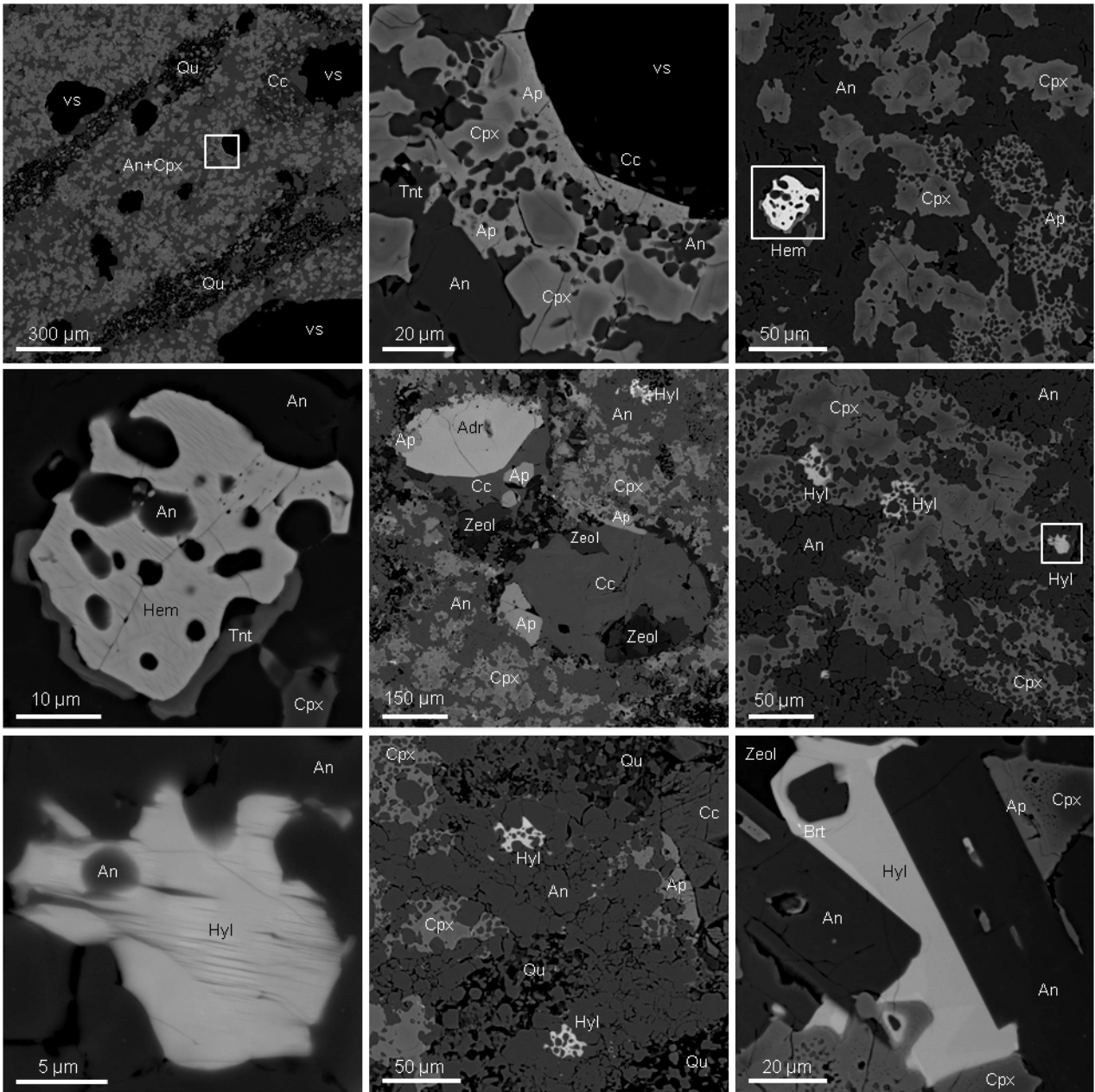


Fig. S2. Mineral association in plagioclase-clinopyroxene rock, Haturim Basin, BSE images.

Symbols: An – anorthite; Cpx – clinopyroxene; Qu – SiO₂ polymorph; Ap – fluorapatite; Tnt – titanite; Hem – hematite; Adr – Ti-andradite; Cc – calcite; Zeol – zeolite-superfgroup minerals; Hyl – “hyalophane”; Brt – baryte; vs – vesicle.

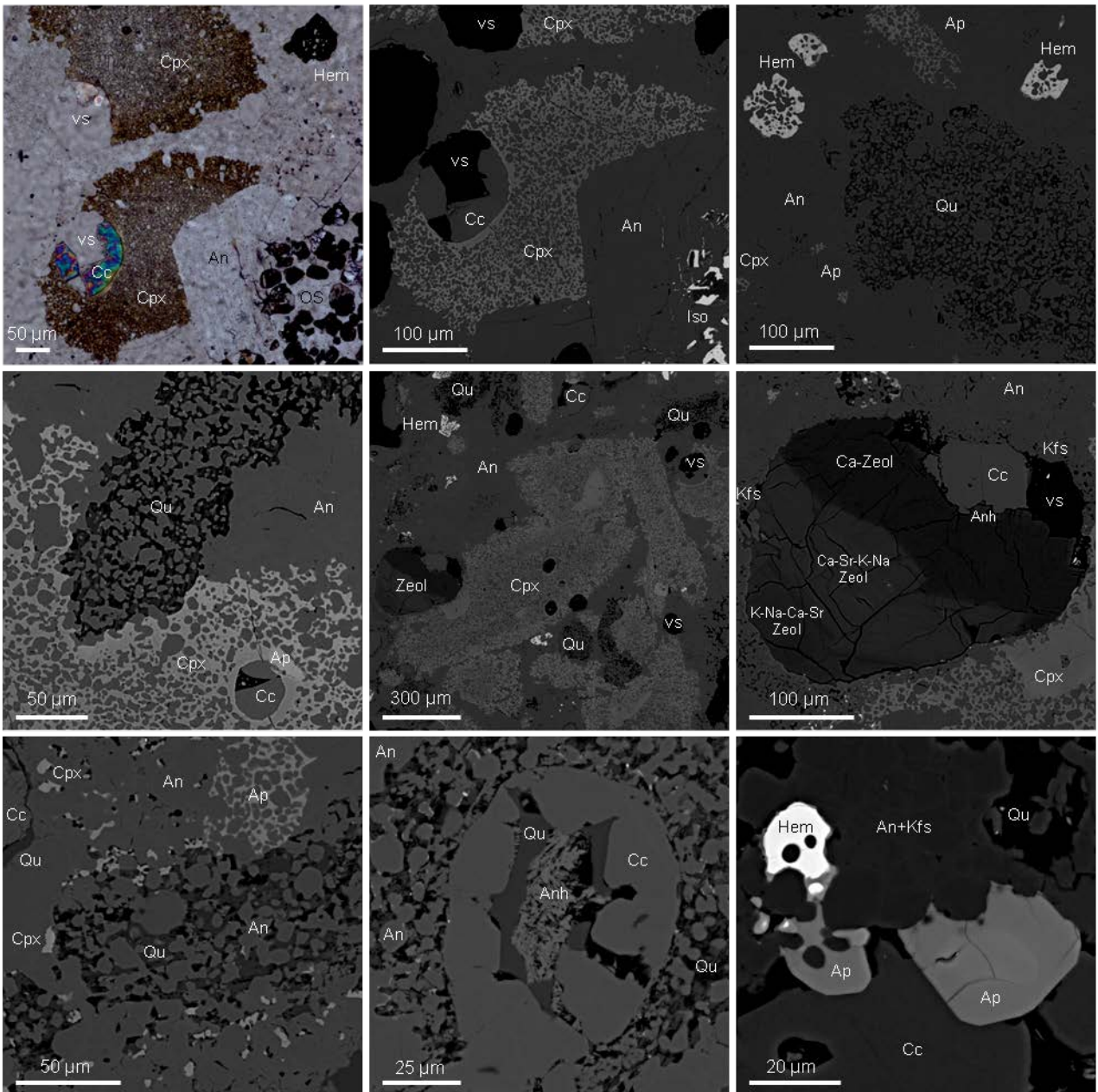


Fig. S3. Mineral relations in leucocratic zone of plagioclase-clinopyroxene rock, Hatrurim Basin, BSE images and photo in polarized light.

Symbols: An – anorthite; Hem – hematite; Cc – calcite; vs – vesicle; OS – opaque corundum-bearing segregation; Cpx – clinopyroxene; Ap – fluorapatite; Qu – SiO₂ polymorph; Zeol – zeolite-super group minerals; Kfs – K-feldspar; Anh – bassanite-anhydride.

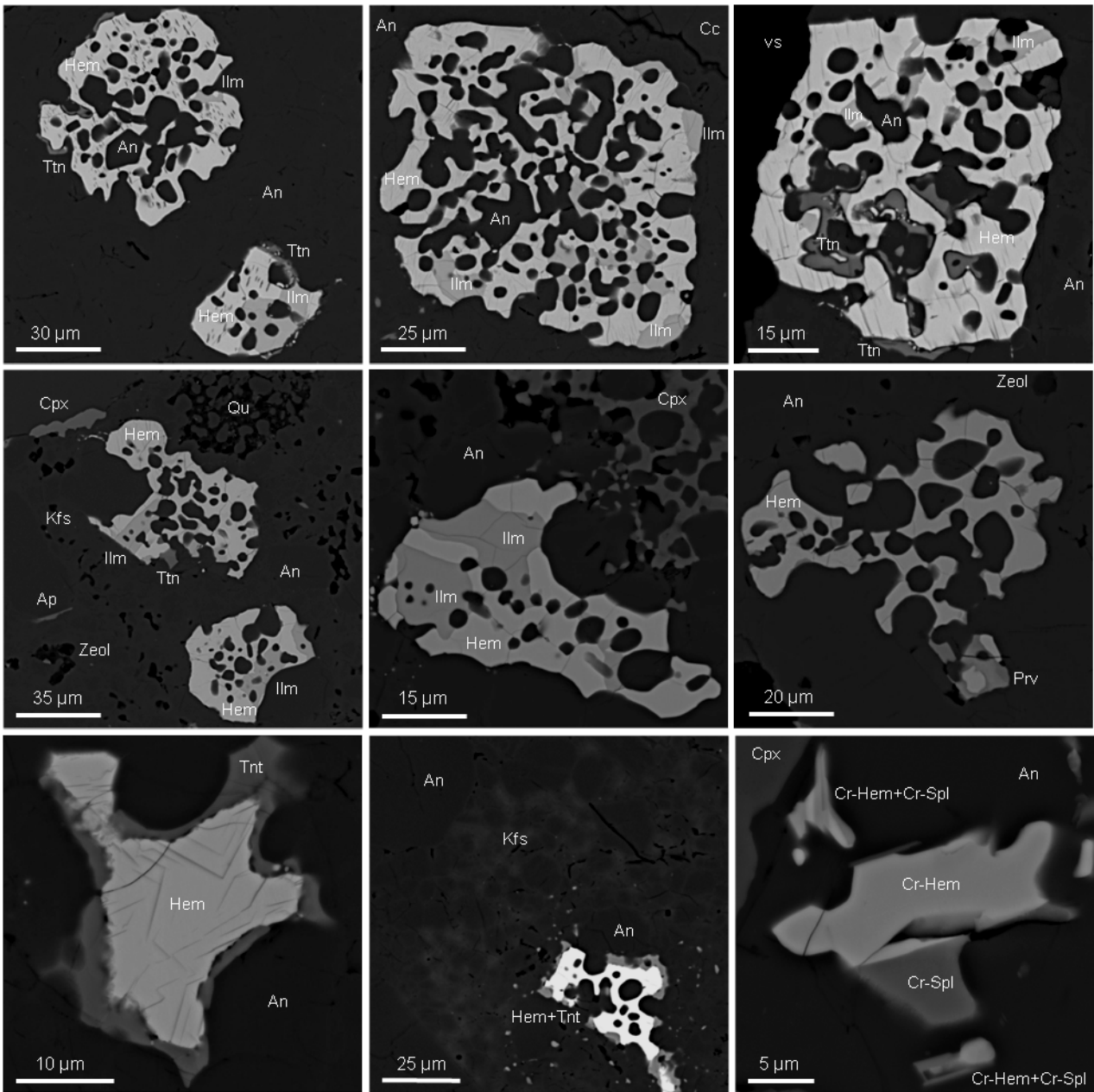
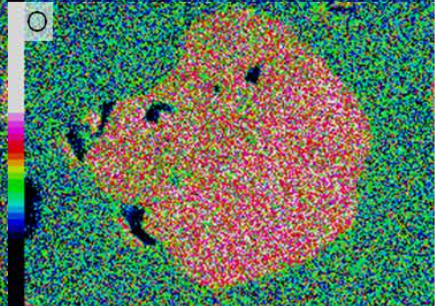
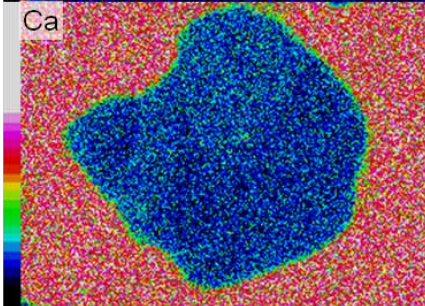
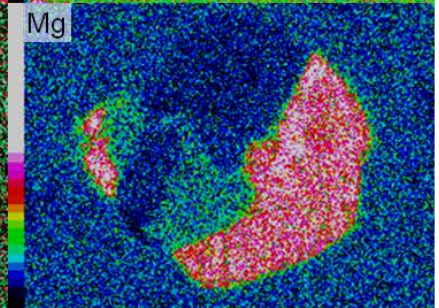
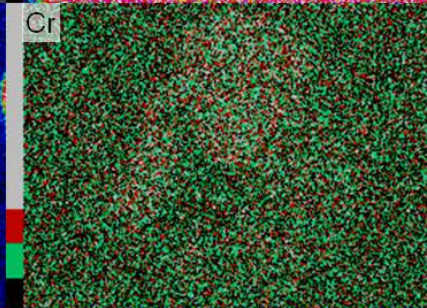
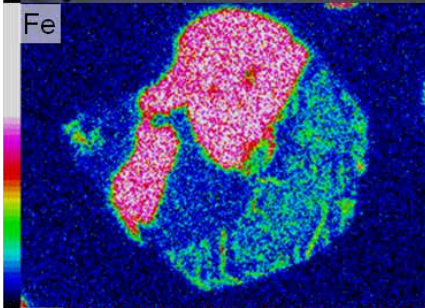
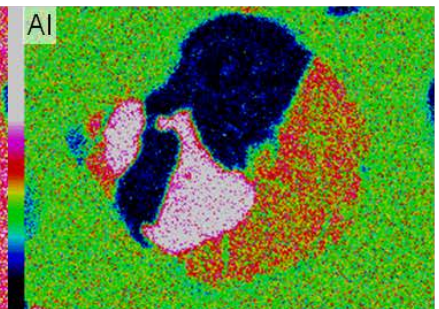
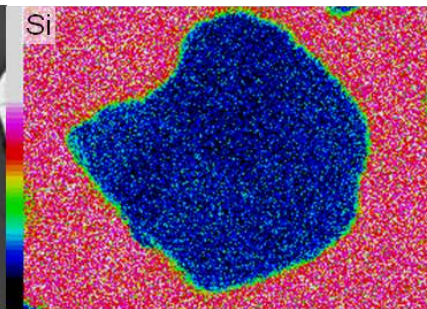
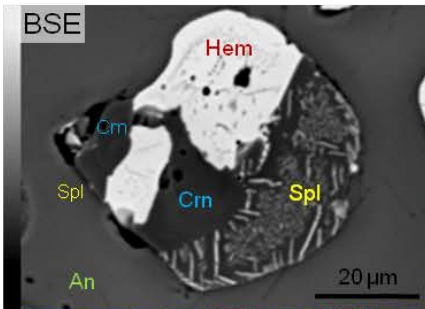
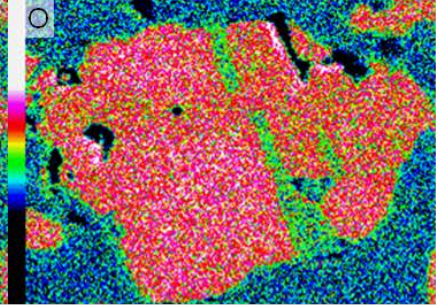
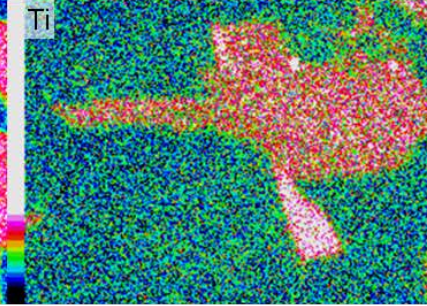
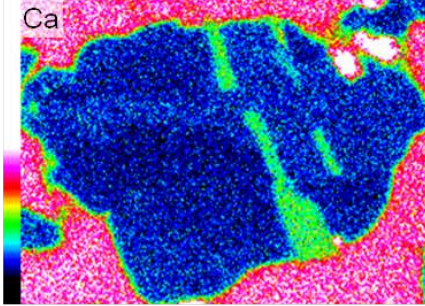
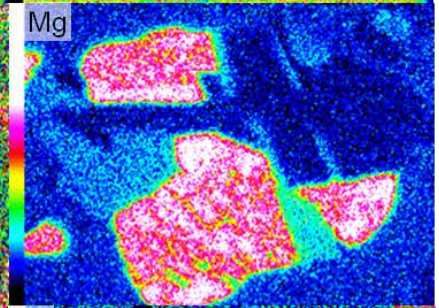
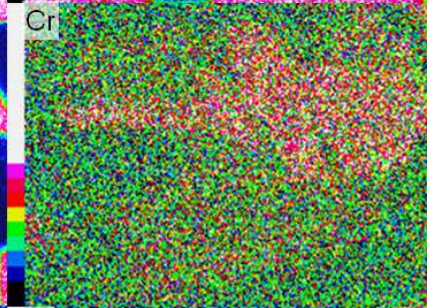
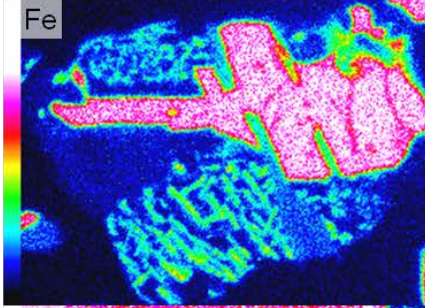
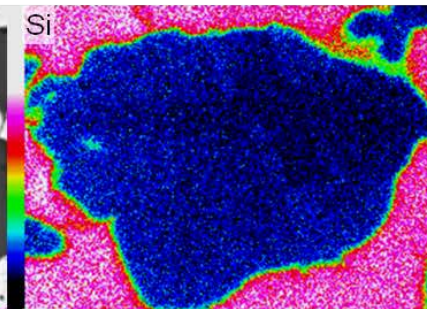
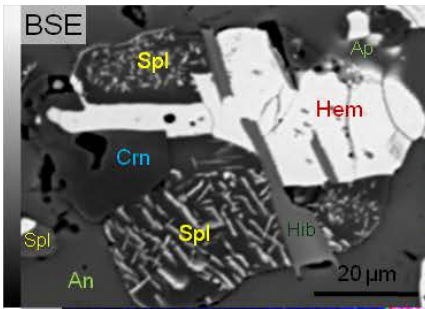
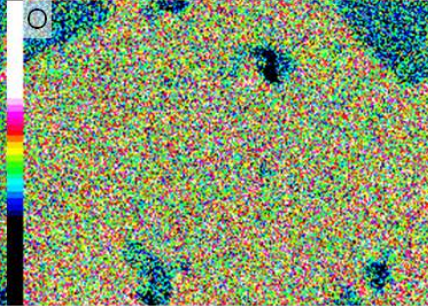
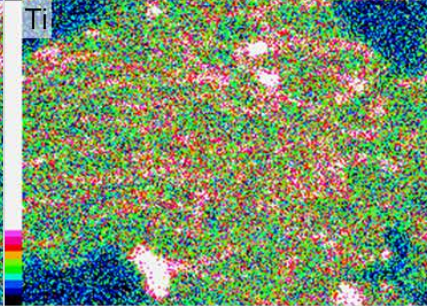
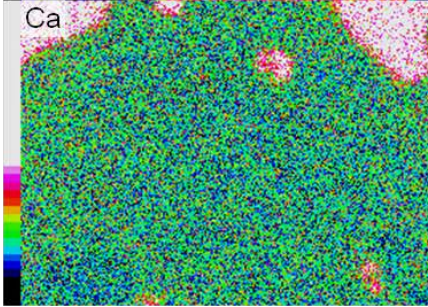
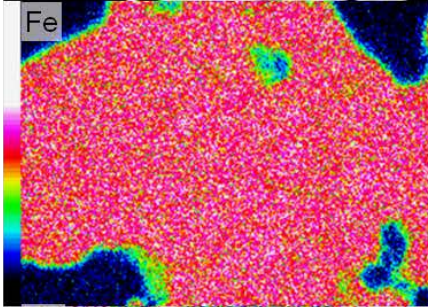
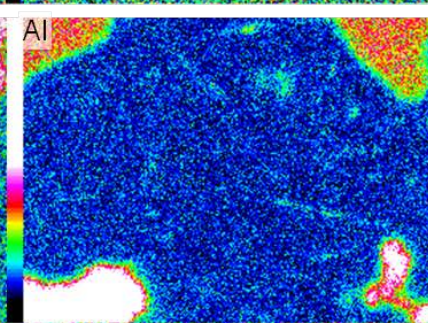
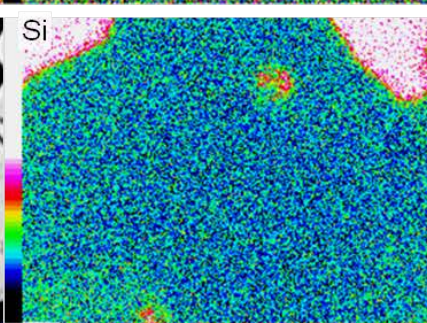
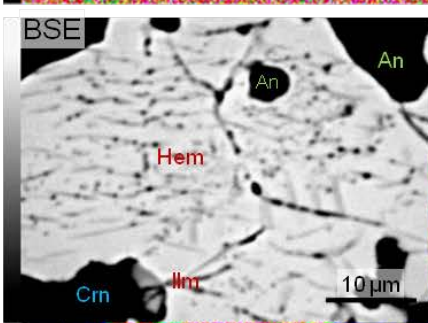
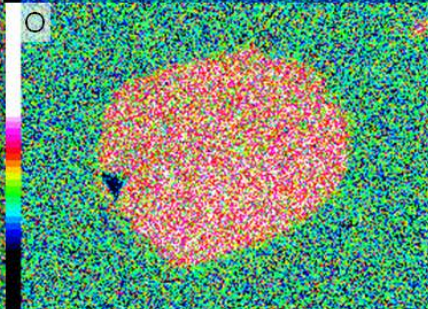
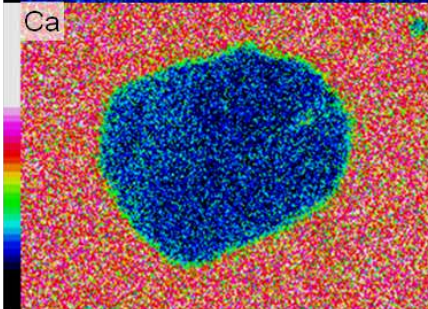
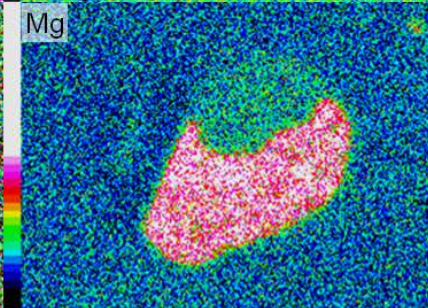
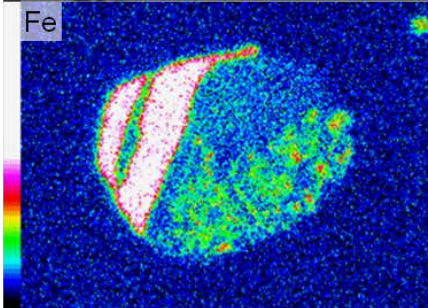
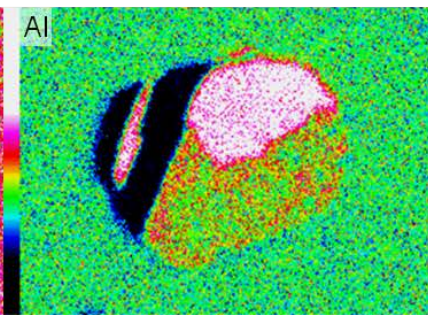
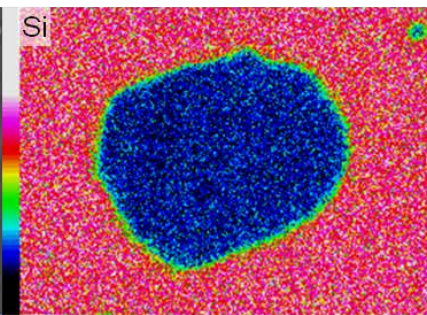
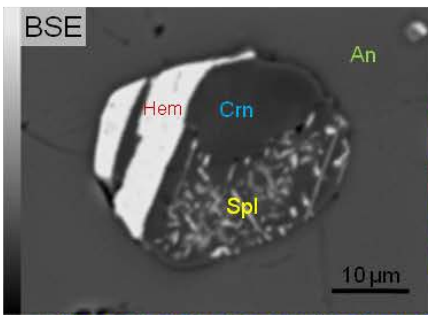
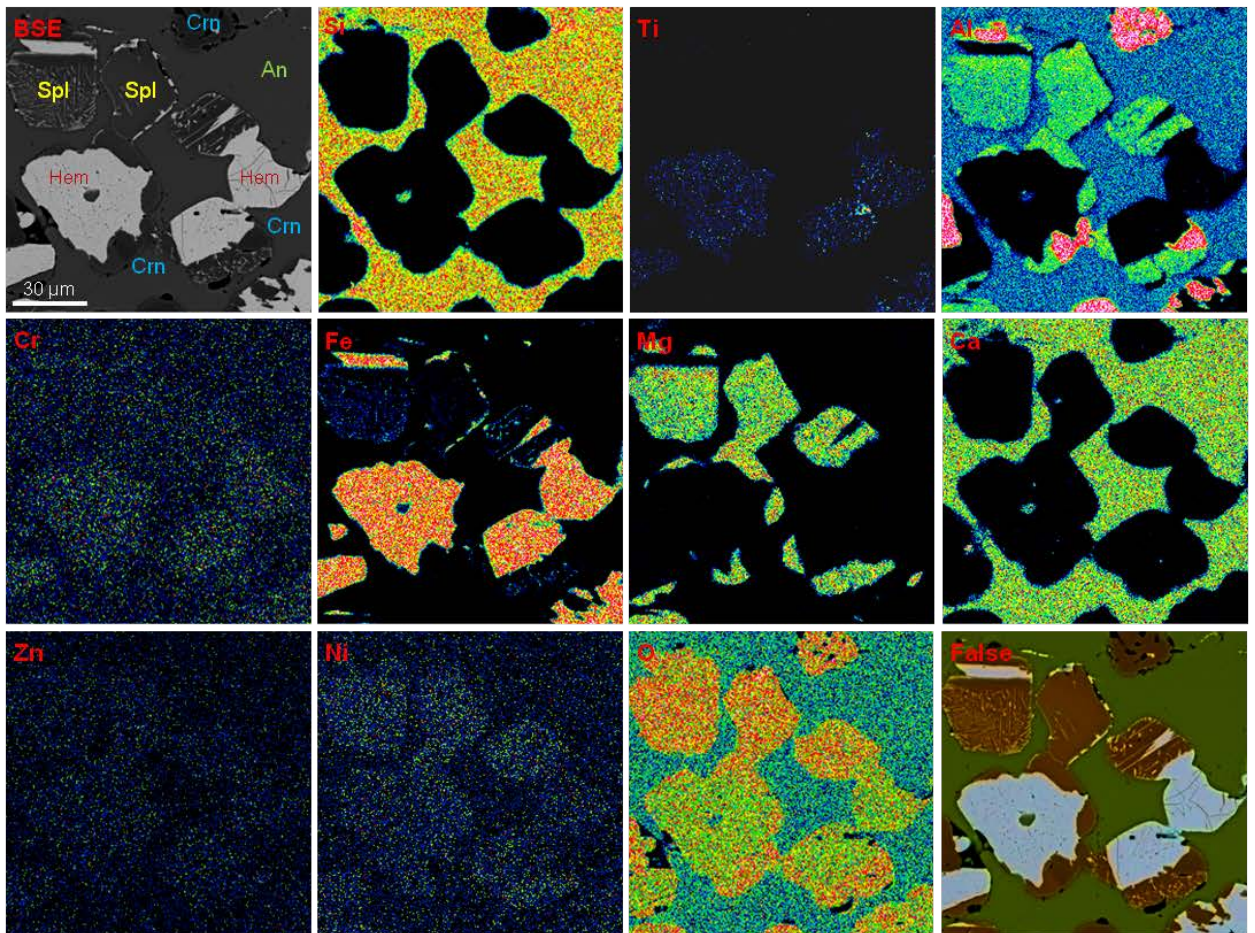
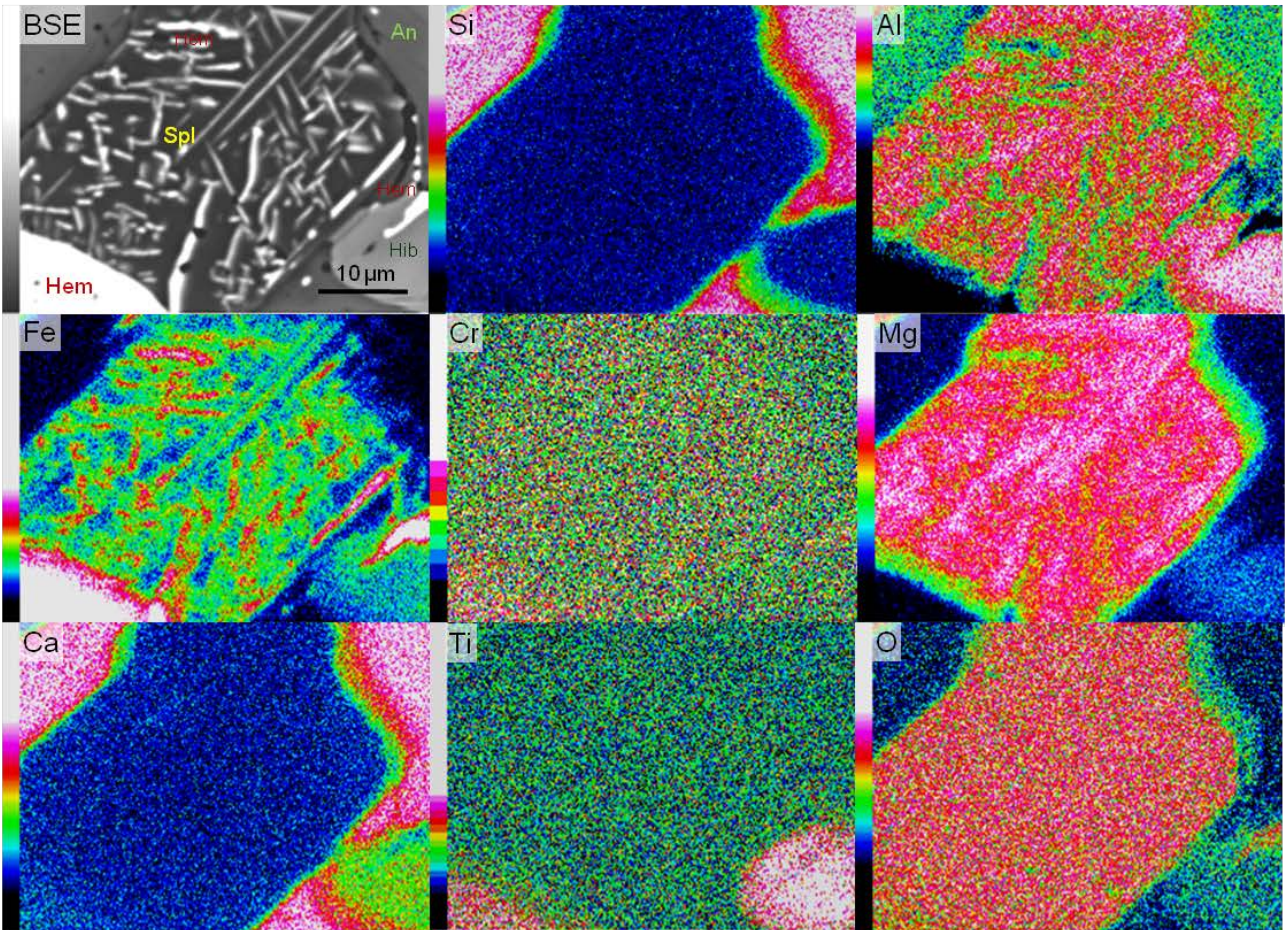


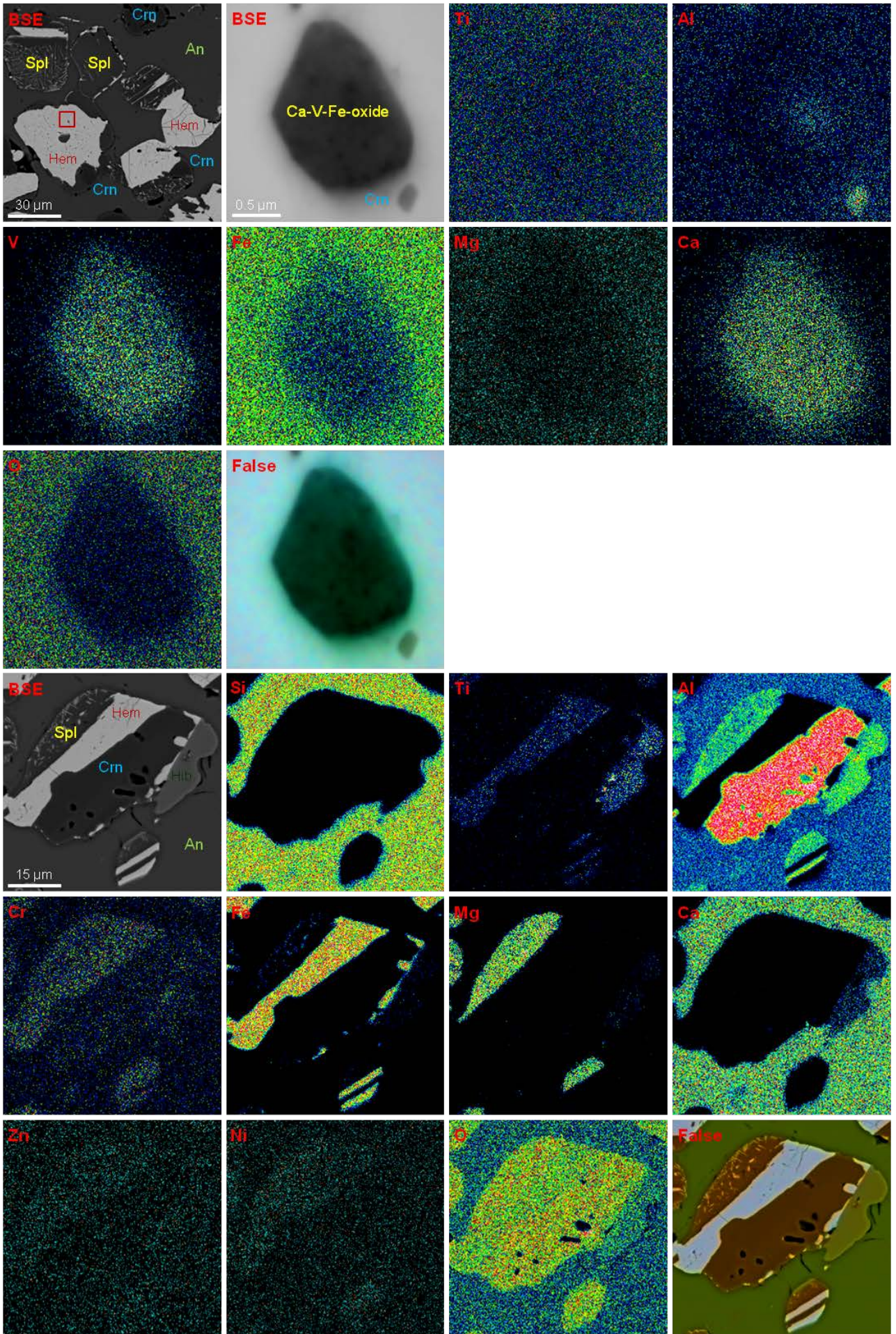
Fig. S4. Opaque minerals in leucocratic zone of plagioclase-clinopyroxene rock, Hatrurim Basin, BSE images.

Symbols: An – anorthite; Hem – hematite; Ilm – hemoilmenite; Tnt – titanite; Cc – calcite; vs – vesicle; Cpx – clinopyroxene; Ap – fluorapatite; Qu – SiO₂ polymorph; Zeol – a zeolite-supergruop mineral; Kfs – K-feldspar; Prv – perovskite; Cr-Hem-Cr-Spl – Cr-rich hematite and spinel.









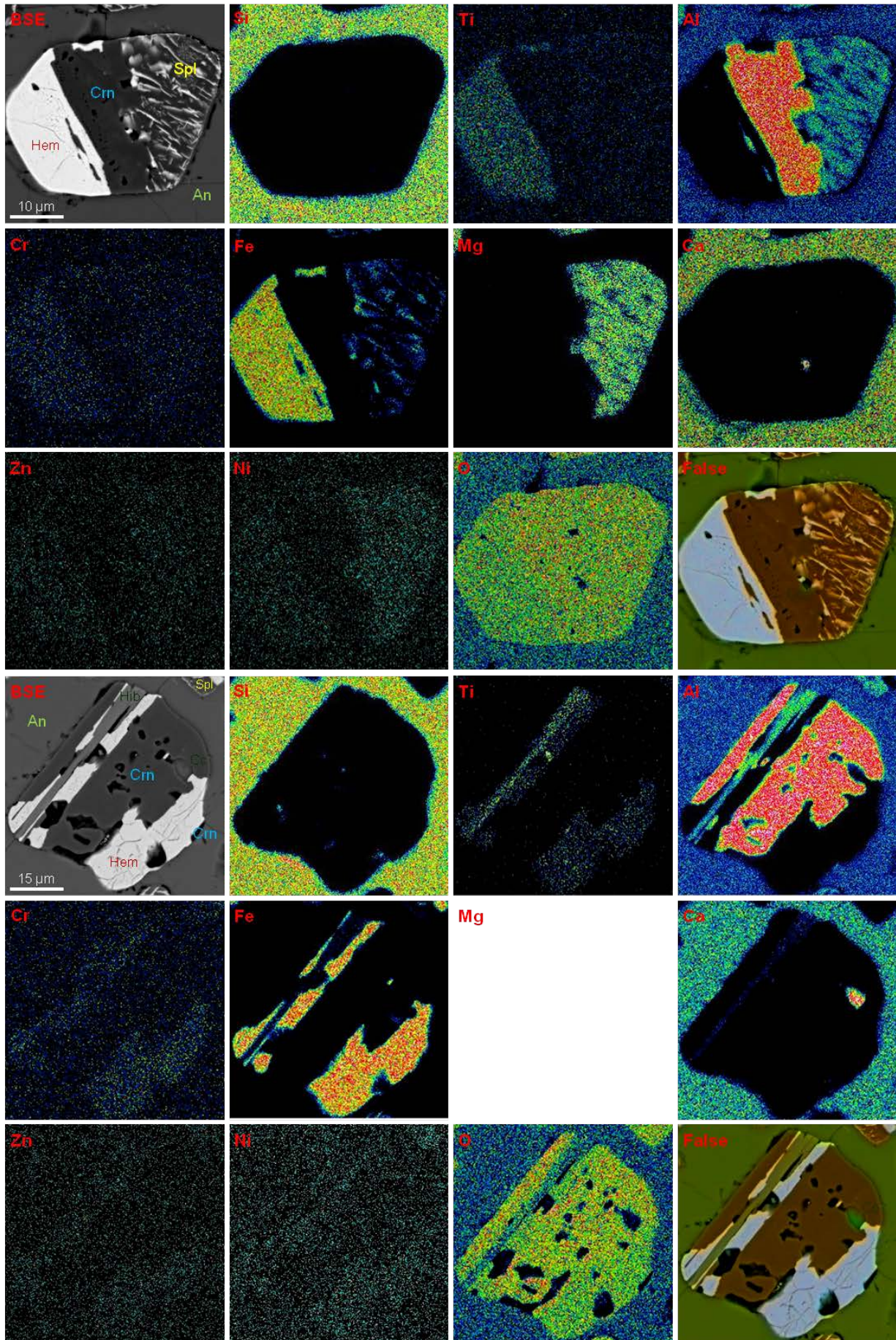
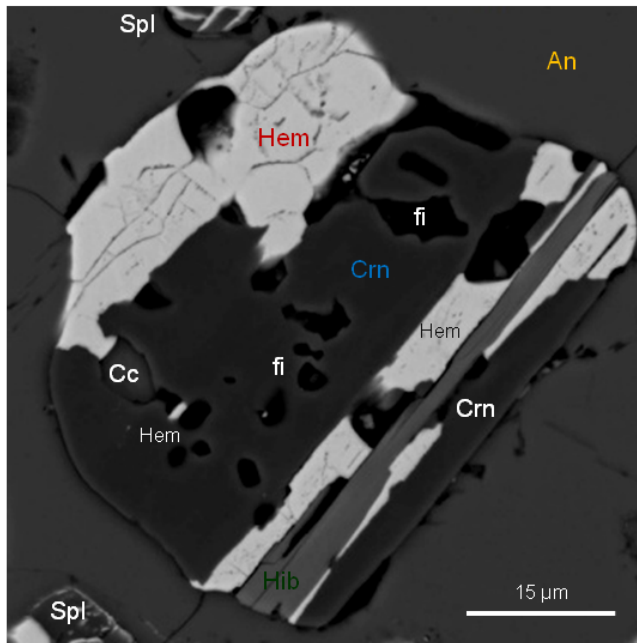


Fig. S5. BSE images and elemental maps for individual intergrowths in opaque isolation from host plagioclase-clinopyroxene rock, Hatrurim Basin, Israel.

Crn – corundum, Spl – spinel, Hem – hematite, Hib – hibonite, An – anorthite, Ap – fluorapatite, Ilm – ilmenite.



Sample	iso-6	
	Crn	Hem
Phase		
<i>n</i>	2	2
TiO ₂	0.09	2.37
Cr ₂ O ₃	0.00	0.50
V ₂ O ₃		0.35
Al ₂ O ₃	95.37	4.87
Fe ₂ O ₃	4.53	90.41
FeO	0.08	0.79
MnO	0.00	0.00
MgO	0.00	0.55
CaO		0.28
Sum	100.06	100.11
XAl ₂ O ₃	0.97	0.09
XFe ₂ O ₃	0.03	0.91

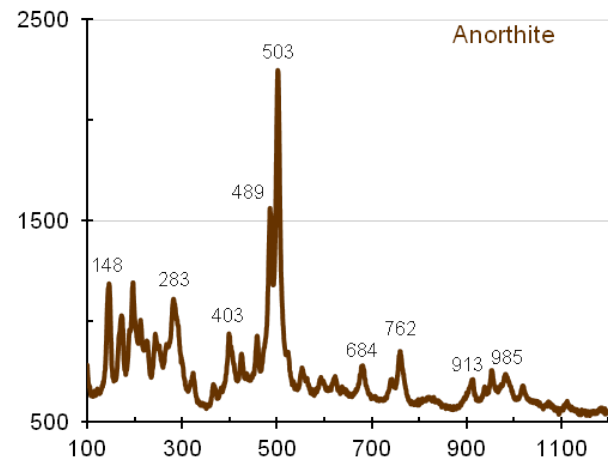
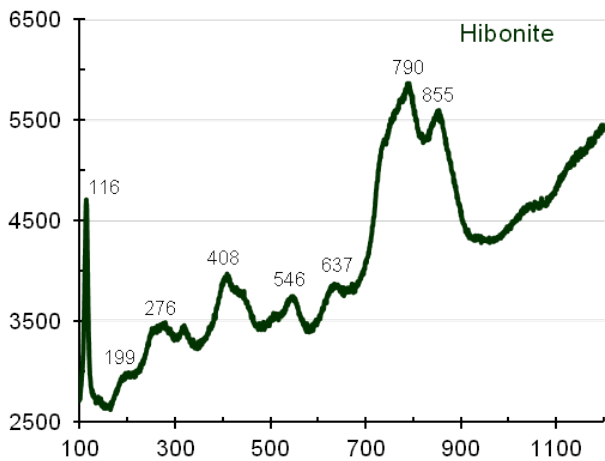
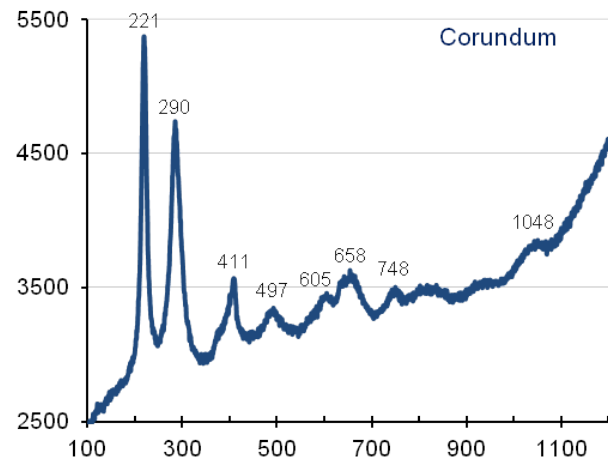
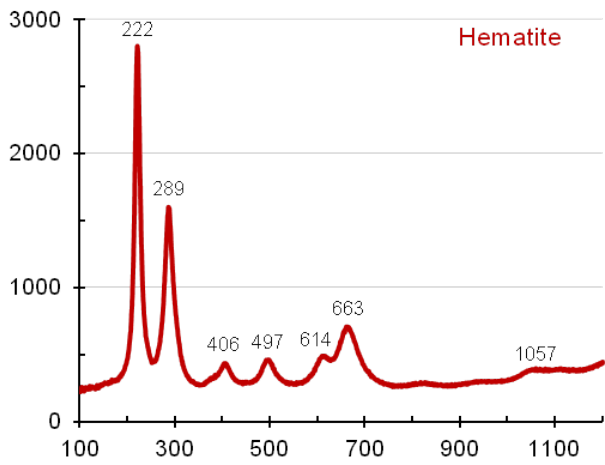


Fig. S6. Raman spectra for mineral intergrowth in anorthite from the opaque segregation, plagioclase-clinopyroxene rock, Hatrurim Basin (BSE image and chemical composition).

Symbols: Hem – hematite, Crn – corundum, Hib – hibonite, Cc – calcite, Spl – spinel, An – anorthite; fi – fluid inclusions in corundum.

Table S1. Chemical composition (EDS+WDS, wt.%) of principal minerals in host plagioclase-clinopyroxene rock, Hatrurim Basin, Israel.

	SiO ₂	TiO ₂	Cr ₂ O ₃	V ₂ O ₃	Al ₂ O ₃	FeO	MnO	MgO	CaO	SrO	BaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	F	Cl	Sum	
Anorthite																			
	42.96	n.a.	n.a.	n.a.	35.54	0.55	n.a.	n.a.	19.50	n.a.	n.a.	0.26	0.00	n.a.	n.a.	n.a.	n.a.	98.81	
	44.03	n.a.	n.a.	n.a.	35.69	0.64	n.a.	n.a.	19.42	n.a.	n.a.	0.39	0.10	n.a.	n.a.	n.a.	n.a.	100.27	
	43.51	n.a.	n.a.	n.a.	35.09	1.34	n.a.	n.a.	19.28	n.a.	n.a.	0.23	0.00	n.a.	n.a.	n.a.	n.a.	99.45	
	45.44	0.00	0.00	n.a.	33.34	1.87	0.00	0.00	18.37	0.00	0.00	0.71	0.24	n.a.	n.a.	n.a.	n.a.	99.97	
Clinopyroxene																			
c	43.73	1.68	0.00	0.00	8.84	12.68	0.00	8.71	23.87	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	99.51	
r	40.22	2.89	0.00	0.00	11.03	16.93	0.00	4.93	23.06	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	99.06	
c	44.88	1.25	0.47	0.00	7.84	11.93	0.00	9.04	23.49	n.a.	n.a.	0.19	n.a.	n.a.	n.a.	n.a.	n.a.	99.09	
r	41.85	1.72	0.00	0.00	8.26	17.55	0.19	6.52	23.25	n.a.	n.a.	0.27	n.a.	n.a.	n.a.	n.a.	n.a.	99.61	
c	46.38	0.82	0.38	0.25	7.33	9.92	0.00	9.88	24.11	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	99.07	
r	41.70	2.34	0.00	0.19	10.11	15.73	0.00	6.37	23.25	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	99.69	
c	46.68	1.27	0.18	0.00	7.44	9.94	0.00	10.07	23.77	n.a.	n.a.	0.18	n.a.	n.a.	n.a.	n.a.	n.a.	99.53	
c	39.31	2.32	0.18		10.11	18.29	0.12	5.92	23.05	n.a.	n.a.	0.19	n.a.	n.a.	n.a.	n.a.	n.a.	99.49	
c	44.67	1.50	0.00	0.19	8.28	11.99	0.00	8.84	23.88	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	99.35	
c	41.76	2.35	0.00	0.22	8.33	17.37	0.00	5.67	23.30	n.a.	n.a.	0.19	n.a.	n.a.	n.a.	n.a.	n.a.	99.19	
Fluorapatite																			
	6.91	n.a.	n.a.	0.00	0.55	0.67	n.a.	n.a.	52.02	1.89	0.44	0.00	n.a.	37.10	0.00	2.33	n.a.	101.91	
	6.10	n.a.	n.a.	0.26	1.32	0.48	n.a.	0.30	51.36	1.65	0.45	0.00	n.a.	35.78	1.15	1.00	0.15	100.00	
	6.14	n.a.	n.a.	0.00	1.10	0.42	n.a.	0.22	51.21	1.60	n.a.	0.00	n.a.	36.24	1.00	1.49	0.11	99.53	
	6.89	n.a.	n.a.	0.00	1.10	0.42	n.a.	0.27	51.25	1.70	n.a.	0.00	n.a.	36.74	0.97	1.00	0.12	100.46	
	5.61	n.a.	n.a.	0.00	0.94	0.36	0.00	0.00	52.08	1.84	n.a.	0.00	n.a.	38.08	0.00	1.50	0.00	100.41	
	6.89	n.a.	n.a.	0.19	1.04	0.33	n.a.	0.27	51.90	1.66	n.a.	0.00	n.a.	35.97	1.15	0.77	0.14	100.31	
	6.72	n.a.	n.a.	0.00	0.79	0.55	n.a.	0.25	52.46	1.68	n.a.	0.00	n.a.	35.75	1.02	1.11	0.10	100.43	
	5.65	n.a.	n.a.	0.00	0.30	0.29	n.a.	0.27	51.47	1.75	0.36	0.00	n.a.	38.04	0.00	3.08	n.a.	101.21	
	4.60	n.a.	n.a.	0.00	0.49	0.58	n.a.	n.a.	51.84	1.84	n.a.	0.00	n.a.	40.03	0.00	3.29	n.a.	102.67	
	5.01	n.a.	n.a.	0.00	0.40	0.84	n.a.	n.a.	51.42	1.99	n.a.	0.00	n.a.	39.60	0.00	3.57	n.a.	102.83	
	4.06	n.a.	n.a.	0.00	0.66	0.30	n.a.	n.a.	52.12	1.89	n.a.	0.00	n.a.	39.61	0.00	3.60	n.a.	102.24	
Andradite																			
c	32.97	4.65	0.00	0.00	3.68	23.16	0.00	0.70	31.58	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	96.74	
m	32.95	4.34	0.00	0.22	3.97	22.27	0.22	0.78	31.65	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	96.40	
r	31.77	6.22	0.19	0.24	3.51	23.22	0.00	0.83	31.50	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	97.48	
“Hyalophane”																			
	42.02	n.a.	n.a.	n.a.	26.38	0.44	n.a.	0.00	2.38	n.a.	24.43	0.00	4.37	n.a.	n.a.	n.a.	n.a.	100.02	
	41.80	n.a.	n.a.	n.a.	26.23	0.51	n.a.	0.00	2.78	n.a.	25.17	0.20	3.81	n.a.	n.a.	n.a.	n.a.	100.50	
	42.68	n.a.	n.a.	n.a.	24.63	0.36	n.a.	0.00	0.99	n.a.	26.22	0.30	4.70	n.a.	n.a.	n.a.	n.a.	99.88	
	42.10	n.a.	n.a.	n.a.	24.78	0.46	n.a.	0.00	1.04	n.a.	26.52	0.28	4.35	n.a.	n.a.	n.a.	n.a.	99.53	
	42.72	n.a.	n.a.	n.a.	24.70	0.46	n.a.	0.00	0.92	n.a.	26.16	0.35	4.72	n.a.	n.a.	n.a.	n.a.	100.03	
	38.19	n.a.	n.a.	n.a.	24.85	0.23	n.a.	0.00	1.37	n.a.	30.47	0.00	3.14	n.a.	n.a.	n.a.	n.a.	98.25	

c, m, r – core, middle and rim of grain, n.a. – not analysed.

Table S2. Chemical composition (EDS+WDS, wt.%) of silicates in leucocratic zone and opaque segregation of plagioclase-clinopyroxene rock, Hatrurim Basin, Israel.

	SiO ₂	TiO ₂	Cr ₂ O ₃	V ₂ O ₃	Al ₂ O ₃	FeO	MnO	MgO	CaO	Ce ₂ O ₃	SrO	BaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	F	Cl	Sum	
Leucocratic zone																				
Anorthite																				
	43.83	0.00	0.00	n.a.	34.82	0.85	0.00	0.00	19.99	n.a.	n.a.	0.00	0.15	0.03	n.a.	n.a.	n.a.	n.a.	99.68	
	43.90	0.00	0.00	n.a.	35.36	0.61	0.00	0.00	19.80	n.a.	n.a.	0.00	0.17	0.00	n.a.	n.a.	n.a.	n.a.	99.83	
	43.41	n.a.	n.a.	n.a.	35.64	0.63	n.a.	n.a.	19.43	n.a.	n.a.	n.a.	0.44	0.11	n.a.	n.a.	n.a.	n.a.	99.66	
	43.22	n.a.	n.a.	n.a.	35.79	0.41	n.a.	n.a.	19.46	n.a.	n.a.	n.a.	0.27	0.00	n.a.	n.a.	n.a.	n.a.	99.15	
	44.07	n.a.	n.a.	n.a.	35.77	0.68	n.a.	n.a.	19.35	n.a.	n.a.	n.a.	0.38	0.00	n.a.	n.a.	n.a.	n.a.	100.25	
	43.39	n.a.	n.a.	n.a.	34.82	1.12	n.a.	n.a.	19.11	n.a.	n.a.	n.a.	0.26	0.12	n.a.	n.a.	n.a.	n.a.	98.82	
	43.59	n.a.	n.a.	n.a.	35.09	0.86	0.00	n.a.	19.31	n.a.	n.a.	n.a.	0.30	0.00	n.a.	n.a.	n.a.	n.a.	99.15	
	43.60	n.a.	n.a.	n.a.	35.48	0.81	n.a.	n.a.	19.09	n.a.	n.a.	n.a.	0.32	0.00	n.a.	n.a.	n.a.	n.a.	99.30	
	44.11	n.a.	n.a.	n.a.	35.81	0.69	n.a.	n.a.	19.23	n.a.	n.a.	n.a.	0.35	0.00	n.a.	n.a.	n.a.	n.a.	100.19	
	43.54	n.a.	n.a.	n.a.	35.58	0.49	n.a.	n.a.	19.57	n.a.	n.a.	n.a.	0.23	0.00	n.a.	n.a.	n.a.	n.a.	99.41	
	43.62	n.a.	n.a.	n.a.	35.43	0.89	n.a.	n.a.	19.85	n.a.	n.a.	n.a.	0.24	0.00	n.a.	n.a.	n.a.	n.a.	100.03	
	43.75	n.a.	n.a.	n.a.	34.37	1.08	n.a.	n.a.	19.82	n.a.	n.a.	n.a.	0.51	0.18	n.a.	n.a.	n.a.	n.a.	99.71	
	43.69	n.a.	n.a.	n.a.	36.05	0.78	n.a.	n.a.	19.63	n.a.	n.a.	n.a.	0.13	0.00	n.a.	n.a.	n.a.	n.a.	100.28	
	43.73	n.a.	n.a.	n.a.	35.96	0.58	n.a.	n.a.	19.52	n.a.	n.a.	n.a.	0.30	0.00	n.a.	n.a.	n.a.	n.a.	100.09	
	43.79	n.a.	n.a.	n.a.	35.54	0.76	n.a.	n.a.	19.42	n.a.	n.a.	0.00	0.32	0.00	n.a.	n.a.	n.a.	n.a.	99.83	
K-feldspar																				
	57.29	n.a.	n.a.	n.a.	23.27	0.77	n.a.	0.00	6.06	n.a.	0.00	1.98	0.23	10.67	n.a.	n.a.	n.a.	n.a.	100.27	
	57.29	n.a.	n.a.	n.a.	22.47	1.18	n.a.	n.a.	5.54	n.a.	n.a.	2.47	0.43	10.71	n.a.	n.a.	n.a.	n.a.	100.09	
Clinopyroxene																				
	44.54	1.40	0.43	n.a.	8.60	11.26	0.03	9.76	24.17	n.a.	n.a.	n.a.	0.07	n.a.	n.a.	n.a.	n.a.	n.a.	100.26	
	44.23	1.45	0.54	n.a.	8.40	11.04	0.04	9.66	23.90	n.a.	n.a.	n.a.	0.07	n.a.	n.a.	n.a.	n.a.	n.a.	99.33	
	45.18	1.42	0.07	n.a.	8.02	10.58	0.02	9.84	24.54	n.a.	n.a.	n.a.	0.07	n.a.	n.a.	n.a.	n.a.	n.a.	99.74	
	42.36	1.37	0.60	n.a.	10.39	12.02	0.00	8.19	23.32	n.a.	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	98.25	
	44.72	1.17	0.32	0.00	8.60	10.58	0.00	9.78	23.58	n.a.	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	98.75	
	42.69	0.88	0.00	0.18	6.46	18.35	0.23	7.68	23.33	n.a.	n.a.	n.a.	0.35	n.a.	n.a.	n.a.	n.a.	n.a.	100.15	
	42.68	2.05	0.00	0.00	9.22	13.29	0.17	7.60	23.68	n.a.	n.a.	n.a.	0.35	n.a.	n.a.	n.a.	n.a.	n.a.	99.04	
	41.68	2.20	0.00	0.18	10.00	14.24	0.00	7.08	23.42	n.a.	n.a.	n.a.	0.49	n.a.	n.a.	n.a.	n.a.	n.a.	99.29	
	43.58	1.98	0.00	0.00	8.94	12.12	0.00	8.11	23.60	n.a.	n.a.	n.a.	0.26	n.a.	n.a.	n.a.	n.a.	n.a.	98.59	
	43.47	1.20	0.50	0.00	8.45	12.35	n.a.	9.02	23.18	n.a.	n.a.	n.a.	0.27	n.a.	n.a.	n.a.	n.a.	n.a.	98.44	
Fluorapatite																				
	2.63	n.a.	n.a.	2.29	n.a.	0.00	0.00	n.a.	53.13	0.00	1.64	n.a.	0.00	n.a.	37.62	0.42	3.53	0.00	101.26	
	6.27	n.a.	n.a.	0.22	0.17	0.54	0.00	n.a.	52.21	0.00	1.86	n.a.	0.00	n.a.	37.83	0.00	1.71	0.00	100.81	
	5.50	n.a.	n.a.	0.00	0.36	0.44	0.00	0.00	52.11	0.00	1.81	0.00	0.24	n.a.	38.31	0.00	2.05	0.00	100.82	
	5.69	n.a.	n.a.	0.00	0.28	0.49	0.00	0.00	52.01	0.00	1.64	0.35	0.00	n.a.	37.83	0.00	2.52	0.00	100.81	
	3.79	n.a.	n.a.	0.78	n.a.	0.41	n.a.	n.a.	53.72	n.a.	1.77	n.a.	0.00	n.a.	37.97	1.55	1.79	0.00	101.78	
	4.98	n.a.	n.a.	0.00	0.00	0.57	n.a.	n.a.	51.53	n.a.	1.87	n.a.	0.00	n.a.	38.66	0.00	2.49	0.00	100.10	
c	6.65	n.a.	n.a.	0.00	0.31	0.75	n.a.	n.a.	52.34	0.42	1.82	0.00	0.00	n.a.	37.69	0.00	1.61	0.00	101.58	
r	3.63	n.a.	n.a.	0.62	0.00	0.37	n.a.	n.a.	53.50	0.00	1.77	0.00	0.00	n.a.	38.08	1.66	2.43	0.00	102.05	
Opaque segregation																				
Anorthite																				
	44.47	0.00	0.00	n.a.	34.32	0.58	0.00	0.00	19.61	n.a.	n.a.	0.00	0.28	0.18	n.a.	n.a.	n.a.	n.a.	99.44	
	44.37	0.00	0.00	n.a.	34.90	0.53	0.00	0.00	19.76	n.a.	n.a.	0.00	0.26	0.04	n.a.	n.a.	n.a.	n.a.	99.87	
	44.19	0.00	0.00	n.a.	34.78	0.59	0.00	0.00	19.81	n.a.	n.a.	0.00	0.18	0.07	n.a.	n.a.	n.a.	n.a.	99.62	
	44.11	n.a.	n.a.	n.a.	35.45	0.48	n.a.	n.a.	19.45	n.a.	n.a.	n.a.	0.00	0.00	n.a.	n.a.	n.a.	n.a.	99.49	
	44.27	n.a.	n.a.	n.a.	34.99	0.44	n.a.	n.a.	19.70	n.a.	n.a.	n.a.	0.00	0.00	n.a.	n.a.	n.a.	n.a.	99.40	
	44.09	n.a.	n.a.	n.a.	35.30	0.68	n.a.	n.a.	19.69	n.a.	n.a.	n.a.	0.00	0.00	n.a.	n.a.	n.a.	n.a.	99.76	
	44.01	n.a.	n.a.	n.a.	35.54	0.73	n.a.	n.a.	19.66	n.a.	n.a.	n.a.	0.15	0.11	n.a.	n.a.	n.a.	n.a.	100.20	
	43.66	n.a.	n.a.	n.a.	35.82	0.95	n.a.	n.a.	19.46	n.a.	n.a.	n.a.	n.a.	0.25	n.a.	n.a.	n.a.	n.a.	100.14	
	44.02	n.a.	n.a.	n.a.	35.63	0.57	n.a.	n.a.	19.90	n.a.	n.a.	n.a.	0.16	0.00	n.a.	n.a.	n.a.	n.a.	100.28	
	43.95	n.a.	n.a.	n.a.	35.79	0.49	n.a.	n.a.	19.39	n.a.	n.a.	n.a.	0.26	0.00	n.a.	n.a.	n.a.	n.a.	99.88	
K+feldspar																				
	63.65	0.00	n.a.	n.a.	17.63	0.78	n.a.	0.00	1.13	n.a.	n.a.	n.a.	0.00	16.18	n.a.	n.a.	n.a.	n.a.	99.37	
Clinopyroxene																				
	42.80	2.35	0.69	n.a.	9.22	13.12	0.03	7.83	23.58	n.a.	n.a.	0.00	0.15	0.00	n.a.	n.a.	n.a.	n.a.	99.78	
	42.95	1.63	0.64	n.a.	9.57	11.68	0.00	8.61	23.70	n.a.	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	98.78	
	42.72	1.52	0.60	n.a.	9.43	11.99	0.00	8.82	23.66	n.a.	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	98.74	
	42.44	1.67	0.67	n.a.	9.66	12.36	0.00	8.14	23.80	n.a.	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	98.74	

n.a. – not analysed.

Table S3. Chemical composition (EDS, wt.%) of opaque mineral associations in leucocratic zone and host plagioclase-clinopyroxene rock, Hatrurim Basin, Israel.

Phase	<i>n</i>	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	V ₂ O ₃	FeO	MnO	MgO	CaO	NiO	ZnO	Nb ₂ O ₅	Y ₂ O ₃	La ₂ O ₃	Ce ₂ O ₃	Sum	
Leucocratic zone																		
Lz-1	Hem	1	n.a.	3.72	2.10	0.00	0.00	84.90	0.31	0.71	0.35	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	92.09
	H-Ilm	2	n.a.	35.35	3.91	0.00	0.00	53.38	0.22	0.75	0.48	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	94.07
	Tnt	1	29.72	35.06	4.36	0.00	0.00	5.38	0.00	0.00	24.88	n.a.	n.a.	0.00	n.a.	n.a.	n.a.	99.40
Lz-2	Hem	4	n.a.	7.76	3.29	0.00	0.19	80.59	0.29	0.56	0.31	0.30	n.a.	n.a.	n.a.	n.a.	n.a.	93.27
	H-Ilm	1	n.a.	35.36	6.41	0.00	0.00	52.04	0.00	0.66	0.49	0.00	n.a.	0.00	n.a.	n.a.	n.a.	94.96
	Tnt	1	29.91	33.41	5.33	0.00	0.00	3.30	0.00	0.00	25.40	n.a.	n.a.	2.57	n.a.	n.a.	n.a.	99.92
Lz-2	Hem	3	n.a.	7.85	3.31	0.00	0.00	80.23	0.26	0.52	0.32	0.11	n.a.	n.a.	n.a.	n.a.	n.a.	92.59
	H-Ilm	2	n.a.	36.22	4.52	0.00	0.17	52.96	0.00	0.48	0.32	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	94.66
Lz-3	Hem	2	n.a.	3.19	0.82	0.00	0.00	86.96	0.12	0.43	0.34	0.38	n.a.	n.a.	n.a.	n.a.	n.a.	92.22
	Tnt	1	29.84	37.13	1.51	0.00	0.00	4.43	0.00	n.a.	25.76	n.a.	n.a.	1.40	n.a.	n.a.	n.a.	100.07
Iso-2-7	Hem	1	n.a.	7.36	2.40	0.00	0.00	79.36	0.00	0.90	0.28	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	90.30
c	Prv	2	0.80	45.35	1.38	0.00	0.00	3.58	0.00	0.00	37.09	0.00	n.a.	9.23	0.33	0.50	0.75	98.99
r	Prv	2	0.29	55.00	1.32	0.00	0.50	2.08	0.00	0.10	38.01	0.00	n.a.	1.07	0.00	0.00	0.00	98.35
Lz-x1	Hem	2	0.00	2.95	1.68	0.00	0.00	84.93	0.21	0.66	0.22	0.30	n.a.	n.a.	n.a.	n.a.	n.a.	90.94
	H-Ilm	1	n.a.	35.31	2.29	0.00	0.34	54.12	0.00	0.68	0.45	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	93.19
Lz-x2	Hem	3	n.a.	3.94	1.70	0.00	0.00	83.65	0.18	0.48	0.37	0.00	n.a.	0.00	n.a.	n.a.	n.a.	90.31
	H-Ilm	3	n.a.	35.16	2.46	0.00	0.25	53.88	0.00	0.59	0.45	0.00	n.a.	0.60	n.a.	n.a.	n.a.	93.39
Lz-x7	Hem	2	0.00	3.47	2.87	0.00	0.00	82.63	0.00	1.03	0.45	0.00	n.a.	0.00	n.a.	n.a.	n.a.	90.44
	H-Ilm	2	0.00	35.93	4.49	0.00	0.64	51.22	0.00	1.14	0.29	0.00	n.a.	0.00	n.a.	n.a.	n.a.	93.70
iso4-6	Hem	2	0.00	3.52	1.57	0.00	0.00	84.21	0.30	0.70	0.31	0.00	n.a.	0.00	n.a.	n.a.	n.a.	90.60
	H-Ilm	1	n.a.	34.94	2.83	0.00	0.37	53.49	0.19	0.46	0.48	n.a.	n.a.	0.43	n.a.	n.a.	n.a.	93.19
	Tnt	1	27.75	34.56	1.53	0.00	1.90	2.75	0.00	n.a.	26.58	n.a.	n.a.	3.13	n.a.	n.a.	n.a.	98.20
iso4-6	Hem	1	n.a.	3.52	1.23	0.00	0.00	84.30	0.35	0.46	0.22	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	90.08
	H-Ilm	2	0.00	34.96	1.85	0.00	0.21	56.39	0.00	0.42	0.32	0.00	n.a.	0.00	n.a.	n.a.	n.a.	94.14
iso-7	Cr-Hem	3	0.00	2.28	7.00	18.09	0.62	62.62	0.00	0.47	0.36	0.00	0.00	n.a.	n.a.	n.a.	n.a.	91.45
	Cr-Spl	1	n.a.	0.00	32.93	22.46	0.00	24.84	0.79	13.08	0.27	0.69	1.41	n.a.	n.a.	n.a.	n.a.	96.47
Host rock																		
h-1-2	Hem	2	0.00	3.97	2.04	0.00	0.00	83.77	0.22	0.58	0.38	0.00	n.a.	0.00	n.a.	n.a.	n.a.	90.96
	Tnt	3	29.82	38.30	0.71	0.00	0.26	1.24	0.00	0.00	27.32	0.00	n.a.	1.40	n.a.	n.a.	n.a.	99.05
h-2	Hem	4	n.a.	5.08	0.64	0.00	0.06	83.53	0.08	0.39	0.41	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	90.18

See Fig. S3. *n* – average; n.a. – not analysed. Hem – hematite; H-Ilm – “hemoilmenite”; Tnt – titanite; Prv – perovskite; Cr-Hem – Cr-hematite; Cr-Spl – Cr-spinel; c, r – core-rim of grain.

Table S4. Chemical composition (EDS, wt.%) of vesicle-related minerals in plagioclase-clinopyroxene rock, Hatrurim Basin, Israel.

Sample	Mineral	SiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	SrO	BaO	Na ₂ O	K ₂ O	SO ₃	Cl	Sum
iso-1-g4	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.37	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.37
Iso-3	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.83	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.83
	Quartz	99.18	n.a.	n.a.	n.a.	n.a.	0.18	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	99.36
	Quartz	99.87	n.a.	n.a.	n.a.	n.a.	0.25	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	100.12
Lz-4	Calcite	n.a.	n.a.	n.a.	n.a.	n.a.	54.44	0.00	n.a.	n.a.	n.a.	0.67	n.a.	55.11
	Calcite	n.a.	n.a.	n.a.	n.a.	n.a.	55.23	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.23
	Quartz	99.89	n.a.	n.a.	n.a.	n.a.	0.55	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	100.44
	Quartz	100.10	n.a.	n.a.	n.a.	n.a.	0.50	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	100.60
	Bassanite	n.a.	n.a.	0.00	n.a.	n.a.	37.18	0.00	n.a.	n.a.	n.a.	55.56	0.37	93.11
	Bassanite	n.a.	n.a.	0.00	n.a.	n.a.	36.79	0.00	n.a.	n.a.	n.a.	54.76	0.36	91.91
Iso-2-3-g	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.55	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.55
	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.43	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.43
	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.16	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.16
	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.59	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.59
	Quartz	98.50	0.53	n.a.	n.a.	n.a.	0.42	n.a.	n.a.	n.a.	0.17	n.a.	n.a.	99.62
Iso-2-7	Ca-K-Zeolite	41.70	25.87	0.37	0.00	n.a.	10.65	0.00	1.17	0.55	4.94	n.a.	n.a.	85.25
Lz-x2	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.29	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.29
Lz-x3	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.44	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.44
	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.42	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.42
	K-Na-Ca-Sr-Zeolite	50.06	22.20	0.00	n.a.	0.36	3.79	2.02	n.a.	3.38	5.38	n.a.	0.16	87.35
	K-Na-Ca-Sr-Zeolite	53.29	22.33	0.00	n.a.	0.43	3.71	1.49	n.a.	3.11	5.82	n.a.	n.a.	90.18
	Ca-Sr-K-Na-Zeolite	42.79	25.81	0.00	n.a.	0.00	5.96	4.61	n.a.	3.11	4.22	n.a.	0.36	86.86
	Ca-Sr-K-Na-Zeolite	44.31	24.64	0.18	n.a.	0.00	6.66	4.41	n.a.	2.55	3.98	n.a.	0.32	87.05
	Ca-Sr-K-Na-Zeolite	42.34	25.81	n.a.	n.a.	0.00	7.23	3.91	n.a.	3.19	3.23	n.a.	0.43	86.14
	Ca-Zeolite	37.25	29.61	0.28	n.a.	0.17	13.88	0.00	n.a.	0.42	1.26	n.a.	n.a.	82.87
Ca-Zeolite	36.16	29.31	0.40	n.a.	n.a.	15.38	0.00	n.a.	0.20	0.23	n.a.	n.a.	81.68	
Lz-x6	Calcite	n.a.	n.a.	0.00	0.00	n.a.	55.40	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.40
Lz-x8	Calcite	n.a.	n.a.	0.22	0.00	0.00	55.22	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.44
Lz-g3	Calcite	n.a.	n.a.	0.00	0.00	0.00	55.54	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	55.54
host-3	Calcite	n.a.	0.00	0.00	0.00	0.00	55.37	0.00	n.a.	n.a.	n.a.	0.75	n.a.	56.12
	Calcite	n.a.	0.00	0.00	0.00	0.00	55.33	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	55.33
	Ca-Sr-K-Na-Zeolite	40.69	23.56	0.00	n.a.	0.18	7.93	3.50	n.a.	0.69	1.13	n.a.	n.a.	77.68
	Ca-Sr-K-Na-Zeolite	41.20	22.13	0.44	n.a.	0.28	7.04	3.47	n.a.	0.75	1.70	n.a.	n.a.	77.01
	Ca-Sr-K-Na-Zeolite	39.90	23.39	0.00	n.a.	0.18	7.57	n.a.	n.a.	0.94	1.23	n.a.	n.a.	73.21
	Ca-Sr-K-Na-Zeolite	40.63	22.92	0.00	n.a.	0.00	7.78	n.a.	n.a.	0.96	1.29	n.a.	n.a.	73.58
	Ca-Zeolite	32.88	27.68	0.22	n.a.	n.a.	14.02	n.a.	n.a.	0.00	0.00	n.a.	n.a.	74.80
	Ca-Zeolite	34.47	27.42	0.19	n.a.	0.23	13.85	n.a.	n.a.	0.31	0.14	n.a.	n.a.	76.61
	Ca-K-Zeolite	37.14	28.91	0.73	n.a.	n.a.	12.94	n.a.	n.a.	3.33	0.17	n.a.	n.a.	83.22
	Ca-K-Zeolite	37.70	27.64	1.04	n.a.	n.a.	12.10	n.a.	n.a.	3.13	n.a.	n.a.	0.28	81.89
	Na-Zeolite	53.72	21.94	0.75	n.a.	0.00	0.39	n.a.	n.a.	12.19	0.10	n.a.	n.a.	89.09
	Na-Zeolite	53.95	21.45	0.71	n.a.	0.00	0.55	n.a.	n.a.	11.32	0.16	n.a.	n.a.	88.14
	Na-Zeolite	52.91	21.65	0.58	n.a.	0.00	1.06	n.a.	n.a.	12.16	0.12	n.a.	n.a.	88.48
Na-Zeolite	51.79	20.46	0.69	n.a.	n.a.	2.00	n.a.	n.a.	9.87	0.00	0.47	n.a.	85.28	
Na-Zeolite	54.45	21.60	1.02	n.a.	n.a.	0.39	n.a.	n.a.	11.61	0.11	n.a.	n.a.	89.18	
host-5	Ca-Sr-K-Na-Zeolite	41.42	23.96	0.00	n.a.	n.a.	6.88	n.a.	n.a.	0.66	1.07	n.a.	n.a.	73.99

See Fig. S3. n.a. – not analysed.

Table S5. Chemical composition (EDS, wt.%) of coexisting corundum and hematite from opaque segregation in plagioclase-clinopyroxene rock, Hatrurim Basin, Israel.

Sample	Phase	<i>n</i>	TiO ₂	Cr ₂ O ₃	V ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	NiO	Sum	X _{Al2O3}	X _{Fe2O3}
iso-1-g4	Crn	1	0.00	0.26	n.a.	92.50	7.45	0.00	0.00	0.00	n.a.	n.a.	100.21	0.95	0.05
	Hem	1	2.69	0.35	0.99	5.57	88.52	1.04	0.00	0.65	0.17	0.00	99.98	0.10	0.90
iso-1-g4	Crn	1	0.00	0.00	n.a.	94.49	5.69	0.00	0.00	0.00	n.a.	n.a.	100.18	0.96	0.04
	Hem	1	1.72	0.50	0.76	4.74	91.33	0.39	0.00	0.50	0.21	0.00	100.15	0.09	0.91
iso-1-g4	Crn	1	0.00	0.00	n.a.	95.74	4.43	0.00	0.00	0.00	n.a.	n.a.	100.17	0.97	0.03
	Hem	1	1.17	0.47	0.82	5.73	90.95	0.46	0.00	0.33	n.a.	0.00	99.93	0.10	0.90
iso-1-g4	Crn	1	0.00	0.00	n.a.	94.89	5.18	0.00	0.00	0.00	n.a.	n.a.	100.07	0.97	0.03
	Hem	1	4.10	0.29	0.59	4.21	88.06	1.89	0.00	0.90	0.15	0.00	100.19	0.08	0.92
iso-1-g4	Crn	1	0.00	0.00	n.a.	95.31	4.63	0.00	0.00	0.00	n.a.	n.a.	99.94	0.97	0.03
	Hem	1	3.00	0.41	0.65	2.72	90.80	1.25	n.a.	0.81	0.00	0.00	99.65	0.06	0.94
iso-2-g	Crn	1	0.00	0.00	n.a.	94.77	4.99	0.00	0.00	0.00	n.a.	n.a.	99.76	0.97	0.03
	Hem	1	1.67	0.35	0.47	3.85	92.91	0.06	0.00	0.65	0.22	0.00	100.18	0.07	0.93
iso-2-g	Crn	1	0.00	0.00	n.a.	94.81	5.19	0.00	0.00	0.00	n.a.	n.a.	100.00	0.97	0.03
	Hem	1	5.30	0.26	0.00	4.70	85.65	2.60	0.00	1.04	0.24	0.00	99.79	0.08	0.92
iso-2-g	Crn	2	0.00	0.00	n.a.	95.19	4.46	0.00	0.00	0.00	n.a.	n.a.	99.65	0.97	0.03
	Hem	1	1.55	0.35	0.19	5.03	92.34	0.00	0.00	0.65	0.18	0.00	100.29	0.08	0.92
iso-2-g	Crn	1	0.00	0.00	n.a.	94.69	5.23	0.00	0.00	0.00	n.a.	n.a.	99.92	0.97	0.03
	Hem	1	0.93	0.34	0.44	4.97	92.63	0.48	0.00	n.a.	0.28	0.00	100.07	0.09	0.91
iso-2-g	Crn	1	0.17	0.32	n.a.	90.98	8.21	0.15	0.00	0.00	0.00	n.a.	99.83	0.95	0.05
	Hem	1	3.32	0.35	0.26	3.10	90.43	1.77	0.00	0.48	0.28	0.00	99.99	0.06	0.94
iso-2-g	Crn	1	0.00	0.00	n.a.	95.62	4.55	0.00	0.00	0.00	n.a.	n.a.	100.17	0.97	0.03
	Hem	1	2.20	0.00	0.50	4.08	91.35	1.08	0.00	0.41	0.13	0.00	99.75	0.07	0.93
iso-2-g2	Crn	1	0.00	0.16	n.a.	94.25	5.51	0.00	0.00	0.00	0.00	n.a.	99.92	0.96	0.04
	Hem	1	1.28	0.00	0.21	4.01	93.72	0.11	0.00	0.41	0.24	0.00	99.98	0.06	0.94
iso-2-g2	Crn	1	0.18	0.37	n.a.	92.55	6.62	0.16	0.00	0.00	n.a.	n.a.	99.88	0.96	0.04
	Hem	1	5.00	0.26	0.44	3.70	87.36	0.72	0.22	1.69	0.18	0.32	99.89	0.07	0.93
iso-2-g2	Crn	1	0.18	0.37	n.a.	93.49	5.78	0.16	0.00	0.00	n.a.	n.a.	99.98	0.96	0.04
	Hem	1	4.74	0.34	0.34	3.59	87.55	2.60	0.00	0.93	n.a.	0.00	100.09	0.07	0.93
iso-2-g2	Crn	1	0.00	0.20	n.a.	94.10	5.95	0.00	0.00	0.00	n.a.	n.a.	100.25	0.96	0.04
	Hem	1	4.09	0.25	0.40	2.82	89.88	0.99	0.00	1.40	0.15	0.00	99.99	0.05	0.95
iso-2-g2	Crn	1	0.00	0.32	n.a.	93.16	6.55	0.00	0.00	0.00	n.a.	n.a.	100.03	0.96	0.04
	Hem	1	4.70	0.39	0.24	1.70	89.42	2.21	0.00	1.03	0.14	0.00	99.83	0.04	0.96
iso-4	Crn	2	0.20	0.35	n.a.	92.96	6.30	0.18	0.00	0.00	n.a.	n.a.	99.99	0.96	0.04
	Hem	2	3.06	0.47	0.26	3.88	90.64	0.19	0.00	1.31	0.18	n.a.	99.99	0.07	0.93
iso-5	Crn	1	0.20	0.57	n.a.	94.02	5.05	0.18	0.00	0.00	n.a.	n.a.	100.02	0.97	0.03
	Hem	1	3.17	2.10	0.25	3.70	88.80	0.14	0.00	1.23	0.17	0.31	99.88	0.09	0.91
iso-6	Crn	1	0.00	0.22	n.a.	94.13	5.88	0.00	0.00	0.00	n.a.	n.a.	100.23	0.96	0.04
	Hem	1	1.92	0.57	0.29	4.01	92.03	0.37	0.00	0.51	0.35	0.00	100.05	0.07	0.93
iso-6	Crn	2	0.09	0.00	n.a.	95.37	4.53	0.08	0.00	0.00	n.a.	n.a.	100.06	0.97	0.03
	Hem	2	2.37	0.50	0.35	4.87	90.41	0.79	0.00	0.55	0.28	n.a.	100.11	0.09	0.91
iso-6	Crn	1	0.00	0.20	n.a.	93.78	6.29	0.00	n.a.	0.00	n.a.	n.a.	100.27	0.96	0.04
	Hem	1	2.32	0.44	n.a.	2.08	93.69	0.35	0.00	0.73	0.34	0.00	99.95	0.04	0.96
iso-6	Crn	1	0.00	0.35	n.a.	93.42	7.32	0.00	0.00	0.00	n.a.	n.a.	101.09	0.95	0.05
	Hem	1	3.05	0.48	0.24	2.10	92.30	0.42	0.00	1.06	0.34	0.00	99.99	0.04	0.96
iso-6	Crn	1	0.00	0.00	n.a.	94.72	5.39	0.00	0.00	0.00	n.a.	n.a.	100.11	0.96	0.04
	Hem	1	2.29	0.44	0.35	5.29	89.96	1.01	0.00	0.38	0.29	0.00	100.01	0.09	0.91
iso-8	Crn	3	0.00	0.53	n.a.	91.53	7.92	0.00	0.00	0.00	n.a.	n.a.	99.97	0.95	0.05
	Hem	1	2.04	0.57	0.63	1.72	93.88	0.03	0.21	0.65	0.17	0.22	100.13	0.04	0.96
iso-9	Crn	3	0.19	0.13	n.a.	93.21	6.52	0.17	0.00	0.00	0.00	n.a.	100.22	0.96	0.04
	Hem	2	4.05	0.21	0.00	2.45	90.93	0.20	0.14	1.63	0.31	n.a.	99.89	0.04	0.96
iso-10	Crn	3	0.00	0.32	n.a.	91.91	7.84	0.00	0.00	0.00	n.a.	n.a.	100.06	0.95	0.05
	Hem	1	2.65	0.39	0.26	4.44	90.75	0.36	0.27	0.98	n.a.	0.00	100.10	0.08	0.92
iso-11	Crn	2	0.23	0.27	n.a.	90.63	8.90	0.20	0.00	0.00	n.a.	n.a.	100.23	0.94	0.06
	Hem	4	2.83	0.35	0.18	5.26	89.38	1.33	0.00	0.58	0.14	n.a.	100.05	0.09	0.91

n.a. – not analysed. Fe₂O₃ and FeO are calculated from charge balance.