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GEOCHEMISTRY

Trace Element Composition and Classification of the Chinga Iron Meteorite

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Abstract—A complete microelement analysis of the Chinga meteorite was performed, and the possibility of attributing it together with a number of other iron meteorites into the IVC subgroup, which is transition between IVA and IVB is proposed.

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It is believed that almost all iron meteorites underwent a melting and fractionation stage and formed at the early stage of the development of the solar system before the formation of the bulk of chondrite bodies. Accordingly, they were subdivided into groups that could correspond to one or similar parental cosmic bodies. The fractionation processes were complicated by numerous impact events, amalgamation with silicate bodies, and remelting. However, some iron meteorites cannot be attributed to one group or another and remain ungrouped [1, 2].

The Chinga meteorite refers to unclassified anomalous iron meteorites with low contents of Ga and Ge. It was found in 1912 on the territory of Tuva (Russia) as a few large fragments with a total weight of up to 250 kg. An incomplete geochemical characteristic of this meteorite is given in several works [3–7]. Study [6] should be noted. The authors of this work proved analytically that the metal used for the statue of Buddha brought from Tibet by the German ethnographer E. Shafer in 1938–1939 and that of the Chinga meteorite are similar in composition. The results of a complete microelement analysis of this meteorite we performed show the possibility to attribute it together with a number of other iron meteorites to a subgroup transitional between IVA and IVB.

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Several 2–3 cm polished meteorite plates were prepared for the study. The microstructural features and the mineral composition of the meteorite were studied with a Tescan MYRA 3 LMU scanning electron microscope, equipped with an Oxford X-Max-80 energy-dispersive X-ray detector at the Sobolev Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences, Novosibirsk. The measurement conditions were 15 kV and 1 nA. The micro-

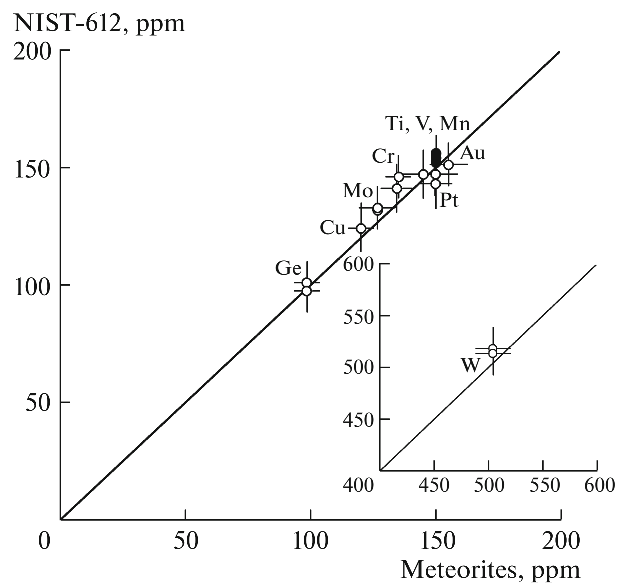

Fig. 1. Concentration ratio of some elements in the standard Ni-5, measured using a LA-ICP-MC calibrated with respect to the contents of these elements in the Hoba and Guadalupe y Calvo (meteorites) iron meteorites and in silicate glass NIST-612. Black circles show the concentrations of Ti, V, and Mn, which were not measured when calibrating with respect to meteorites and accepted at the nominal concentration of 150 ppm.

Table 1. The composition of the metal phase of the Chinga meteorite

Element	Ni-5		1	2	3	4	Aver.		[5]	[6]
Fe	95.59	±0.28	82.67	82.71	82.28	82.50	82.54	±0.20	83.8	83.41
Ni	4.54	±0.11	16.62	16.57	17.01	16.79	16.75	±0.20	16.2	15.98
Total	100.13		99.29	99.29	99.29	99.29	99.29		100.0	99.39
Si	–		486.6	455.4	483.7	461.2	471.7	±15.7	–	–
P	–		423.4	422.8	447.1	435.4	432.2	±11.5	–	443.5
Ti	154.4*	±13.1	0.83	0.64	0.80	0.71	0.75	±0.09	–	–
V	156.1*	±9.6	6.55	6.85	6.54	6.70	6.66	±0.15	–	8.11
Cr	135.2	±6.8	776.3	794.4	782.0	784.3	784.2	±7.5	–	896
Mn	152.4*	±12.5	3.13	3.26	3.23	3.29	3.23	±0.07	–	–
Co	145.0	±18.0	5286	5346	5308	5337	5319	±28	–	6000
Cu	120.1	±3.7	12.45	12.77	13.11	12.89	12.80	±0.27	–	14
Zn	–		0.092	0.095	0.093	0.096	0.094	±0.002	–	–
Ga	–		0.185	0.173	0.198	0.181	0.184	±0.011	–	0.22
Ge	98.4	±4.5	0.354	0.554	0.458	0.509	0.469	±0.086	–	3.12
As	–		2.95	2.74	2.71	2.78	2.80	±0.11	–	–
Mo	126.7	±8.2	6.66	6.83	6.69	6.73	6.73	±0.07	7.42	6.85
Ru	114.1	±6.6	6.91	7.26	7.17	7.18	7.13	±0.16	7.86	6.82
Rh	152.3	±8.8	1.84	1.91	1.84	1.85	1.86	±0.03	2.46	1.77
Pd	138.0	±8.4	6.52	6.48	6.72	6.59	6.58	±0.11	7.89	6.64
Sn	–		0.065	0.087	0.046	0.079	0.069	±0.018	–	–
W	504	±33	0.59	0.56	0.55	0.58	0.57	±0.02	0.569	0.61
Re	134.4	±7.6	0.92	0.89	0.97	0.95	0.93	±0.03	1.028	–
Os	124.8	±7.1	8.34	7.86	8.04	8.10	8.09	±0.19	8.34	–
Ir	127	±8.0	3.56	3.54	3.60	3.58	3.57	±0.03	4.13	3.31
Pt	149.8	±12.4	7.95	7.93	8.02	7.99	7.97	±0.04	9.56	7.94
Au	155.0	±15.0	0.427	0.436	0.427	0.435	0.431	±0.005	0.524	–

Fe, Ni, wt %; other elements, ppm. Ni-5, composition of the standard (see text), calibrated with respect to known element contents in iron meteorites. *1–4*, analyses of the Chinga meteorite; aver., average composition. * Elements calibrated respect to the standard NIST-612.

elemental analysis was performed with laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) (Element XR, Thermo Fisher Scientific) at Tokyo University (Japan). As a standard for most siderophilic elements, the Ni-5 alloy, synthesized in an inert atmosphere at 2700°C by the arc melting method, was used (the detailed characterization of Ni-5 standard will be reported elsewhere). The composition and contents of microelements in the standard determined by the same LA-ICP-MS method are shown in Table 1. The element contents are calibrated with respect to known contents in the Hoba and Guadalupe y Calvo meteorites. For other elements, NIST-612 silicate glass was used as the standard. Calibration of the contents of some elements with respect to the standards is shown in Fig. 1. It is important to note that the calibration with respect to silicate glass gives results similar to those obtained for metals and, accordingly, gives insignificant errors in determining the contents of trace elements despite the significant difference in the matrix of silicate glass and metal. The radiation intensity of the Nd-YAG laser was 80 μJ/cm^2. The beam diameter is 100 μm. The analysis lasted 3 min, including 60 s for determining the background values, 60 s for counting the signal from the sample, and 60 s for the signal depression to background values. The standards were recorded before and after measuring the meteorite samples.

The Chinga meteorite has ataxite texture. The Fe phases are described in detail in [8, 9]. The microplessite matrix in our samples contains no other primary minerals. The Ni content varies in the range of 15.9–17.1 wt % (16.75 wt %, on average). There are small inclusions of kamasite (7.15 wt % Ni, 0.97 wt % Co), as well as larger rounded inclusions of troilite (1.33 wt % Cr, 0.8 wt % V), and dobreelite (18.7 wt % Fe, 36.2 wt % Cr) [6].

The microelemental composition of the metal phase of the Chinga meteorite is given in Table 1 and

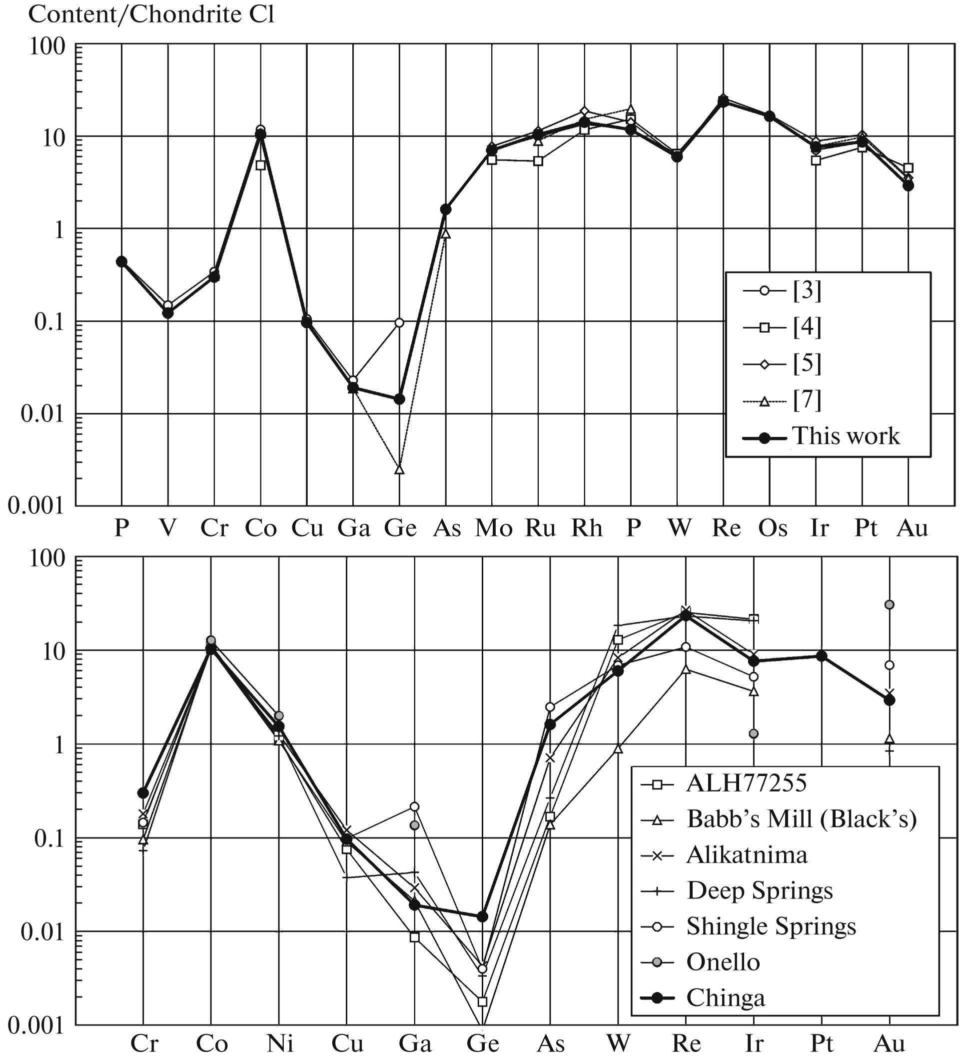

Fig. 2. Chondrite Cl-normalized trace element distribution spectra: (a) meteorite Chinga, (b) anomalous meteorites of close composition.

in Fig. 2. The concentrations of Sc, Se, Y, Zr, Nb, Ag, Cd, In, Sb, Te, Hf, Ta, Pb, Th, and U are below the detection limit. On multielement diagrams, the meteorite composition measured by us agrees well with the previously obtained data (Fig. 2a). There are only essential variations in the Ge content. The spectrum profile has no analogues among iron meteorites of the distinguished groups. Therefore, the Chinga meteorite was previously classified as anomalous with a vague similarity to meteorites of the group IVB. Nonetheless, it differs greatly in Ga, Ir, and other components. It is important to note significant concentrations of Si = 455–487 ppm and P = 422–447 ppm.

In the classification diagrams of Ni versus Ge, Ga, and Ir, the Chinga meteorite lies in the field between the IVA and IVB groups together with a number of other anomalous meteorites (Fig. 3). Among them one can distinguish a group of meteorites that has a similar distribution spectrum of trace elements (Fig. 2b) and close concentrations in the element ratio diagrams (Figs. 3, 4). The following meteorites are included in this group: Babb's Mill (Black's) meteorites (Ni = 11.8 wt %), Allan Hills A77255 (Ni = 12.4 wt %), Deep Springs (Ni = 13.2 wt %), Alikatnima (Ni = 13.9 wt %), and Shingle Springs (Ni = 17.0 wt %) [3, 4, 10]. In terms of chemical composition, the Alikatnima and Shingle Springs meteorites are the closest to the Chinga meteorite. The Shingle Springs meteorite differs essentially only in the Ga content. It is possible that the Onello meteorite (Ni = 21.7 wt%) (Figs. 2, 3) also belongs to this subgroup, but the data available on its composition are still insufficient [11]. Distinct trends in the composition variations or concentration in one group are seen in the classification diagrams of Ni and Ge, Cu, As, Au ratios of (Figs. 3, 4). The only Babb's Mill (Black's) meteorite stands apart other meteorites in the W content. The identification

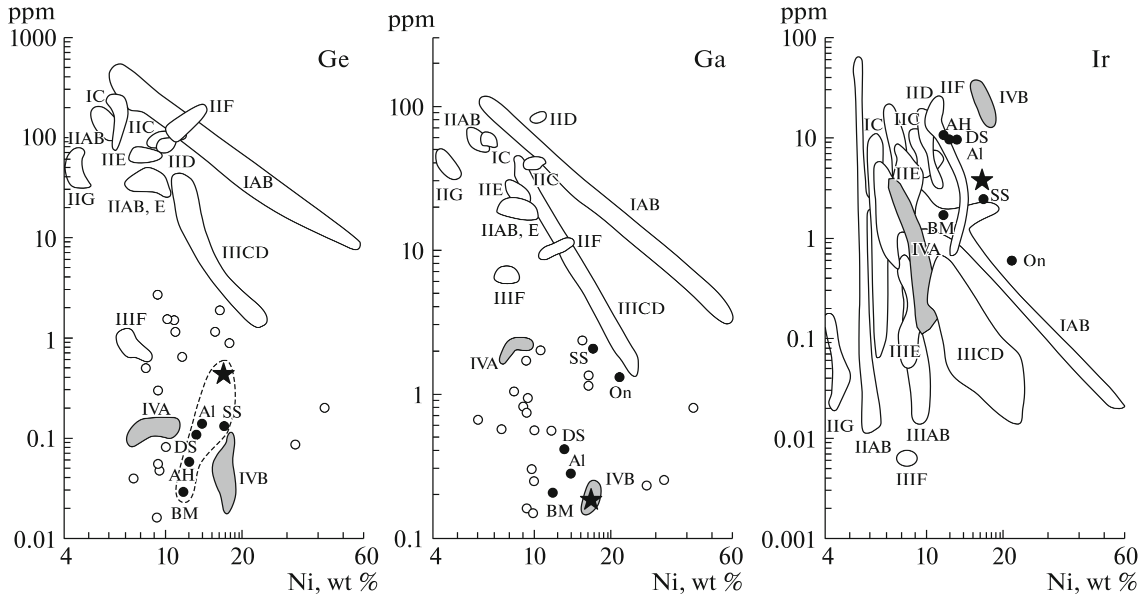

Fig. 3. Classification diagrams showing compositions of anomalous iron meteorites with low contents of Ga and Ge (circles) relative to distinguished groups (for sources of information, see [2] and the Meteorite bulletin database (https://www.lpi.usra.edu/meteor/)). A star shows the composition of the Chinga meteorite, black circles show ataxites of close composition with a high Ni content: BM, Babb's Mill (Black's); AH, Allan Hills A77255; DS, Deep Springs; Al, Alikatnima; SS, Shingle Springs; On, Onello.

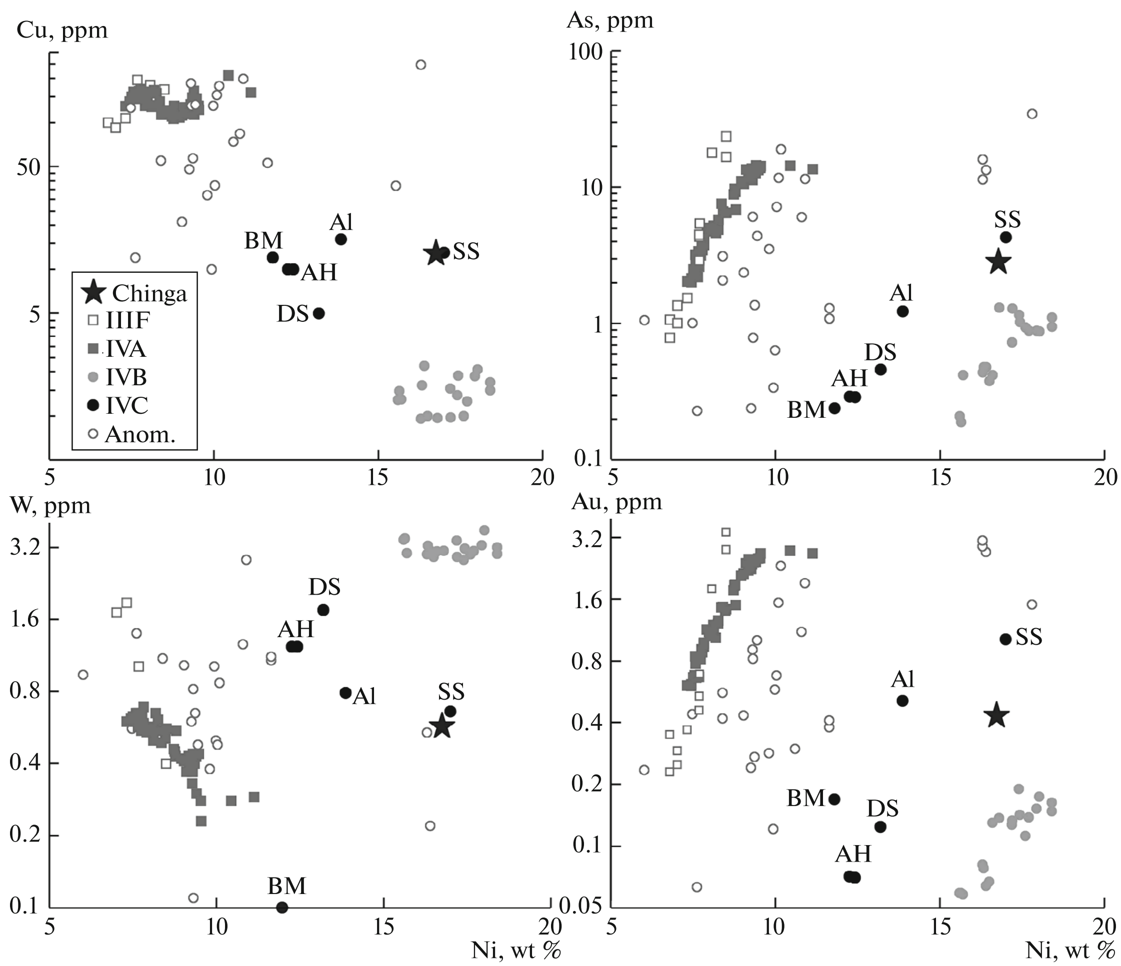

Fig. 4. Concentrations of trace elements relative to the Ni content in groups of iron meteorites with low contents of Ga and Ge (IIIF, IVA, IVB). Anom., anomalous meteorites. For symbols of some meteorites of group IVC, see Fig. 3.

of this group of meteorites in terms of the Ga and Ir contents is less pronounced. Despite some anomalies, this group of meteorites is characterized by close trace element compositions and can give a new trend in the composition diagrams of iron meteorites, which can be classified as an IVC group. It should be noted that almost all the meteorites mentioned are poorly characterized as a whole; only the contents of a number of key trace elements have been measured in them.

The classification of several meteorites into a separate group means that they could have originated from a single parent cosmic body or a similar group of bodies. This supposition should be confirmed not only by the microelement composition data, but also by isotope data. Only the Chinga meteorite from the noticed group of meteorites has been studied using various isotope techniques. Most of the isotope characteristics, for example, $\delta^{187}Re$, $\varepsilon^{182}W$, $\varepsilon^{184}W$, are in good agreement with those obtained for meteorites of the group IVB, which is evidence of the parent cosmic bodies of these meteorites [12, 13]. However, the $^{187}Re/^{188}Os = 0.5650$ and $^{187}Os/^{188}Os = 0.14075$ ratios do not fit the isochron for the group IVB [14].

Thus, this work presents the notion that a transition subgroup can be identified for iron meteorites with low contents of Ga and Ge, apart from the previously distinguished groups IVA and IVB. This subgroup, preliminarily named IVC, includes the Chinga meteorite. For further clarification of this classification, it is necessary to perform additional study of meteorites, which we have attributed to the IVC group, since data on the trace elemental and isotope composition are still insufficient.

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