SCIENTIFIC NOTE

AN UPDATE ON THE MINERALOGY AND CHEMISTRY OF THE ALTA'AMEEM METEORITE

Alta'ameem meteorite fell in 1977 near the village of Humaira, Kirkuk (Alta'ameem) Governorate. The mineralogy and chemical composition was studied by Al-Bassam (1978) and the meteorite was classified as a metamorphosed chondrite of the LL group. It is a light gray, brecciated meteorite with black fusion crust (Fig.1a). It is composed of olivine (Fig.1b and 1c), orthopyroxene (Fig.1d) and plagioclase (Fig.1e). Other minerals include troilite, kamacite, taenite and chromite (Fig.1f, 1g and 1h). Ilmenite, apatite, clinopyroxene and chalcopyrite were also reported (Al-Bassam, 1978).

Several small samples were delivered to major natural history museums and scientific institutes in the world. The meteorite is kept at the US National Museum of Natural History under no. 5964, and it is classified as LL 4 chondrite in the Catalogue of Meteorites (Grady, 2001) and as LL5 chondrite by Kallemeyn *et al*. (1989).

Since the publication of Al-Bassam article in 1978, little additional work was published on this rare meteorite. It was mentioned in the work of Kallemeyn *et al*. (1989) as one of 66 other ordinary chondrites in an attempt to find petrologic and chemical criteria for chondrite classification.

Hiroi *et al*. (2006) compared the near infrared reflectance spectrum of Alta'ameem meteorite with that of the asteroid 2543 Itokawa. Among all the meteorite samples studied by Hiroi and his co-workers, Alta'ameem meteorite said to be the only one that have a near-identical reflectance spectra to that of some areas on the Itokawa asteroid (Hiroi *et al*., 2006). The asteroid was discovered in 1998 by LINER Project as part of the Hayabusa space mission (Japan). It is a near-Earth, rubble pile asteroid, 535 x 294 x 209 m in dimensions. It could have been the parent body of the Alta'ameem meteorite.

To meet the international curiosity and interest, and being a rare meteorite, the present scientific note is published to introduce new information on the mineralogy and mineral chemistry of the Alta'ameem meteorite. The analytical results presented here are based mostly on electron probe microanalysis and neutron activation analysis carried out in the Geological Survey of Hungary.

The new results include chemical analysis of bulk meteorite (major and trace elements) and electron probe microanalysis of kamacite, taenite, chromite, plagioclase, apatite, native copper, olivine and pyroxene. The results are presented in Tables (1 and 2). Indicator parameters for classification of the meteorite were calculated and presented in Table (3).

The results confirm that Alta'ameem meteorite is an olivine – hypersthene chondrite (Group C) based on mineralogical composition (Mason, 1962 and 1967) and it is a low-Fe chondrite (LL-Group) according to chemical composition based on Fe, V, Cu, Sc, Ir, Au and Ni contents and Co/ Ni ratio (Mason and Wiik, 1964, and Van Schmus and Wood, 1967). According to Kallemeyn *et al*. (1989) classification, it is an LL5 chondrite. The LL chondrites are the least abundant among ordinary chondrites. They are low in total Fe (19 – 22%), metallic Fe (0.3 – 3%), Fe in olivine (26 – 32 mole % Fa) and they contain the largest chondrules among ordinary chondrites (Tschermak 1964).

The Alta'ameem meteorite composition is consistent, as indicated by the multiple analysis carried out on separate samples and in different laboratories (Table 1). This chemical homogeneity indicates a metamorphic history, which is supported by the near disintegration of most chondrules (especially those composed of olivine, Fig.1c). The metamorphism of the meteorite is also indicated by the presence of well-developed plagioclase crystals (Fig.1e), the deficiency of Ni in the sulfide phase, the high Ni taenite phase (Al-Bassam, 1978) and the transparent and recrystallized matrix; all of which are considered evidence of relatively high degree of metamorphism (Van Schmus and Wood, 1967).

Most LL chondrites are thermally metamorphosed to petrologic types 5 and 6 (the most common among the LL chondrites), leading to equilibrated chondrules, homogeneous minerals composition and chondrules boundaries difficult to identify (Tschermak, 1964). However, not all chondrules have boundaries difficult to discern in the Alta'ameem meteorite, some of which (olivine and pyroxene chondrules) are with well-defined boundaries (Fig.1b and 1d). Rounded spheroids of metal phase (Ni-Fe) and chromite, sometimes forming linear trends, were noticed (Fig.1g and 1h). These microtextures were interpreted by Buseck *et al*. (1966) to indicate violent shock. Based on present and previous petrologic and chemical results, the Alta'ameem meteorite is accepted as an LL5 chondrite.

Table 1: Chemical analysis of bulk meteorite

	Major chemical constituents (wt. %)					**Trace elements (ppm)**			
	(1)	**(2)**	**(3)**	**(4)**	**(6)**		**(4)**	**(5)**	**(6)**
Fe	3.31	2.73	3.39	n.a	n.a	V	77	72	77.2
Ni	1.10	0.93	1.13	1.1	1.05	Cu	n.a	130	n.a
Co	0.05	0.05	0.05	0.05	0.05	Sc	8.4	9.1	8.25
FeS	6.58	6.96	6.48	n.a	n.a	Ce	n.a	19	n.a
SiO_2	40.76	40.73	39.48	n.a	n.a	Sm	0.2	0.2	0.2
TiO_2	0.09	0.09	0.28	n.a	n.a	Ir	0.42	0.41	0.37
Al_2O_3	2.26	2.25	2.25	2.19	2.26	Au	0.14	0.50	0.13
FeO	16.18	16.74	16.46	n.a	n.a				
MnO	0.32	0.33	0.40	0.34	0.34				
MgO	24.77	24.51	25.66	25.7	25.37				
CaO	1.93	1.89	1.47	1.87	1.87				
Na_2O	1.03	0.99	1.05	0.94	0.95				
K_2O	0.15	0.14	0.15	0.09	0.12				
P_2O_5	0.22	0.22	0.47	n.a	n.a				
Cr_2O_3	0.63	0.57	0.45	0.55	0.56				
H_2O^-	0.08	0.04	----	----	------				
Total	99.46	99.17	99.17						

n.a: not analyzed

(1) present study (analyst: C. Ahlsved, Hungary)

(2) present study (analyst: Ojanpera, Hungary)

(3) Al-Bassam, 1978 (analysts: M. Kandala, A. Al-Saud and Y. Al-Janabi, Geosurv-Iraq)

(4) Kallemeyn *et al*., 1989 (Institute of Geophysics and Planetary Physics, University of California, Los Angeles, USA)

(5) present study (analyst: J. Berczi, Hungary)

(6) average LL5 chondrites (Kallemeyn *et al*., 1989)

Table 2: Microprobe mineral analysis *

(1)	**Kamacite**: Fe 93.6 %, Ni 4.7%
(2)	**Taenite**: Fe 60.0%, Ni 31.4%
(3)	**Chromite** (average of 3 points): FeO 32.0 %, Cr_2O_3 55.2%, MgO 2.9 %, Al_2O_3 7.9%. Formula based on 32 oxygens: Fe 7.74, Cr 12.61, Mg 1.27, Al 2.72 (atoms/ unit cell)
(4)	**Olivine** (average of 4 points): SiO_2 36.8 %, FeO 25.5 %, MgO 37.7 %. Formula based on 4 oxygens: Si 0.98, Fe 0.56, Mg 1.49 (atoms/ unit cell). Average Fa 27.3 mole %
(5)	**Orthopyroxene** (average of 7 points, 2 grains): SiO_2 54.4%, FeO 16.8%, MgO 28.0%, CaO 1.2%. Formula based on 6 oxygens: Si 1.97, Fe 0.51, Mg 1.51, Ca 0.05 (atoms/ unit cell). Average Fs 24.6 mole %
(6)	**Plagioclase**: SiO_2 66.3%, Al_2O_3 21.2%, CaO 2.1%, K_2O 0.5%, Na_2O 9.4%. Formula based on 32 oxygens: Si 11.67, Al 4.39, Ca 0.41, K 0.12, Na 3.21 (atoms/ unit cell). An 11 mole %
(7)	**Apatite**: Cl-rich (chlor apatite)
(8)	**Clinopyroxene** rim around orthopyroxene: pigeonite
(9)	**Native copper** (described as chalcopyrite in Al-Bassam, 1978)

* Analyst: G. Dobosi, Hungary.

Table 3: CIPW norms (wt. %) and parameters collected from analysis in Table (1)

	(1)	**(2)**	**(3)**	**(4)**	**(6)**
Ol	47.76	47.59	53.24		
Hy	22.50	23.40	19.05		
Di	5.81	5.51	2.86		
Ab	8.71	8.37	8.88		
An	1.10	1.28	0.99		
Or	0.89	0.83	0.89		
Ap	0.52	0.52	1.11		
Ch	0.93	0.84	0.66		
Il	0.17	0.17	0.53		
Troilite	6.58	6.96	6.48		
Ni-Fe	4.46	3.71	4.52		
Total	99.43	99.19	99.21		
Fe-metal	3.31	2.73	3.39		
Troilite	6.58	6.96	6.48		
Fe-silicates	12.58	13.01	12.79		
Fe-troilite	4.18	4.42	4.12		
Fe-total	20.07	20.16	20.30	18.8	18.3
Fe-metal/ Fe-total	0.16	0.14	0.17		
Fe-total/ SiO_2	0.49	0.49	0.51		
SiO_2/ MgO	1.65	1.66	1.54		
Cox100/ Ni	4.55	5.38	4.42	4.55	4.76

(1) present study

(2) present study

(3) Al-Bassam (1978)

(4) Kallemeyn *et al*., (1989)

(6) Average LL5 chondrites (Kallemeyn *et al*., 1989)

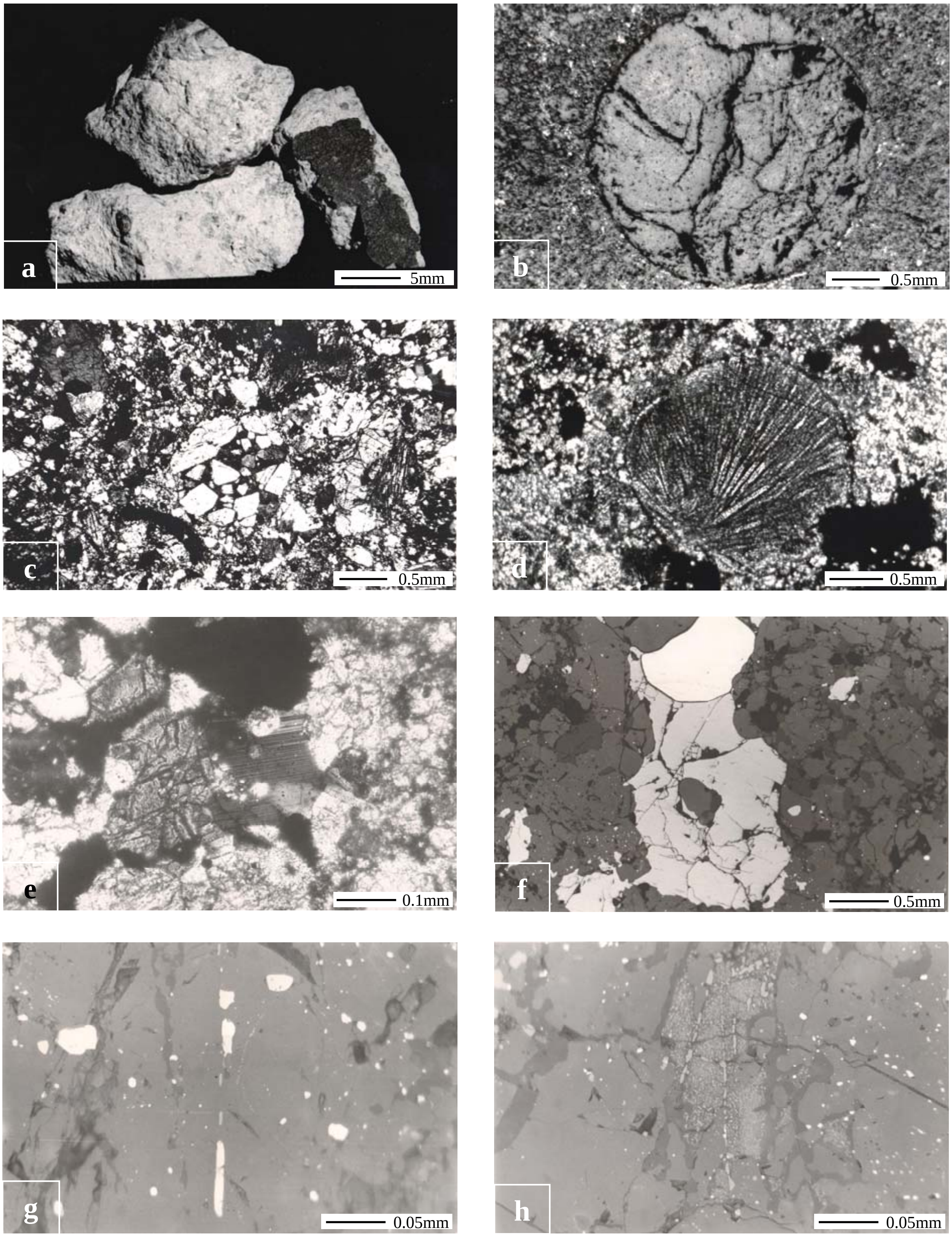

Fig.1: **(a)** hand specimens **(b)** well-defined olivine chondrule **(c)** recrystallized and deformed olivine chondrule **(d)** well-defined pyroxene chondrule **(e)** twinned plagioclase **(f)** Ni-Fe (white) and troilite (light gray) **(g)** Ni-Fe and troilite spheroids and oriented blebs **(h)** chromite (light gray) oriented blebs

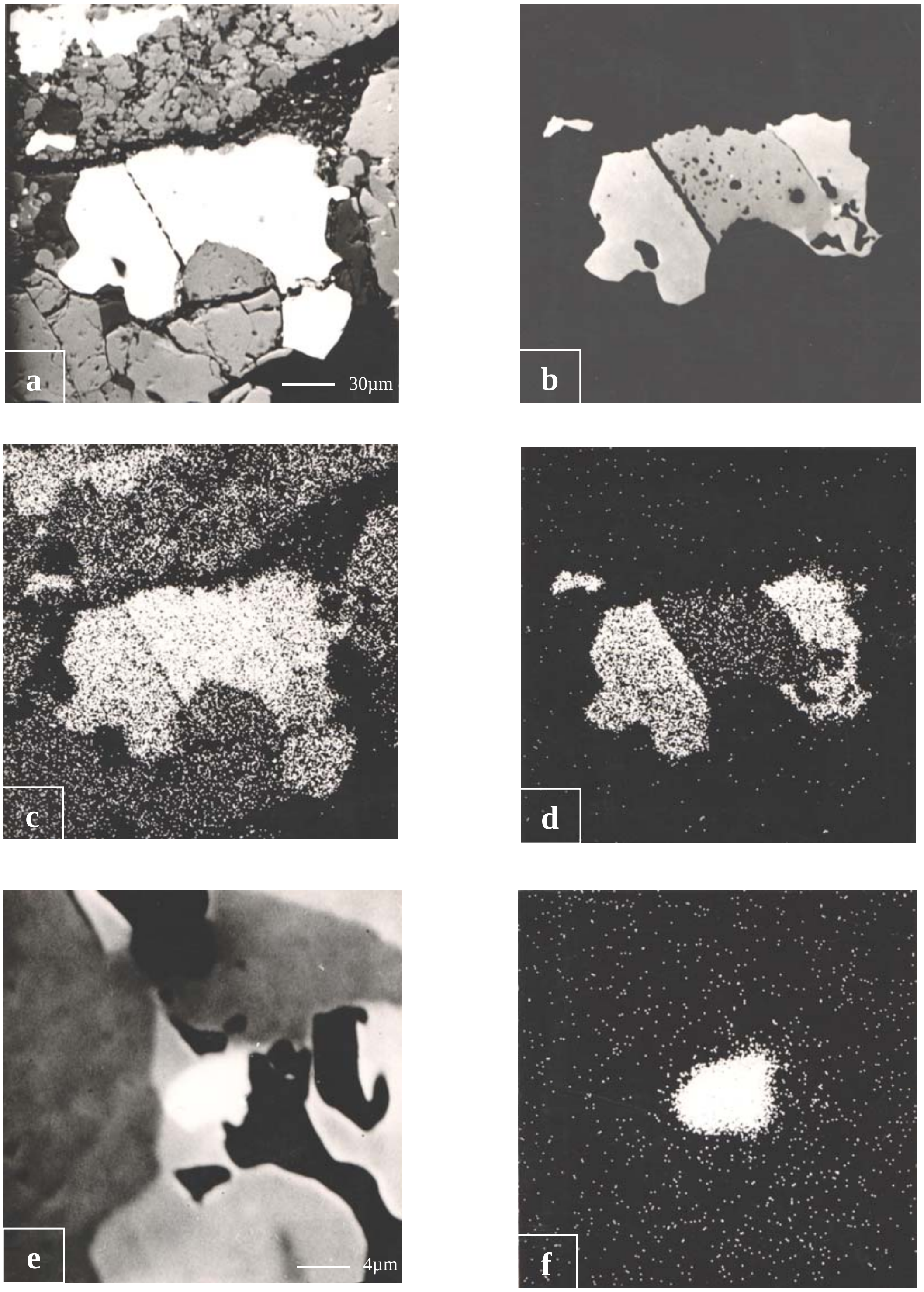

Fig.2: **(a)** Taenite and Kamacite (reflected light) **(b)** Backscattered electron image of (a) **(c)** Fe X-ray image **(d)** Ni X-ray image **(e)** Native copper backscattered electron image **(f)** Cu X-ray image

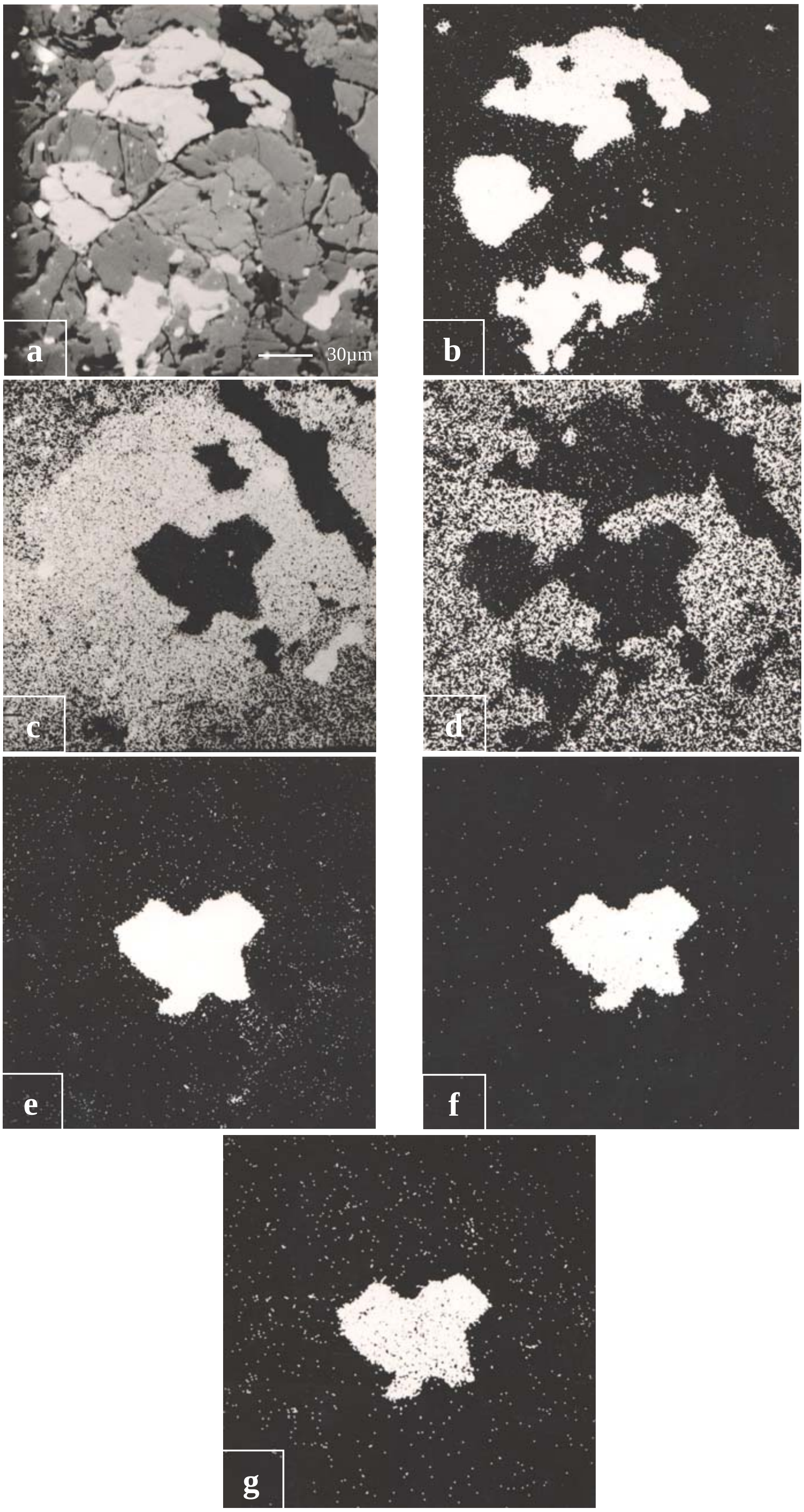

Fig.3: **(a)** Chromite/ apatite backscattered electron image **(b)** Cr X-ray image **(c)** Fe X-ray image **(d)** Mg X-ray image **(e)** P X-ray image **(f)** Ca X-ray image **(g)** Cl X-ray image

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