Geological Quarterly, 2001, **45** (3): 263–280

Petrography of the Baszkówka chondrite

Jacek SIEMIĄTKOWSKI

Siemiątkowski J. (2001) — Petrography of the Baszkówka chondrite. Geol. Quart., **45** (3): 263–280. Warszawa.

The Baszkówka chondrite comprises chondrules, individual crystals of olivine, xenomorphic concentrations of kamacite and troilite, matrix and pores up to 3.0 mm in diameter; porosity reaches 20% by volume. Measurements of 697 chondrules in an area of 250 m^2 enabled distinction of three populations. The chondrules and olivine crystals have been sintered at high temperatures. Six structural types showing transitions between porphyritic and granular structures have been discriminated. Rims showing a similar diversity surround about 10% of chondrules. The composition and structure of the chondrules suggest a source from the nebular dust disk around the Sun. The abudance of voids and their relatively large size and a lack of fissures, indicate a small size of the host body, which must have been derived from an early phase of protoplanet formation.

Jacek Siemiątkowski, Lower Silesian Branch, Polish Geological Institute, Jaworowa 19, PL-53-122 Wrocław, Poland (received: July 3, 2000; accepted: October 17, 2000).

Key words: ordinary chondrite (OC), chondrules, structures, petrography, classification, origin.

INTRODUCTION

Petrographic studies were based on microscopic observations of polished thin sections in transmitted and reflected light, and of polished sections in reflected light. In addition, X-ray diffraction and microprobe analyses previously published (Borucki and Stępniewski, 2001) were taken into consideration.

The Baszkówka chondrite consists of similarly sized automorphic and xenomorphic components showing a chaotic arrangement, numerous pores having a range of size and arrangement similar to those of the remaining chondrite components.

These components include automorphic individual crystals of olivine, automorphic chondrules, parautomorphic fragments of chondrules, xenomorphic fragments of kamacite and troilite, and small amounts of matrix. A preliminary petrographic description of this chondrite was published in 1998 (Siemiątkowski, 1998; Stępniewski *et al.*, 1998*a*, *b*).

CHONDRITE STRUCTURE

Apart from large its porosity, the most characteristic feature of this meteorite is numerous spherical and ellipsoidal chondrules (Pl. I, Figs. 1 and 2). The diameter of complete and fragmental chondrules varies from 0.04 to 3.0 mm. Systematic measurements were taken on polished sections within a selected area of 250 mm^2. Wholly preserved chondrules make up from 30 to 50% of the whole area examined (Table 1). In the Baszkówka meteorite 697 chondrules varying from 0.04 to 2.46 mm in size were found (Pl. II). Within 10 measured areas of 25 mm^2 each, the number of chondrules ranged from 45 to 92. The reliability of such measurements on thin sections was discussed on the basis of the two meteorites Bjurböle (L4) and Chainpur (LL3) by Hughes in 1978. As mentioned before, the chondrules are spheroidal and ellipsoidal. Their size was determined by measuring average diameters in circular sections, and minimal and maximal diameters in elliptical sections. Spheroidal chondrules constitute 60% of the total number. The histogram shows the diameter of spheroidal chondrules and the major diameter of elliptical ones (Figs. 1A, B).

Table 1

Planimetric analysis of polished section Baszkówka (B-1)

Appearance	Mineral	Number of measuring points						From-to
		10 000	2000	2000	2000	2000	2000	
Individual concentrations	troilite	6.10	6.1	7.5	6.9	5.6	4.1	4.1–7.5
	kamacite	2.63	2.8	2.1	3.4	2.0	2.9	2.0–3.4
	chromite	0.28	0.3	0.2	0.3	0.1	0.3	0.1–0.3
	silicates and voids	87.34	81.9	87.2	86.8	89.2	90.9	81.9–99.0
Inclusions in chondrules	troilite	0.46	1.4	0.5	trace	0.3	0.2	trace–1.4
	kamacite	0.23	0.5	–	0.1	0.5	–	0.0–0.5
	spinel	0.13	0.2	–	0.3	0.0	0.2	trace–0.3
	silicate	2.84	6.5	2.3	2.2	1.7	1.7	1.7–6.5
Total		100.01	99.7	99.8	100.0	99.4	100.3	–

Area 400 mm^2, measuring lines every 2 mm, stage interval 0.2 mm

Histograms show three populations: small chondrules are 0.04–0.29 mm in diameter, their total number being 336, medium ones range from 0.30–1.00 mm and number 323, and large ones range from 1.00–2.46 mm and number 39. The last-mentioned lie outside the histogram. These results are consistent with earlier published ones (Heide and Wlotzka, 1994).

Composite chondrules whose proportion exceeds 10% were also found too. These form adhering aggregates or interpenetrating clusters. This feature is shown by fine-grained chondrules of similar mineralogical composition, no larger than surrounding homogenous chondrules. A common rim usually envelops aggregates. In addition, aggregates may be completely surrounded by a larger chondrule generally of very different mineralogical composition. A comparable example is the L3 chondrite Y-74191 (Kitamura and Watanabe, 1985). Some elliptical chondrules in Baszkówka were formed by combining two spherical chondrules of the same mineralogical composition, yet in a fused state (protochondrules, chondrule precursors).

The surface of chondrules may be smooth or rough (Pl. III, Figs. 1–4). There are many surface types. Most of the chondrules show a granular surface, and consist of separate, mostly automorphic crystals of olivine and pyroxene. The crystals make up chondrules or surrounding rims. These minerals form thin rims or crust of individual crystal thickness. Some chondrules reveal abraded surfaces similar to those described by Kitamura and Watanabe (1985). This is seen especially in chondrules that contain non-fused crystals protruding out of their surface. Small protochondrules may adhere to chondrules forming composite chondrules (Pl. IV, Figs. 1–4) similar to those found in the Antarctic chondrite ALH-77015 (Nagahara, 1983*a*, *b*). The adherence results from a high surface tension of silicate or aluminosilicate alloy. No reaction between chondrule minerals was noted. Chondrules particularly small ones, may show indented surfaces (Pl. III, Figs. 3 and 4).

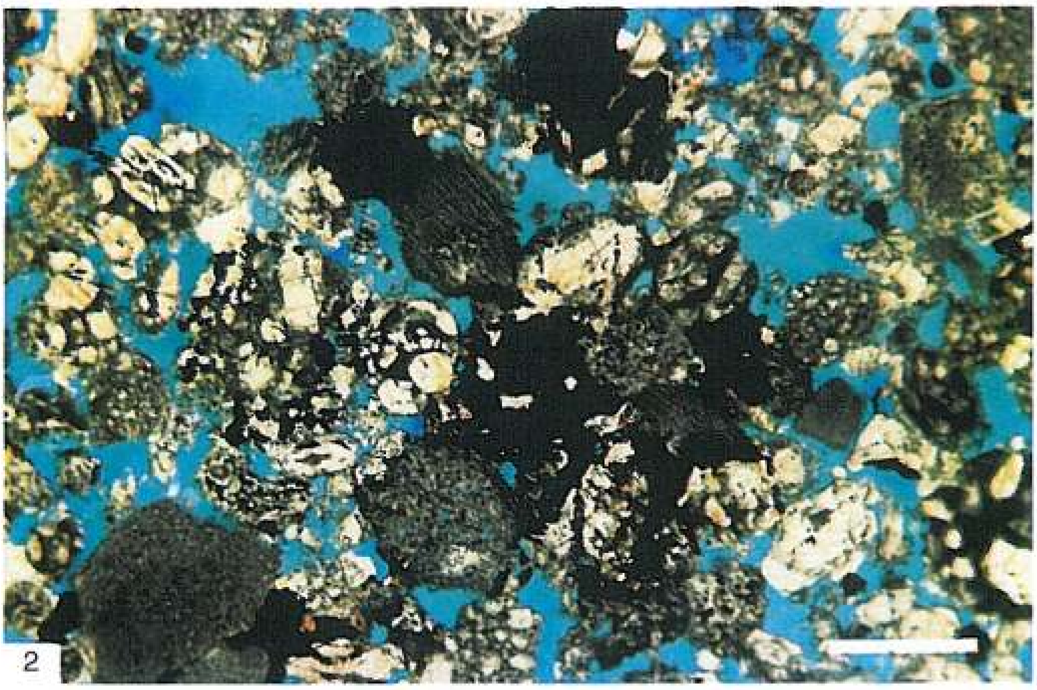
Fragments of chondrules with preserved portions of outer surfaces are numerous and easily identified (Pl. IV, Fig. 1). They reveal structures and mineral composition similar to those of neighbouring complete chondrules. The average and maximum sizes of chondrule fragments reach those of the complete chondrules, suggesting that the biggest fragments derive from yet larger chondrules, accreted to the chondrite after fragmentation. As these fragments make up about 30% (by volume) of chondrite, this process was very effective. No reactions or phase transitions were observed between minerals of adjacent chondrules or fragments.

The next chondrite constituent comprises separate olivine crystals of automorphic or panautomorphic shape, commonly with overgrowing epitaxial rims (Pl. V, Figs. 2a and b). This feature distinguishes them from olivines of similar composition infilling the inner parts of chondrules (Pl. V, Figs. 1a, 2a and b). Similar individual olivines were observed in the Benghazi meteorite (Żelaźniewicz, 1987).

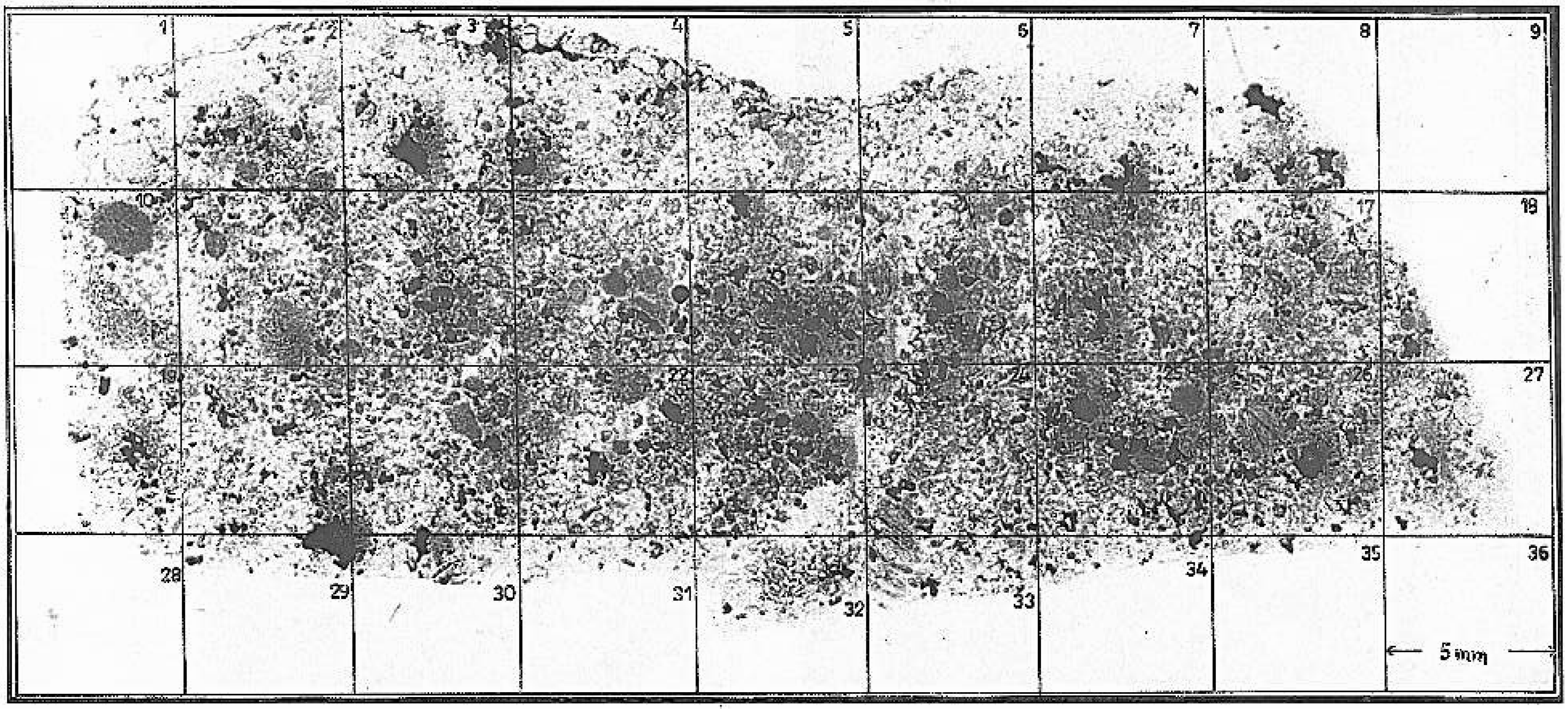
Chondrules and their fragments, and individual olivine crystals of the Baszkówka meteorite are slightly welded to one another as a result of sintering at high temperatures (corresponding at least to the melting point of feldspars).

Among the essential meteorite constituents (and simultaneously of its cement) are xenomorphic aggregates of troilite, kamacite and chromite; the amount of troilite is double that of kamacite (Table 1). Troilite contains tiny inclusions of xenomorphic chalcopyrite. Aggregates of these fusible constituents vary in size, reaching 1.4 mm. These adjoin chondrites and their fragments, as well as individual olivine crystals. These aggregates contain tiny ingrained automorphic olivine crystals of the same composition as those in chondrules (Borucki and Stępniewski, 2001). Concentrations of kamacite and troilite make about 10% of meteorite by volume; the high bulk density of these minerals makes their mass fraction higher, and highlights the low bulk density of the whole meteorite, of

PLATE I



1. Part of polished thin section B-10 encompassing areas: 3, 4, 12, 13, 21, 22, 30 and 31 marked in Table 2; scale bar 1 mm. ***2.*** Part of thin section (B1n) of chondrite filled with coloured resin, showing preserved primary meteorite voids; scale bar 1 mm

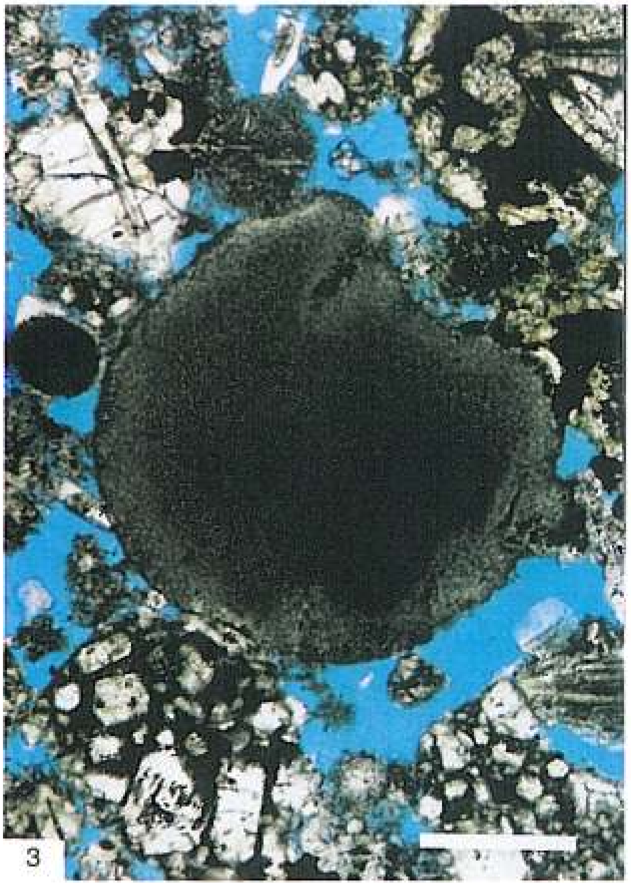


Scanned image (definition 600 x 600) of polished thin section, showing selected areas and numbers for statistical studies

PLATE III


1

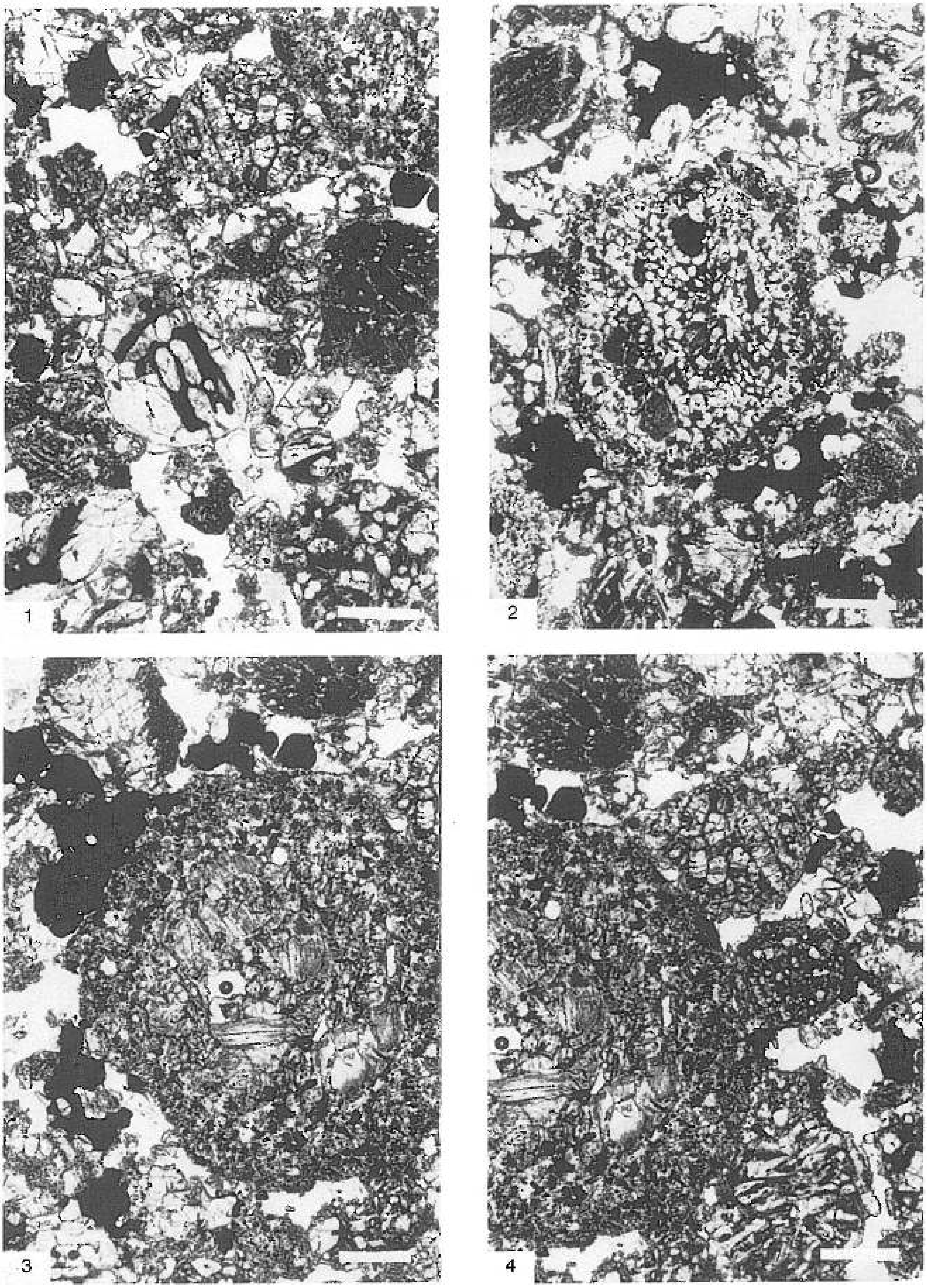

2


3


4

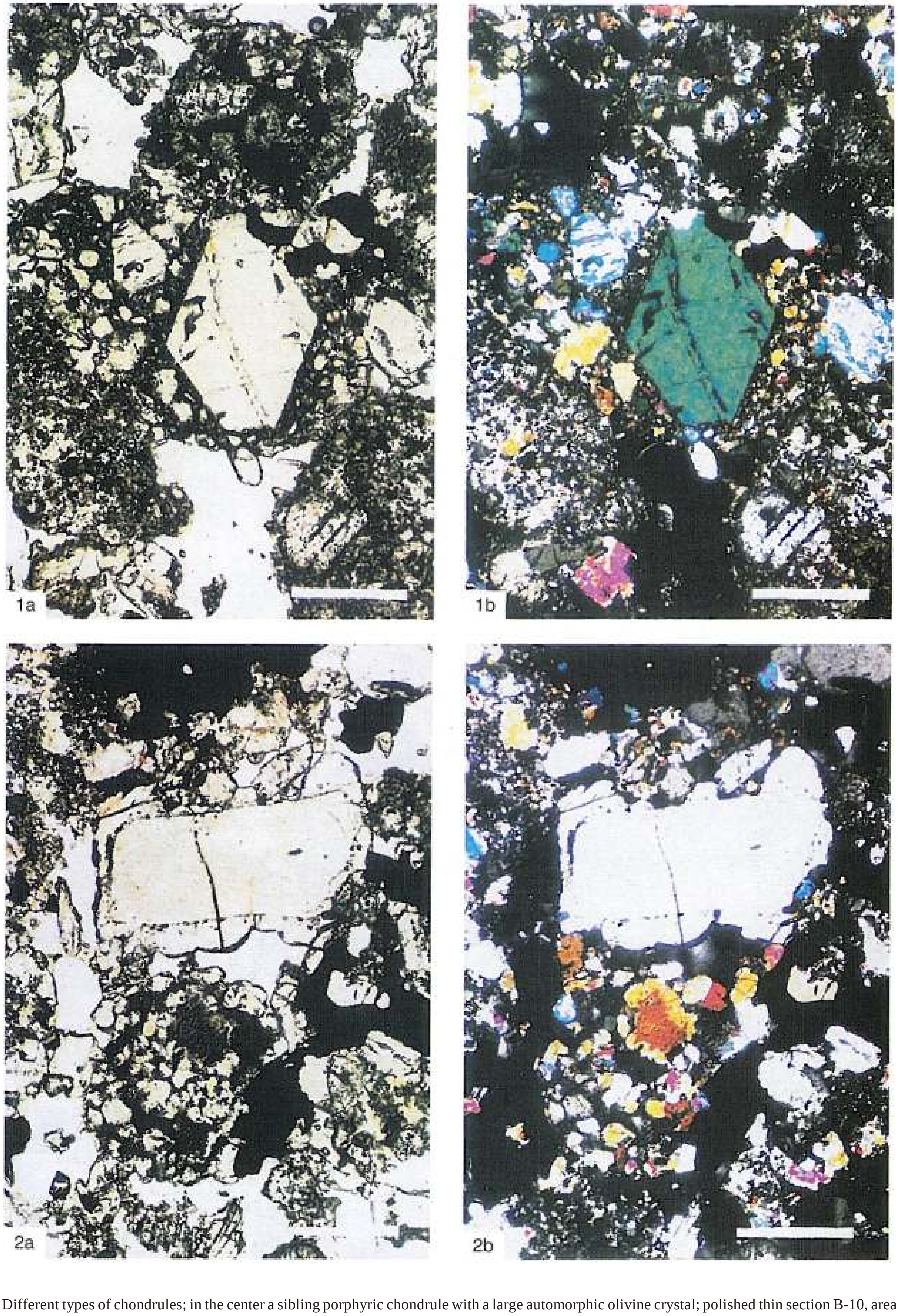
1. Natural fracture of chondrite with distinct chondrules and irregular voids; rusty speckles are coatings of iron hydroxides derived from terrestrial weathering of kamacite and troilite; scale bar 1 mm. ***2***. A typical chondrite fragment with distinct black voids; scale bar 1 mm. ***3.*** Different types of chondrules and their fragments; in the centre an indented chondrule; a thin section (B10) of chondrite filled with coloured resin; scale bar 0.5 mm. ***4.*** Part of photo from Figure 3; scale bar 0.25 mm

PLATE IV



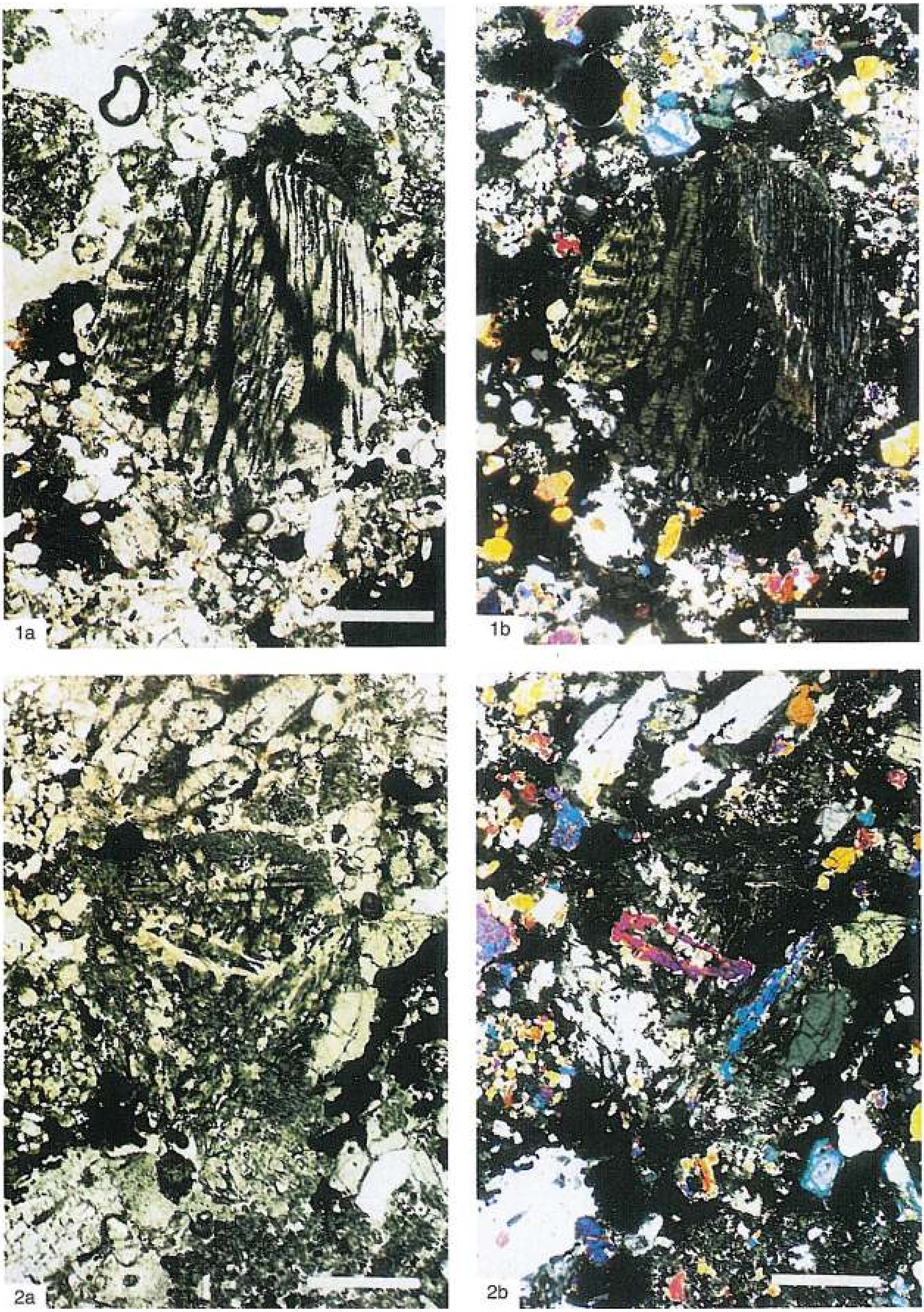
1. Different types of chondrules and their fragments; polished thin section B-10, area 16, chondrules: 4, 28, 33 and 34; scale bar 0.5 mm. ***2***. A porphyritic olivine chondrule with a rim abundant in opaque minerals; polished thin section B-10, area 14, chondrules: 1, 14 and 27; scale bar 0.5 mm. ***3***. A large olivine chondrule with a rim and adhering small chondrules; polished thin section B-10, area 16, chondrules: 1, 21, 22 and 23; scale bar 0.5 mm. ***4***. A large olivine chondrule with adhering opaque mineral concentrations; polished thin section B-10, chondrule 1; scale bar 0.5 mm

PLATE V



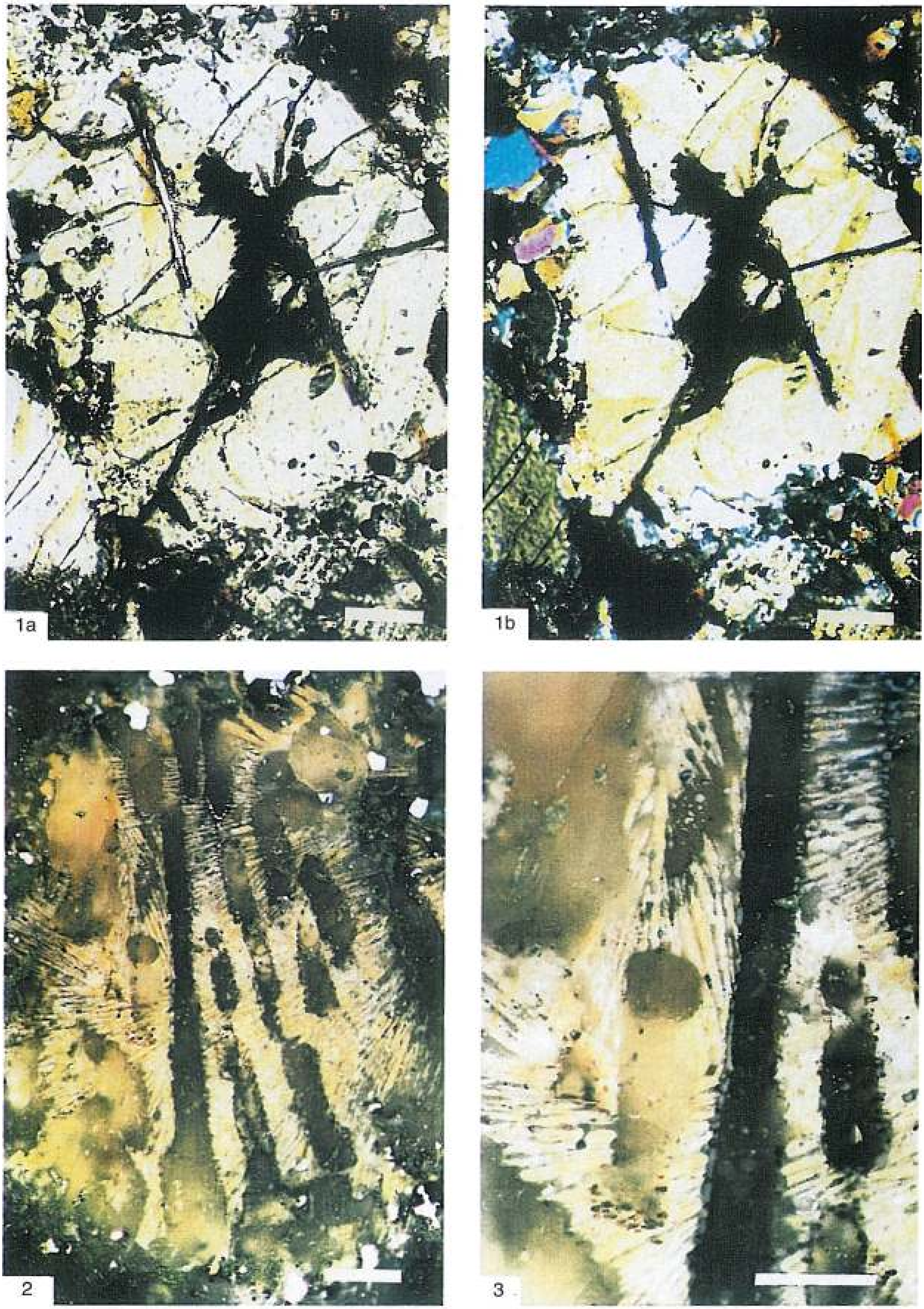
1a. Different types of chondrules; in the center a sibling porphyric chondrule with a large automorphic olivine crystal; polished thin section B-10, area 11, chondrules 28 and 29; scale bar 0.25 mm. ***1b***. As above, crossed nicols. ***2a***. An individual automorphic olivine with an epitaxial rim; polished thin section B-10, area 3, chondrule 15, and olivine; scale bar 0.25 mm. ***2b***. As above, crossed nicols

PLATE VI



1a. A sectorial porphyritic chondrule with a twinned pyroxene; polished thin section B-10, area 26, chondrule 1; scale bar 0.5 mm. ***1b***. As above, crossed nicols. ***2a***. A poikilitic pyroxene-olivine chondrule among fragments of different chondrule types; polished thin section B-10, area 17, chondrules: 1, 11 and 28; scale bar 0.5 mm. ***2b***. As above, crossed nicols

PLATE VII



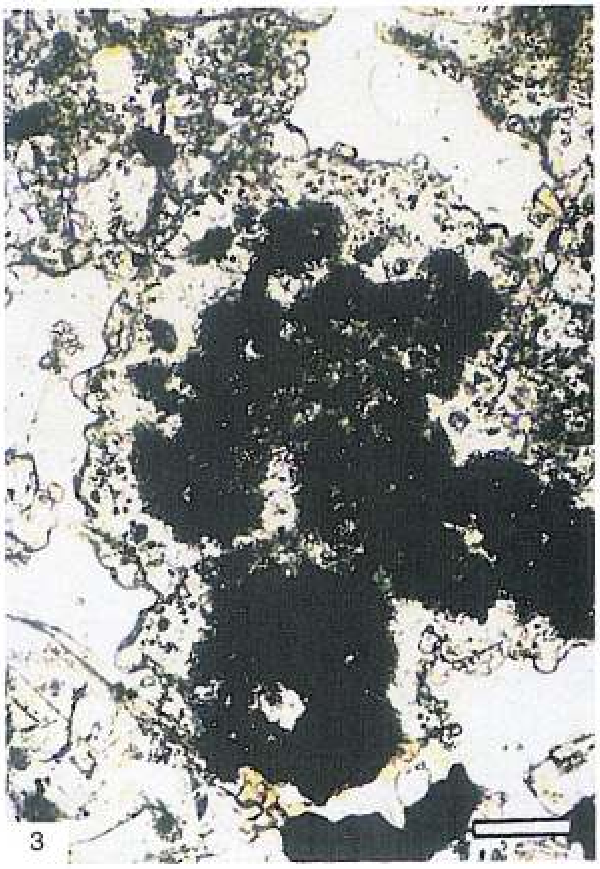
1a. A porphyritic olivine chondrule with feldspar mesostasis; showing contractional fissures; polished thin section B-10, area 14, chondrule 26; scale bar 0.01 mm. ***1b***. As above, crossed nicols. ***2***. A laminar olivine chondrule with abundant mesostasis composed of pyroxene, feldspar and chromite polished section B-2, reflected light; scale bar 0.1 mm. ***3.*** A fragment of photo from Figure 2; olivine — dark, Ca-pyroxene — light, chromite — gray; scale bar 0.01 mm

PLATE VIII

1a

1b

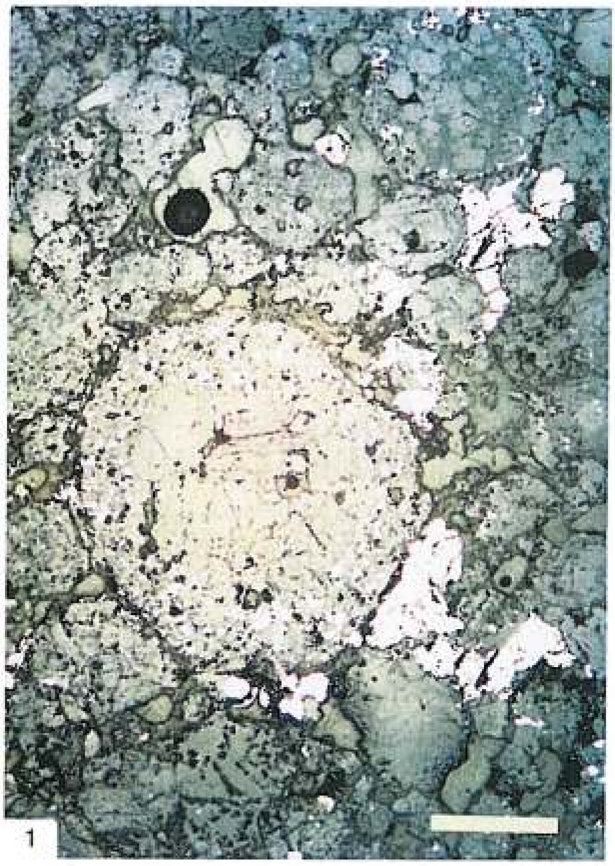
2



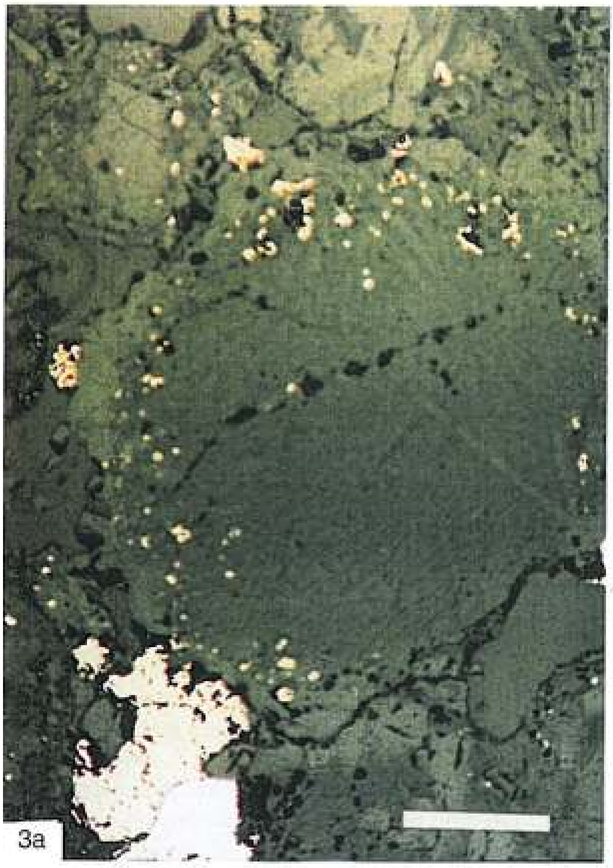
3

1a. A fine-grained composite olivine-pyroxene chondrule with a large olivine, coated with a rim with abundant troilite; polished thin section B-10, area 12, chondrules 20 and 37; scale bar 0.25 mm. ***1b***. As above, crossed nicols. ***2***. Different types of chondrules; in the centre a composite chromite-feldspar chondrule 0.25 mm in diameter; polished thin section B-10, area 11, chondrules: 34, 32, and partially 3; scale bar 0.25 mm. ***3.*** A composite chromite-feldspar chondrule; a fragment of photo from Fig. 2; scale bar 0.25 mm

PLATE IX


1


2


3a


3b

1. Chondrules with rims abundant in kamacite and troilite; nearby a large concentration of troilite (yellow) and kamacite (white); polished thin section B-10, area 16, chondrule 1, and area 6, chondrule 1 (bottom left); scale bar 1 mm. ***2***. A chondrule with troilite (yellow) and kamacite (white) surrounded with a rim enriched in troilite; polished thin section B2Ww; reflected light; scale bar 1 mm. ***3a***. A sectorial porphyritic chondrule with a rim abundant in troilite; polished thin section B-10, area 11, chondrule 2; reflected light; scale bar 0.25 mm. ***3b***. As above, crossed nicols

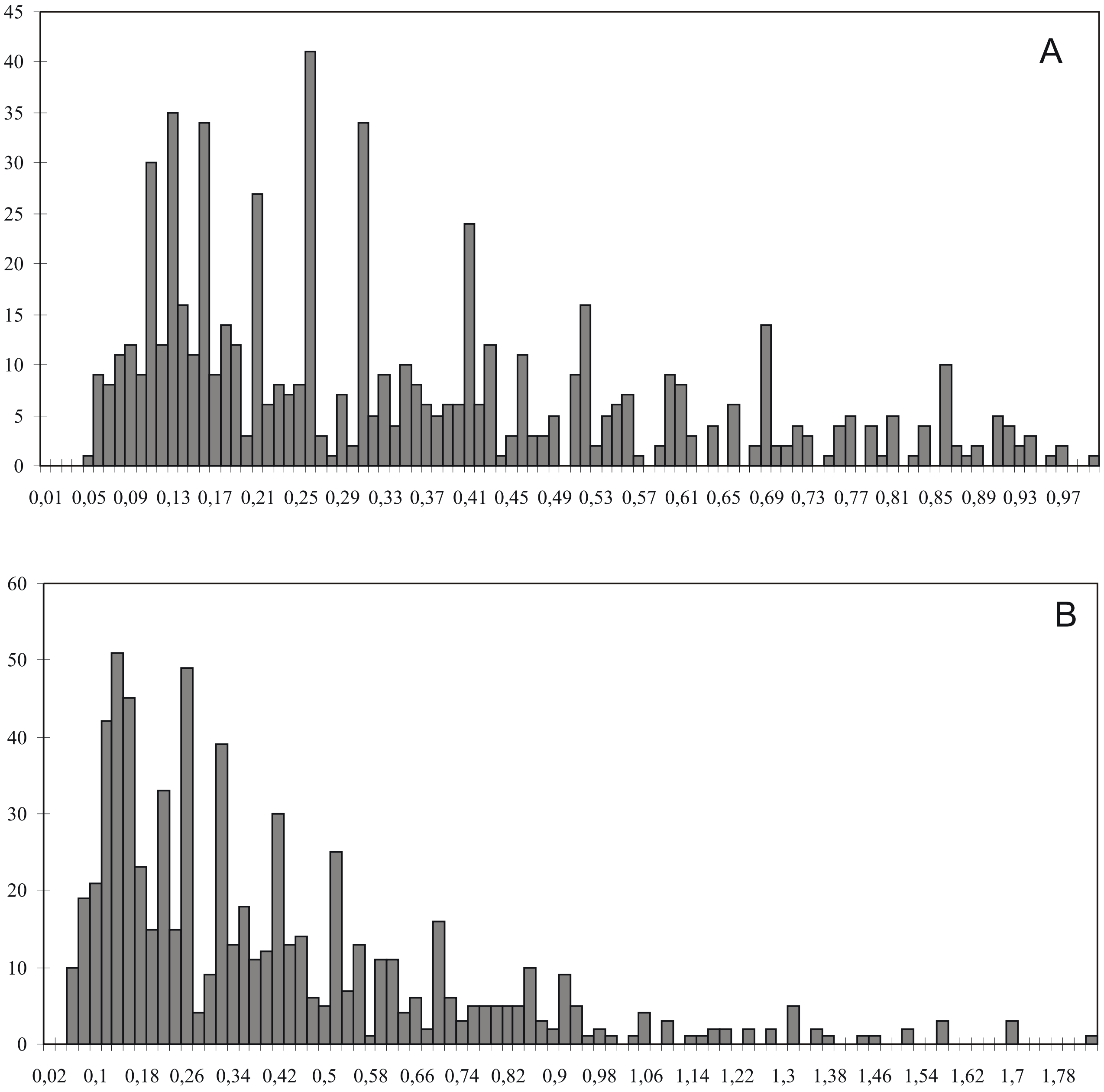


Fig. 1. Histograms showing average sizes of chondrules from the Baszkówka meteorite

A — for 659 chondrules varying from 0.04 to 1 mm in size, 0.01 mm intervals; B — for 696 chondrules varying from 0.04 to 2 mm in size, 0.02 mm intervals

2.9 g/cm^3. In one thin section, a small amount of matrix was found. It comprises tiny fragmented crystals of silicates (olivine and pyroxene), troilite and kamacite, locally associated with native copper and scarce void space.

Pores between chondrite ingredients vary from 0.01 to 3 mm in size and, play an important role. Most of these pores are elongated and chaoticically aligned (Pl. III, Figs. 1–4). The walls of these voids show small, usually automorphic silicate crystals; most of these walls are the same as the chondrule surfaces mentioned above. Other authors (Horii *et al*., 1990) describe similar structures. The Vatican collection also includes L type meteorites of low bulk density (Consolmagno and Britt, 1998). Flynn *et al.* (1999) described similar porous meteorites, including Bjurböle, Saratov, Mt. Tazerzait and Holbook.

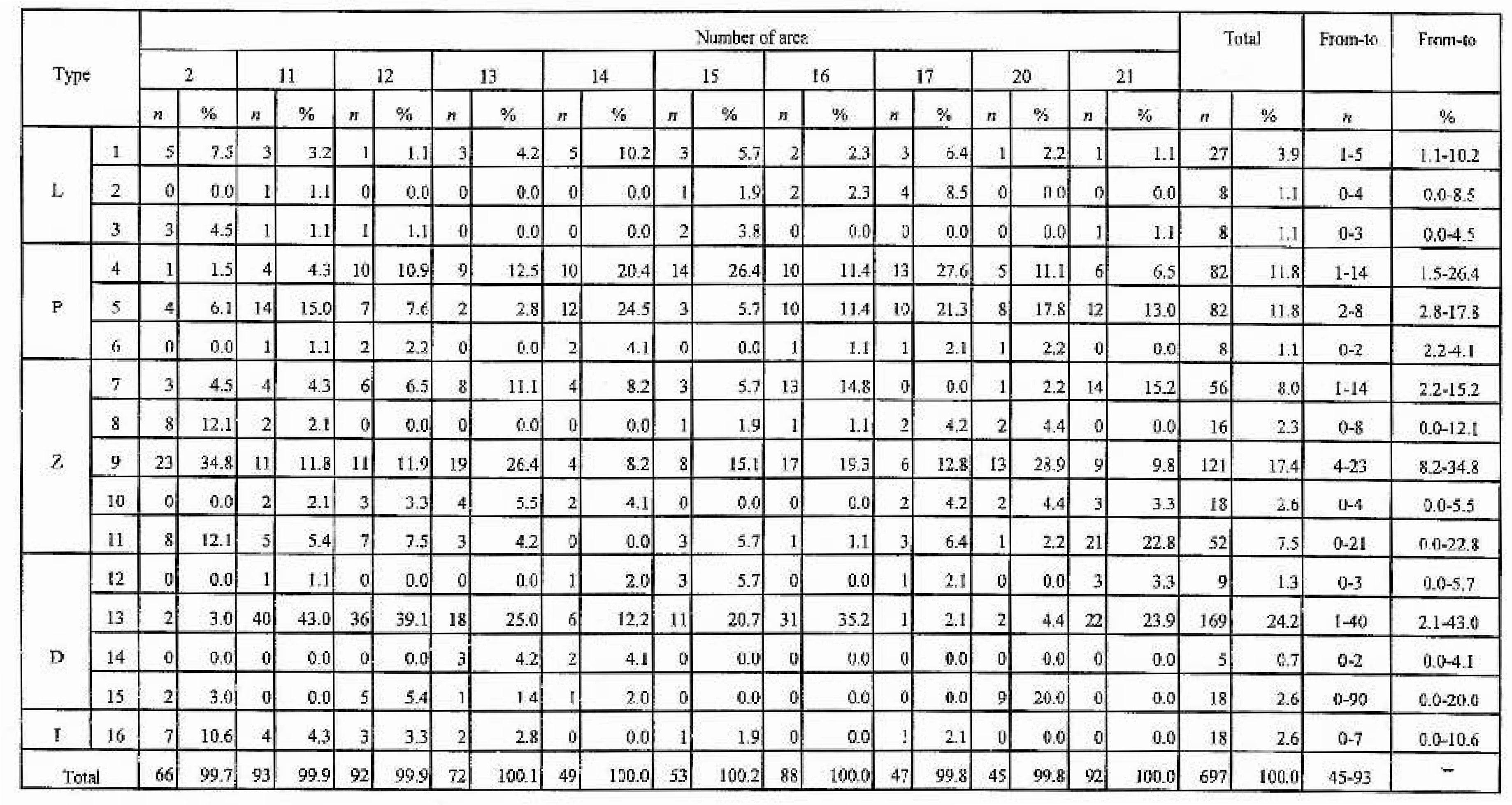
CHONDRULE STRUCTURE

Chondrule internal structure, including the size and aligment of crystals and texture, vary. Each chondrule shows individual features (Pl. III, Figs. 3 and 4). Nonetheless, there are some constraints to this variety. First, chondrites consist only of several minerals (olivine, orthopyroxene, clinopyroxene, feldspars, troilite, kamacite and chromite), second; second, the chondrule size determine the sizes of crystals.

Chondrule structures have aroused interest among researchers since the first descriptions were made by Sorby in 1864 and 1877, with more detailed work by Tschermak (1885), and numerous publications by Japanese and American petrologists on chondrites found in Antarctic ice-sheets. The results of

Table 2

Statistical analysis of structural types of Baszkówka meteorite chondrules in an area of 250 mm^2 in 10 areas of polished thin section (B-10)



Type		Number of area																				Total		From-to	From-to
		2		11		12		13		14		15		16		17		20		21					
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
L	1	5	7.5	3	3.2	1	1.1	3	4.2	5	10.2	3	5.7	2	2.3	3	6.4	1	2.2	1	1.1	27	3.9	1-5	1.1-10.2
	2	0	0.0	1	1.1	0	0.0	0	0.0	0	0.0	1	1.9	2	2.3	4	8.5	0	0.0	0	0.0	8	1.1	0-4	0.0-8.5
	3	3	4.5	1	1.1	1	1.1	0	0.0	0	0.0	2	3.8	0	0.0	0	0.0	0	0.0	1	1.1	8	1.1	0-3	0.0-4.5
P	4	1	1.5	4	4.3	10	10.9	9	12.5	10	20.4	14	26.4	10	11.4	13	27.6	5	11.1	6	6.5	82	11.8	1-14	1.5-26.4
	5	4	6.1	14	15.0	7	7.6	2	2.8	12	24.5	3	5.7	10	11.4	10	21.3	8	17.8	12	13.0	82	11.8	2-8	2.8-17.8
	6	0	0.0	1	1.1	2	2.2	0	0.0	2	4.1	0	0.0	1	1.1	1	2.1	1	2.2	0	0.0	8	1.1	0-2	2.2-4.1
Z	7	3	4.5	4	4.3	6	6.5	8	11.1	4	8.2	3	5.7	13	14.8	0	0.0	1	2.2	14	15.2	56	8.0	1-14	2.2-15.2
	8	8	12.1	2	2.1	0	0.0	0	0.0	0	0.0	1	1.9	1	1.1	2	4.2	2	4.4	0	0.0	16	2.3	0-8	0.0-12.1
	9	23	34.8	11	11.8	11	11.9	19	26.4	4	8.2	8	15.1	17	19.3	6	12.8	13	28.9	9	9.8	121	17.4	4-23	8.2-34.8
	10	0	0.0	2	2.1	3	3.3	4	5.5	2	4.1	0	0.0	0	0.0	2	4.2	2	4.4	3	3.3	18	2.6	0-4	0.0-5.5
	11	8	12.1	5	5.4	7	7.5	3	4.2	0	0.0	3	5.7	1	1.1	3	6.4	1	2.2	21	22.8	52	7.5	0-21	0.0-22.8
D	12	0	0.0	1	1.1	0	0.0	0	0.0	1	2.0	3	5.7	0	0.0	1	2.1	0	0.0	3	3.3	9	1.3	0-3	0.0-5.7
	13	2	3.0	40	43.0	36	39.1	18	25.0	6	12.2	11	20.7	31	35.2	1	2.1	2	4.4	22	23.9	169	24.2	1-40	2.1-43.0
	14	0	0.0	0	0.0	0	0.0	3	4.2	2	4.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	5	0.7	0-2	0.0-4.1
	15	2	3.0	0	0.0	5	5.4	1	1.4	1	2.0	0	0.0	0	0.0	0	0.0	9	20.0	0	0.0	18	2.6	0-90	0.0-20.0
I	16	7	10.6	4	4.3	3	3.3	2	2.8	0	0.0	1	1.9	0	0.0	1	2.1	0	0.0	0	0.0	18	2.6	0-7	0.0-10.6
Total		66	99.7	93	99.9	92	99.9	72	100.1	49	100.0	53	100.2	88	100.0	47	99.8	45	99.8	92	100.0	697	100.0	45-93	–

L — pared, P — porphyritic, Z — granular, D — fine crystalin, I — other

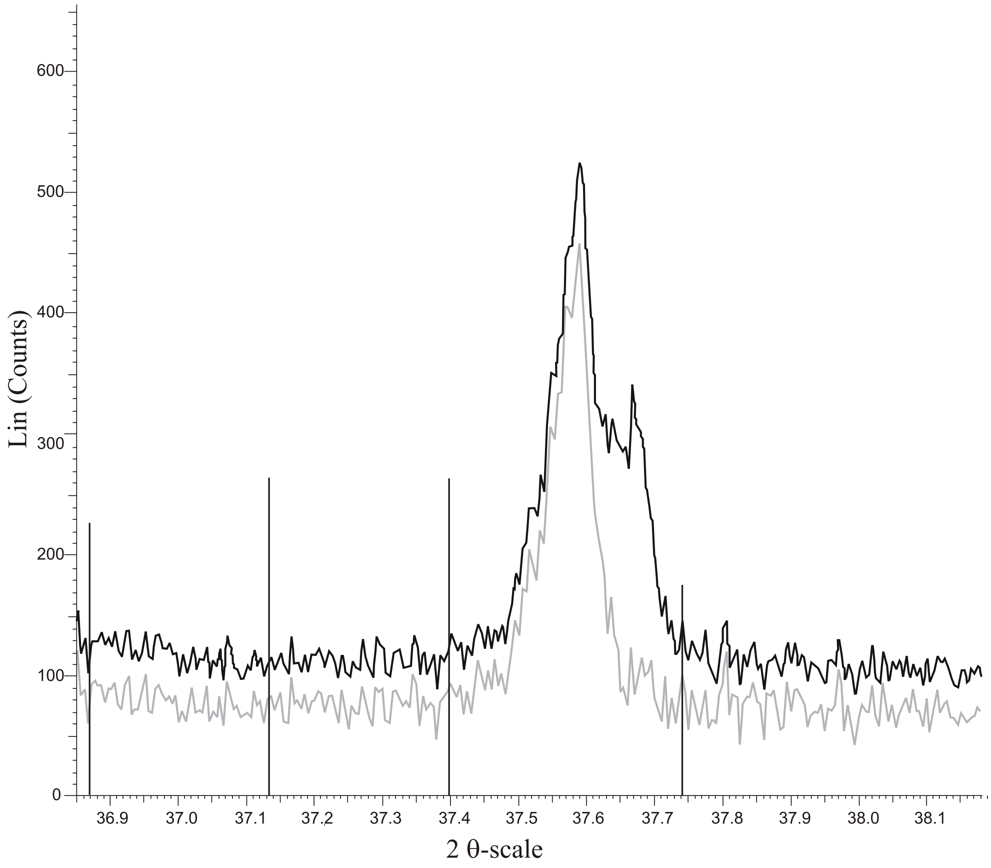


Fig. 2. Part of a diffraction pattern for silicate phases from the Baszkówka meteorite with d_{130} = 2.7772 Å (olivine)

The positions of planes d_{130} for synthetic fayalite (2Θ 36.87), Fe-forsterite (2Θ 37.74) and synthetic forsterite (2Θ 37.58) are marked; CoKα ray was used; black line — Kα, grey line — Kα1 (the analysis was made at the Institute of Geologic Sciences, Wrocław University)

these studies were published in special issues of the National Institute of Polar Research, Smithsonian Contribution to Astrophysics, and other publications. The scope of interest also includes meteorites which falled in the Poland's area.

As a result of these studies, six structural types of chondrules have been distinguished. They are as follows: laminar, radial, porphyric, granular, fine-grained, and others (Gooding and Keil, 1981; Nagahara, 1981; Wasson, 1993).

1. Lamella or "barred" (BO) chondrules consist of olivine or olivine and pyroxene, and feldspar mesostasis, commonly with chromite or only kamacite and troilite. A distinctive feature of most olivine laminar chondrules, often encountered in different varieties of meteorites, is of an outer crust closing laminae (Weisberg, 1987; Stępniewski *et al*., 1998*b*, figs. 17, 18, 20 and 21).

2. Radial chondrules are formed of fine-lamella or even needle-shaped pyroxenes. The spaces between these crystals are filled by feldspar mesostasis with tiny Ca-rich pyroxenes and a variable though small amount of kamacite, troilite and chromite (Pl. VI, Figs. 1a and b).

These two chondrule types (barred and radial) can be also divided into (1) chondrules whose laminae, parallel or radial, infill the whole object, and (2) chondrules which contain sectors of different orientation of parallel and radial laminae. These structures have been commonly described in chondrites (Manecki, 1972; Weisberg, 1987), and are the main reason why these chondrules were assigned to the same type, in the statistical analysis.

3. Porphyritic chondrules (relative to terrestrial and lunar volcanic rocks) are made of large crystals of olivine and/or pyroxene, and a variable fine-grained (mesostasis). This mesostasis consists of feldspar and monoclinic pyroxenes with a considerable amount of calcium and a variable amount of chromite, kamacite and troilite; chromite is more abundant than phosphate (whitlockite) (Borucki and Stępniewski, 2001). The mesostasis, composed of very fine-grained crystals with an admixture of opaque minerals, is black in transmitted light (Pl. VII, Figs. 1a and b). Individual crystals can be identified in reflected light images at high magnifications.

4. Granular chondrules consist of olivine and/or pyroxene crystals of the same size with little mesostasis. Like other types, these chondrules can contain variable amounts of kamacite, troilite and chromite. Some reveal poikilitic structure (Pl. VI, Figs. 2a and b) as found in other meteorites (Nagahara, 1983*a*; Scott and Taylor, 1983).

Table 3

Comparison of results in different areas (fields)

Type			Number of area						From-to	Total	
			2 +12 + 20		12 + 13 + 14		15 + 16 + 17				
			n	%	*n*	%	*n*	%	%	*n*	%
L	1	px	9	4.2	9	4.4	8	4.2	4.2–4.4	27	3.9
	2	px+ol	1	0.5	0	0.0	7	3.7	0.3–3.7	8	1.1
	3	ol	4	1.9	1	0.5	2	1.1	0.5–1.9	8	1.1
P	4	ol	10	4.7	29	14.1	37	19.7	4.7–19.7	82	11.8
	5	ol+px	26	12.1	21	10.2	23	12.2	10.2–12.2	82	11.8
	6	px	2	0.9	4	1.9	2	1.1	0.9–1.9	8	1.1
Z	7	ol	8	3.7	18	8.7	16	8.5	3.7–8.7	56	8
	8	ol+r	12	5.6	0	0.0	4	2.1	0.0–5.6	16	2.3
	9	ol+px	57	26.6	34	16.5	31	16.5	16.5–26.6	121	17.4
	10	px	4	1.9	9	4.4	2	1.1	1.1–4.4	18	2.6
	11	(ol+px)p	14	6.5	10	4.8	7	3.7	3.7–6.5	52	
D	12	ol	1	0.5	1	0.5	4	2.1	0.5–2.1	9	1.3
	13	ol+px	44	20.6	53	25.7	43	22.9	20.6–25.7	169	24.2
	14	krypto	0	0.0	5	2.4	0	0.0	0.0–2.4	5	0.7
	15	px	11	5.1	7	3.4	0	0.0	0.0–5.1	18	2.6
I	16	other	11	5.1	5	2.4	2	1.1	1.1–5.1	18	2.6
Total			214	99.9	206	99.9	188	100	605	697	100

px — piroxene, ol — olivine, p — poikilite, r — opaque minerals, krypto — cryptocrystalline; other explanations see Table 2

5. Fine-grained chondrules, like their cryptocrystalline equivalents, contain minerals hard to identify optically (Pl. VIII, Figs. 1 and 2).

6. Chondrules that do not fall into this classification are scarce. They includes chondrules composed primarily of feldspar with an admixture of chromite, or chromite chondrules with scarce feldspar mesostasis (Pl. VIII, Figs. 2 and 3), similar to those described by Ramdohr (1967, 1973) and Krot *et al.* (1993).

This division is arbitrary, especially when it comes to discriminating porphyritic chondrules with scarce mesostasis, and equigranular ones with a large amount of mesostasis; there are transitional forms between porphyritic and granular structures.

Each structural type has been further divided taking into account the presence of the main silicates (olivine and pyroxene) and opaque minerals (kamacite, troilite and chromite). This division enabled the distinction of 16 chondrule types: calculation has been made of their percentage concentrations in the Baszkówka chondrite. These were established on a polished thin section (B-10), in which 10 squares of 5 by 5 mm (25 mm^2) were selected. In these 10 areas, totalling 250 mm^2, 463 single chondrules and 87 aggregates of interpenetrating chondrules (including 34 sibling chondrules) were found. This enabled measurement and classification of 697 chondrules. These were counted in each area, starting with the largest. The observations were carried out simultaneously using two microscopes, using reflected and transmitting light respectively. Examinations in reflected light are especially useful for determining very fine-grained mesostasis, opaque in transmitting light. These studies indicated that more than half of the chondrules contain variable amounts (or at least traces) of troilite, kamacite and chromite. The results are presented in Table 2. Differences in the number of particular chondrule types in consecutive areas are distinct enough, but distributed chaotically, as indicated by calculations shown in Table 3. Comparison with studies of structural types in other chondrites is shown in Table 4. Chondrules from the Baszkówka meteorite are similar to those described by Sobotovich and Semenenko (1984), whereas the frequency of chondrule occurrence per surface unit is similar to that in carbonaceous chondrites described by Baryshnikova *et al.* (1991). These results differ from data derived from chondrites of higher petrographic types.

CHONDRULE RIMS

Rims which in composition and structure show a similar diversity to the chondrules themselves surround some of the chondrules in the Baszkówka meteorite. Such phenomena have been observed in other chondrites (Rubin and Krot, 1996). In microscopic thin sections about 10% of such chondrules were noted (Pl. IV, Fig. 2; Pl. IV, Figs. 3 and 4; Pl. IX, Figs. 1, 2, 3a

Table 4

Percentage content comparison of structural chondrule types in different meteorites

Description of the lines	Bishunpur Hallingeberg Saratov Tennasilim	ALH 77015	Krymka Andreevka Saratov Carev Elenovka	Krymka	Kainasaz	Different 12	Baszkówka
Type of chondrite	L3 + L4	L3	L3 + L4 + L5	L3	CO	H + L = LL	L5
Number of chondrules	528	108	627	422	536	1674	697
Area of section	?	?	1290 mm^2	650 mm^2	132 mm^2	?	250 mm^2
Frequency per 100 mm^2	about 131 per section	?	48	65	406	140	279
Porphyric	82%	52.7%	41.4%	39%	11.6%	81%	24.7%
Bar	3%	9.2%	2.3%	2%	5.6%	4%	2.3%
Radial	9%	12%	8.6%	6%	0.0%	7%	3.9%
Granular	2%	19.4%	35.6%	465%	77.6%	3%	37.7%
Fine-grained	3%	5.5%	12.1%	7%	3.6%	5%	28.8%
Others	1%	0%	0%	0%	1.5%	0%	2.6%
Author	Gooding and Keil(1981)	Nagahara (1981)	Sobotovich and Semenenko (1984)	Sobotovich and Semenenko (1984)	Baryshnikova *et al.* (1991)	Wasson (1993)	Siemiątkowski (this issue)

and b). Of the rims mentioned, numerous types revealing a similar diversity to chondrules can be identified:

1. Rims concordantly overgrowing chondrule minerals are enriched primarily with small inclusions of fusible constituents, i.e. kamacite, troilite, chromite and feldspars.

2. Fine-grained rims of composition similar to that of chondrule mesostasis.

3. Rims showing an abundance of troilite, kamacite and chromite; see Metzler and Bischoff (1996).

4. Rims forming more porphyric structures than the centre of chondrule, i.e. those showing more mesostasis.

5. Fine-grained rims of composition different that of the enclosed to chondrule, for example, a pyroxene chondrule with an olivine rim (Stępniewski *et al.*, 1998*b*, figs. 19 and 20).

CONCLUSIONS

The structure of the chondrules and their surrounding matrix corresponds to petrographic type “5”. This is not the effect of thermal metamorphism, but the conditions in which the chondrules and their fragments formed and accumulated. The fragments show the same composition as complete chondrules. There is a lack of feldspar and of tiny inclusions of kamacite and troilite, which are common in the matrix of other chondrites, indicating the unique position of the Baszkówka chondrite.

The considerable number of chondrule fragments and the presence of individual olivine crystals indicates that the constituents of the Baszkówka meteorite, prior to accretion of host chondrite, were subject to disintegration.

The loosely-packed chondrules and their fragments, a nearly total lack of matrix and thermal reactions between minerals of contacting chondrules indicate an absence of thermal metamorphism.

The Baszkówka meteorite, in the proportion of preserved chondrules, resembles chondrites of the 3rd petrographic type, for example Bjurböle and Saratov, and carbonaceous meteorites (Hughes, 1978; Baryshnikova *et al.*, 1991).

The olivines (Fig. 2), and Ca-depleted pyroxenes and clinopyroxenes, show equilibrium crystallisation and indicate assignation of this meteorite to equilibrium chondrites of group L. Points in the fayalite-forsterite diagram (Fig. 3) for mineral pairs occurring in one chondrule, and pure olivine and pyroxene chondrules correspond with meteorites assigned to group L. These occur close to the main chondrite trend characteristic for chondrites (Yanai and Koijma, 1991) and to heavier ordinary chondrites (OC) selected from the list published in *Meteoritical*

Bulletin No. 79 (Grossman and Score, 1996), No. 82 (Grossman, 1998), and from Roosevelt Country (Scott *et al*., 1986).

The mesostasis in the most typical chondrules corresponds to the A5 area distinguished by Sears *et al*. (1992 *fide* Huang and Sears, 1997; 1995). The results obtained confirm the high petrographic degree of this meteorite.

A diversity of structure and mineralogical composition, the presence of rims, sibling chondrules and interpenetrating clusters, as well as different amounts of kamacite, troilite and chromite and considerable differences in chondrule size indicate that the source of minerals for the chondrules must have been a nebula of dust around the Sun, not a protoplanet formed and affected by differentiation (Boss, 1996; Hood and Kring, 1996). The abundant and substantial voids and the great number of complete chondrules and large fragments, as well as a lack of fissures in the chondrite, indicate the small size of parent body. Contractional fissures only are present in olivines (Pl. VII, Figs. 1a and b). The structure of the chondrite and its low bulk density highlight the uniqueness of the Baszkówka meteorite, though it is similar to other meteorites, including Bjurböle, Islafegh, Holbrook, Mt. Tazerzait, Saratov (Flynn *et al*., 1999) and to some Antarctic meteorites (Matsui *et al*., 1980).

The parent body of the Baszkówka meteorite must have been derived from an early stage of protoplanet formation, in the course of which no thermal metamorphism and brecciation occurred. This is the main reason why the porosity (and low bulk density) of the chondrite was preserved see also Scott *et al*. (1986).

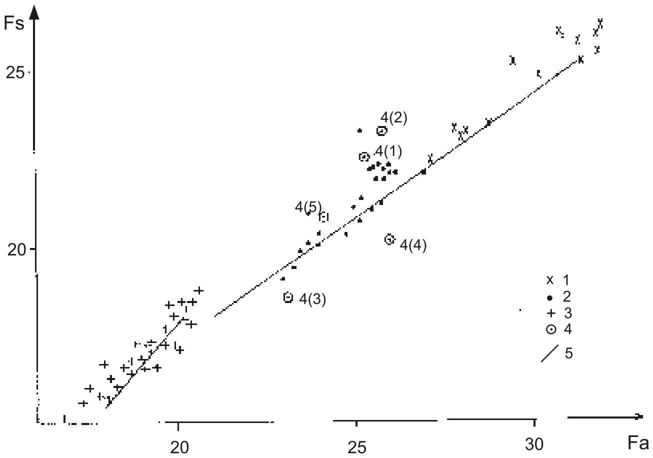


Fig. 3. The content of iron expressed in molecular percentage for olivine — Fe_2SiO_4 (fayalite) and $FeSiO_3$ (ferrosilite), and Ca-depleted pyroxene in equilibrium chondrites

1 — chondrite group LL; 2 — chondrite group L; 3 — chondrite group H (according to Scott *et al*., 1986; Grossman and Score, 1996; Grossman, 1998); 4 — chondrite group L, Baszkówka (Fa/Fs): 4(1) — 25.3/22.4, 4(2) — 25.8/23.2, 4(3) — 23.1/18.4, 4(4) — 26.0/20.1, 4(5) — 24.2/20.8; 5 — Fa-Fs correlation in chondrites after Yanai and Koijma (1991)

Acknowledgements. The author thanks Prof. Dr. hab. M. Sachanbiński and Dr. hab. N. Bakun-Czubarow for valuable remarks on the text. Colleagues of mine from different scientific institutes in Wrocław, including S. Achramowicz, M. Awdankiewicz, J. Badura, S. Dziągwa, B. Przybylski and P. Raczyński helped with photography, for which I express my gratitude. I also thank Dr. C. August for X-ray diffraction analysis.

REFERENCES

BARYSHNIKOVA G. V., STAKHEEV S. A., IGNATIEVA K. I., LAVRENTIEVA A. K. and LAVRUKHINA A. K. (1991) — Khondry khondryta Kainsaz CO: sostav silikatnykh mineralov, ikh assocjacij i sravnene s khondrami drugikh uglistykh i obyknavennykh khondritov. Meteoritika, **50**: 37–51.

BORUCKI J. and STĘPNIEWSKI M. (2001) — Mineralogy of the Baszkówka chondrite (L5S1): new data on silicates, opaques and minor minerals. Geol. Quart., **45** (3): 229–255.

BOSS A. P. (1996) — A concise guide to chondrule formation models. In: Chondrules and the Protoplanetary Disk (eds. R. H. Hewins, R. D. Jones and E. R. D. Scott): 257–263. Cambridge Univ. Press.

CONSOLMAGNO G. J. and BRITT D. T. (1998) — The density and porosity of meteorites from the Vatican collection. Meteor. Planet. Sc., **33**: 1231–1241.

FLYNN G. J., MOORE L. B. and KLOCK W. (1999) — Density and porosity, cratering, and collisional disruption of asteroid. Icarus, **142**: 97–105.

GOODING J. L. and KEIL K. (1981) — Relative abundances of chondrule primary textural types in ordinary chondrites and their bearing on conditions of chondrule formation. Meteoritics, **16**:17–43.

GROSSMAN J. N. (1998) — Saharan meteorites from: Libya and Niger. Meteor. Bull., **82**. Meteor. Planet. Sc., **33**: A227–A234.

GROSSMAN J. N. and SCORE R. (1996) — Recently classified specimens in the United States Antarctic Collection (1994–1996). Meteor. Bull., **79**. Meteor. Planet. Sc., **31**: A161–A174.

HEIDE F. and WLOTZKA F. (1994) — Meteorites. Messenger from Space. Springer Verlag. Berlin.

HORII Y., FUIJ N. and TAKEDA H. (1990) — Hardness analysis of metallic particles in ordinary chondrites. Proc. NIPR, Symp. Antarctic Meteorites, **3**: 254–263.

HOOD L. L. and KRING D. A. (1996) — Models for multiple heating mechanisms. In: Chondrules and Protoplanetary Disk (eds. R. H. Hewins, R. D. Jones and E. R. D. Scott): 265–276. Cambridge Univ. Press.

HUANG S. and SEARS D. W. G. (1997) — Formation and metamorphism of group A5 chondrules in ordinary chondrites. Geochim. Cosmochim. Acta, **61** (21): 4689–4704.

HUGHES D. W. (1978) — A disaggregation and thin section analysis of the size and mass distribution of the chondrules in the Bjurböle and Chainpur meteorites. Earth. Planet. Sc. Lett., **119**: 569–584.

KITAMURA M. and WATANABE S. (1985) — Adhesive growth and abrasion of chondrules during the acreation process. Mem. NIPR, Spec. Issue, **41**: 22–234.

KROT A. N., IVANOVA M. A. and WASSON J. T. (1993) — The origin of chromitic chondrules and the volatility of Cr under a range of nebular conditions. Earth Planet. Sc. Lett., **119**: 569–584.

MATSUI T., HOMANO Y. and HONDA M. (1980) — Porosity and compressional-weve velocity measure of Antarctic meteorites. Mem. NIPR, Spec. Issue, **17**: 268–275.

MANECKI A. (1972) — Mineralogical and petrographical study of the Pułtusk meteorite (in Polish with English summary). Pr. Miner. Komis. Nauk Miner. PAN Kraków, **27**: 53–65.

METZLER K. and BISCHOFF A. (1996) — Constraints an chondrite agglomeration from fine-grained chondrules rims. In: Chondrules and Protoplanetary Disk (eds. R. H. Hewins, R. D. Jones and E. R. D. Scott):153–161. Cambridge Univ. Press.

NAGAHARA H. (1981) — Petrology of chondrules in ALH –77015 (L3) chondrite. Mem. NIPR, Spec. Issue, **20**: 145–160.

NAGAHARA H. (1983*a*) — Texture of chondrules. Mem. NIPR, Spec. Issue, **30**: 71–83.

NAGAHARA H. (1983*b*) — Chondrules formed through incomplete melting of the pre-existing mineral dusters and the origin of chondrules. In: Chondrules and their Origin: 211–222. Houston.

RAMDOHR P. (1967) — Chromite and chromite chondrules in meteorite. Geochim. Cosmochim. Acta, **31**:1961–1967.

RAMDOHR P. (1973) — The Opaque Minerals in Stony Meteorites. Berlin.

RUBIN A. and KROT A. N. (1996) — Multiple heating of chondrules. In: Chondrules and the Protoplanetary Disk (eds. R. H. Hewins, R. D. Jones and E. R. D. Scott): 173–180. Cambridge Univ. Press.

SCOTT E. R. D. and TAYLOR G. J. (1983) — Chondrules and other components in C, O, and E chondrites: similarites in their properties and origin. J. Geophys. Res., suppl., **88**: B275–B286.

SCOTT E. R. D., TAYLOR G. F. and KEIL K. (1986) — Accretion, metamorphism, and brecciation of ordinary chondrites: evidence from petrological studies of meteorites from Roosevelt County, New Mexico. J. Geophys. Res., **91**: E115–E123.

SEARS D. W. G., HUANG S. and BENOIT P. H. (1995) — Chondrule formation, metamorphism, brecciated an important new primary chondrule group and the classification of chondrules. Earth. Planet. Sc. Lett., **131** (1–2): 27–39.

SIEMIĄTKOWSKI J. (1998) — Petrografia chondrytu Baszkówka. Pol. Tow. Miner., Pr. Spec., **11**: 160–161.

SOBOTOVICH E. V., SEMENENKO V. P. (1984) — Veschestvo meteoritov. Naukova Dumka. Kijev.

SORBY H. C. (1864) — On the microscopical structure of meteorites. Proc. Roy. Soc., **13**: 333–334.

SORBY H. C. (1877) — On the structure and origin of meteorites. Nature, **15**: 495–498.

STĘPNIEWSKI M., BORUCKI J. and SIEMIĄTKOWSKI J. (1998*a*) — New data on the L5(S1) chondrite Baszkówka (Poland). 61th Meteoritical Society Meeting, July 27–31,1998, Trinity College, Dublin. Meteor. Planet. Sc., suppl., **33** (4): A150–A151.

STĘPNIEWSKI M., SIEMIĄTKOWSKI J., BORUCKI J. and RADLICZ K. (1998*b*) — Fall, recovery and preliminary study of the Baszkówka meteorite (Poland). Arch. Miner., **51** (1–2): 131–152.

TSCHERMAK G. (1885) — The microscopic properties of meteorites. Smithson. Cont. Astroph., **4** (6).

WASSON J. T. (1993) — Constrains on chondrule origins. Meteoritics, **24**: 14–28.

WEISBERG M. K. (1987) — Barred olivine chondrules in ordinary chondrites. J. Geophys. Res., **92** (4): E663–E678.

YANAI K. and KOIJMA H. (1991) — Yamato — 74 063: chondritic meteorite classified between E and H chondritic groups. Proc. NIPR, Symp. Antarctic Meteorites, **4**: 118–130.

ŻELAŹNIEWICZ A. (1987) — On the Benghazi meteorite. Acta Univ. Wratisl., **788**. Pr. Geol. Miner., **10**: 91–97.