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THE MINNICHHOF METEORITE

Cs. L. Ravasz, M. Emszt and Gy. Pantó

ABSTRACT

The dominant minerals of the Minnichhof meteorite are olivine ($Fa_{25.3}$) and hypersthene ($Fa_{21.5}$) with nickel-iron (kamacite, taenite, plessite), plagioclase (An_{12}), diopside of minor quantity and accessory chromite, merrillite, ilmenite, daubréelite and limonite. Specific gravity: 3.53.

On the basis of the given electron-probe microanalysis as well as the complete chemical analysis, *X*-ray diffractometric diagrams, spectrographical and mineral-petrographical examinations the stone is an olivine-hypersthene chondrite [Mason, 1962 and 1965], equilibrated, ordinary chondrite [Dodd—Van Schmus—Wood, 1967] which belongs to the L-group [Urey—Craig, 1953] and can be classed into the L5—L6 types [Van Schmus—Wood, 1967].

INTRODUCTION

The meteorite fell on May 27, 1905, 10^{45} a.m. on the territory of the village Malomháza (Felsőpulya district, Sopron county, Hungary). Its geographical coordinates: 47° 32′ N and 16° 38′ E. In the report, which can be considered as a source, F. Berwerth [1912] applies the German — Minnichhof — name of this locality, and the Hungarian name was misdescribed as a synonym.

Though in the L. Tokody-M. Dudich Vendl catalogue [1951] Malomháza is denoted as the locality of fall, both the Prior-Hey [1953] and Hey [1966] catalogues use Minnichhof. Because the village was annexed in 1921 to Austria, and because till that date neither the detailed study of the stone, nor the elucidation of the name of the locality were performed, we also use and accept the name Minnichhof (Burgenland, Austria) in our catalogue [1961] and the present paper as well. We know a little about the story of the stone and about the circumstances and the date of acquisition, because — owing to the 1956 fire in the Mineralogical and Petrographical Depertment of the Hungarian Natural History Museum — the inventory books were destroyed. It was identified on the basis of the inventory number — being on the stone — and of the data included in the 1951 catalogue. The weight of the present piece proved 54.8 g. less than the value given in the Tokody-Dudich catalogue, at the same time a thin, wedged slice was missing. Its volume is proportional to the deviation in weight. The missing slice has probably been cut for the purpose of a designed investigation, but no evidence can be found referring either to the examination or to its results. This fact made necessary the more thorough investigations of the meteorite, which has been considered only as a white chondrite. Sampling and testing could have been carried available for the most important partial experiments.

EXPERIMENTAL METHODS AND TECHNIQUE

Sampling

The material to be tested was obtained by cutting slices parallel with the previously cut surface. One slice was used for making thin section and gave the dominant part of the tested material, the other one served as preparatum for the electron-probe microanalysis (at the same for ore microscopic examination) and another thin section and the remaining parts supplied the tested material as well. After making the electron-probe preparation and thin section, about 2 g of the particles (2–3 mm in diameter) was reserved for the determination of specific gravity. The residue (about 20 g) was pulverized graduelly to 0.2 mm ∅ grains, while paramagnetic fraction was separated by a handmagnet and the pieces of fusion crust were also selected. The further separation into silica and non-silica mineral fractions was carried out by centrifuge on Clerici-Solution of 4.22 spec. gravity. The result of the separation to heavy and light fractions was controlled under microscope, and the procedure was repeated till the mixing of the two fractions diminished to the minimum. Thereafter both fractions were centrifuged in distilled water till thallium-ionfree state. It was controlled with 0.1 n solution of KJ. The material of both heavy and light fractions were desiccated in water bath and subjected to trace element detection, X-ray examination and chemical analysis.

Electron-probe microanalysis

The quantitative chemical analyses of each mineral were carried ot by JEOL JXA–5 electron-probe microanalyser in the Geochemical Research Laboratory of the Hungarian Academy of Sciences. Accelerating voltage: 25 kV. The polished section and the standards were coated by aluminium simultaneously. The applied standards for Fe (in silicate phase) Mg and Si — olivine, for Al — topaz, for Na — oligoclase, for K — orthoclase, for Fe — iron metal, for Ni — nickel metal, for Ti — titanium metal. For correction computer was applied [cp. G. NAGY, 1970].

X-ray analysis

Two X-ray powder diffractograms were made both from the heavy and the light fractions on a Philips–Mueller 111 type X-ray diffractometer, using Cu radiation and Ni filter, at 26 kV, 36 mA, goniometer speed: 2°/min and 1°/min, intensity factor: 8, slits: 1°, 0.1°, registration speed: 27 mm/min, angular range: 2°–63° 2Θ. (Analyst: MISS A. SZEMETHY.)

Spectrophotometric analysis

Sample preparation: grain size 60 μ, mixed with Pd containing spec. pure carbon powder in equal proportion. — Electrode: 6 mm ∅ carbon rod — Excitation: A. C. arc, 16 amper, analytical gap: 3 mm — Exposure time: 180 sec till the total evaporation — Optic: Jobin–Yvon Z3 Quartz Spectrograph, two-step filter; — Slit width: 15 μ; — Evaluation: Zeiss Schnellphotometer, l-transformation, background correction, Pd internal standard.

In the heavy fraction the values of Pd and Zr were not analyzed because of the interfering effects of Fe and Co. (Analyst: MRS. M. VIGH).

Chemical analysis

After decomposing by aqua regia the material of the heavy (2 g) and the light (14 g) fractions, the solution was repeatedly evaporated by 1:1 diluted HCl solution in order to eliminate nitrates. Finally the dry residue was dissolved in hot 1:10 diluted HCl solution and filtered. The residue was repeatedly washed till chlorid-free, the iltrate was reserved. After burning, the insoluble residue was fused by Na_2CO_3, issolved in HCl and combined with the reserved filtrate, and evaporated to dryness. his was followed by the usual silicate analytical method. Silica was determined by ravimetric method. Total iron, aluminium, manganese, phosphorus, chrome and cobalt were determined by spectrophotometric method. The gravimetric determina-ion of nickel was made after GROVES' [1951] method, the determination of metallic ron after the WILNER–MERCK method [Merck, 1902] and that of the alkalies was carried out by flamephotometry. The sulphur content of troilite was determined fter RADER–GRIMALDI'S [1961] gas-volumetric method.

The reserved material for specific gravity determination was weighed, put in Cl_4 into a picnometer, was boiled in vacuum, induced by pneumatic water-pump: or 3 minutes. The spec. gravity was determined at 20° C.

MEGASCOPIC DESCRIPTION

The shape of the meteorite can be compared to a scalene pyramid of blunted dges and corners. Its frontside is rounded, the rearside is almost quite flat, the ross-section is trapezoid, of the four further planes two are convex and two are oncave *(Fig. 1/a)*. Its greatest diamaters are: 71.52 and 45 mm; weight: 462.2 g. n the sides of the stone two bigger and several smaller piezoglypts can be seen. riginally the whole stone was covered by a black — in thin veins brownish-black — usion crust. This crust of velvety lustre is relatively uniform in thickness, on an verage of 0.5 mm, growing thin in some places. 1–2 mm thick reddish dark-brown oloured oxidized crust can be found sporadically, terminated vaguely towards the nterior. The surface of the stone is ragged due to the bulging chondrules and metallic articles, i.e. to the irregularly scattered furrows and flutings, in a lesser extent. n the bulging structural elements the fusion crust has a weak vitreous lustre. On he crust of the meteorite there are some smaller cracks, while inside one dominant nd several very thin ones *(Fig. 1/b)*. The specific gravity of the meteorite is 3.52.

The bulk of the stone is a dark-grey coloured, compact material of medium ardness. In this material relatively few chondrules and irregularly disseminated etallic particles are embedded. Chondrules break together with the groundmass. One part of them is white, round, generally 1.0 mm (0.5–1.4 mm) in diameter, the thers are grey with ovoid, round or irregular cross-section, mostly 1.5 mm (1.0–.0 mm) in diameter. Some of the grey chondrules show spherulitic texture. The etallic particles on the fresh cut surface are of vivid metallic lustre, generally 0.2 mm (0.1–1.2 mm) in diameter, often jagged along the irregular contours.

MINERALOGICAL COMPOSITION AND STRUCTURE

The dominant minerals of the stone are: olivine and hypersthene, a relatively igher amount of palgioclase and diopside, Ni-Fe particles and troilite. Chromite, errillite, ilmenite and daubréellite, are accessories as well as the secondary limonite Tables 1, 2, 3).

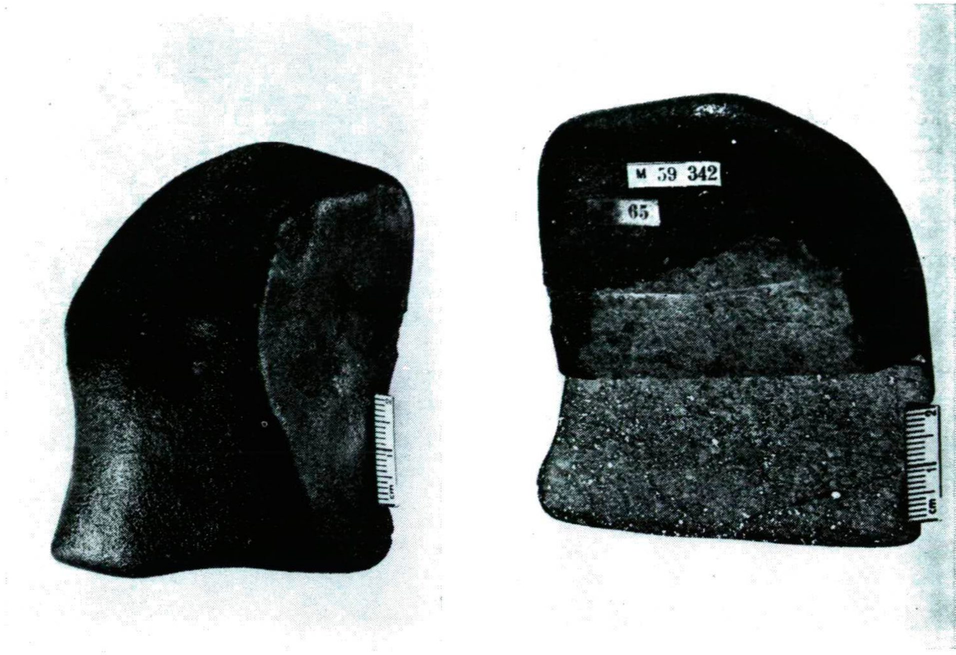


Fig. 1.
a) Photograph of the Minnichhof meteorite. *b)* Photograph of an other side of the stone.

Crystallized groundmass intergrown with the condrules is characteristic of the texture. There are only a few sharply defined chondrules, glass is completely missing. Metallic components are irregularly scattered in the groundmass, they are frequent in schondrules and on the outer edge of them, and appear in narrow veinlets as filling metarial as well.

The *olivine* ($Fo_{75}Fa_{25}$) crystals are colourless, some of them have light-brown, reddish-brown colour. Colour can be observed along the cleavages and parting traces and in irregularly scattered small patches. Most of the crystals are allotriomorphic, wavy margins are frequent. Hypidiomorphic or almost idiomorphic, dipyramid-terminated crystals of short prismatic habit are uncommon. Its biggest dimensions (600–800 μ) appear in the monosomatic chondrules. In the porphyritic chondrules this value is 500–600 μ, in the matrix 50–500 μ. It contains plagioclase, monoclinic and orthorhombic pyroxenes, troilite and Ni-Fe particles as inclusions *(Fig. 2/a, b)*.

On the basis of electron-probe microanalyses perfected on three crystals the composition of olivine is uniformly $Fe_2SiO_3 \sim 25.3$ mole% (Tables 4, 5). On the X-ray diffractometer chart of the light fraction, the d_{130}-reflection shows sharp and well-defined peaks; on the basis of YODER–SAHAMA [1957] determinative curve this corresponds to $Fe_2SiO_4 = 25$ mole%. According to POLLACK's and CHI's method [1972] we got a value slightly lower than the former ones.

Hypersthene ($En_{76}Fs_{22}Wo_2$). The dominant part of the crystals are water clear and pale pinkish, some of them are cloudy having a faint shade of greyish colour. Most of them are allotriomorphic, but in the chondrules some hypidiomorphic

TABLE 1

Results of chemical and trace analyses

Chemical composition (in weight %)				Trace elements (in ppm)		
	bulk analysis	heavy fraction	light fraction		heavy fraction	light fraction
SiO_2	40.44	1.09	46.06	P	nd	1200
TiO_2	0.18	0.21	0.18	Ti	350	650
Al_2O_3	2.12	0.25	2.41	Cr	nd	2000
Fe_2O_3	0.18	0.02	0.20	Mn	800	2000
FeO	14.56	1.54	16.39	Co	1000	35
MnO	0.34	0.06	0.38	Ni	nd	1250
MgO	25.53	1.00	29.04	Cu	75	35
CaO	2.44	0.17	2.76	Ge	8	< 1
Na_2O	1.04	0.38	1.14	Zr	nd	200
K_2O	0.12	0.10	0.12	Ga	5	1
P_2O_5	0.18	0.02	0.21	Mo	8	< 2
Cr_2O_3	0.48	1.96	0.26	Sn	< 1	< 1
$-H_2O$	0.02	—	0.02	Pb	< 2	< 2
Fe	6.84	53.33	0.21	V	7	nd
Ni	1.24	8.24	0.24	Zn	220	nd
Co	0.02	0.17	0.004	Ag	3.4	nd
Fe	2.87	19.81	0.45	Bi	< 3	nd
S	1.64	11.38	0.26			
S	0.05	0.46	—			
Total	100.29	100.19	100.334			

TABLE 2

Results of electron-probe analyses (in wt.%)

Metal phase	Fe	Ni	S	Total	Analysed particle
Kamacite	91.5	6.1	—	97.6	Main mass *(Fig. 6.)*
Taenite	82.5	15.9	—	98.4	Inclusion *(Fig. 6a, b)*
Taenite	—	40.3	—	—	Diffusion border of the inclusion *(Fig. 6c)*
Troilite	63.1	—	35.9	99.0	Average value of three particles (two of them on *Fig. 7a, b*)

Silicate minerals	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	K_2O	Na_2O	Total
Olivine	37.5	—	—	23.7	39.2	—	—	—	100.4
Hyperstehene	55.1	—	—	14.2	28.1	1.0	—	—	98.4
Diopside	55.0	0.2	0.1	4.2	16.0	23.7	—	—	99.2
Oligoclase	64,6	—	21.6	—	—	2.4	0.8	10.5	99.9

elongated prismatic crystals, and in a monosomatic chondrule an equidimensional, 800 μ large and almost idiomorphic crystal can be observed. Except some twinned specimens they are monocrystals, 50–60 μ of grain size. Hypersthene occurs mainly

TABLE 3

Mineral composition, calculated from values of chemical and electron-probe analyses (in wt.%)

Or ($K_2O.Al_2O_3.6\,SiO_2$)	0.70		
Ab ($Na_2O.Al_2O_3.6\,SiO_2$)	8.12		
An ($CaO.Al_2O_3.2\,SiO_2$)	1.18		
Feldspar $Or_4Ab_{84}An_{12}$		10.00	
En ($MgO.SiO_2$)	14.25		
Fs ($FeO.SiO_2$)	5.32		
Wo ($CaO.SiO_2$)	0.41		
Orthopyroxene $En_{76}Fs_{22}Wo_2$		19.98	
En ($MgO.SiO_2$)	4.45		
Fs ($FeO.SiO_2$)	0.47		
Wo ($CaO.SiO_2$)	3.93		
Ilm ($FeO.TiO_2$)	0.04		
Clinopyroxene $En_{45}Fs_7Wo_{48}$		8.89	
Fo ($2\,MgO.SiO_2$)	31.39		
Fa ($2\,FeO.SiO_2$)	15.40		
Olivine $Fo_{75}Fa_{25}$		46.79	
Silicate minerals			**85.66**
Merrillite ($3\,CaO.Na_2O.P_2O_5$)	0.48		
Ilmenite ($FeO.TiO_3$)	0.30		
Chromite ($FeO.Cr_2O_3$)	0.64		
Limonite ($FeOOH$)	0.20		
Accessory Minerals			**1.62**
Ni-Fe ($Ni_{15.4}Fe_{84.4}Co_{0.25}$)	8.08		
Troilite (FeS)	4.51		
Daubréelite ($FeCr_2S_4$)	0.11		
Metal phase			**12.70**
Silicate + accessory minerals: 87.28			
Metal + sulphide minerals: 12.70			
Total 99.98			

in chondrules, in porphyritic and barred form, or in groups of oriented intergrown crystal groundmass it occurs as phenocryst or in interstitial position. As inclusions diopside and feldspar are most common.

On the basis of electron-probe microanalysis (Tables 4, 5) the composition of hypersthene can be characterized by the value $FeSiO_3 \sim 21.5$ mole%. Though the calculated atomic ratios — when compared to the data known from the literature [DEER, HOWIE, ZUSSMAN, 1965] are referring to a composition similar to the bronzite, the reflections on the X-ray pattern correspond to hypersthene and not to bronzite. Based on electron-probe microanalysis the monoclinic pyroxene is *diopside* ($En_{45}Fs_7Wo_{48}$), its calculated amount is 9 wt%. On X-ray diagram it is represented by well-defined reflections. Under the microscope it is colourless and transparent with characteristic cleavage traces. Extinction angle: 38–42°. It occurs mainly in the crystalline groundmass *(Figs. 2/c, d)*, less in the chondrules, and can be found as inclusion in olivine and hypersthene. The dimension of dominantly allotrio-

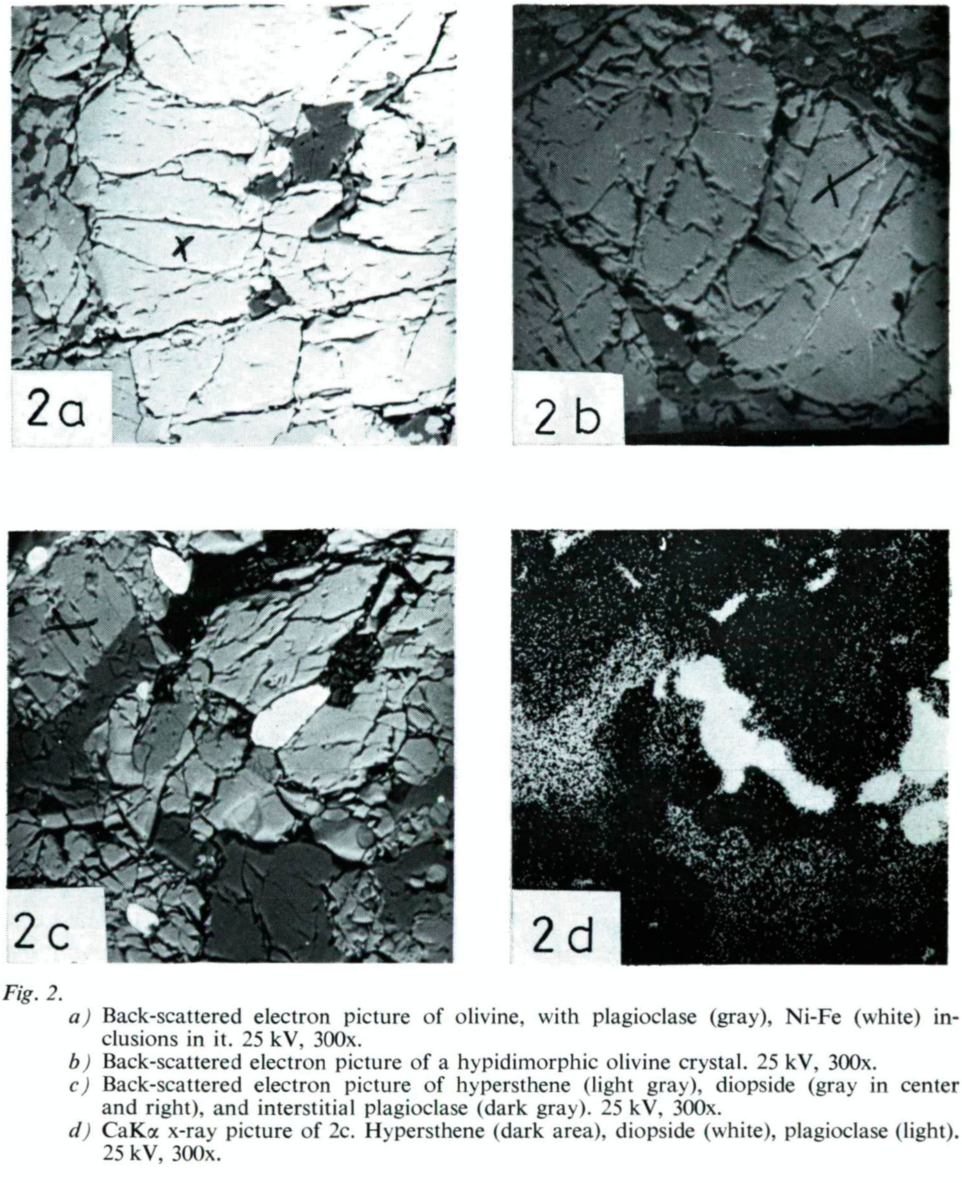


Fig. 2.

- *a)* Back-scattered electron picture of olivine, with plagioclase (gray), Ni-Fe (white) inclusions in it. 25 kV, 300x.
- *b)* Back-scattered electron picture of a hypidimorphic olivine crystal. 25 kV, 300x.
- *c)* Back-scattered electron picture of hypersthene (light gray), diopside (gray in center and right), and interstitial plagioclase (dark gray). 25 kV, 300x.
- *d)* CaKα x-ray picture of 2c. Hypersthene (dark area), diopside (white), plagioclase (light). 25 kV, 300x.

morphic — rarely hypidiomorphic-crystals in the groundmass is 60–80 μ, infrequently 100–200 μ. In sections its 200–300 μ large crystals form discontinuous ring around the porphyric chondrules. In the radial chondrules it can be observed alternating with orthopyroxene and plagioclase in columnar or fibrous development.

The amount of feldspars is 10 wt%. On the basis of the electron-probe microanalysis the modal composition is $Or_4Ab_{84}An_{12}$ mole%, i.e. *plagioclase,* acid oligoclase. On the X-ray diagram the reflections of plagioclase give characteristic sharp peaks corresponding to the high oligoclase [Goodyear, Duffin 1965]. In polarized

Table 4

Crystallochemical data, calculated from the results of electron-probe analysis

Mineral	Composition in wt. %		Numbers of ions on the basis of			Atomic ratios	Formula
Olivine				4 oxygens			$Mg_{1.49}Fe_{0.51}[Si_{0.96}O_4]$
	SiO_2	37.5	Si	0.956			
	FeO	23.7	Fe^{2+}	0.505	1.99	25.3	
	MgO	39.2	Mg	1.489		74.7	
	Total	100.4					
Hypersthene				6 oxygens			$(Mg_{1.52}Fe_{0.43}Ca_{0.04})\ [Si_2O_6]$
	SiO_2	55.1	Si	2.002			
	FeO	14.2	Fe^{2+}	0.432		21.7	
	MgO	28.1	Mg	1.522	1.99	76.4	
	CaO	1.0	Ca	0.039		1.9	
	Total	98.4					
Diopside				6 oxygens			$Ca^{[8]}_{0.93}(Mg_{0.88}Fe_{0.13}Al_{0.004}Ti_{0.006})^{[6]}\ [Si_2O_6]$
	SiO_2	55.0	Si	2.020			
	TiO_2	0.2	Ti	0.006			
	Al_2O_3	0.1	Al	0.004			
	FeO	4.2	Fe^{2+}	0.129	1.95	6.6	
	MgO	16.0	Mg	0.876		45.2	
	CaO	23.7	Ca	0.933		48.1	
	Total	99.2					

TABLE 5

The more important chemical parameters

	wt. %		wt. %
$Fe_{metallic}$	= 6.82	$Fe_{metallic}/Fe_{total}$	= 0.45
$Fe_{sulphidic}$	= 2.89	$Fe_{metallic}/Ni$	= 5.5
$Fe_{metal\ phase}$	= 9.71	Fe_{total}/Ni	= 17.0
$Fe_{silicate\ phase}$	= 11.45	Fe_{total}/SiO_2	= 0.52
Fe_{total}	= 21.16	SiO_2/MgO	= 1.58

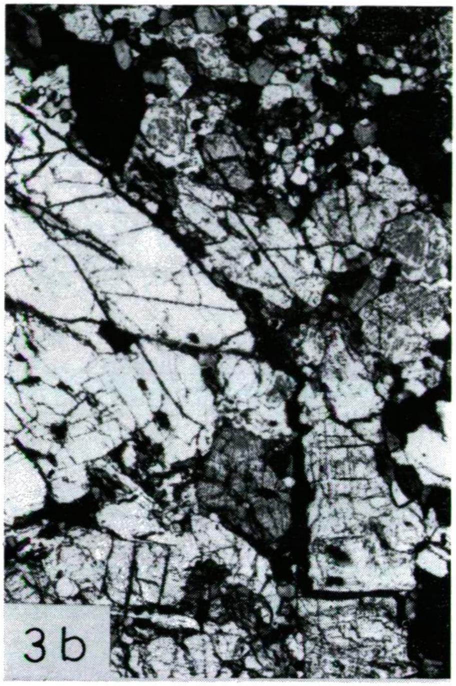
Fe_2SiO_4 in olivine = 25.3 mole %
$Fe^{o}_{olivine}$ = 18.4 wt. %
$FeSiO_3$ in hypersthene = 21.5 mole %
$Fe^{o}_{hypersthene}$ = 11.0 wt. %

light the allotriomorphic crystals are quite clear showing no cleavages, $n \leqq n_{Canada\ balsam}$. The crystals are 20–120 μ large, finer grains form aggregates with pyroxene and olivine in some patches. The rarely observable, weak, uneven extinction marks the recrystallization of glass. One third of the crystals are twin-lamellar according to the albite law. The dominant part of plagioclases is in interstitial settlement, related both to the groundmass and to the chondrules *(Figs. 2/c, d* and *3/b, c, d)*. In accordance with the texture of chondrules plagioclase appears as a component of the matrix in the barred type, while it is mosaic-like, interstitial in the radial chondrules and forms inclusions in the monosomatic orthopyroxene ones. Within a little patch of the thin section, in the plagioclase aggregates, fine grained orthopyroxene crystals are embedded.

Regarding their shape, texture and mineralogical composition the *chondrules* are rather varied, at the same time they are quite uniform in dimensions (1–2 mm). Most of the chondrules have round or oval cross-section. In the microscope they cannot — or can hardly — be distinguished from the groundmass. More exactly: while the cores of the monosomatic, radiated and barred chondrules are clearly discernible the polysomatic, mixed and porphyritic chondrules merge absolutely into their well-crystallized environment *(Fig. 3/a)*. The monomineralic chondrules are often surrounded by loose or ragged rim of differing minerals, or metallic particles, troilite. These rims indicate the original contour of the condrule, therefore from the aspect of rock-texture these chondrules can be regarded as transitional members *(Figs. 3/b, c, d)*. The few, sharply delineated chondrules are whole and have round cross-sections, or are fragments. The former ones are of monosomatic or excentro-radial texture. Some of the broken chondrules are 20–80 μ diameter and are localized generally along fissures filled by troilite.

Regarding the composition, the chondrules broken by micro-faults are: monosomatic orthopyroxene chondrule with plagioclase inclusions of undulatory extinction *(Figs. 4/a, b)*; polysomatic orthopyroxene chondrule; barred olivine and porphyric (mixed) orthopyroxene-olivine chondrule. The other part of broken chondrules, restricted to some pieces, are embedded into the crystalline groundmass, they are isolated or joined with other chondrules and consist of fibrous and barred ortho-and monoclinic pyroxene *(Figs. 4/c, d)*.


3a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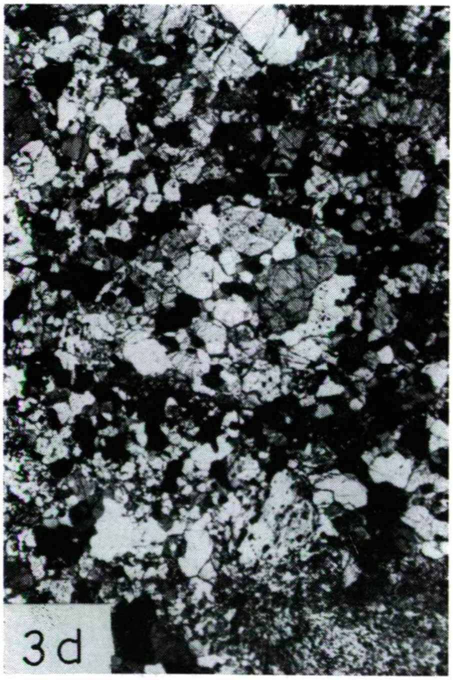
3d

Regarding their mineral composition the chondrules mainly consist of the dominant minerals. Porphyric olivine is more common than the barred one, sometimes monosomatic. Orthopyroxene is abundant in monosomatic and porphyric chondrule, it is rare in polysomatic barred chondrule intergrown with diopside, and there are only a few specimens of structurless appearance. In the latter group, among the 50–200 μ large allotriomorphic hypersthene crystals, intersticial diopsides of 15–25 μ grain size can be observed. As condrule-forming mineral the diopside as a fibrous and radial aggregate is rarely observable.

In addition to the above discussed role of the plagioclase it must be noted that plagioclase — similarly to the metallic particles — can be found as intersticial component in each chondrules or surrounded them as aggregates *(Figs. 3, 4, 5).*

The grain size of the microholocrystalline *groundmass* is varying. The patches consisting of 15–50 μ large ortho-, clino-pyroxene and plagioclase crystals can be considered as typical matrix, still they constitute only a small part of the groundmass. On the contrary the microcrystalline groundmass of porphyric texture is widely distributed. It consists of 20–75 μ large allotriomorphic ortho-, clinopyroxene, olivine and plagioclase crystals 150–200 μ large allotriomorphic — rarely hypidiomorphic — olivine and some orthopyroxene crystals. The latter are embedded into the former ones. The scattered or interstitial 40–100 μ large metallic particles and troilite crystals bordered by irregular contoures must also be considered to belong to the groundmass.

Metallic particles

On the basis of the optical investigations, chemical analyses and X-ray diagrams of the heavy fraction it can be stated that the metallic phase is represented by Ni-Fe particles, troilite, minimal amount of chromite, ilmenite, daubréelite and secondary limonite (Tables 1, 2, 3).

The shape and composition of Ni-Fe particles are very variegated. Two groups can be quite clear distinguished. The equidimensional, rounded, drop-like 60–200 μ large particles can be put to the first group and the elongated 400–1200 μ large particles showing jagged borders into the second one. One part of the metallic particles are broken and some of them from loose chain along the cracks which is observable even macroscopically.

Kamacite of minor amount occurs rarely as isolated grains, most of it is joining with other Ni-Fe particles and with troilite. Single crystals or polycrystalline masses are common, hypidiomorphic forms are exceptional. Well-developed, straight, broad NEUMANN-lines forming at most four-directional network can be found only in the larger crystalline aggregates. On an other particle two types of texture can be observed: the first shows close parallel straight lines, the other faintly distorted ones. Finally, between two kamacite particles, like a bridge, a third kamacite particle can be found patterned by narrow lines. Taenite borders are very common and

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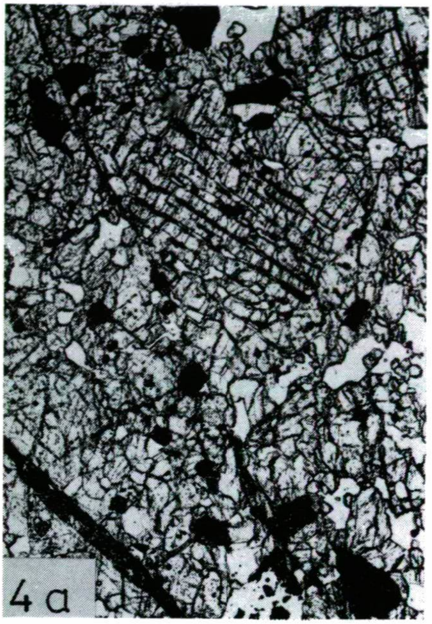
Fig. 3.

a) Textural picture. The chondrules merge into the crystalline groundmass. +N, 27.5x.

b) Monosomatic, barred hypersthene chondrule (white) surrounded by clinopyroxene and plagioclase. +N, 68x.

c) Crystalline porphyric chondrule (centre) in troilite and chromite (black) internal ring, bordered by plagioclase, diopside, troilite (white, grey, black) in the crystalline groundmass. //N, 27.5x.

d) id. +N.



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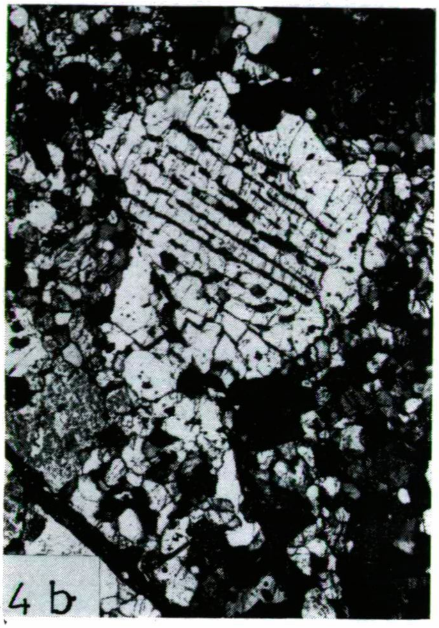

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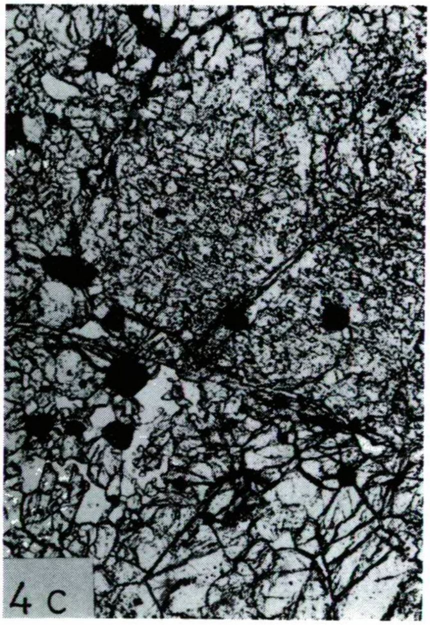

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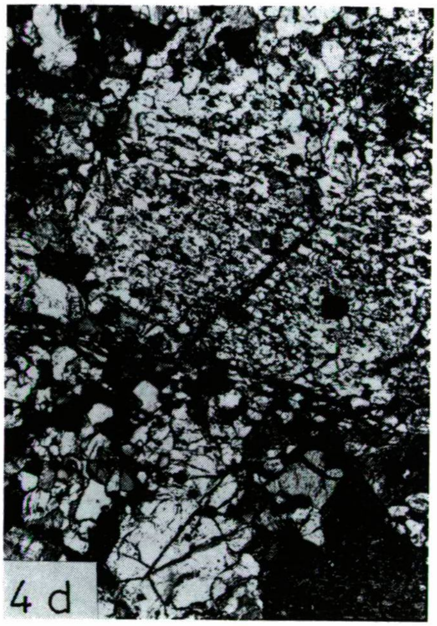

4 d

taenite inclusions and intrusions as well *(Fig. 6)*. In reflected light kamacite is greyish white with strong metallic lustre. After etching by "nital" it turns to light-grey, reflects weaker. On the basis of electron-probe microanalysis its Ni-content is 6.1 wt%.

Taenite — in addition to the above mentioned appearance as diffusion border — can be observed as discrete particle, too. In reflected light it has a yellowish-white colour and strong metallic lustre, which characteristics are preserved after the etching as well. Its Ni-content is 16–30 wt%, though very fluctuating (max. 40 wt%) even with in a certain particle *(Fig. 6)*. It is attached most frequently to kamacite and to plessite; the phase boundaries can be either straight edges or irregularly jagged contacts. It generally contains plessite as inclusion.

The alternately fine or coarse grained *plessite* is the most common metallic component. The size of grains for sure identification under microscope are 0.5 mm. The particles are elongated, dissected by appendices and embayments. The vermicular intergrowth of taenite and kamacite appears mainly after etching, and this characteristic structure can be studied on the screen of microanalyser as well *(Figs. 7/c, d)*. The coarse plessite particles have generally broad Ni-diffusion borders. In the particles bearing teanite or kamacite cores, the fine plessite forms rim, sometimes little droplets, within the diffusion border. WIDMANSTÄTTEN structure could have been observed only on a single particle found on the one side of a larger, elongated, mainly polycrystalline kamacite particle, varying in composition. It is limited by a faint line towards the interior of the kamacite, and by a straight fracture along the margin of the particle. On the other side of the micro-fracture a teanite splinter can be observed. In the inner part, of the splinter of Ni-diffusion border fine plessite rim is to be found in one part some tiny fine plessite droplets are observable in the other.

The *troilite* forms allotriomorphic crystals with irregular contours, and rarely hypidiomorphic ones with hexagonal cross-section. These appear as single crystals or form irregularly distributed aggregates. Troilite can be observed as inclusion in silicates, as rim around some chondrules and as filling mineral in veinlets. Its amount is 4.5 wt%, on the basis of electron-probe microanalysis its composition is: Fe$\sim$50.2 and S$\sim$49.8 mole%. The dimension of troilite drops is generally 150–200 μ, the diameter of the amoebiform aggregates is 400–600 μ long. The troilite is light-yellow, the strongly reflecting patches are fresh-yellow, with a characteristic bronze tinge. Most of the crystals are cracked, dissected by cleavage and parting traces and have rugged rims *(Figs. 7/a, b)*. In some cases pressure effect, polysynthetic twinning can be seen. It rarely joins with Ni-Fe particles, but when it does, it can be found intruding into them and contacting the silicate-surrounding only with one side. In other cases troilite can be seen in the embayments of metallic particles or joining

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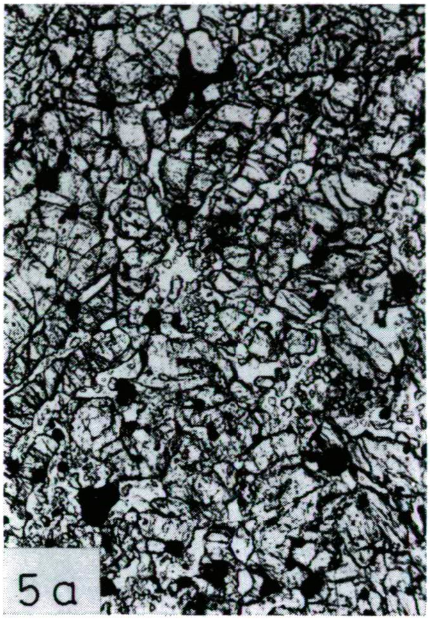
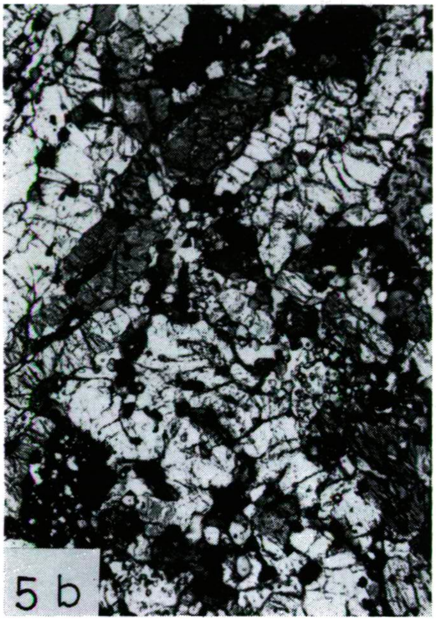
Fig. 4.

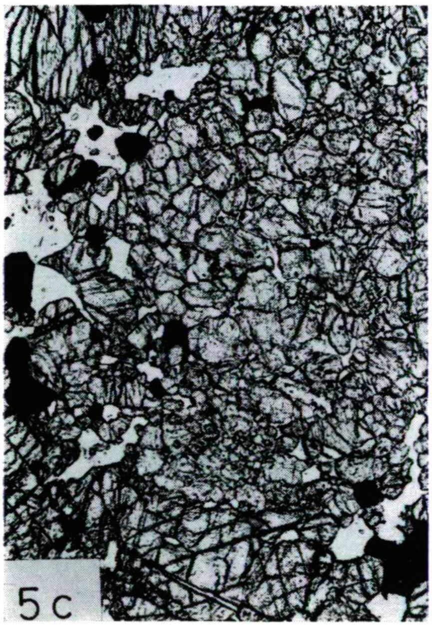
a) Disrupted and dislocated monosomatic hypersthene chondrule (upper third) with interstitial plagioclase (white), ore and troilite inclusions (black), troilite veins (black NW—SE oriented) //N, 68x.

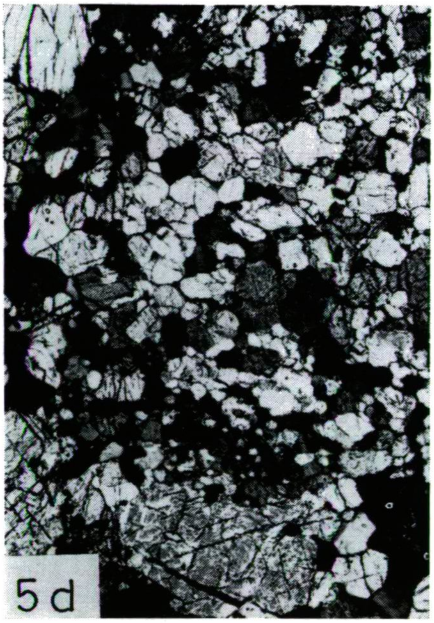
b) id. +N. Note: along the cleavage oriented NW—SE the hypersthene chondrule (white) moved by 226μ.

c) Radial, fibrous pyroxene chondrule sharply delineated by two fractures (above right) in crystalline groundmass, with a lot of intersticial plagioclase (white), and scattered metallic particles (black). //N, 68x.


5a


5b


5c


5d

them as tags, finally forming bridge between two Ni-Fe particles. The irregular aggregates have a pore-filling role, the equant particles are embedded into the crystalline mass of silica minerals as interstitial material.

Accessory minerals

Chromite occurs as some larger (200–400 μ) hypidiomorphic and as some smaller (15–20 μ) allotriomorphic crystals. On the larger crystals octahedric parting can be observable, on the rim of a rhombohedric crystal in cross-section a slight alteration can be seen. Fine grained chromite in regular form can be examined only in a single place in the preparatum, in a chondrule, where its grains form a ring parallel with the margin of the chondrule *(Figs. 3/c, d)*. *Ilmenite* succeeded to be identified only in a single case. In a red limonitic environment, in the vicinity of a Ni-Fe particle it forms a group consisting of three plates of 20–25 μ. The hypidiomorphic, tabular crystals are joined each other by crystal faces. On all the three crystals lamellar twinning $(10\bar{1}1)$ can be recognized.

Daubréelite could be identified only on X-ray diagrams and in spite of the thorough investigation of troilite particles they could not be observed under the ore microscope. The small dimensions of the preparatum may be responsible for it. After the normative calculations we established the amount of *merrillite* in 0.48 wt%. Its allotriomorphic crystals occur sporadically in the groundmass, in thin sections they can be hardly observed.

Secondary *limonite* appears as filling material along the "in situ" disruptions or along the rim of metallic particles, troilite and olivine. The thickening of veins results in patches. Limonite forms thin coating on the oxidized parts of the fusion crust.

INTERPRETATION OF OBSERVATIONS

Owing to the fact, that the purpose of the present paper was — first of all — the thorough testing of the Minnichhof meteorite and consequently the publication of the results arranged in certain respect, therefore, only the measured and observed data most important from the viewpoint of systematization are stressed. Similarly, we tried to discuss our conclusions relating to genetics within a compass corresponding to the profoundity of investigations. The material of Minnichhof meteorite after Mason's system [1962, 1965] is an olivine-hypersthene chondrite. According to the Rose–Tschermak–Brezina [1812, 1872, 1904] system it belongs to the intermedier crystalline chondrite group, after the Prior-system [1920] it can be ranged into the hypersthene-olivine chondrite group. On the basis the data of bulk analysis, the electron-probe microanalysis of the dominant minerals and on the strength of the index-numbers formed of these values the meteorite belongs to Urey–Craig's [1953] L-group. Comparing the above data to the mineral constituents and textural

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Fig. 5.

a) Pyroxene and olivine bars, interstitial plagioclase (white) and metallic particles (black) in mixed, barred chondrule //N, 68x.

b) id. +N.

c) Fine grained mixed chondrule, interstitial plagioclase (white) — inside and around the chondrule — metallic particles and troilite (black) in holocrystalline porphyric groundmass. //N, 68x.

d) id. +N.

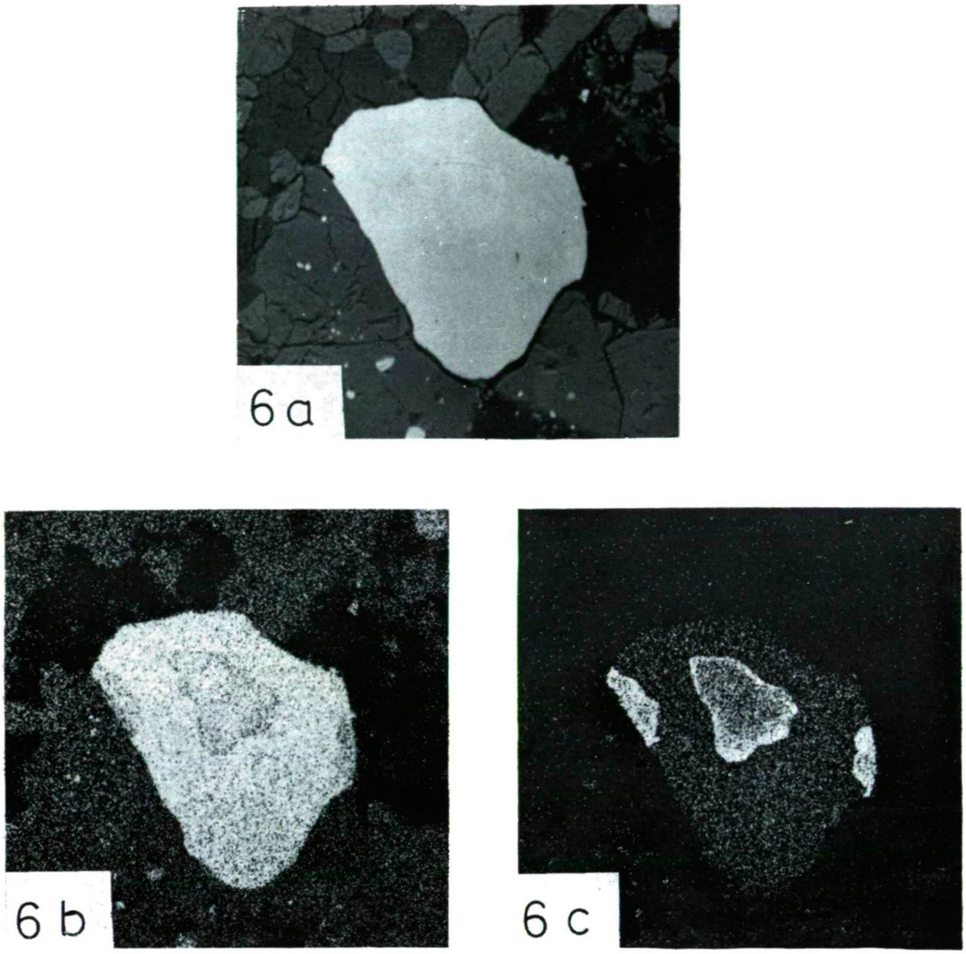


Fig. 6.

a) Back-scattered electron picture of kamacite particle with taenite inclusion and intrusions, surrounded by silicates. 25 kV, 300x.

b) FeKα x-ray picture of 6a, 300x.

c) NiKα x-ray picture of 6a, 300x.

Fig. 7.

a) Back-scattered electron picture of polycrystalline troilite intruded into silicates. 25 kV, 300x.

b) Back-scattered electron picture of troilite embedded in silicates. Some of the crystalls are nearly equant. 25 kV, 300x.

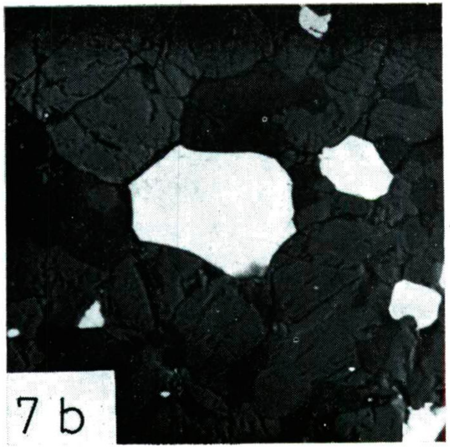
c) Back-scattered electron picture of coarse plessite with irregular taenite border. 25 kV, 300x.

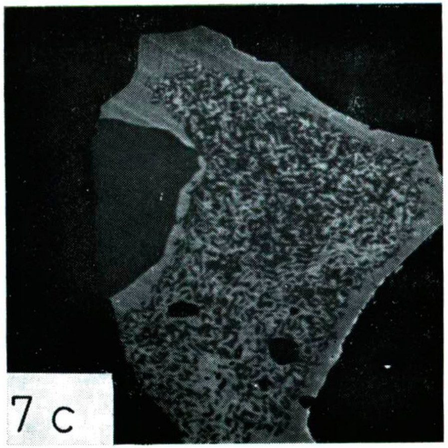
d) Back-scattered electron picture of coarse plessite. Same as 7c, enlarged. The line indicates the track of the distribution profiles in 7e and 7f. 25 kV, 1200x.

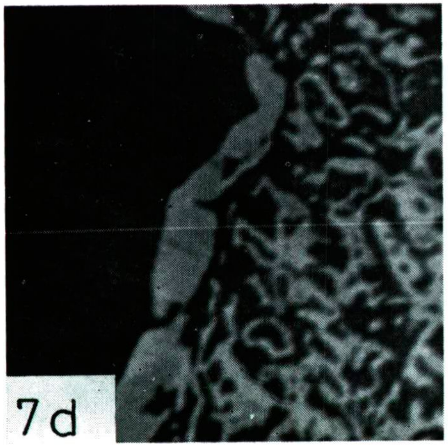
e) FeKα distribution along the line of 7d, 1200x.

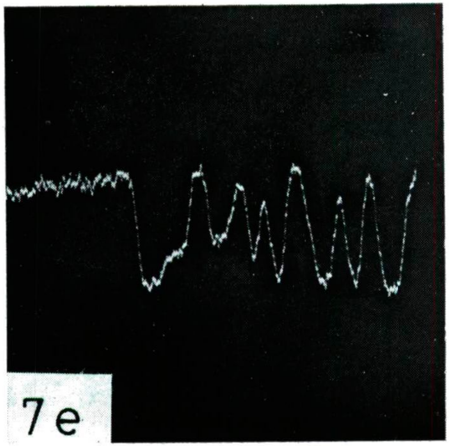
f) NiKα distribution along the line of 7d, 1200x.


7a


7b


7c


7d


7e


7f

characteristics, is near to the L5–L6 types of VAN SCHMUS–WOOD's [1967] chemical-petrological classification. Finally, considering the DODD–VAN SCHMUS–KOFFMAN [1967] system the meteorite is an equilibrated ordinary chondrite with an advanced textural integration. Comparing the values of chemical analysis, modal and normative mineralogical composition to the data published by MASON [1965]:

(i) they show concordance: FeO, MgO, Cr_2O_3, TiO_2, Fe, Ni wt% in chemical analyses, and Ol, Or, Ab wt% values in normative mineralogical composition;
(ii) they are similar: Al_2O_3, Na_2O, K_2O, Co, total silicate, total Fe, i.e. Hy, Cm, Ilm wt%;
(iii) or they are within the given limits: SiO_2, CaO, P_2O_5, FeS, i.e. Di, An wt%.

The ranging into the olivine-hypersthene group is supported by the values Fa=25.3 mole% in olivine and Fs=21.5 mole% in orthopyroxene which values were verified by different investigations. If we compare the data of the 94 superior analyses published in UREY–CRAIG's paper [1953] to the results of our bulk analysis we get a very similar result. In some values of the silicate phase the difference is 1–0.5 wt% in SiO_2, MgO and CaO, — similarly to the MASON-values — but this difference is balanced in the total sum of the silicate phase. Greater difference appears at the metallic phase and the FeS values. More exactly: though the total amount of metallic Fe, Ni and Co is almost equal with the average, because of the relatively less amount of Fe(+Co) and Fe-sulphides and of the relatively greater amount of Ni, the values of the Fe-metallic phase, Fe total and Fe_{metal}/Ni shows a deficit of 1%. This means that it draws near to LL-group [KEIL and FREDERIKKSON, 1964], at the same time the value of Fe_{total}/Ni is characteristic to the H-group (Table 5). The above discussed quantitative relationships cause that in the wt% relation of silicate: troilite: iron phase the sulphide iron: iron ration corresponds to the value 85:6:9 given by UREY [1952], but the wt% relation of silicate: metallic phase does not correspond to it. Concerning the GOLDSCHMIDT-values (10:1:2), the discussed ratios do not answer to them at all. In conformity with the above mentioned aggreements and similarities can be pointed out with WIIK's analytical values [1956]. If we compare our data to the values of the table in WAHL's paper [1950] which contains the average, normative mineralogical composition of L-group, in case of Fo, Fa, Cm and Ilm we get absolute concordance, the values of other minerals are more or less different.

The results published in the chapter on chemical differences of the paper written by VAN SCHMUS and WOOD [1967] and the indices gained by the new grouping of chemical parameters confirm that the tested meteorite belongs to the L-group. In accordance with the above details of this paper we can establish that the homogeneity of olivine and pyroxene, the lack of the low Ca-clinopyroxene and the glass, the composition, grain size and the arrangement of plagioclase; further the sort, shape, Ni-content, mechanical distortion, and paragenesis of the metallic particles and iron sulphides, finally the value of H_2O content and the homogenized texture reflect the equilibrated condition. In spite of this wide range of data the petrological classification rise difficulties, because the determination of the homogeneity of olivine and pyroxene based upon a few measurements, and because in the texture characterized by crystalline groundmass and many poorly defined chondrules there are some well-defined chondrules too. *On the basis of all these results the Minnichhof meteorite can be considered as a variety between the L5–L6 types of* VAN SCHMUS–WOOD *two-dimensional classification.*

If we take into consideration the classifying criteria of DODD, VAN SCHMUS and KOFFMAN [1967] we can conclude to a result very similar to the mentioned ones. Summing up the data got from the chemical analyses, the calculated values of Fe^{o}/Fe, SiO_2/MgO, Fe and Fa in olivine, Fe and Fs in pyroxene as well as the data relating to textural features and mineralogical composition the Minnichhof meteorite is an almost equilibrated, metamorphosed chondrite, belonging to the L-group, with an advanced textural integration.

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REFERENCES

BERWERTH, F. [1912]: Fortschritte in der Meteoritkunde seit 1900. — Fortschr. Min. Krist. Petr., *2*, pp. 227—255.

BLANDER, M., ABDEL-GAWAD, M. [1969]: The origin of meteorites and the constrained equilibrium condensation theory. — Geochim. Cosmochim. Acta, *33*, pp. 701—716.

BROWN, H., PATTERSON, C. [1947]: The composition of Meteoritic Matter —I. The composition of the silicate phase of stony meteorites. — II The composition of iron meteorites and the metal phase of stony meteorites. — J. Geol., *55*, pp. 405—411 and 508—510.

DEER, W. A., HOWIE, R. A., ZUSSMAN, J. [1965]: Rock-forming minerals. — 1—2, Longmans-Green, London.

DODD, R. T., JR., VAN SCHMUS, W. R., KOFFMAN, D. M. [1967]: A survey of the unequilibrated ordinary chondrites. — Geochim. Cosmochim. Acta, *31*, pp. 921—951.

FREDERIKKSON, K., MASON, B. [1967]: The Show meteorite. — Geochim. Cosmochim. Acta, *31*, pp. 1705—1709.

GOODYEAR, J., DUFFIN, W. J. [1965]: The identification and determination of plagioclase feldspars by the X-ray powder method. — Mineral. Mag., *30*, pp. 306—326.

GROVES, A. W. [1951]: Silicate Analysis (2nd edition). — Allen and Unwin, London.

HENDERSON, E. P. [1941]: Methods of determining Ni and Co in meteoritic iron. — Amer. J. Sci., No. *5*, p. 372.

HEY, M. H. [1966]: Catalogue of Meteorites (3rd edition). — British Museum, London.

MASON, B. [1963]: Olivine composition in chondrites. — Geochim. Cosmochim. Acta, *27*, pp. 1011—1023.

MASON, B. [1965]: The chemical composition of olivine-bronzite and olivine-hypersthene chondrites. — Amer. Mus. Novitates, No. *2223*, pp. 1—38.

MASON, B. [1967a]: Extraterrestrial Mineralogy. — Amer. Mineral., *52*, pp. 307—327.

MASON, B. [1967b]: Olivine composition in chondrites — a supplement. — Geochim. Cosmochim. Acta, *31*, pp. 1100—1103.

MERCK, E. [1902]: Über die Werthbestimmung von Ferrum reductum. — Z. Anal. Chem., *41*, p. 710.

NAGY, G. [1970]: Quantitative analysis by electronmicroprobe. (In Hungarian with German abstract.) — Földt. Kutatás, *13*, No. 2, pp. 27—38.

RADER, L. F., GRIMALDI, F. S. [1961]: Chemical Analyses for Selected Minor Elements in Pierre Shale. — U. S. Geol. Surv. Prof. Paper, *391—A*.

RAMDOHR, P. [1973]: The Opaque Minerals in Stony Meteorites. — Akademie-Verlag, Berlin.

RAVASZ, Cs. L. [1969]: Catalogue of meteorites of the Hungarian Natural History Museum. — Fragm. Min. Pal., *1*, pp. 3—110.

SZTRÓKAY, K. I., FÖLDVÁRI—VOGL, M. [1954]: A new stone meteorite from Hungary. — Acta Geol. Hung., *2*, pp. 313—326.

TOKODY, L., DUDICH—VENDL, M. [1951]: Meteorite collections in Hungary. — Publ. House of Hung. Ac. Sci., Budapest.

TSCHERMAK, G. [1885]: Die Mikroskopische Beschaffenheit der Meteoriten. — Schweizerbart'sche Verlagshandlung, Stuttgart.
UHLIG, H. H. [1954]: Contibution of metallurgy to the origin of meteorites. — I. Structure of metallic meteorites, their composition and the effect of pressure. — Geochim. Cosmochim. Acta, *6*, p. 282.
UREY, H. C. [1952]: Chemical fractionation in the meteorites and the abundance of elements. — Geochim. Cosmochim. Acta, *2*, pp. 269—282.
UREY, H. C., CRAIG, H. [1953]: The composition of the stone meteorites and the origin of the meteorites. — Geochim. Cosmochim. Acta, *4*, pp. 36—82.
UREY, H. C., MAYEDA, T. K. [1959]: The metallic particles of some chondrites. — Geochim. Cosmochim. Acta, *17*, pp. 113—124.
VAN SCHMUS, W. R., WOOD, J. A. [1967]: A chemical-petrologic classification for chondritic meteorites. — Geochim. Cosmochim. Acta, *31*, pp. 747—765.
WAHL, W. [1950]: A check on some previously reported analyses of stony meteorites with exceptionally high salic contents. — Geochim. Cosmochim. Acta, *1*, pp. 28—32.
WAHL, W., WIIK, H. B. [1950]: A check on some previously reported analyses of chondrites with exceptionally high content of sulphur, chromium or manganese. — Geochim. Cosmochim. Acta, *1*, pp. 123—126.
WIIK, H. B. [1956]: The chemical composition of some stony meteorites. — Geochim. Cosmochim. Acta, *9*, pp. 279—289.
WOOD, J. A. [1962]: Metamorphism in chondrites. — Geochim. Cosmochim. Acta, *26*, pp. 739—749.
YODER, H. S., JR., SAHAMA, T. G. [1957]: Olivine X-ray determinative curve. — Amer. Mineral., *42*, pp. 475—491.

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DR. CSABA L. RAVASZ
DR. MIHÁLY EMSZT
Hungarian Geological Survey
Népstadion út 14.
H-1142 Budapest, Pf. 106. Hungary

DR. GYÖRGY PANTÓ
Laboratory for Geochemical Research
of
Hungarian Academy of Sciences
H-1502 Budapest 112. Pf. 132.