Classification of Four New Irons, Including Common (IIAB) and Uncommon (IIIF, Unusual IAB) Types

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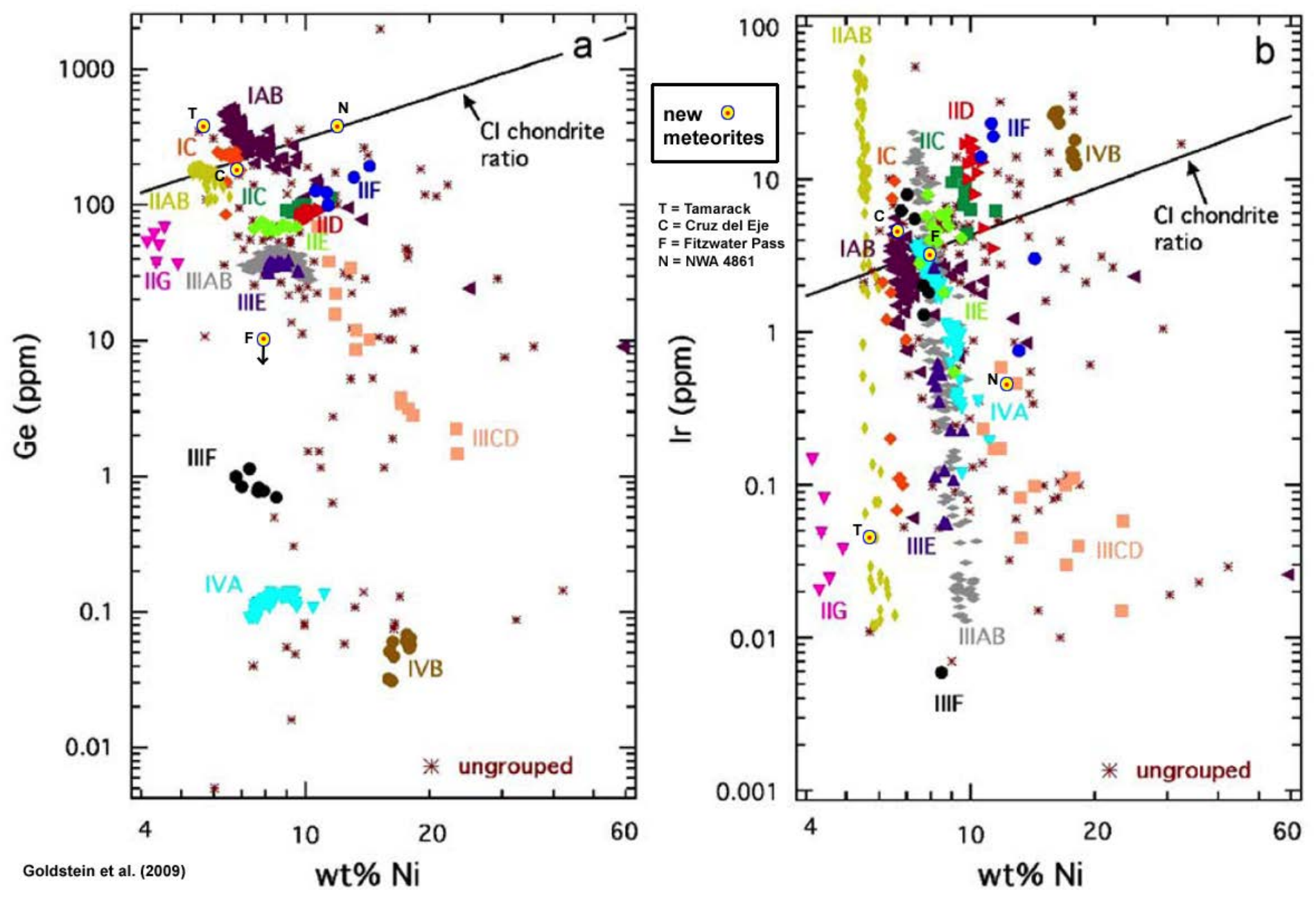
Introduction: Correctly classifying iron meteorites and understanding intragroup chemical variations is crucial to understanding nebular, melting, and impact processes and the relationship of iron meteorites to other meteorite classes. However, the classification of iron meteorites has been an evolving and sometimes contentious area. Iron meteorites have been grouped on the basis of trace element abundances, with the number of groups fluctuating over time but now comprising thirteen generally accepted groups [e.g., 1,2,3]. While some groups contain dozens of individual meteorites, others are represented by fewer than ten individuals [4]. Chemical variations within individual meteorites in many of these groups can be explained by fractional crystallization during cooling from a melt [e.g., 1, 2, 3, 4]. In other groups, intragroup chemical variations are not as well understood. In addition to the defined chemical groups, roughly 15% of iron meteorites are ungrouped [e.g., 1, 3]. In 2002, Wasson and Kallemeyn [4] argued that the IAB and IIICD groups, as well as a number of ungrouped irons, were all related, with chemical variations resulting from impact processes. They suggested eliminating the IIICD group and proposed six subgroups within a newly defined IAB complex [4]. Recent reviews have chosen to keep the IAB and IIICD groups separate and indicate that iron meteorites comprise either thirteen [3] or fourteen [1] chemically distinct groups, along with a number of ungrouped iron meteorites. Here we present data for four newly classified iron meteorites.

INAA data for four newly classified iron meteorites
(numbers in parentheses represent formal analytical error):

Meteorite	**Tamarack**	**NWA 4861**	**Fitzwater Pass**	**Cruz del Eje**
As ppm	10.4 (0.3)	31.8 (1)	17.9 (0.5)	12.8 (0.4)
Au ppm	1.09 (0.03)	3.03 (0.09)	1.8 (0.05)	1.52 (0.05)
Co mg/g	5.03 (0.15)	6.02 (0.18)	5.06 (0.15)	4.62 (0.14)
Cr ppm	20 (6)	9 (3)	34 (10)	21 (6)
Cu ppm	103 (8)	145 (11)	180 (14)	108 (8)
Ga ppm	74 (1)	76 (2)	10 (0.2)	44 (1)
Ge ppm	370 (56)	350 (53)	<10	130 (20)
Ir ppm	0.044 (0.022)	0.458 (0.023)	2.54 (0.13)	4.21 (0.21)
Ni mg/g	58.6 (4.4)	119 (9)	80.7 (6.1)	68.9 (5.2)
Pt ppm	4.6 (0.9)	<0.1	9.2 (1.8)	11.6 (2.3)
Re ppm	<0.01	0.07 (0.03)	0.23 (0.01)	0.38 (0.01)
Sb ppm	<20	<20	<20	<20
W ppm	<10	<10	<10	<10
Group	**IIAB**	**IAB, sHL?**	**IIIF**	**IAB, main group?**
comments	Ga ~30% high, Ge >2x too high	enriched in Ga and Ge	Ga ~30% high	depleted in Ga and Ge

Ni vs. Ge and Ir diagrams from [1] showing chemical data for the four new meteorites in relation to established groups and illustrating some of the difficulties inherent in iron meteorite classification. Nickel and Ir contents for Tamarack (T), Cruz del Eje (C) and NWA 4861 (N) suggest designations of IIAB, IAB, and IIICD, respectively, but Ge values are discrepant by factors of two or more probably owing to analytical errors of this order in our Ge data. However, Ge data for Fitzwater Pass (F), although an upper limit of 10 ppm, are still useful as the concentrations of Ge and Ni rule out all but the IIIF and IVA groups. IVA can be ruled out on the basis of kamacite bandwidth and other trace element concentrations (see chemical plot for Fitzwater Pass).

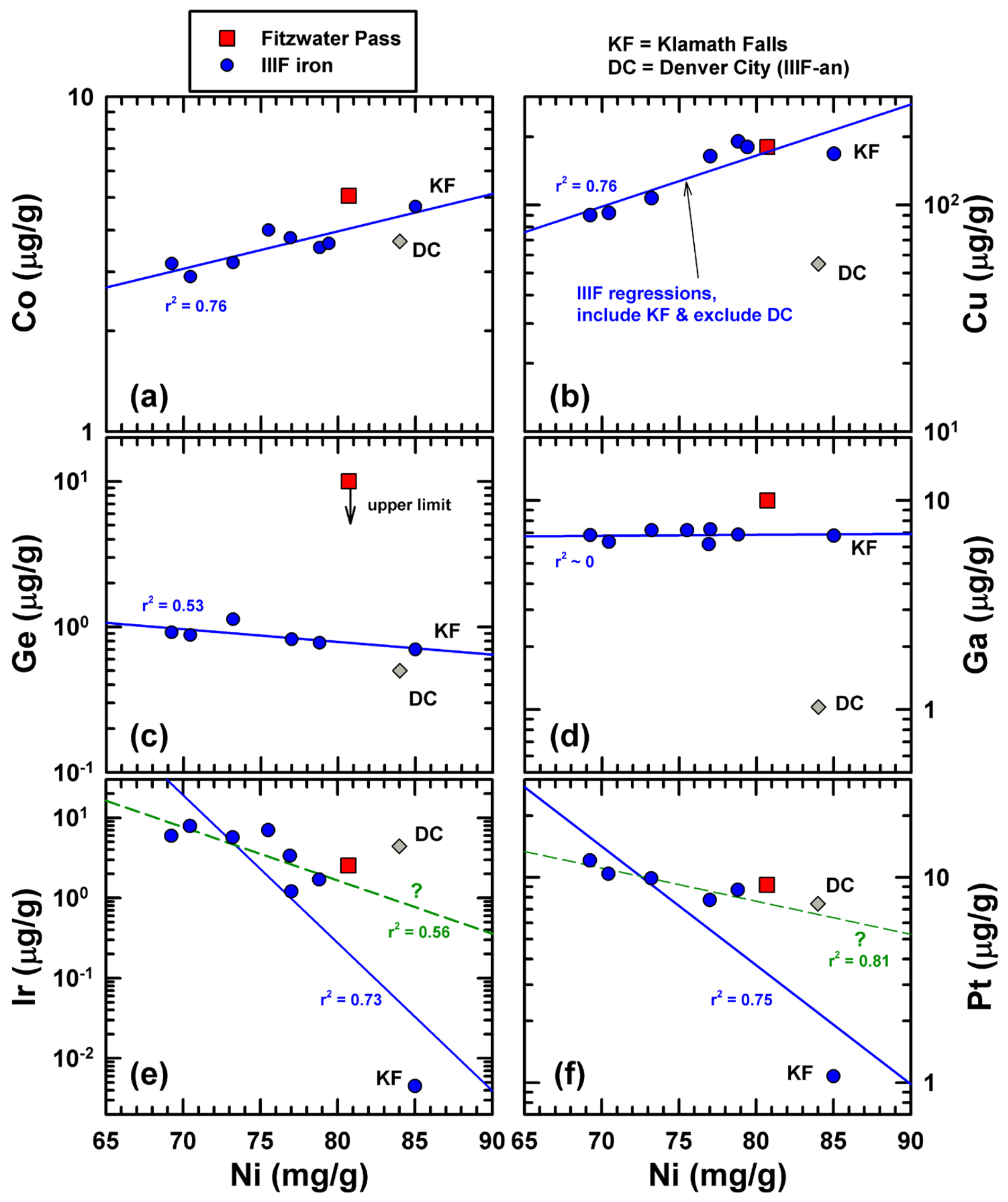


Tamarack: Two small specimens (16 and 25 g) were found in 2004 shallowly buried in soil on a hillside in Idaho (USA) ~15-30 m apart. Both specimens have prominent regmaglypts and are largely coated by reddish rust stains and a dull brown patina; they have blacker edges and corners (apparent fusion crust) that show exposed metal from the interior at abrasion points. The smaller individual (measuring ~3 x 1 x 1 cm) was donated to the Cascadia Meteorite Laboratory (CML) and used for petrographic and chemical analyses. Microscopic examination of cut, etched faces reveals primarily kamacite, with apparent bandwidth of ~3 mm (uncertain owing to small size of sample). Kamacite contains Neumann lines and numerous rhabdites. No traces of a heat-affected zone are preserved in the interior. Microhardness measurements yielded VHN = 208 for kamacite, indicating moderate work hardening. Texture and element concentrations suggest this meteorite is a IIAB iron coarsest octahedrite, a relatively common type.

From left to right: Picture taken by finder (Joe Adams) showing both pieces of Tamarack; piece donated to CML and analyzed; piece retained by finder.

Conclusions: Classification of iron meteorites and definition of chemical trends shown by different groups is a necessary step to better understand early solar system accretion and melting processes but is not always a straight-forward proposition, as evidenced by our work on four new irons. For example, although Fitzwater Pass appears to be the ninth known IIIF, there are too few IIIF meteorites to define a clear chemical trend for some elements.
NWA 4861 and Cruz del Eje appear to be part of the chemically variable IAB complex [4], but assignment to subgroups is uncertain owing to analytical errors in Ge and Ga as well as to the poorly-defined chemical boundaries and trends within this association. Most likely, NWA 4861 corresponds to the IAB-sHL subgroup (former IIICD group), and Cruz del Eje to the IAB main group. More analyses of the 'IAB complex' meteorites might help to better interpret the significance of this possible association and the members within it.

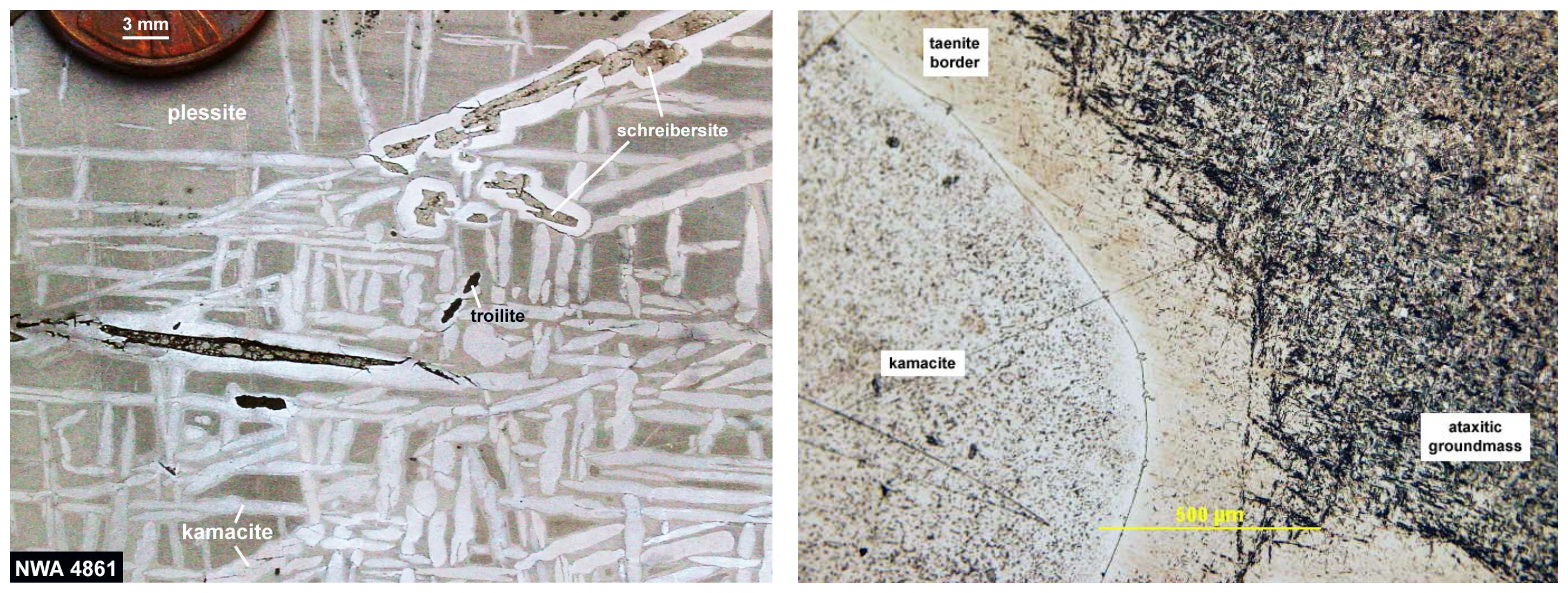
Fitzwater Pass: This small (~65 g) iron from Oregon (USA), only the sixth meteorite from this relatively large state, was found on a remote mountaintop ~5 km from the California border in 1971. The specimen is a small (~4 x 2 x 2 cm) iron meteorite that has a rough, blocky and lineated surface texture which appears to reflect the internal Widmanstatten structure. It is almost completely covered with a dark brown to black weathering patina. Microscopic examination of cut and etched surfaces show that the meteorite is a coarse octahedrite with bandwidth 1.44 ± 0.29 mm and kamacite L:W = 3:1 (all widths corrected according to the procedure of [5]). Microhardness measurements yielded VHN =2.2 for kamacite and VHN =299 for taenite, indicating moderate work hardening. Minor sulfide is present, along with an exterior weathering rind ~0.5-1 mm thick containing iron oxide/hydroxide minerals.



Nickel variation diagrams (at right) show chemical compositions of Fitzwater Pass and IIIF irons (IIIF data from [6]). The IIIF group as defined by [1] includes one other Oregon meteorite (Klamath Falls, KF), but does not include Denver City (DC), which is classified as an anomalous IIIF [6]. In the diagrams, the blue regression line is fitted to the IIIF data (blue symbols), excluding Denver City and Fitzwater Pass. The dashed green regression line is fitted to the same data, but with Klamath Falls also excluded. The composition of Fitzwater Pass is consistent with this meteorite being a member of the IIIF group, which contains only 8 individuals [1], although Ga concentrations are clearly ~30% too high (see Ni-Ga diagram, part d), probably reflecting analytical error. Fitzwater Pass was found only ~78 km away from Klamath Falls, but does not appear to be another individual of Klamath Falls as the latter has a smaller kamacite bandwidth (0.5 mm), and contains much lower concentrations of Ir and Pt (parts e and f). The new data for Fitzwater Pass reaffirm previous Ni-Co and Ni-Cu trends for IIIF irons, but could be interpreted to indicate that Klamath Falls does not belong to the same Ni-Ir and Ni-Pt trend as other IIIF irons (parts e and f).

NWA 4861: A single specimen with a total mass of ~2.4 kg purchased in Morocco by Edwin Thompson in 2005 has a rounded exterior surface with a dark, black- to purple-tinted weathering patina. Cut and etched faces have a striking appearance, with tapering kamacite spindles ranging from ~2-32 mm long and ~0.5-1.5 mm wide, set in a taenite-rich, plessitic (ataxitic) groundmass. Clear-etching taenite zones surround the kamacite spindles. The spindles display three orientations on cut surfaces, indicating that the meteorite is a plessitic octahedrite. Coarse schreibersite is present, including acicular grains up to 25 mm long, which are surrounded by swathing kamacite. Only minor troilite and no heat-affected zone is visible. Microhardness measurements yielded VHN = 276 for the kamacite spindles, 209 for the swathing kamacite, and 231 for the microtextured matrix. Elemental concentrations suggest assignment to the IAB complex, similar to subgroup sHL (high Au/Ni) of [4], except that the new iron is significantly enriched in Ga and Ge (by ~4x and ~10x, respectively) compared to other IAB-sHL members. These large discrepancies, especially for Ga, significantly exceed our likely uncertainty based on analyses of an Odessa internal standard and the previous two meteorites in the same run. NWA 4861 is best classified as an ungrouped member of the IAB complex related to subgroup sHL (or a IIICD according to recent reviews by [1] and [3]).

Images of cut and etched surfaces of NWA 4861, obtained in handspecimen (left) and with reflected light microscopy (right).



Cruz del Eje: This large iron (~14 kg) was found in Argentina in 1971. The exterior surface has a brown-to-black weathering patina. Microscopic examination of cut and etched surfaces show that the meteorite is a coarsest octahedrite, containing taenite but dominated by irregularly-shaped kamacite grains with bandwidth >3.3 mm. Microhardness measurements for kamacite yielded VHN = 201, indicating moderate work hardening. Most elemental concentrations are similar to those reported for the IAB main group [4], except that the concentration of Ga is lower by ~50% and that of Ge is lower by ~60%. We cannot rule out that the determinations of Ga and Ge are somewhat in error and that the meteorite is a normal member of the IAB main group. However, the discrepancy for Ga is larger than the apparent error we infer for Ga in this run (~14-30%), which implies that the Cruz del Eje iron is best described as an ungrouped member of the IAB complex related to the main group.

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