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Pseudometeorite from Łapino (Pomerania, North Poland)

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A boulder, found in a gravel pit by Łapino near Gdańsk in 1954, was noted as unusual. Among various erratics ice-derived from Scandinavia in the Quaternary, this one had an extraordinary appearance; unusually dark, heavy and strongly magnetic. An extraterrestrial origin was suggested. The border resembles an intrusive breccia with numerous periclase-bearing fragments in a magnetite-clinopyroxene-olivine matrix. A single grain with a metallic luster, a few centimetres in diameter, was identified as the iron silicide (Fe_3Si). Only two natural occurrences of iron silicide have been described, both from meteorites. However, the isotopic analysis showed an absence of radiogenic nuclides (^{10}Be, ^{26}Al, ^{36}Cl), and the ratio of oxygen isotopes (δ^{17}O and δ^{18}O) suggested a terrestrial origin. Thus the stone is probable artifact, presumably the product of an unidentified foundry.

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INTRODUCTION

Terrestrial rocks, Moon rocks, Martian rocks and; as far as can be conjectured at present, rocks from other inner planets, may show strong similarities (Shearer *et al*., 1998), and possibly similar also to some artefacts. For, some of main components of terrestrial rocks, such as olivine, pyroxene and plagioclase, are also the main components of stony meteorites (Rubin, 1997). Moreover, rare minerals crystallised at low oxygen fugacity in a more or less anhydrous environment (e.g. suessite — an iron silicide that was identified in the Łapino boulder) may seem to represent critical indicators of an extraterrestrial origin; in fact they are produced, sometimes in large quantities, in terrestrial laboratories and ironworks (Wala, pers. comm.).

This study was restricted to resolving the origin of the Łapino boulder: whether meteoritic, or terrestrial.

METHODS

Mineral components of the boulder were identified by X-ray powder diffraction using a *Philips Analyser 1840* combined with optical microscopy (*Ernst Leitz, Wetzlar*, Germany). An X-ray fluorescence spectrometer (*Rigaku RTX2100*) was to analyse the matrix and the periclase-bearing fragments. An electron microscope (*Jeol JSM35*, Japan) coupled with an electron energy dispersive microprobe (*Oxford-ISIS*) was used to analyse individual mineral grains. A thin section for microscopic observations and one polished chip for the electron microscopic analyses were prepared and analysed. The samples were taken at the contact between a periclase-bearing fragment and the matrix, with large fringes covering each, enabling simultaneous analyses of both mineral types as well as the contact between them.

RESULTS

LOCATION

The boulder was found in summer 1954 in a gravel pit on the slope of the Radunia valley, near the little settlement of Lower Łapino (18°28’20” E, 54°16’20” N) in the Pomerania region, some 20 km south from Gdańsk. The pit was active here from 1888 till about 1975, and at present the partly drowned workings are covered with young trees and bushes. The boulder was noticed by miners in 1954 and its meteoritic origin was suggested because of its notable magnetic susceptibility and

Fig. 1. Dark, enigmatic Łapino boulder collected in 1954 is quite different from common, abundant in the region erratics, mostly granite and gneiss, dragged here from Scandinavia by the Quaternary continental glaciers

unusual appearance. The boulder Łapino is quite unlike the erratic boulders (mostly granitoids and gneisses) brought from Scandinavia by Quaternary continental glaciers, which are abundant in the glacial deposits (Rühle, 1974). The boulder was conveyed to the Astronomical Observatory of the Warsaw University, where it was stored up till 1996. Then it was transferred to the Polish Geological Institute, to resolve the origin of the stone (Stępniewski, 1997; Stępniewski and Pilski, 1998).

Fig. 2. On a cut surface the rock looks like a volcanic breccia with numerous brown-pink fragments immersed in the olive-black matrix

APPEARANCE

The boulder is pear-shaped (~70 x 45 cm) and weighs ~250 kg (Fig. 1). The surface of the stone is damaged by casual sampling carried out over forty years. Examination of the remaining surface did not reveal any trace of an ablation crust, and initial examination of the rock revealed an absence of Fe, Ni-metal and of chondrules. Therefore, if meteoritic the boulder must represent an achondrite.

The freshly exposed surface displays a breccia structure with an abundant, porous, fine-grained groundmass, in which two main components are discernable to the unaided eye. About 70–80 vol.% is composed of a magnetite or a similar Fe-spinel. Olivine, makes up the other 20–30 vol.%.

In the groundmass there are numerous pink, gray or brown fragments up to some centimetres across (Fig. 2). These resemble a fine-grained, well-sorted sandstone, composed of rounded, deep maroon, sub-millimetre grains. An unidentified cement binds the grains. The surfaces of the fragments are smooth and covered with a black enamel-like substances.

Abundant spherical vesicles up to a few millimetres across are unevenly distributed in the groundmass, the rock varying from massive to vesicular or scoriaceous on a cm-scale. Small euhedral green crystals of olivine line the walls of many vesicles in the groundmass. Vesicles also occur in the fragments, though they are smaller and their distribution is much more uniform.

A single grain a few centimetres across, later identified as an iron silicide, is bright gray-golden in colour with a metallic lustre (Fig. 3).

The texture of this rock did not resemble any known meteorite (e.g. those described in Papike *et al.*, 1998; McSween and Treiman, 1998) or terrestrial ultramafic rock (Streckeisen, 1967; IUGS, 1973), the groundmass was similar to some iron-chromium ores.

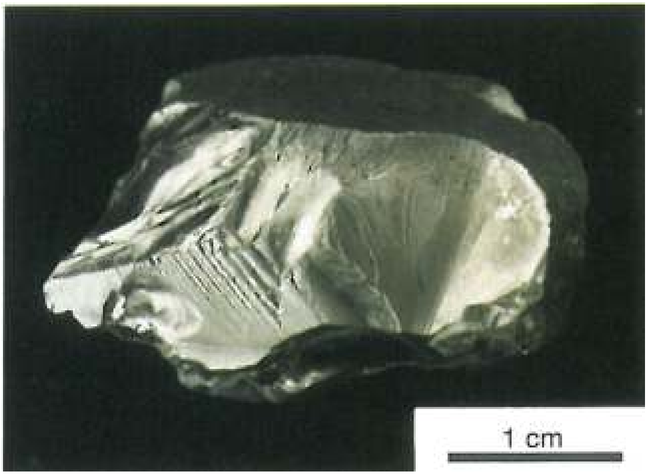

Fig. 3. A steel-gray fragment of an iron silicide extracted from stone has a metallic luster at the surface of the conchoidal fracture; some other specimen could remain inside the stone apparently invisible the external observations

COMPOSITION

The dark matrix and fragments possess low contents of silica ($SiO_2 \approx 23$ and ≈10 wt.% respectively; Table 1) indicating the presence of oxides in both components of the rock. The levels of iron (> 46 wt.% Fe_2O_3), chromium (> 5 wt.% Cr_2O_3), zinc (> 1 wt.% ZnO) and manganese (~1 wt.% MnO) in the matrix suggest classification as an Fe-Cr-ore. Powder diffraction patterns show only the lines of dominant magnetite (JCPDS 19-0629), as well as less abundant augite (JCPDS 41-1483) and forsterite (JCPDS 45-0946). The fragments show high contents of magnesium and calcium (MgO + CaO > 80 wt.%) and low silica, suggesting an abundance of oxides, confirmed by the strong periclase lines in the powder diffraction pattern (JCPDS 45-0946). Thus, the composition of the fragments resembled refractory fire-brick linings rather than any natural product. The "bright gray-golden" grain (Table 2) is composed exclusively of ~81–87 wt.% Fe and ~13–16 wt.% Si (the contents of Cr, Ti, Cu and Ni are less than 1 wt.%), consistent with iron silicide Fe_3Si (verified by a powder diffraction analysis JCPDS 45-1207), which is an intermediate product in the manufacture of some kinds of the special-purpose steel (Wala, pers. comm.).

Table 1

Chemical composition of the matrix and of a fragment (in wt. %) approximative modal mineral composition of the matrix (in vol. %)

Components	Matrix	Fragment
Fe_2O_3*	46.33	6.17
MgO	12.43	75.40
SiO_2	23.56	10.30
CaO	3.65	5.15
Cr_2O_3	5.15	0.14
Al_2O_3	3.83	1.44
Na_2O_3	1.62	0.19
K_2O	0.76	0.31
ZnO	1.16	0.03
MnO	0.97	0.53
TiO_2	0.14	0.05
P_2O_5	0.16	0.26
CuO	0.03	0.01
Cl	0.01	–
NiO	0.06	0.01
J	0.03	–
V_2O_5	0.02	–
SO_3	0.03	0.01
PbO	0.03	0.004
Ga_2O_3	0.01	–
SnO_2	0.02	–
ZrO_2	0.01	–
SrO	0.07	0.07
	Minerals	
Spinel	36	
Olivine	25	
Augite	19	
Glas	19	
Vacuoles	1	
Total	100	

*Fe_{total} recalculated to Fe_2O_3

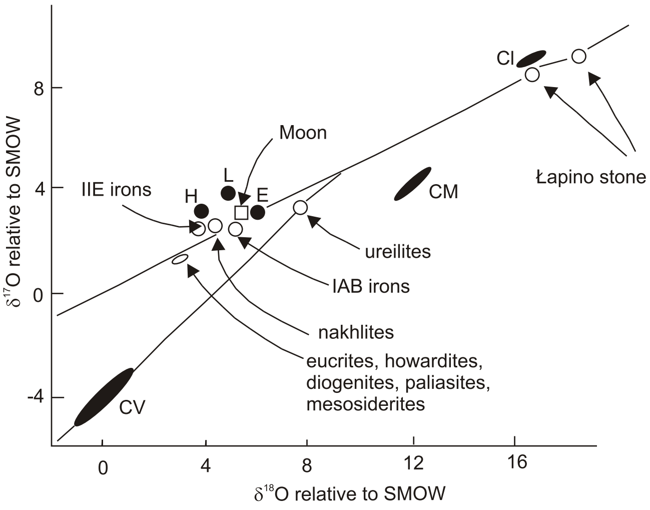

Fig. 4. The distribution of the oxygen isotopes in meteorites and in the Łapino boulder

The upper line with slope ~0.5 is referred to as the "terrestrial mass — fractionation" line

MICROSCOPIC OBSERVATIONS

The matrix include variable proportions of (in crystallization sequence): spinel → olivine → pyroxene → residual glass.

Spinel, mostly in swarms of small skeletal crystals with rounded edges, has an composition of Cr-magnesioferrite or Cr-magnetite with low contents of Al and Zn. Na and Mg is probably absent from the spinel. There are only slight chemical changes at grain boundaries (Table 2; points E, F and G), though grains of spinel located near (Table 3; points C and D) and at a contact with a fragment (Table 3; points A and B) show decreases of Fe, Cr and Na, an increases in Mg, Mn and Al. A few transparent, wine-red domains, inside the spinel suggest a possible local decrease in Fe and picotite spinel formation. Abundant poikilitic structures are build of large, mostly anhedral forsterites (Table 3; points D and E) enclosing spinel. The former are frequently fractured and show mosaic extinction between crossed polar. They have rather smooth contours (well formed pinacoid and pyramid faces are rather scarce) with numerous corrosion sinuses at the contacts with the residual glass and xenomorphic outlines at the euhedral faces of pyroxene grains. Short, subhedral, clinopyroxene prisms, 0.1–0.8 mm across and ~3 mm long, with frequent pinacoid and pyramid faces show pale olive coloration, insignificant pleochroism, zoned structure and mostly uniform extinction. Chemical analyses (Table 3; points F and G) suggest of aegirite-augite, consistent with the angle $n_\gamma/[100] \approx 60°$. Limpid and isotropic residual glass, containing dendritic crystallites, fills intergranular voids and re-entrants in the grains.

These features suggest rapid solidification in dynamic conditions, the matrix matching the composition of a Fe-Cr ore.

Table 2

Chemical composition of spinel from the Łapino boulder (in wt. %)

Components	Fragment		Contact		Matrix		
Point	A	B	C	D	E	F	G
Na_2O	–	–	–	3.0	2.3	2.3	2.5
MgO	18.6	22.8	20.6	10.5	8.4	8.3	8.3
Al_2O_3	4.4	4.4	3.7	1.6	0.9	1.4	1.1
CaO	0.1	0.1	–	–	–	–	–
TiO_2	0.4	0.4	0.3	–	–	–	–
Cr_2O_3	4.0	3.6	2.4	9.0	9.0	10.8	9.6
MnO	1.7	1.6	1.2	1.1		–	–
FeO*	64.9	66.0	69.4	71.8	75.8	72.5	72.2
ZnO	1.1	1.0	1.1	3.7	3.7	3.7	3.8
CuO	0.6	0.4	0.4	0.5	–	–	–
Total	95.8	100.3	99.1	101.2	100.1	99.0	97.5
Atomic ratios on the basis of 4 atoms of oxygen							
Na	–	–	–	0.231	0.184	0.185	0.204
Mg	1.134	1.302	1.220	0.649	0.540	0.535	0.542
Al	0.212	0.199	0.173	0.078	0.046	0.071	0.057
Ca	0.004	0.004	–	–	–	–	–
Ti	0.012	0.012	0.009	–	–	–	–
Cr	0.129	0.109	0.075	0.295	0.307	0.369	0.333
Mn	0.059	0.052	0.040	0.039	–	–	–
Fe	2.220	2.115	2.307	2.489	2.734	2.622	2.647
Zn	0.033	0.028	0.032	0.113	0.118	0.118	0.123
Cu	0.019	0.012	0.012	0.016	–	–	–

*Total iron

Table 3

Chemical composition of olivine (OLI), orthopyroxene (OPX) and periclase (PER) from the matrix (MTX) and fragment (FRG) of the Łapino stone (in wt. %)

Components	OLI					OPX		PER
	FRG			MTX		MTX		FRG
Point	A	B	C	D	E	F	G	H
Na_2O		–	–	–	–	1.99	1.77	–
MgO	54.31	51.01	53.38	51.02	50.54	16.32	16.04	45.0
Al_2O_3	–	–	–	–	–	0.94	0.92	1.0
SiO_2	42.28	40.88	41.41	41.71	41.84	51.72	50.82	–
CaO	3.31	3.28	2.93	0.47	0.34	20.63	21.43	0.3
Cr_2O_3	–	–	–	–	–	–	–	2.5
MnO	–	–	–	0.81	0.84	0.30	0.52	1.0
FeO*	0.58	0.66	0.75	6.35	5.36	7.82	7.79	44.4
CuO	0.50	0.31	0.44	0.41	–	–	–	0.1
ZnO	–	–	–	1.19	–	–	–	1.2
Total	100.98	96.14	98.91	101.96	98.92	99.72	99.29	95.5
	–	–	–	–	–	–	–	–
Forsterite	91.1	90.5	91.5	92.2	92.8	–	–	–
Fayalite	0.6	0.3	0.8	6.6	6.3	–	–	–
Monticellite	8.3	9.2	7.7	1.2	0.9	–	–	–
Enstatite	–	–	–	–	–	45.7	44.8	–
Ferrosilite	–	–	–	–	–	12.6	12.2	–
Wollastonite	–	–	–	–	–	41.7	43.0	–

*Total Fe

Enclosed fragments of the Łapino boulder include pink-gray and light brown fragments comprising silt-sized, well rounded grains of periclase. The grains are pink in reflected light and pale green in transmitted light, have turbid cores full of (< 5 μm) goethite microgranules, and limpid thin margins (< 10 μm). Grains in the centre of the fragment contain rare haematite granules (~5 to ~25 μm). Analysis (Table 3; point H) shows a magnesium-iron oxides composition. Grains are locally bordered by haematite rims.

IRON SILICIDE

Part of the single iron silicide grain was extracted for analysis. The X-ray powder diffraction pattern (interplanar distances 2.00, 1.41 and 1.15 Å) and the chemical composition (Table 4) match the characteristics of suessite, gupeiite and synthetic Fe_3Si.

Table 4

Mean ($\bar{x}$) and standard deviation (σ) of 7 analyses of the iron silicide grain from the Łapino boulder

Elements	$\bar{x} \pm \sigma$ [wt. %]	Atoms/1 Si
Si	14.09±0.96	1.000
Fe	84.92±1.85	3.028
Ti	0.14±0.10	0.006
Cr	0.18±0.12	0.007
Cu	0.29±0.36	0.009
Ni	0.06±0.12	0.002
Total	99.68	–

COSMOGENIC RADIONUCLIDES AND OXYGEN ISOTOPES

No cosmogenic radionuclides (^{10}Be, ^{26}Al and ^{36}Cl) were discovered in samples from the Łapino boulder. The O-isotopic composition ($\delta^{17}O$ = 8.56 and 9.53, $\delta^{18}O$ =16.88 and 18.84; Fig. 4; data in ‰ related to the SMOW standard) suggests a terrestrial origin. The variable $\Delta^{17}O = \delta^{17}O - 0.52 \cdot \delta^{18}O$ calculated for the boulder is –0.25, whereas the nearest CI chondrites show a value of ≈ 0.27 (calculated from Clayton, 1981). Moreover the high $\delta^{18}O$ ~18 determined in the Łapino boulder is within the range of terrestrial hydrothermal waters (Taylor, 1974).

DISCUSSION AND CONCLUSIONS

If the Łapino boulder was meteoritic the absence of chondrules and Fe, Ni-iron might be consitent with an achondrite. The presence of periclase and Fe_3Si in the boulder, and occurrence of periclase in the CAIs of the carbonaceous chondrites (Greshake *et al.*, 1996*a*, *b*), of suessite in the North Haig ureilite (Keil *et al.*, 1980), and of gupeiite and xingfeite among the micrometeorites in the Yanshan provice in China (Yu, 1984); might also support such an interpretation.

Only the Moon and Mars are recognised as the differentiated parent bodies of the achondrites collected till now on Earth, and the Łapino boulder resembles neither Martian nor lunar rocks (Papike *et al.*, 1998; McSween and Treiman, 1998). And, the large mass of the boulder, as compared with the few-kilograms Martian and lunar meteorites, suggest ejection by high energy impacts that would rather destroy the rocks than launch them into the space (Melosh, 1984).

The Łapino boulder does not, either, represent terrestrial impact ejecta (Melosh and Tonks, 1993), as it lacks any effects of shock metamorphism (Żbik and Gostin, 1995) such as multiple planar fractures, planar deformation features, undulatory extinction and partial isotropisation in quartz and in plagioclase, related to shock pressures of 20–35 GPa (Stöffler *et al.*, 1991). In the Łapino boulder, the fracturing of pyroxene, mosaic texture of olivine and appearance of the residual glass rather represents the results of rapid cooling.

A meteoritic origin for the Łapino boulder can thus be definitely excluded. The distinctive iron silicide grain rules out most natural magmatic or metamorphic process. Petrographically, the boulder's matrix resembles an iron-chromium ore together with fragments of a blast-furnace refractory lining (Sawitzky *et al.*, 1985). In this context, the elevated contents of sodium in the matrix seem reasonable, since sodium salts are frequent furnace additives. The components of the boulder originated probably during an accident in a metallurgical plant. Nevertheless, because of the absence of any metallurgical industry in this region, the question: wherefrom? remains unresolved.

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