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The Ischgl meteorite, a new LL6 chondrite from Tyrol, Austria

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(With 10 figures and 3 tables)

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Abstract

The Ischgl meteorite is a LL6 chondrite found in 1976 near Ischgl, Tyrol, Austria. This is only the 7th meteorite named after a location in Austria. The meteorite is covered with a fresh fusion crust and shows only minor signs of terrestrial weathering. The olivines and orthopyroxenes are equilibrated and have average compositions of $Fa_{28.9}$ and $Fs_{23.8}$, respectively. The opaque phases consist predominately of nickel-iron, troilite, and chromite. Other minerals include plagioclase ($Ab_{85}An_{10}Or_{5}$), clinopyroxene ($Fs_{10.5}En_{46.3}Wo_{43.2}$), chlorapatite, whitlockite, ilmenite, and native copper. The texture of the meteorite is characterized by intense recrystallization of the matrix and former chondrules – remnants of which are present only as a few relic chondrules. Shock features indicate that the meteorite experienced only weak shock metamorphism (S3).

Keywords: Meteorite, LL chondrite, Ischgl, Tyrol, Austria, petrography, mineralogy

Zusammenfassung

Der Ischgl-Meteorit ist ein LL6-Chondrit, der 1976 in Österreich in der Nähe von Ischgl in Tirol gefunden wurde. Es handelt sich hierbei um den siebenten benannten Meteoriten, der auf österreichischem Staatsgebiet gefunden wurde. Der Meteorit ist mit einer frischen Schmelzkruste überzogen und weist kaum Spuren irdischer Verwitterung auf.

Olivine und Orthopyroxene sind equilibriert und haben die durchschnittliche Zusammensetzung $Fa_{28.9}$ bzw. $Fs_{23.8}$. Bei den opaken Phasen sind Nickel-Eisen, Troilit und Chromit vorherrschend. Weitere Minerale sind Plagioklas ($Ab_{85}An_{10}Or_{5}$), Klinopyroxen ($Fs_{10.5}En_{46.3}Wo_{43.2}$), Chlorapatit, Whitlockit, Ilmenit und gediegen Kupfer. Das Gefüge des Meteoriten ist durch eine intensive Rekristallisation von Matrix und den ehemaligen Chondren – die nur mehr vereinzelt als Relikte

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vorhanden sind – gekennzeichnet. Schockmerkmale weisen darauf hin, dass auf den Meteoriten nur eine schwache Schockmetamorphose (S3) eingewirkt hat.

Schlüsselworte: Meteorit, LL-Chondrit, Ischgl, Tirol, Österreich, Petrographie, Mineralogie

Introduction

Up to now, only a few meteorites were recovered on Austrian territory. The last meteorite named after an Austrian finding site is the Ybbsitz meteorite, which was discovered in 1977 (Schnabel 1985; Brandstätter et al. 1985). In total, meteorites named after Austrian locations comprise two finds and four falls (In addition, one of three fragments of the Neuschwanstein meteorite, which fell at the border between Germany and Austria, was recovered from Austrian territory, but this meteorite was named after its first finding location in Germany; Oberst et al. 2004). Thus, Ischgl is the seventh Austrian meteorite and the third recovered find.

In this paper, we report the results of our preliminary mineralogical investigations of the meteorite, using a variety of techniques. A polished thin section was prepared from a slab cut at the University of Innsbruck from the original main piece. Petrographic characterization was performed by using optical microscopy (transmitted and reflected light) and analytical scanning electron microscopy (SEM, JEOL JSM-6610LV). Mineral analyses were carried out with a JEOL Superprobe 8100 electron microprobe operated at 15 kV accelerating voltage and 20 nA beam current. The bulk chemical composition of the meteorite was obtained by instrumental neutron activation analysis (INAA) at the University of Vienna; for details on this method, see Mader & Koeberl (2009).

History

In June 1976, while clearing a mountain road (about 2 km NW of the Tyrolian town Ischgl) from remnants of snow avalanches, a single black stone, weighing about 1 kg was found by Josef Pfefferle. According to the finder, the fist-sized stone apparently had fallen out of the snow and was lying in the middle of the road. The finding site has an altitude of ca. 2000 m above sea level and its coordinates are 47°1.58' N, 10°16.40' E. Mr. Pfefferle recognized the unusual appearance of the rock. He suspected that it might be a meteorite and took the stone to his home. However, all people to whom he showed his find disregarded his idea that he might have found a meteorite. Finally, he put the rock into a box and kept it for more than thirty years without paying further attention to it. In 2007, Austrian news media reported on a court case involving a meteorite found near the Tyrolian town of Reutte. These reports reminded the finder about his find. He then brought the stone to the University of Innsbruck, where its meteoritic nature was confirmed. In 2011, the meteorite was purchased from the finder by the Natural History Museum, Vienna. An estimated mass of about 200–300 g is missing from the original main mass, as parts of it were chipped off early on using a hammer, and later a small fragment was cut off at the University of Innsbruck.

Fig. 1. Fusion crusted exterior of the main piece of the Ischgl meteorite exhibiting numerous well-developed regmaglypts.

As the meteorite apparently had been fallen out of the snow of an avalanche it very likely fell during the previous winter. However, there are no corresponding fireball reports for 1976 and 1975 (personal communication: Prof. H. Mucke, Astronomisches Büro, Wien).

Petrography

Macroscopic description

The remaining main mass of the meteorite, weighing 710 g, measures approximately 9×8×6 cm. Its exterior is totally fusion-crusted except for the parts that have been chipped and cut off and exhibits well developed regmaglypts (Figs 1, 2). The fusion crust looks very fresh and has a dull black color. The exposed interior of the meteorite shows a uniform light-grey colored rock without any distinct clasts. The cut surface exhibits a chondritic texture with a few poorly defined chondrule-like outlines and finely dispersed small (average diameter <1 mm) metal grains.

Fig. 2. View of the Ischgl meteorite showing its light-grey colored interior. Some patchy brown oxidized areas are visible on the cut and broken surface.

Microscopic description

The meteorite is a monomict breccia consisting predominantly of coarse-grained mm- to cm-sized clasts set in a finer-grained breccia matrix (Figs 3A, B). Clasts and matrix are strongly recrystallized. Chondrules exhibiting well-delineated outlines are completely absent and only a few relic chondrules were encountered (Fig. 4).

Average grain sizes of the main silicates olivine and orthopyroxene are about <0.1–1 mm and <0.1 mm in the clasts and the finer grained breccia matrix, respectively. The apparent diameter of the plagioclase crystals is >50 µm and its size exceeds in places 100 µm (Fig. 5). Several of the larger feldspar grains exhibit polysynthetic twinning. Clinopyroxene (diopside) is a minor constituent and occurs as relatively large crystals (up to 50 µm in diameter) in association with orthopyroxene and plagioclase. Apatite and whitlockite are present as anhedral to subhedral grains >50 µm in size (Figs 6, 7).

The opaque phases are dominated by anhedral grains of nickel-iron metal (<0.1–0.5 mm) and troilite (<0.1–1 mm). They are present as isolated single grains within the silicate matrix or, more commonly, form metal-sulfide intergrowths (Fig. 8), which in places are several mm in size. A minor opaque phase is chromite, occurring as anhedral aggregates (>100 µm) within silicates or in association with metal or troilite (Fig. 9). In addition,

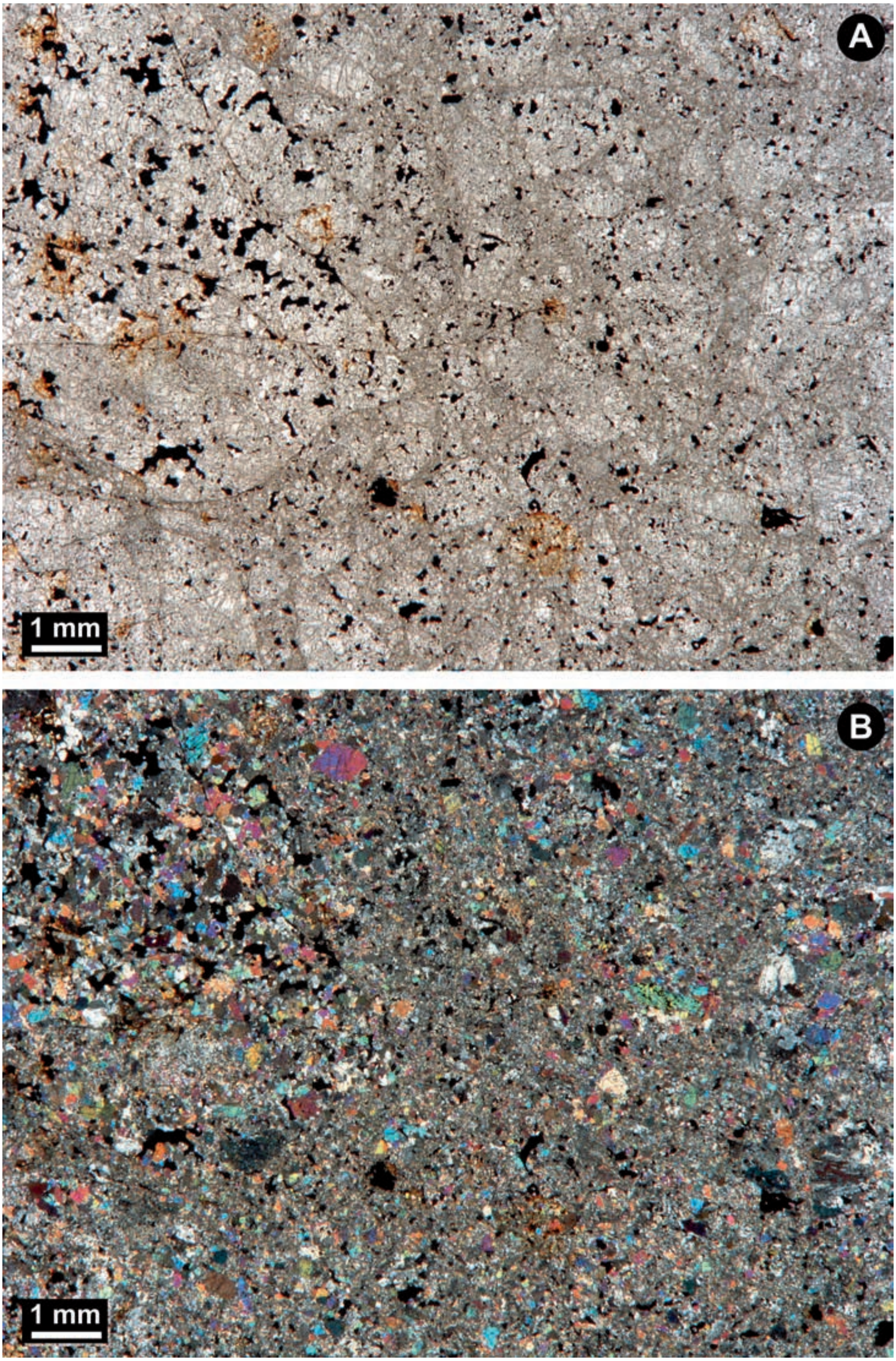

Fig. 3. Photomicrographs showing the characteristic texture of the Ischgl meteorite, consisting of a strongly recrystallized monomict breccia; A: plain polarized light, B: crossed polarizers.

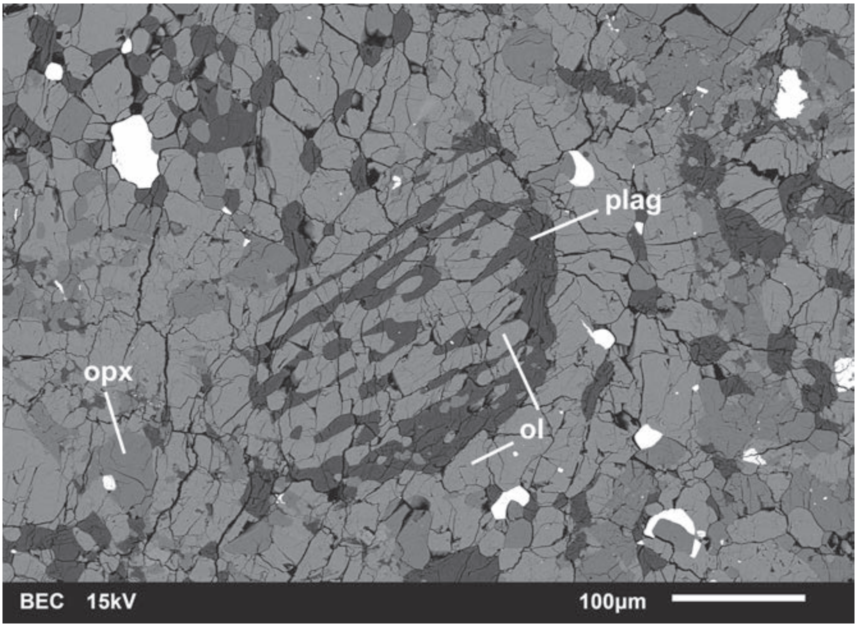

Fig. 4. Backscattered electron (BSE) image of a relic barred olivine chondrule. The surrounding silicate matrix consists mainly of olivine (light grey), orthopyroxene (medium grey), and plagioclase (dark grey).

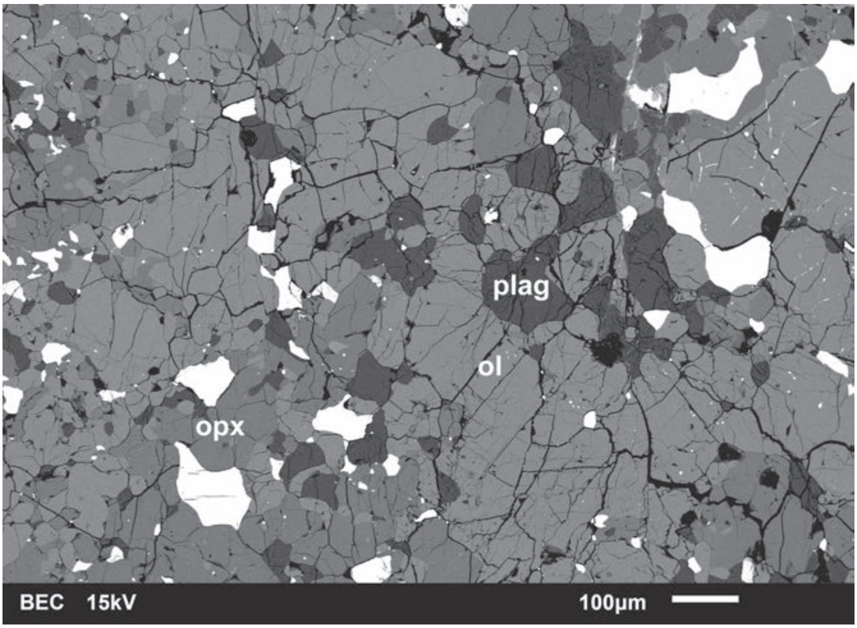

Fig. 5. BSE image exhibiting the strongly recrystallized lithology, consisting mainly of olivine (light grey), orthopyroxene (medium grey), plagioclase (dark grey), and anhedral grains of metal and troilite (white).

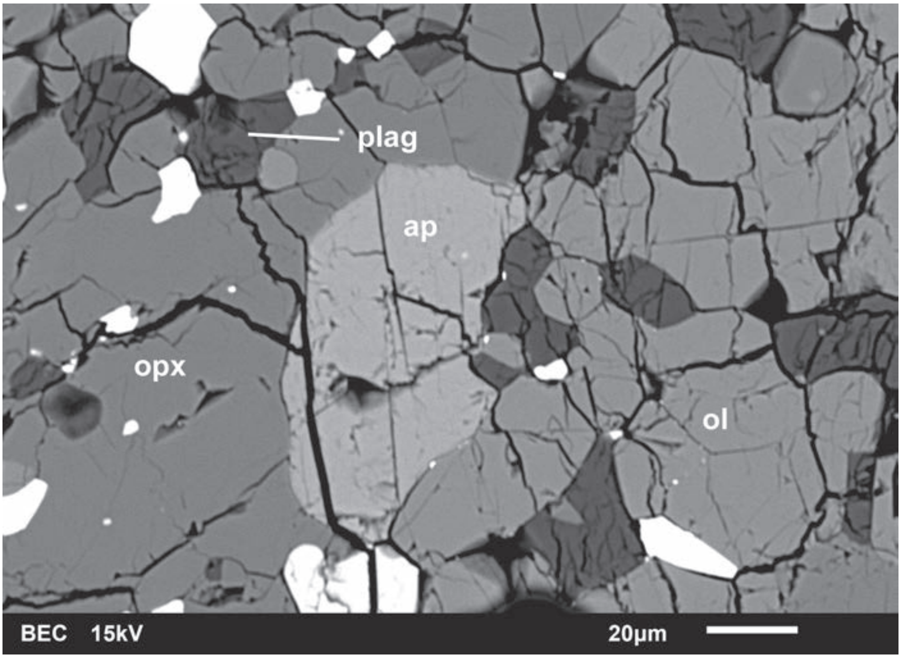

Fig. 6. BSE image of a subhedral apatite grain associated with olivine, orthopyroxene, and plagioclase.

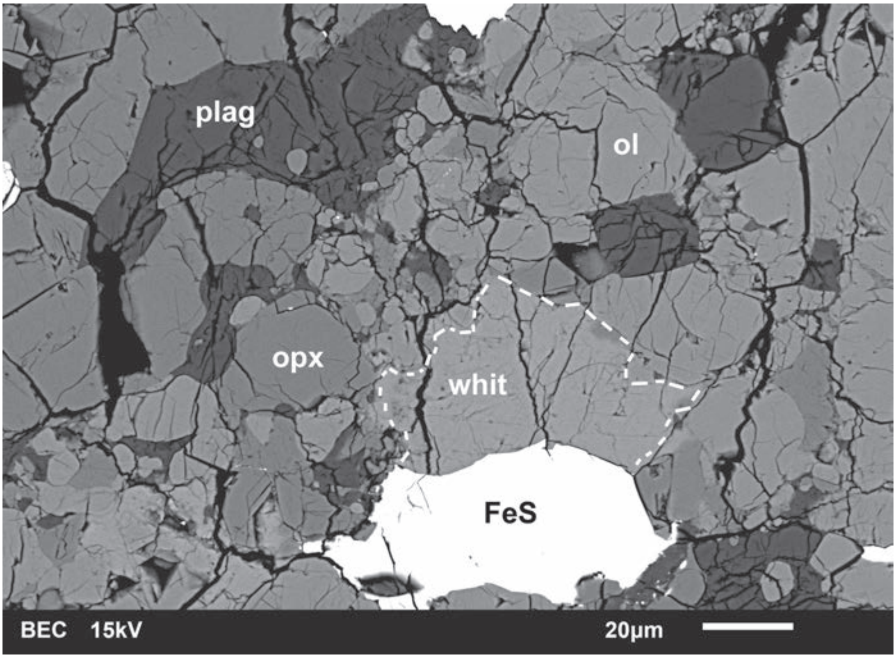

Fig. 7. BSE image of an anhedral whitlockite grain associated with olivine, orthopyroxene, and troilite.

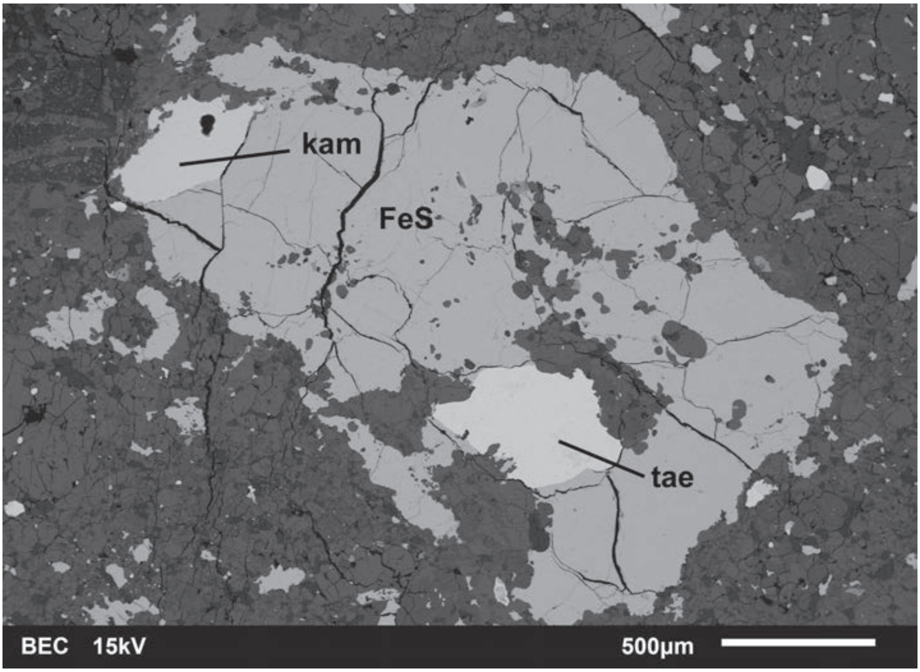

Fig. 8. BSE image of a large metal-sulfide intergrowth consisting of troilite, kamacite, and taenite.

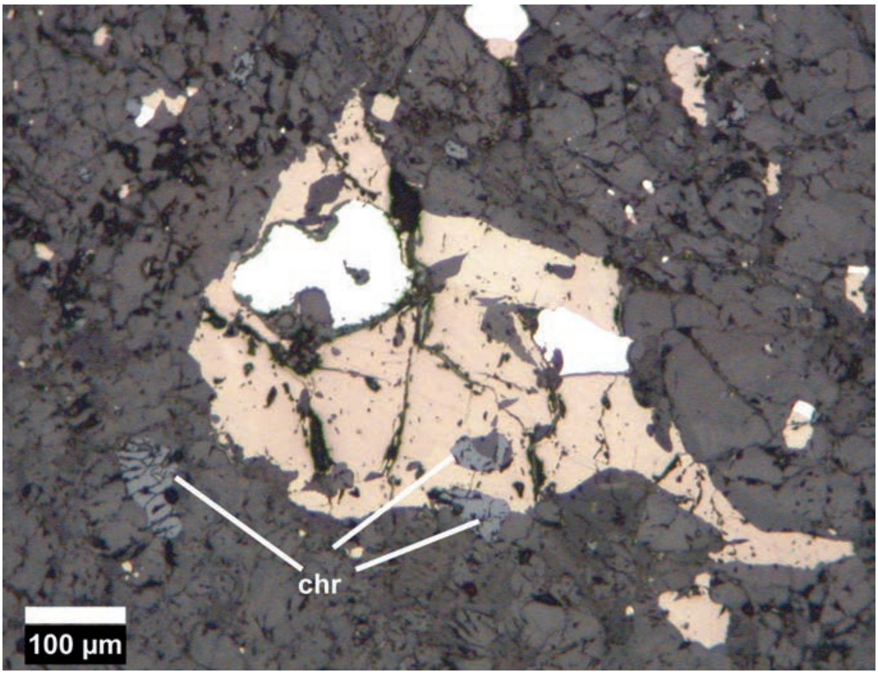

Fig. 9. Photomicrograph (reflected light) showing chromite grains (medium grey) occurring in the silicate matrix, as well as in association with troilite (light yellow) and metal (white).

ilmenite (<100 µm) occurs as a rare constituent and a few grains of native copper (ca. 10 µm in diameter) were observed in association with troilite.

The petrographic features described above clearly indicate that the Ischgl meteorite is an ordinary chondrite of petrologic type 6 according to the classification scheme of VAN SCHMUS & WOOD (1967).

Shock metamorphism

The meteorite underwent weak shock metamorphism. This is evident from i) the undulatory extinction of olivine, pyroxene, and plagioclase, ii) the presence of planar fractures in olivine, and the presence of opaque shock veins (Figs 10A, B). Thus, based on the classification scheme of STÖFFLER et al. (1991) shock stage S3 can be assigned to the Ischgl meteorite.

Weathering

The exterior and interior of the meteorite are very fresh although some brownish oxidized areas are visible on the cut and broken surface (Fig. 3). Other weathering features are mainly restricted to some limonitic staining in transmitted light. Therefore, weathering grade W0 on the scale devised by WLOTZKA (1993) is assigned to the Ischgl meteorite.

Mineral chemistry

Compositions of the major silicate phases olivine, orthopyroxene, clinopyroxene, and plagioclase are given in Table 1. All contents of major and minor elements of these analyzed minerals are in the normal range reported for type 4–6 ordinary chondrites (BREARLEY & JONES 1998).

Olivines have equilibrated compositions with an average fayalite component of $Fa_{28.9 +/- 0.4}$ (N=19). Their minor elements contents are very low with TiO_2, Al_2O_3, and Cr_2O_3 < 0.05 weight-percent. Similar to olivine, orthopyroxenes are equilibrated with an average composition of $Fs_{23.8+/-0.8}Wo_{2.1+/-0.3}$ (N=28). Their minor element contents are low but significantly above the detection limit of the electron microprobe with 0.17 weight-percent TiO_2, 0.16 weight-percent Al_2O_3, and 0.14 weight-percent Cr_2O_3.

Clinopyroxene is diopsidic in composition. Its mean contents (N=5) of major elements are 21.1 weight-percent CaO, 16.3 weight-percent MgO, and 6.6 weight-percent FeO with a corresponding molar formula $Fs_{10.5}En_{46.3}Wo_{43.2}$. Plagioclase feldspar is compositionally an oligoclase with an average composition $Ab_{85}An_{10}Or_5$ (N=12). The averaged compositions of the Ca-phosphates chlorapatite (N=7) and whitlockite (N=3) give the approximate formulas $Ca_5(PO_4)_3(Cl_{0.73}F_{0.13}OH_{0.14})$ and $Ca_{2.56}Na_{0.27}Mg_{0.27}(PO_4)_2$, respectively, and are in the range reported for equilibrated ordinary chondrites (JOLIFF et al. 2006).

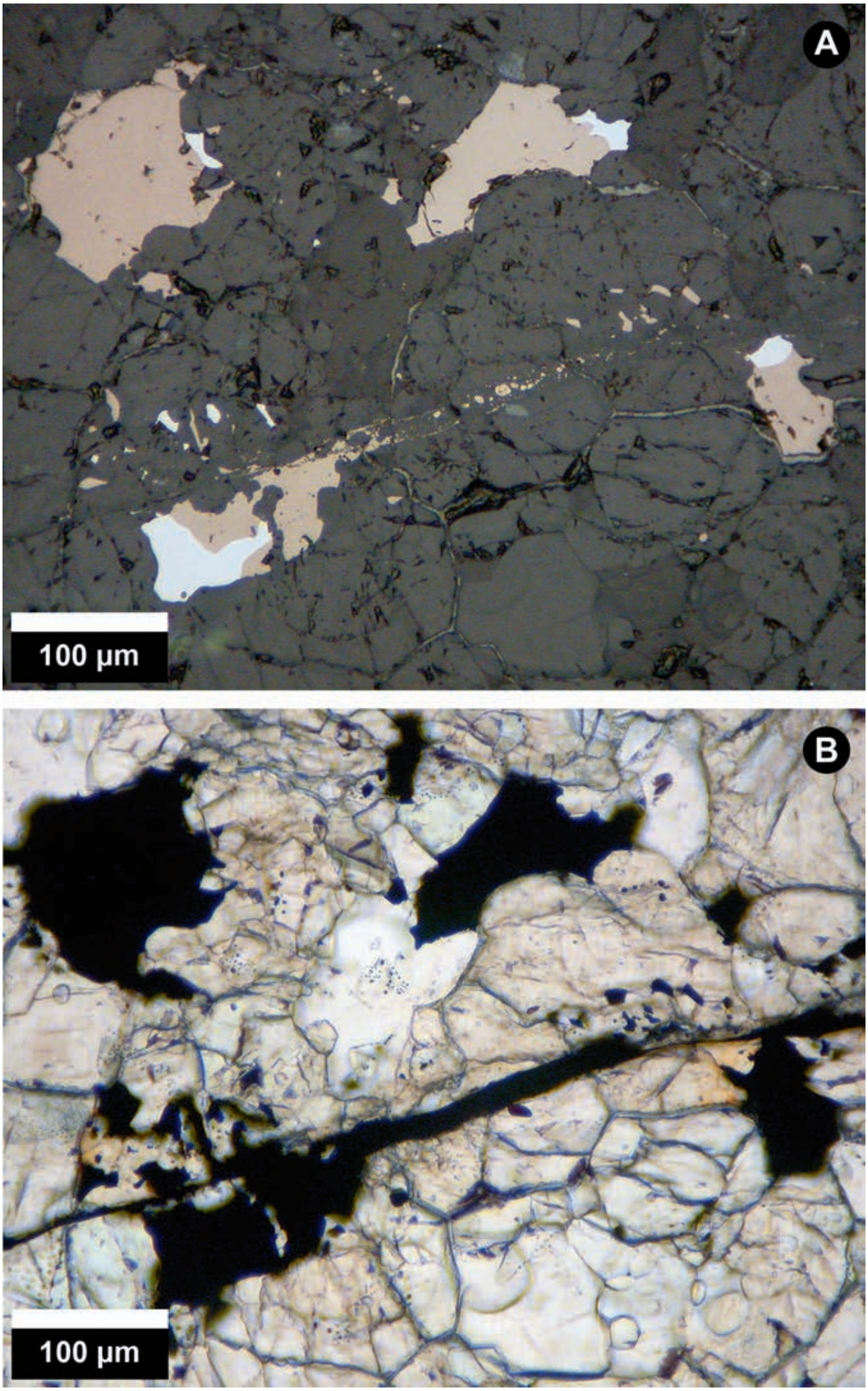

Fig. 10. A: Photomicrograph (reflected light) of a typical shock vein with sulfide droplets from the Ischgl meteorite. Opaque phases are mainly troilite (light yellow) and nickel-iron metal (white). B: Photomicrograph (transmitted light), same area as in A.

Averaged analyses and compositional ranges of nickel-iron metal phases are presented in Table 2. Kamacite has average (N= 21) contents of 4.42 weight-percent Ni (range 3.0–5.37 weight-percent) and 3.37 weight-percent Co (range 2.77–4.26 weight-percent). These contents lie within the compositional range of kamacite reported from a suite of equilibrated LL chondrites (RUBIN 1990). The cobalt contents (mean 1.10

Table 1. Averaged electron microprobe analyses of silicates from the Ischgl meteorite (in weight-percent), standard deviations (in units of the last digit) in brackets, N = number of analyses, bd = below detection limit, nd = not determined.

	olivine	orthopyroxene	clinopyroxene	plagioclase
N	19	28	5	12
SiO_2	38.42 (28)	55.47 (45)	54.34 (17)	65.66 (58)
TiO_2	bd	0.17 (03)	0.40 (05)	nd
Al_2O_3	bd	0.16 (04)	0.49 (03)	21.65 (11)
Cr_2O_3	bd	0.14 (04)	0.76 (07)	nd
FeO	25.82 (56)	15.75 (52)	6.57 (35)	0.52 (18)
MnO	0.42 (09)	0.49 (06)	0.23 (05)	bd
NiO	bd	bd	bd	nd
MgO	35.67 (21)	27.53 (54)	16.26 (46)	0.10 (08)
CaO	bd	1.10 (16)	21.12 (17)	2.11 (06)
Na_2O	nd	bd	0.59 (02)	9.88 (16)
K_2O	nd	bd	bd	0.89 (18)
Total	100.36 (82)	100.83 (71)	100.76 (64)	100.80 (78)

	cation formula based on			
	4 oxygens	6 oxygens	6 oxygens	8 oxygens
Si	1.011	1.988	1.986	2.877
Ti	-	0.005	0.011	-
Al	-	0.007	0.021	1.118
Cr	-	0.004	0.022	-
Fe	0.568	0.472	0.201	0.019
Mn	0.009	0.015	0.007	-
Ni	-	-	-	-
Mg	1.399	1.470	0.885	0.007
Ca	-	0.042	0.827	0.099
Na	-	-	0.042	0.840
K	-	-	-	0.050
Total	2.989	4.003	4.002	5.009

weight-percent, range 0.71–1.87 weight-percent, N=15) and Ni contents (mean 38.84 weight-percent, range 33.24–46.78 weight-percent) of taenite and their positive correlation agrees well with the compositions reported by AFIATTALAB & WASSON (1980) for taenite in LL chondrites.

Table 2. Averaged electron microprobe analyses and compositional range of metal phases from the Ischgl meteorite (in weight-percent), N = number of analyses.

	taenite			kamacite		
N	15			21		
	mean	min	max	mean	min	max
Fe	60.16	52.39	66.23	92.55	89.74	94.13
Ni	38.84	33.24	46.78	4.42	2.99	5.37
Co	1.10	0.71	1.87	3.37	2.77	4.26
Total	100.10			100.34		

Table 3. Bulk chemical composition of the Ischgl meteorite (in ppm, except as noted) as determined by INAA of two fragments. Masses of fragments #1 and #2 are 172.4 mg and 120.7 mg, respectively. * LL6 mean element concentrations (from KALLEMEYN et al. 1989)

	Frag#1	Frag#2	LL6*		Frag#1	Frag#2	LL6*
Na (wt%)	0.76	0.75	0.71	Ba	19	16	-
K (wt%)	<0.2	<0.3	0.087	La	0.38	0.40	0.32
Sc	8.31	8.75	8.21	Ce	0.87	1.04	-
Cr	3412	3424	3820	Nd	<2.8	<3.2	-
Fe (wt%)	18.4	18.7	18.4	Sm	0.18	0.19	0.197
Co	404	439	457	Eu	0.13	0.14	0.076
Ni	7528	8132	9500	Gd	<1.7	<1.5	-
Zn	47	53	45	Tb	<0.05	0.07	-
Ga	46.6	42.1	52.9	Tm	<0.15	<0.15	-
As	1.03	1.05	1.16	Yb	0.22	0.19	0.225
Se	18.0	15.9	88	Lu	0.02	0.02	0.033
Br	<0.6	<0.7	-	Hf	0.16	0.17	-
Rb	12.9	8.33	-	Ta	<0.1	<0.03	-
Sr	<52	<40	-	W	<4.4	<5.1	-
Zr	<56	<49	-	Ir (ppb)	272	235	338
Sb	0.06	0.04	0.058	Au (ppb)	22	24	60
Cs	0.06	<0.2	-	Th	<0.1	<0.1	-

Bulk chemistry

The bulk chemical compositions for 34 major and trace elements in two samples of the Ischgl meteorite are given in Table 3. The results obtained for the two different samples are very similar within the expected range of the natural heterogeneity of the analyzed fragments. It is well known that siderophile element abundances can be used to distinguish H, L, and LL ordinary chondrites. A comparison of the INAA data obtained for Ischgl with the mean bulk concentrations reported by KALLEMEYN et al. (1989) for LL6 ordinary chondrites (Table 3) shows an excellent match. The bulk chemical data leave no doubt that Ischgl is an LL ordinary chondrite.

Conclusions

Based on the iron-rich composition of the ferromagnesian silicates olivine and orthopyroxene, the Ischgl meteorite belongs to the LL-group of ordinary chondrites. This classification is consistent with the high Co content of kamacite and the low overall abundance of metal phases in the meteorite. Petrographic evidence such as i) the absence of recognizeable chondrule boundaries, ii) the highly recrystallized matrix, iii) the presence of large (>50 µm) and in places polysynthetic twinning in feldspar grains suggest petrologic type 6 for the Ischgl meteorite. The assignment of type 6 is also consistent with the high wollastonite content ($Wo_{2.1}$) of the orthopyroxenes. According to the classification scheme of STÖFFLER et al. (1991), the Ischgl meteorite experienced shock stage S3.

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