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Drelów, the 13th and latest meteorite fall in Poland—A typical L6 chondrite with shock veins

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Abstract–On Tuesday, February 18, 2025, at 18:04:14 local time, residents of Poland observed a bright fireball registered by many Polish fireball stations belonging to the Skytinel Network established a few months before by Mateusz Żmija. Thus, the meteoroid's orbit, atmospheric trajectory, and the strewn field were calculated, and over 70 fragments with a mass of approximately 3900 g were found near Drelów (Lublin Voivodeship, Poland; The Meteorite Bulletin Database, 2025). The samples were recovered by scientists, private searchers, and dealers, and many samples were offered immediately for collections and scientific research on the international meteorite market. Drelów is the 13th officially registered meteorite fall in Poland and is now officially classified as an L6 ordinary chondrite (S3, W0; The Meteorite Bulletin Database, 2025). Short-lived radionuclides were measured on a small sample shortly after recovery, and the results confirm that the meteorite specimen studied here derived from the bolide fireball event. The equilibrated and recrystallized type 6 character is also supported by the large plagioclase grains (An_{9-12}; with grains >100 μm) and the homogeneous compositions of olivine ($Fa_{24.7\pm0.4}$) and low-Ca pyroxene ($Fs_{20.8\pm0.3}$). The olivine in Drelów is dominated by grains with planar fractures, but in the Münster samples a significant fraction of olivine shows weak mosaicism, indicating a moderately shocked S4 (C-S4) chondritic rock. Such mosaic olivine grains appear to lack in other fragments of Drelów requiring a S3 (C-S3) classification. Thus, Drelów experienced an equilibrium shock pressure close to the strength that defines the S3/S4 transition, which requires an equilibrium shock pressure of slightly above 20 GPa. The meteorite shows easily visible dark shock veins that cross-cut the bulk rock; the high-pressure phases maskelynite and wadsleyite were detected within or close to the veins. The O isotope data and the bulk chemical composition are consistent with the L-group membership. This is also confirmed by the density and the magnetic susceptibility measurements. The soluble organic compositions of Drelów are consistent with the profiles of unbrecciated L6 chondrites and comparable to Braunschweig (L6), showing molecular characteristics consistent with the complex shock and metamorphic history of the parent rock.

INTRODUCTION—THE DRELÓW METEORITE AND OTHER NOTABLE FALLS IN POLAND

On Tuesday, February 18, 2025, at 18:04:14 local time, residents of Poland observed a bright fireball above the eastern horizon. The phenomenon was registered by 10 Polish fireball stations belonging to Skytinel Network, which was installed only 10 months before this event (Żmija et al., 2025). Thanks to the new network, the meteoroid's atmospheric trajectory and heliocentric orbit could be analyzed. See also: https://skytinel.com/prawdopodobny-spadek-meteorytow-na-lubelszczyznie/.

Upon entering the atmosphere and the remaining space rock fragmented into many pieces, which (displaced by high-altitude winds) fell into a strewn field near the township of Drelów, Lublin Voivodeship, Biała Podlaska county, Poland (Figure 1). After intense search activities by scientists, private searchers, and dealers, over 70 pieces of an ordinary chondrite with a total mass of about 3900 g were found. The largest stony meteorite found so far weighs ~517 g (The Meteorite Bulletin Database, 2025). See also: https://en.uj.edu.pl/en_GB/news/-/journal_content/56_INSTANCE_SxA5QO0R5BDs/81541894/158200023.

Details on the meteorite fall (atmospheric trajectory and heliocentric orbit) will be presented by Polish colleagues (Żmija et al., 2026; personal communication) and are not topics on the presented research about mineralogical, chemical, isotopic, and physical details of the rock. Immediately after the first recoveries, many samples were presented in the internet and offered for collections and scientific research on the international meteorite market. Since the photographs on the Drelów chondrite displayed visible shock veins, the fresh meteorite sample fitted excellently in the actual science topic about the occurrence and infrared (IR) characteristics of high-pressure phases in chondrites (Bischoff et al., 2026; Bischoff, Schleiting, & Patzek, 2019; Reitze et al., 2026). Thus, a main aim was defined to obtain IR data on the mineralogy and the possible high-pressure phases within the shock veins of Drelów in order to have these data in the MERTIS Database for comparison with BepiColombo data on Mercury and to compare these data with mineralogy and bulk chemistry.

The Drelów meteorite was officially classified as an L6 ordinary chondrite (S3, W0), as it has a thoroughly recrystallized texture showing rare relict chondrules and easily visible dark shock veins cross-cutting its light grayish interior (Szopa et al., 2025; The Meteoritical Bulletin Database, 2025).

Drelów is the 13th officially registered meteorite fall in Poland (Figure 1). Figure 2 shows typical images from the landscape of the strewn field, which is dominated by farmland and small forests. Before Drelów, the most recently confirmed meteorite fall in Poland was Antonin (L4-5; Bischoff et al., 2022; Shrbeny et al., 2022), which fell in 2021. The next most recent falls were registered in 2011 (Sołtmany, L6 ordinary chondrite; e.g., Karwowski, 2012; Szurgot et al., 2012), in 1995 (Baszkowka, L5 ordinary chondrite; Stępniewski et al., 1996) and in 1935 (Łowicz, mesosiderite; Jaskólski, 1938; Thugutt, 1938; The Meteoritical Bulletin Database, 2025, November). Given that most regions in Poland are lush, have abundant vegetation, and are sparsely populated, not many meteorites have historically been recovered in Poland. The largest stony meteorite fall in Poland, with a total mass of 250 kg, was the chondrite Pułtusk (H5) consisting of more than 100,000 fragments; it fell in 1856 and produced a huge strewn field. Thus, it is likely one of the most studied chondrite samples from Poland (e.g., Chen & Wasserburg, 1980; Ganapathy & Anders, 1973; Krzesińska et al., 2015; Lang & Kowalski, 1971; Łuszczek & Wach, 2025; Stöffler et al., 1991). The most important and well-studied achondritic fall in Poland was the polymict eucrite Bialystok (e.g., Delaney et al., 1983; Metzler & Stöffler, 1987). Other well-studied Polish meteorite finds include the iron meteorite Morasko having the largest mass among all Polish samples (~1–2 t) and Zakłodzie, a scientifically important ungrouped enstatite-rich melt rock (an impact melted EH chondrite) (e.g., Barrat et al., 2023; Buchwald, 1975; Kracher et al., 1980; Krzesińska et al., 2019; Patzer et al., 2002; Przylibski et al., 2005; Slavik & Spencer, 1928; Stępniewski et al., 2000).

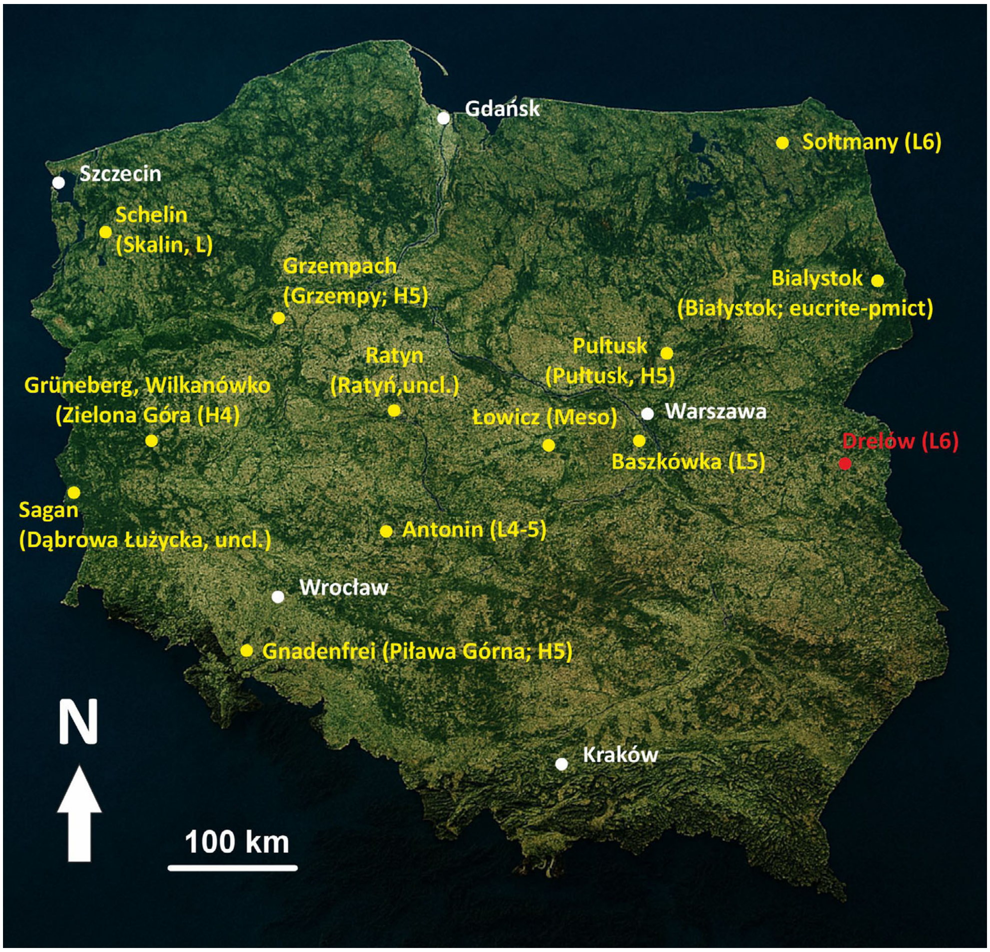

FIGURE 1. In Poland, 13 meteorite falls have been recorded (The Meteorite Bulletin Database, 2025). The latest falls from 2025 and 2021 were Drelów (L6) and Antonin (L4–5), respectively. The names on the map include the official meteorite names from the Meteorite Bulletin and the locations in Polish language. (Color figure can be viewed at wileyonlinelibrary.com)

In this study, we present the mineralogical, chemical, physical, spectroscopic, and isotopic characteristics of the new meteorite Drelów accepted by the Nomenclature Committee (The Meteoritical Bulletin Database, 2025). We also include data on the organics, short- and long-lived cosmogenic radionuclides, and the magnetic susceptibility (MS). All details about the fireball details, fall circumstances, and search activities will be presented independently by Polish colleagues (Żmija et al., 2026; Kozłowski et al., 2026, personal communication).

SAMPLES AND ANALYTICAL METHODS

Several fragments of the rock were used for the scientific studies. The first sample for research weighing 77 g was delivered by Kryspin Kmieciak. The Museum of Earth Sciences at the University of Silesia in Katowice houses a deposited specimen used for primary geochemical and petrographic studies, weighing approximately 16 grams and bearing the catalog number WNoZ/Mt/141. Furthermore, a specimen from the Jagiellonian University's Centre for Natural Education in Kraków (CEP-DG-26021-N) collection, first characterized by Szopa et al. (2025), was also used in this study.

In Münster, two polished thin sections (PL25101 and PL25102) were used for mineralogical studies on Drelów prepared from a fragment recovered by Leon Thannheiser. Thin section PL25101 represents the bulk rock, and PL25102 mainly consists of several millimeter-sized macrochondrules (Weyrauch & Bischoff, 2012a). A fusion crust-free fragment of 0.52 g from the Institut für Planetologie (Münster) was used to obtain a homogeneous powder for spectroscopic (IR spectroscopy), isotopic (O isotopes), and chemical studies on the bulk rock. The short-lived cosmogenic radionuclides were obtained from a ~15 g sample located at the University of Münster. The density and MS of five Drelów specimens in the mass range between 2 and 16 g were analyzed. Some samples were provided by anonymous finders.

FIGURE 2. Drelów landscapes within the strewn field: (a) and (b) show a low-nutrient grassland in front of a pine and birch forest in the expected 100–200 g mass area of the strewn field. It is located 1.4 km south-east of Wólka Lózecka (a) viewing to the east and (b) to the north; (c) and (d) are located in a large peat bog meadow area, which is 2.3 km east of Ostròwki, in the low-mass sector of the suggested strewn field: (a) viewing to the west and (b) to the north (Photographs: Leon Thannheiser). (Color figure can be viewed at wileyonlinelibrary.com)

Mineralogical Studies by Microscopy, Electron Microprobe Analysis, and IR Spectroscopy

An Axiophot polarizing microscope (Fa. ZEISS) was used for optical microscopy in transmitted and reflected light at the Institut für Planetologie (University of Münster, Germany), and details of the Drelów sample were further resolved with a JEOL 6610-LV scanning electron microscopy (SEM) at the same institute. During this process, mineral phases were identified and parageneses could be photographed as backscattered electron (BSE) images. The INCA analytical program provided by Oxford Instruments for energy dispersive spectrometry (EDS) supported this research step.

At the same institute, a Bruker VERTEX 70v equipped with a liquid nitrogen-cooled mercury-cadmium-telluride (MCT) detector was used for mid-infrared (mid-IR) analysis set to a spectral resolution of 4 cm^{-1}. A bulk powder aliquot of the Drelów meteorite was measured with a varying angle unit providing biconical reflectance after standardization against a rough gold-coated mirror. The angle of incidence for the IR radiation was set to 20° (i20) and the emergent angle was set to 30° (e30), as well as to i30; e30 and i13; e13. The sample chamber was at room temperature with a vacuum pressure of 2 hPa during measurements.

Furthermore, a thin section of the Drelów Meteorite was investigated using a Bruker Hyperion 3000 IR microscope equipped with a focal plane array (FPA) detector, which simultaneously measures the IR reflectance spectra of larger areas with a resolution of up to 2.5 μm, depending on the wavelength. During the mid-IR microscope measurements, the custom-made sample chamber was purged with zero-air ("dry-air") to reduce and stabilize the influence of water vapor bands. The gathered spectra were investigated by identifying the characteristic mid-IR bands, namely the Christiansen feature (CF), which is a characteristic reflectance minimum (or emission maximum), the Reststrahlen bands (RBs), which are associated with vibration modes of the Si-O bonds within silicates, and the transparency feature (TF), occurring in powdered samples with small grain size. The IR microscope enables measuring the spectra of single phases on the samples surface; here, many pixels covering single phases were accumulated to calculate the mean spectra of the respective phases. The IR microscope measurements focused on the region around melt veins and aimed to find high-pressure phases. All gathered spectra are available in the IRIS MERTIS infrared database (http://iris.uni-muenster.de/; Weber et al., 2018, 2025).

Quantitative mineral analyses (wavelength-dispersive spectrometry [WDS] analyses) by electron microprobe were performed in Warsaw and Münster. A CAMECA SX-100 electron microprobe was used in Warsaw operating with an accelerating voltage of 15 kV and a beam current of 20 nA. Rutile (Ti), diopside (Mg, Si, Ca), orthoclase (K, Al), albite (Na), hematite (Fe), rhodonite (Mn), phlogopite (F), tugtupite (Cl), and chromium oxide (Cr) were used as standards for the main elements. In Münster, microprobe data were obtained with a JEOL JXA 8530F electron probe micro analyzer (EPMA) at the Institut für Mineralogie (University of Münster) operating at 15 kV and with a probe current of 15 nA. For WDS, distinct synthetic and natural standards were selected: Jadeite (Na), San Carlos olivine (Mg), kyanite (Al), hypersthene (Si), fluorite (F), fayalite (Fe), apatite (P), sanidine (K), chromium oxide (Cr), diopside (Ca), rhodonite (Mn), rutile (Ti), celestine (S), Co-metal (Co), and nickel oxide (Ni).

Cathodoluminescence (CL) imaging was performed in the Faculty of Natural Sciences at the University of Silesia in Katowice, Poland, using a CITL Mk5 cold-cathode CL unit operating at maximum 30 kV, 0.003 mbar, and 250 mA of beam voltage, vacuum, and current, respectively. Typical operating conditions for the sample analysis were 10 kV and 280–300 mA. The CL unit was mounted on a Nikon Eclipse optical microscope.

Physical, Isotopic, and Bulk Chemical Analyses of Samples from Drelów

The bulk chemical composition of Drelów was obtained by inductively coupled plasma-sector field mass spectrometry (ICP-SFMS). Here, a ~110 mg sample from the crushed and homogenized material from an aliquot of about 0.52 g was analyzed at the University of Brest (France), as reported in more detail in previous studies by Barrat et al. (2012, 2016). The concentration reproducibility was generally better than 5%.

The O isotope composition of the Drelów ordinary chondrite was obtained from the homogenized powder of ~0.52 g at the University of Göttingen (Germany). Two removed samples (weighing 2.116 and 2.151 mg) were obtained by means of laser fluorination in combination with a gas source mass spectrometer. Details about the analytical techniques are given in Pack and Herwartz (2014), Herwartz et al. (2014), Pack et al. (2016, 2017), and Peters et al. (2020). The $\delta^{17}O$ and $\delta^{18}O$ values are presented on the VSMOW (Vienna Standard Mean Ocean Water) scale. The measurement uncertainties are ±0.1‰ for $\delta^{18}O$ and ±0.01‰ for $\Delta'^{17}O$, and the estimated values are also based on replicate analyses of the San Carlos olivine standard (1 SD). The analytical procedures were similar to those described in the recent O isotope studies of the Elmshorn and Kindberg meteorite samples (Bischoff et al., 2024; Bischoff et al., 2026).

Following surface and CT-scan techniques to obtain the correct density, the meteorite's MS was measured with the handheld device SM-30 from ZH Instruments (www.zhinstruments.cz) in Nördlingen (Germany).

A destructive methanolic solvent extraction of organic matter was performed using a small piece of about 10 mg from the Drelów meteorite at the Helmholtz-Zentrum, Munich (Germany). Negative electrospray ionization (ESI)-mode Fourier-transform ion cyclotron resonance mass spectrometry (FT-ICR MS) was undertaken using the standard operation procedure as described previously by Schmitt-Kopplin et al. (2010, 2012). Analytical details and information on data processing in earlier studies are given in Schmitt-Kopplin et al. (2010, 2012), Tziotis et al. (2011), Hertkorn et al. (2015), and Ruf et al. (2017). The analytical procedures were similar to those described in recent studies on the organic components of the Stubenberg, Flensburg, Renchen, Braunschweig, and Matera meteorite samples (Bartoschewitz et al., 2017; Bischoff et al., 2017, 2021; Bischoff, Barrat, et al., 2019; Pratesi et al., 2025).

Radionuclides by Gamma Spectrometry

The analysis of cosmogenic and primordial radionuclides in a fragment of the Drelów meteorite with a mass of ~15.2 g was carried out using nondestructive ultra-low-level gamma spectrometry at the Felsenkeller low-level measurement laboratory (Niese et al., 1998) of VKTA (Radiation protection, Analytics & Disposal Rossendorf e. V.), called Lab1 in the following. A similar ultra-low-level gamma spectrometry measurement was also performed with a more sensitive detector at TU

Dresden (Turkat et al., 2023), called Lab2. Background spectra shown below in the appropriate figure represent measurements of the detector signal acquired without any sample present and are used to quantify and subtract the intrinsic and environmental background contribution of the measurement system. This is required in order to reliably extract the weak radioactive signals originating from the meteorite sample.

RESULTS

Mineralogy

A characteristic feature of the meteorite is its fusion crust. The meteorite's crust is fresh and glassy and not overgrown with iron (hydr)oxides. In general, it is black and not dull. The crust is compact, not having visible cracks. Thin sections provide an excellent view of the fusion crust (Figure 3). The outermost part of the fusion crust is glassy and (partially) foamy with numerous pores reaching up to ~30 μm in diameter. However, small skeletal crystals of Fe-rich spinel are visible. Its chemical composition is similar to that of magnetite, but the grains contain a small concentration of Ni. No mechanically incorporated grains of terrestrial minerals from the soil (e.g., quartz) were found within the glassy crust, a typical feature observed in the crusts of some other meteorite falls (e.g., see Karwowski et al., 2021).

Drelów is a well-recrystallized chondrite (Figure 3) containing only very few recrystallized relict chondrules (Figure 3). Most of these were probably radial pyroxene (RP) or barred olivine (BO) chondrules prior to recrystallization during parent body metamorphism. However, the most impressive relict chondrule is a 4.9-mm-sized porphyritic macrochondrule (Weyrauch & Bischoff, 2012a) that is rich in large olivine grains (PO; Figure 3c). Shock veins cutting throughout the bulk rock of Drelów represent another important characteristic (see "Shock Metamorphism" section). The most abundant minerals are olivine and low-Ca pyroxene. The olivines within the macrochondrule can be large (up to ~1 mm) and show slight effects of shock-induced mosaicism (Figure 3c), whereas most of the olivines in the bulk rock are <200 μm. As a typical indicator for strongly recrystallized chondritic rocks, large plagioclase grains (>100 μm in apparent size) can frequently be observed (Figure 4a). Chromites can reach sizes of 200–300 μm (Figure 4b). As accessory phases, Cl apatite and merrillite were observed (Figures 4f and 5). The largest troilites occur within the porphyritic macrochondrule and are >500 μm in the longest dimension (Figure 4c), but sulfide grains of ~500 μm can also be found within the bulk rock (Figure 4d). As metals, kamacite, taenite, and tetrataenite are present and the taenites are sometimes zoned (Figure 4e). Most grains are relatively small (<100 μm), but some metals can be >1 mm in the longest dimension (Figure 6c). In several cases, native copper grains were detected associated with kamacite. Phosphates are best recognized using CL techniques. Among the phosphates, merrillites predominate over apatites. Merrillites have a characteristic pink color in CL (Figure 5). Apatite is a chlorine-rich member (chlorapatite) as mentioned above. Typically, the apatite grains are much smaller than those of merrillite. Both types of phosphate co-exist.

Mineral Chemistry

The main minerals of Drelów, olivine and low-Ca pyroxene, are well equilibrated, with mean $Fa_{24.7\pm0.4}$ and $Fs_{20.8\pm0.3}Wo_{1.4\pm0.3}$, respectively. Olivines have a range of 22.5–26.7 mole% Fa, whereas all low-Ca pyroxenes have Fs contents between 20.2 and 21.6 mole% (Table 1). The Ca pyroxenes are $Fs_{8.0\pm0.4}Wo_{44.5\pm0.6}$ on average. As in other metamorphosed chondrites, plagioclase is An-poor, having a mean composition of $An_{10.8}Ab_{83.6}Or_{5.6}$ (Table 1). The values vary between 9.7 and 13.4 mole% An. The chemical composition of apatites is similar to those of apatites in many other ordinary chondrites (Ward et al., 2017). On average, the apatites contain 5.2 wt% Cl and 0.65 wt% F. The mean composition of merrillites has 2.83 wt% Na_2O and 3.6 wt% MgO (Table 1). Regarding Drelów's chromites, we found mean MgO, Al_2O_3, and TiO_2 concentrations of 2.49, 5.4, and 2.83 wt%, respectively (Table 1). The sulfides are pure troilites and homogeneous in composition, whereas the metals have variable compositions (Table 2): The Ni-poor kamacites have 3.3–7.2 wt% Ni (mean: 6.0 wt%) and 1.0–1.3 wt% Co (mean: 1.10 wt%; Table 2). The taenites, which are more abundant than kamacites, have a mean Ni concentration of 24.7 wt% (range: 14–38 wt%), and their Co concentrations have an average value of 0.67 wt% (Table 2). The extremely rare tetrataenite phase contains Ni ranging from 49.7 to 50.5 wt%. The Co concentration in this investigated tetrataenite is up to 0.2 wt%. One analyzed Cu grain contains Fe and Ni concentrations of up to 4 and 1.5 wt%, respectively. Similar grains were reported to occur in various ordinary chondrites (Bischoff et al., 2026; Rubin, 1994).

Shock Metamorphism

The Drelów bulk rock is unbrecciated, but abundant shock veins are visible (Figure 6a). Close to metals and sulfides, the veins are dominated by phases embedding silicate clasts (Figure 6c). The opposite is the case in silicate-rich areas of the Drelów bulk rock, where the shock veins only contain minor abundances of metals and sulfides (Figure 6d). Impact melt pools contain abundant roundish metal- and sulfide-rich particles (Figure 6e). A

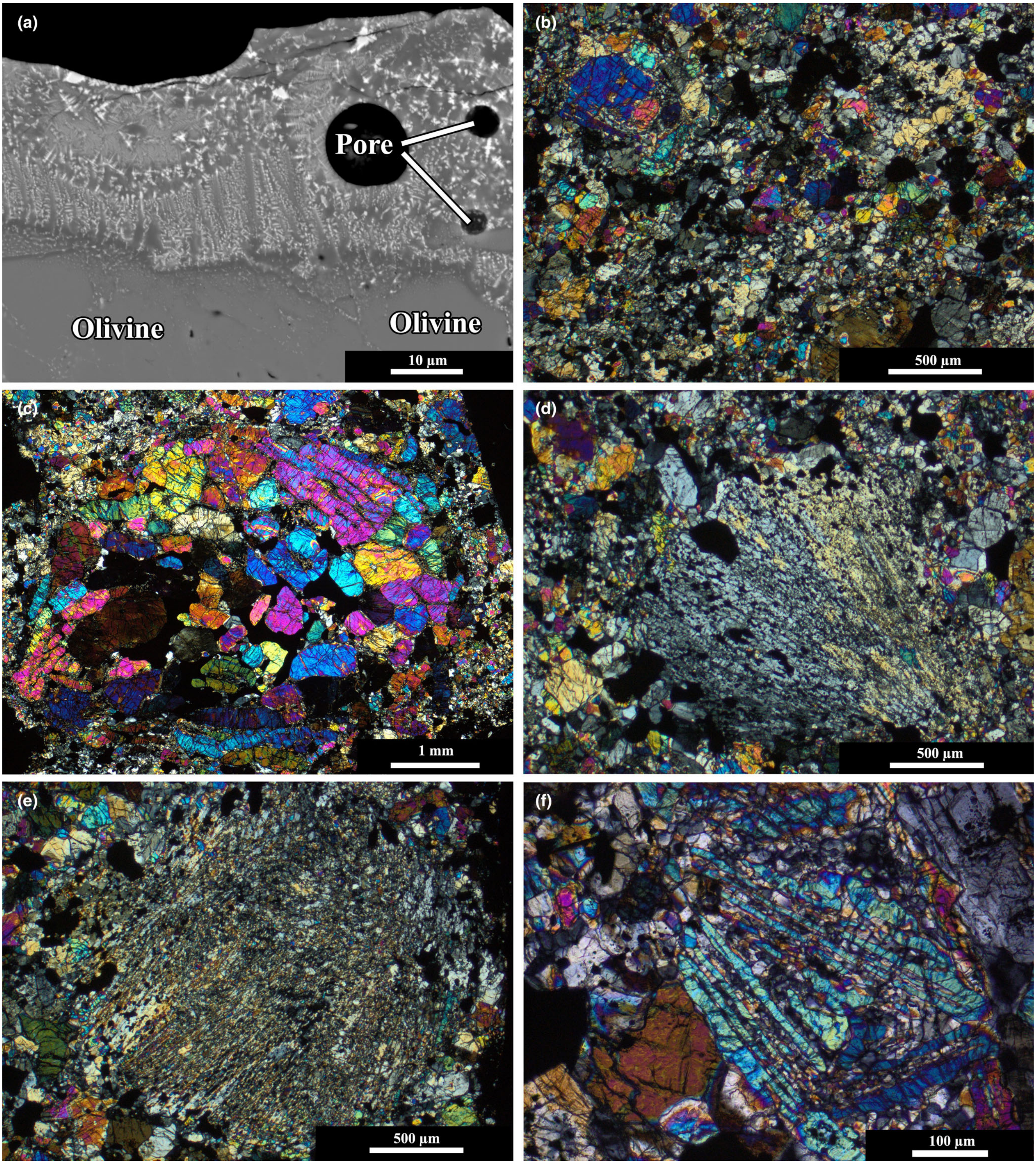

FIGURE 3. (a) Fusion crust of Drelów with an outer area containing abundant skeletal (partly Fe- and Ni-bearing) crystals and pores (black). Some phases appear to be silicates and magnetites (light gray); backscattered electron (BSE) image. (b) Image showing the typical texture of the recrystallized type 6 chondrite Drelów. (c–f) Relict chondrules in Drelów: (c) large macrochondrule (4.9 mm in apparent size); (d) radial pyroxene (RP) chondrule; (e) recrystallized RP chondrule; (f) relict of a barred olivine (BO) chondrule. All images (except (a)) in polarized light, crossed nicols. (Color figure can be viewed at wileyonlinelibrary.com)

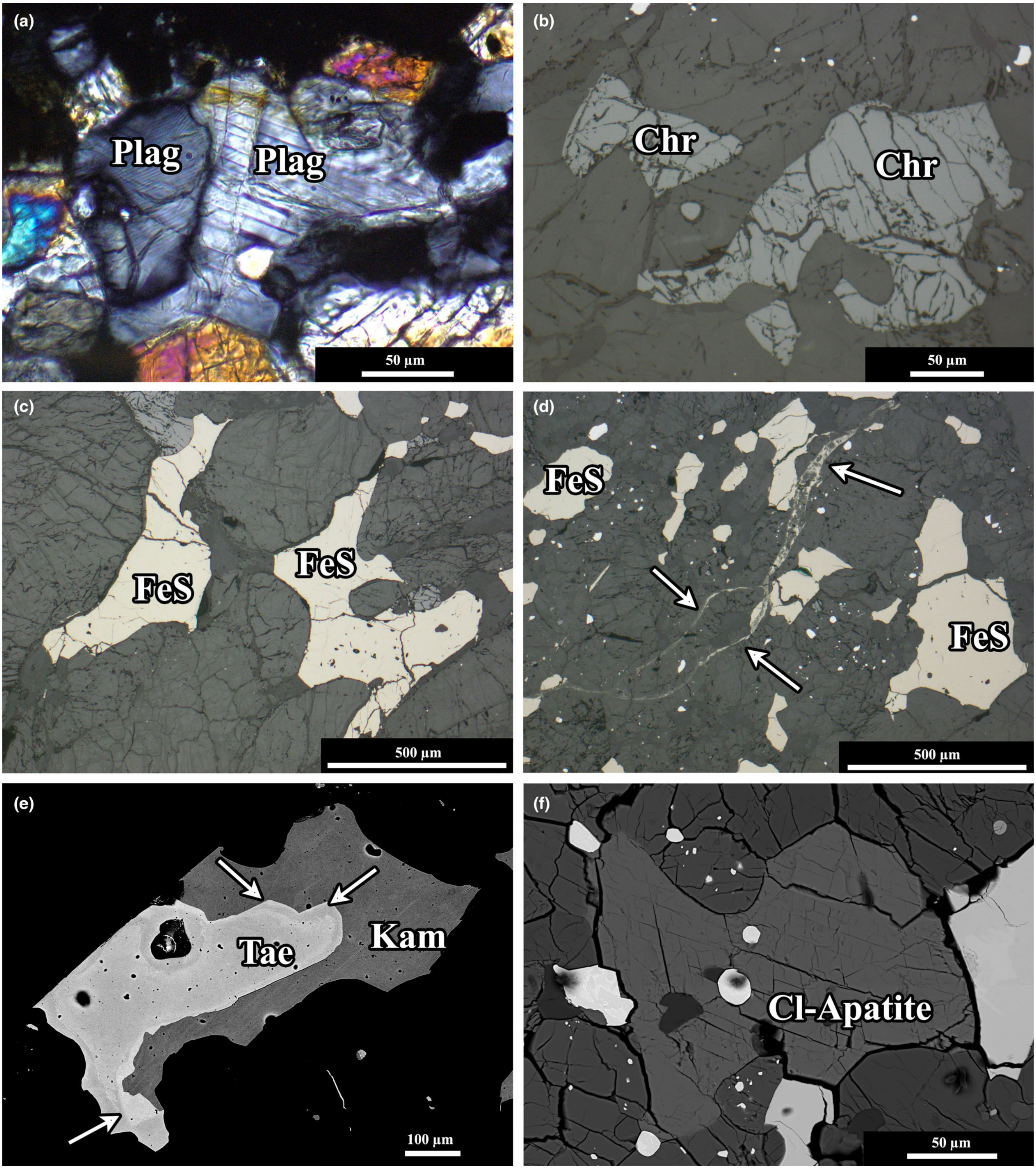

FIGURE 4. Typical mineral features in Drelów. (a) Two plagioclase grains (>100 μm in apparent size; Plag). (b) Two chromite grains (Chr): reflected light. (c) The largest sulfides (FeS) occur in the 4.9-mm-sized macrochondrule (Figure 3c): reflected light. (d) The largest sulfide grain (FeS) in the bulk rock outside the macrochondrule close to a thin shock vein (arrows): reflected light. (e) Metal grain in Drelów containing kamacite (Kam) and zoned taenite (Tae) with variable Ni concentrations (arrows): backscattered electron (BSE) image. (f) Typical Cl-apatite enclosing kamacite (white) and plagioclase (black) grains and displaying fractures, probably due to impact shock: BSE image. (Color figure can be viewed at wileyonlinelibrary.com)

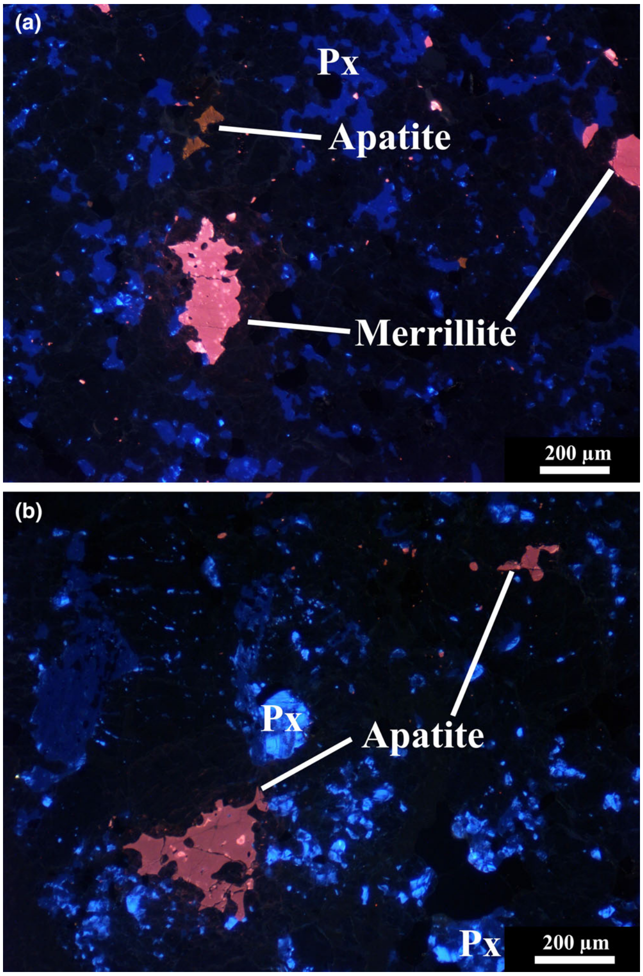

FIGURE 5. Phosphates in Drelów. (a) Two large merrillite and some small apatite grains. (b) Two apatite grains. The larger one is enclosing tiny merrillite particles. Cathodoluminescence (CL) images. (Color figure can be viewed at wileyonlinelibrary.com)

metal-sulfide spherule is shown in Figure 6f. Close to the shock veins plagioclase has been transformed into maskelynite; however, the abundance of plagioclase in the bulk rock is far below 70% as required for an S5 shock classification after Stöffler et al. (1991). Large olivines in the bulk rock show abundant planar fractures and very weak mosaicism (Figure 6b). The shock classification of the Drelów bulk rock will be given below in the section "Classification of Drelów."

Mid-IR Spectroscopy

To study the spectroscopic characteristics of Drelów, a bulk sample powder was analyzed by mid-IR spectroscopy. Spectra were obtained in the range between 6 and 18 µm (Figure 7a).

The bulk powder spectrum of Drelów shows a CF at 8.60 µm (1163 cm^{-1}). However, the CF is not the global minimum in the spectrum for the analyzed wavelength region, between 6 and 18 µm. The global minimum in this wavelength range occurs at 15.23 µm (657 cm^{-1}). RBs occur at 9.07 µm (1103 cm^{-1}), 9.45 µm (1053 cm^{-1}), 10.25 µm (976 cm^{-1}), 10.74 µm (931 cm^{-1}), 11.26 µm (888 cm^{-1}), and 11.98 µm (835 cm^{-1}). Two further weak visible RB shoulders are located at approximately 8.75 µm (1143 cm^{-1}) and 10.00 µm (1000 cm^{-1}). The peak of a broad CF is located around 13 µm (769 cm^{-1}).

With the mid-IR microscope, we identified two phases associated with high shock pressure (Figure 7b). One spectrum shows a typical signal of glass, with one broad band. This band has a maximum at 9.57 µm (1045 cm^{-1}), and the CF is approximately at 7.79 µm (1284 cm^{-1}). The phase was identified as maskelynite. The other phase was identified as wadsleyite with a CF at 8.75 µm (1144 cm^{-1}) and two doublet-like RBs at 10.85 µm (923 cm^{-1})/11.23 µm (891 cm^{-1}) and at 12.00 µm (833 cm^{-1}) /12.29 µm (814 cm^{-1}). A further subdued band is located at 9.33 µm (1027 cm^{-1}), maybe associated with majorite.

Oxygen Isotopes

Two samples (2.116, 2.151 mg) of Drelów were analyzed for oxygen isotopes, with results showing the following values: $\delta^{17}O = 3.630‰$, $3.647‰$ and $\delta^{18}O = 4.839‰$, $4.848‰$, respectively (Table 3). The mean $\Delta'^{17}O$ value is 1.081‰, calculated relative to a reference line with a slope of 0.528. The data plot in a field covered by other L chondrites as well as LL chondrites (Figure 8), making a classification solely based on the O isotope composition impossible.

Bulk Chemical Composition

The bulk chemical composition of Drelów (Table 4) obtained from a homogenized powder is very similar to the compositions of previously analyzed L chondrite breccias in the same laboratory. The data are consistent with the mean composition of L chondrites (Lodders & Fegley, 1998). However, some siderophile elements (e.g., Fe, Co, and Ni) are slightly enriched, whereas the Cr and V concentrations are somewhat below those of other L chondrites (Table 4; Figure 9). Variable abundances of metals are well-known among individual groups (H, L, and LL) of ordinary chondrites (Dunn et al., 2010) as well as within individual samples (Bischoff et al., 2022).

Magnetic Susceptibility (χ) and Density

The MS (Figure 10), measured at 11 Drelów specimens, gave a mean value of $\log\chi = 4.61 \pm 0.03$ (with χ in 10^{-9} m^3 kg^{-1}). The data indicate only minor

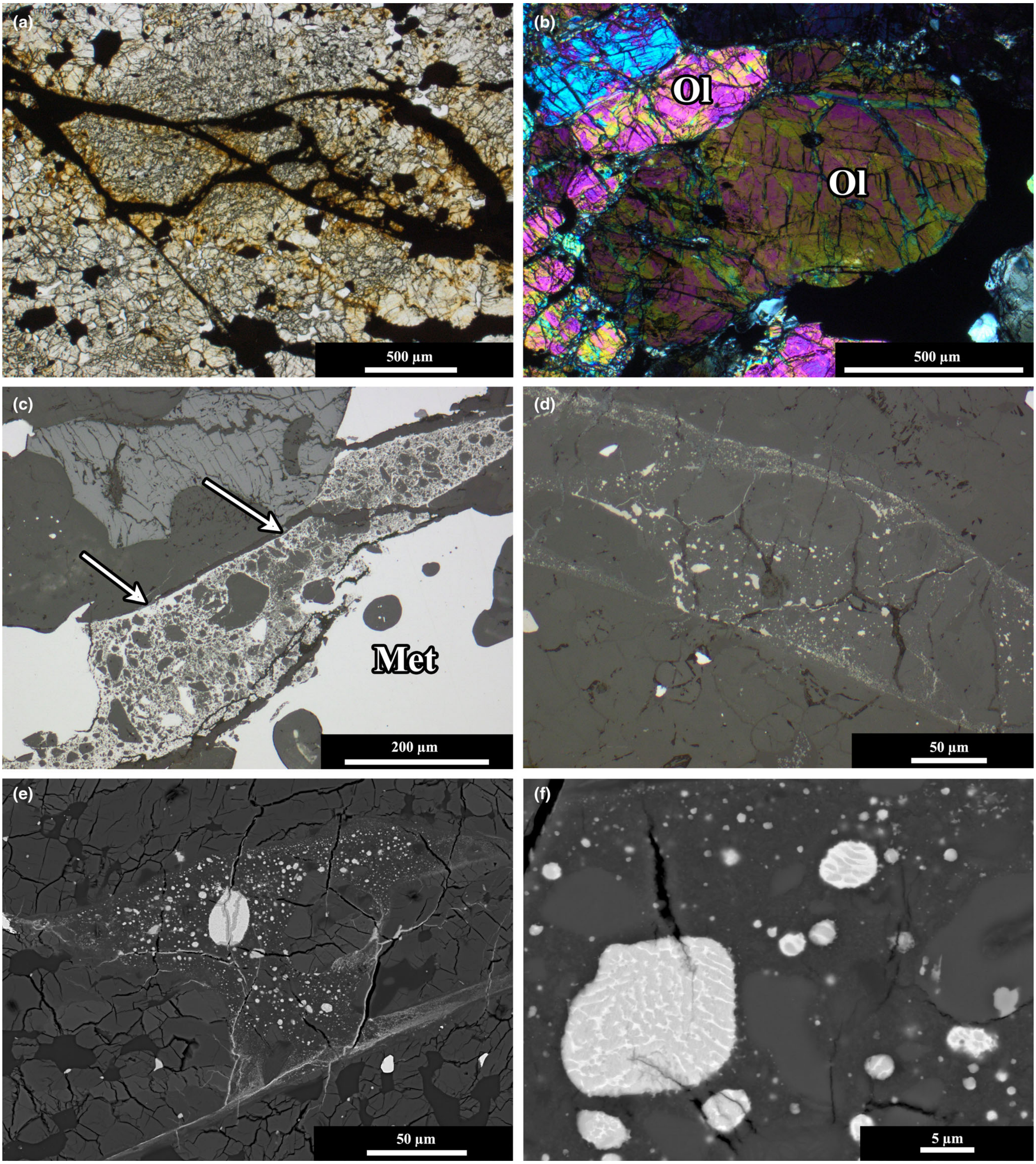

FIGURE 6. (a) Shock veins in the Drelów bulk rock: polarized light. (b) Olivines (Ol) show planar fractures and very weak effects of mosaicism (S4): polarized light, crossed nicols. (c) Shock vein (arrows) close to the largest metal (Met) found in the studied thin section. The shock vein is dominated by metallic components: reflected light. (d) The same shock vein within the silicate-dominated area of the rock containing only minor abundances of metal or sulfide particles; reflected light. (e) Shock vein and adjacent melt pool containing roundish Ni-rich metal (~10 wt% Ni) and sulfide particles: backscattered electron (BSE) image. (f) Detailed BSE image of a Ni-rich metal/sulfide nodule within an impact melt pool. (Color figure can be viewed at wileyonlinelibrary.com)

TABLE 1. Mean chemical composition of the main phases in Drelów (L6).

	Olivine n = 187	Px n = 124	Ca-Px n = 22	Plag n = 10	Apatite n = 6	Merrilite n = 6	Chromite n = 9
SiO_2	38.1 ± 0.4	55.3 ± 0.5	53.9 ± 0.5	65.1 ± 1.5	0.13	0.06	<0.02
TiO_2	<0.01	0.18	0.44	0.04	<0.01	<0.01	2.83
Al_2O_3	<0.01	0.16	0.49	20.5 ± 0.4	<0.01	<0.01	5.4
Cr_2O_3	<0.03	0.13	0.84	0.04	<0.01	0.13	56.2
FeO	22.7 ± 0.4	13.9 ± 0.2	5.0 ± 0.3	0.40	0.76	0.96	30.4
MnO	0.47	0.48	0.25	<0.01	<0.03	<0.02	0.76
MgO	38.8 ± 0.6	29.1 ± 0.4	16.7 ± 0.4	0.03	0.05	3.6	2.49
CaO	<0.01	0.74 ± 0.15	21.8 ± 0.5	2.21 ± 0.25	53.3	46.9	n.d.
Na_2O	<0.01	<0.02	0.56	9.7 ± 0.4	0.46	2.83	<0.03
K_2O	<0.01	<0.01	<0.01	0.97 ± 0.24	<0.02	0.06	<0.01
P_2O_5	<0.02	<0.01	<0.02	<0.01	39.0	42.8	n.d.
Total	100.17	100.03	100.01	99.01	99.63[a]	97.54[b]	98.14
Fa	24.7 ± 0.4						
Fo	75.3 ± 0.4						
Fs		20.8 ± 0.3	8.0 ± 0.4				
Wo		1.4 ± 0.3	44.5 ± 0.6				
An				10.6 ± 1.0			
Or				5.6 ± 1.5			

Note: All oxide data in wt%, others in mole% (second part of table).
Abbreviations: Ca-Px, Ca pyroxene; n, number of analyses; n.d., not detected; Plag, plagioclase; Px, low-Ca pyroxene.
[a]Contains 5.2 wt% Cl and 0.65 wt% F.
[b]Contains 0.16 wt% F.

TABLE 2. Mean chemical composition of metals and sulfide (troilite) from Drelów (L6).

Element	Kamacite n = 17	Taenite n = 8	Troilite n = 38
Mg	<0.01	<0.01	<0.01
Mn	<0.01	<0.01	<0.01
Fe	92.4	75.0	62.2
Co	1.10	0.67	0.10
Ni	6.0 (3.3–7.2)	24.7 (14–38)	0.02
S	n.d.	n.d.	35.9
Total	99.52	100.39	98.85

Note: All data in wt%.
Abbreviation: n.d., not detected.

inhomogeneity. The mean bulk density value of two fragments with more than 10 g is 3.30 ± 0.05 g cm^{-3}.

Short- and Long-Lived Radionuclides by Gamma Spectrometry

In Drelów, we detected six cosmogenic radionuclides with half-lives between 53.2 d (^{7}Be) up to 0.7 Ma (^{26}Al). The six radionuclides were detected in both laboratories (Table 5; Figure 11). Within the measurement uncertainties, the values between the two laboratories are in good agreement. The anthropogenic radionuclide Cs-137 could not be detected, although the discovery site was affected by the Chernobyl fallout.

The activity data from the natural decay chains (see Table 5) do not provide conclusive evidence regarding potential disequilibria within the decay series. However, under the assumptions of secular equilibrium, terrestrial isotopic abundances, and a uniform distribution of radionuclide activity within the analyzed material, the elemental concentrations derived from Lab1 measurements are 14.6 ± 2.4 ng g^{-1} (U), <39 ng g^{-1} (Th), and 861 ± 94 μg g^{-1} (K), and for Lab2 12.7 ± 2.7 ng g^{-1} (U), 41 ± 12 ng g^{-1} (Th), and 979 ± 99 μg g^{-1} (K).

Solvent-Soluble Organic Matter

Very similar results were found in analyses of the methanol-soluble organic fraction (SOM) of Drelów and Braunschweig L6 (S4), which we compared with that of the brecciated chondrite Renchen (L5-6). The main characteristic of the Drelów analysis is a high density of m/z signals (with many signals in each nominal mass) over a mass range from 150 to 800 amu (Figure 12a). This enormous number of exact m/z signals is annotated to thousands of molecular formulas with respect to C-, H-, N-, O-, S-, and Mg in their elementary composition. The compositional space is predominantly ruled by CHO and CHOMg, and only minorly by sulfur- and nitrogen-containing compounds. This is similar to data from Braunschweig (Figure 12b). Renchen shows different characteristics (Figure 12c), as indicated by its high

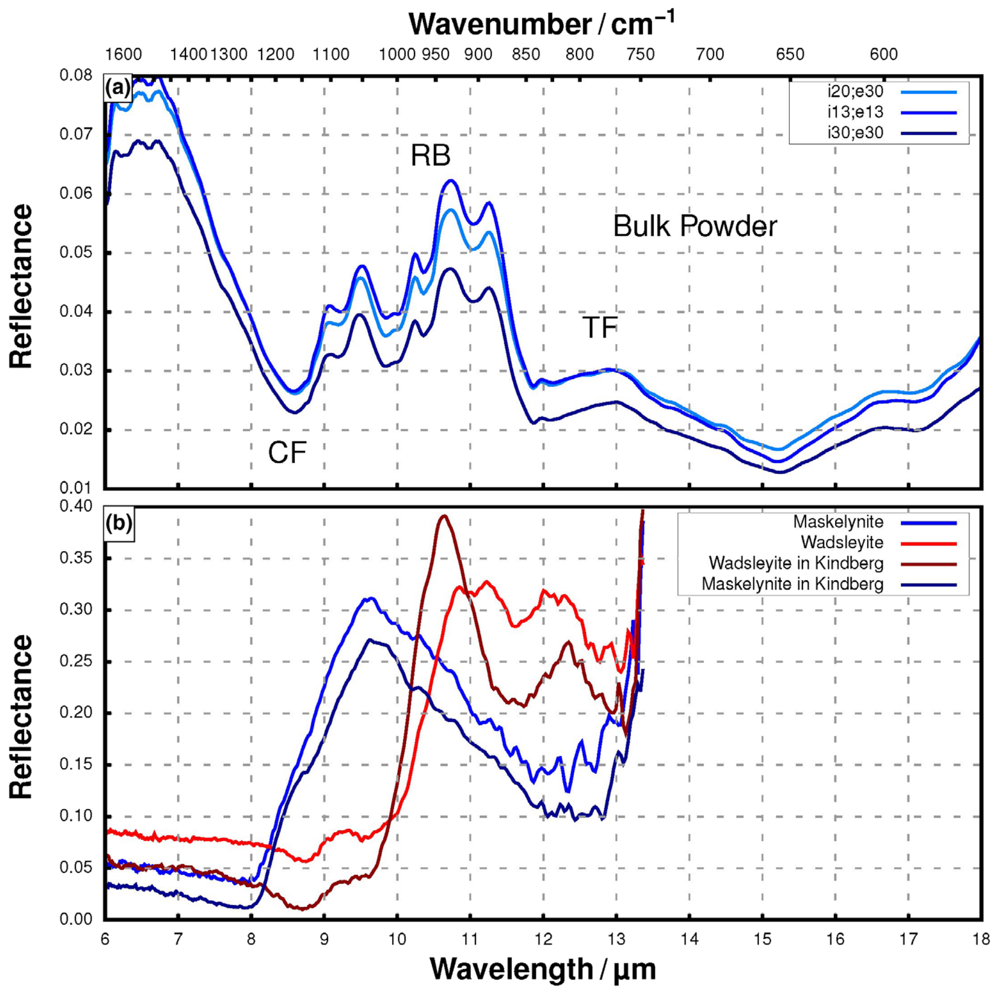

FIGURE 7. (a) Bulk powder infrared (IR) spectrum of the Drelów meteorite measured with different phase angles. CF denotes the Christiansen feature, RB the Reststrahlen bands, and TF the transparency feature. (b) Spectra of high-pressure phases found in the vicinity of a shock vein in comparison with spectra of the same phases in the Kindberg meteorite (ID 691; Bischoff et al., 2026). The band around 9.2 µm in the wadsleyite spectrum most likely originated from majorite, which could not be resolved separately in the IR microscope measurements. (Color figure can be viewed at wileyonlinelibrary.com)

TABLE 3. Oxygen isotope composition of Drelów compared with data from the L chondrite falls of the Polish meteorite Antonin (Bischoff et al., 2022) and that of Saint-Pierre-le-Viger (Saint-Pierre; Bischoff et al., 2023), which were recently analyzed in the same laboratory.

Sample name	Sample mass (mg)	$\delta^{17}O$	$\delta^{18}O$	$\Delta'^{17}O$
Drelów	2.116	3.630	4.839	1.075
Drelów	2.151	3.647	4.848	1.087
Antonin	2.078	3.421	4.651	0.965
Antonin	2.171	3.583	4.750	1.075
Antonin	1.998	3.501	4.704	1.017
Saint-Pierre	2.073	3.304	4.195	1.089
Saint-Pierre	1.967	3.417	4.418	1.084

number of annotations (7600) compared with those of Drelów and Braunschweig (1750 and 1950, respectively).

DISCUSSION

General Remarks Based on Radionuclides

Nondestructive gamma spectrometry of the Drelów meteorite was carried out between April 10 and 30, 2025, with a total counting time of 18.3 days in Lab2 and directly afterwards between April 30 and May 26, 2025, with a total counting time of 25.4 days in Lab1. Evidence for the recent exposure to cosmic radiation is the short-lived cosmogenic radionuclide ^{7}Be with a half-life of 53.22 d. However, ^{7}Be as a partial surface contamination

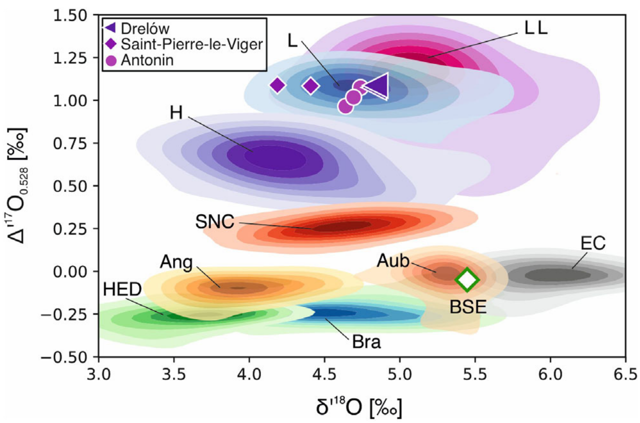

FIGURE 8. Two samples of Drelów (~2 mg each) were analyzed for O isotopes. The data are presented in a plot of $\Delta'^{17}O$ versus $\delta'^{18}O$ and compared with the values of Antonin (L4-5) and Saint-Pierre-le-Viger (L5-6) analyzed in the same laboratory (Table 3; Bischoff et al., 2022, 2023). The data are also compared with those of ordinary chondrites (H, L, LL) in general, the bulk silicate Earth (BSE; Peters et al., 2021), and other groups of meteorites as indicated: Ang, angrites; Aub, aubrites; Bra, brachinites; EC, enstatite chondrites; HED, howardites, eucrites, diogenites; SNC, shergottites, nakhlites, chassignites. The compilation of meteorite reference compositions is based on data from The Meteoritical Bulletin Database (https://www.lpi.usra.edu/meteor/). See Bischoff et al. (2023) for the basic diagram with further details. (Color figure can be viewed at wileyonlinelibrary.com)

(from atmospheric production), such as seen in Renchen (Bischoff, Barrat, et al., 2019), cannot be fully excluded.

The results confirm that the analyzed sample from the Drelów meteorite originates from the bolide event that occurred over Poland on February 18, 2025. The measured $^{22}Na/^{26}Al$ ratios of 1.4 ± 0.3 (Lab1) and 1.6 ± 0.4 (Lab2) are consistent with the long-term average value of 1.7 ± 0.2 for L chondrites over a solar cycle, as reported by Bhandari et al. (2002). Given the relative uncertainties of approximately 20% in the activity measurements for both ^{22}Na and ^{26}Al in each laboratory, the extent to which sample-specific properties can be constrained is limited. Nonetheless, when compared to radius- and depth-dependent saturation production rate models for ^{22}Na (Leya et al., 2021), very small pre-atmospheric radii (<8 cm) can be excluded.

The uncertainties in the measured ^{22}Na and ^{26}Al activities are predominantly systematic, with statistical contributions on the order of 5%. Both ^{22}Na and ^{26}Al are positron emitters (β^+), leading to significant summing effects between the gamma ray and 511 keV positron annihilation photons—approximately 30% as illustrated in Figure 11. The annihilation location of the positron, whether within or outside the sample, has a strong impact on detection efficiency. This effect is highly sensitive to the sample's geometry and homogeneity on the millimeter scale.

The U concentration of Drelów is slightly higher than that determined by ICP-SFMS (Table 4; 9.4 ng g^{-1}), while Th and K are comparable at 36 ng g^{-1} and 837 μg g^{-1} (Table 4), respectively. The U, Th, and K element concentrations of the Drelów chondrite can be compared with those found in the analyses of recent common L and LL chondrite cases, such as Stubenberg or Renchen (Bischoff et al., 2017; Bischoff, Barrat, et al., 2019). The U, Th, and K values are in good agreement with Renchen and Stubenberg.

Classification of Drelów

As shown in Figure 2, Drelów is a well-recrystallized chondrite with only very few recrystallized relict chondrules; these mainly constitute RP or BO (Figure 3). One of these relict objects is a 4.9-mm-sized porphyritic macrochondrule; see brief discussion in the next section (Figure 3a). Another characteristic feature of Drelów is the shock veins that cut through the bulk rock. Furthermore, large plagioclase grains (>100 μm) can frequently be observed (Figure 4a), indicating a strong degree of metamorphism. Olivine and low-Ca pyroxene, being the main minerals of Drelów, are well equilibrated, with mean $Fa_{24.7\pm0.4}$ and $Fs_{20.8\pm0.3}Wo_{1.4\pm0.3}$, respectively (Table 1). The Ca pyroxenes are, on average, $Fs_{8.0\pm0.4}Wo_{44.5\pm0\text{–}6}$. Typical for metamorphosed chondrites, the plagioclase is An-poor, having a mean composition of $An_{10.8}Ab_{83.6}Or_{5.6}$ (Table 1) with values varying between 9.7 and 13.4 mole% An. The chemical compositions of the apatites are similar to those of apatites in many other ordinary chondrites (Ward et al., 2017). Considering the above-mentioned mean compositions of olivine and low-Ca pyroxene and the degree of recrystallization, the rock clearly must be classified as an L6 ordinary chondrite. The oxygen isotope composition (Figure 8) and the bulk chemical composition also strongly support the L-group membership (Table 4). The MS χ of several Drelów specimens is similar to that of other L chondrites, but the values plot close to those in the LL field (Figure 10).

As discussed above, olivine in Drelów shows abundant planar fractures and very weak mosaicism. The Münster working group still thinks that because early signs of mosaicism are present and because the abundance of slightly mosaic olivines is >25%, the S4 shock classification is appropriate. On the contrary, the Polish group favors an S3 classification for the degree of shock metamorphism. Stöffler et al. (1991) defined an equilibrium shock pressure of about 20 GPa to be related to the S3/S4 transition. Since Drelów certainly does not contain abundant maskelynite (an abundance >70% of transformed plagioclase is required according Stöffler et al. (1991)), an S5 classification is ruled out. The S4/S5

TABLE 4. Major and trace element abundances of Drelów.

Element	Renchen L5-6	Braunschweig L6	Antonin L4-5	Saint-Pierre L5-6	Drelów L6	Mean L
Si						
Al	1.01[a]	1.16[a]	1.01[a]	0.80[a]	1.05[a]	1.16[a]
Fe	21.5[a]	21.6[a]	22.0[a]	21.6[a]	23.1[a]	21.8[a]
Mg	16.6[a]	15.0[a]	14.4[a]	11.2[a]	12.5[a]	14.9[a]
Na	0.54[a]	0.71[a]	0.65[a]	0.61[a]	0.65[a]	0.69[a]
Ni	0.91[a]	1.23[a]	1.56[a]	1.38[a]	2.00[a]	1.24[a]
P	844	1310	905	919	883	1030
K	907	1021	873	854	837	920
Ca	1.33[a]	1.41[a]	1.21[a]	1.16[a]	1.19[a]	1.33
Sc	9.13	10.01	8.52	8.00	8.31	8.1
Ti	634	644	610	617	542	670
V	70.3	70.1	62.1	70.9	53.0	75
Cr	4372	3804	3048	3042	2171	3690
Mn	0.30[a]	0.27[a]	2478	2778	2503	2590
Co	518	601	582	626	723	580
Cu			84.6	80.6	92.9	90
Zn	29.9	43.96	42.4	50.3	44.0	57
Ga	4.11	5.05	4.81	5.28	5.14	5.4
Rb	2.73	3.06	2.59	3.01	3.01	2.8
Sr	10.7	11.3	10.5	10.06	10.3	11
Y	2.14	2.32	1.98	1.95	2.08	1.8
Zr	5.69	6.48	5.02	4.56	5.18	6.4
Nb	0.494	0.46	0.43	0.45	0.42	0.4
Cs	0.088	0.048	0.030	0.027	0.068	
Ba	4.17	3.78	3.53	3.32	3.46	4.1
La	0.317	0.328	0.277	0.275	0.287	0.318
Ce	0.816	0.873	0.711	0.705	0.748	0.970
Pr	0.162	0.128	0.107	0.106	0.112	0.140
Nd	0.757	0.649	0.538	0.533	0.564	0.700
Sm	0.195	0.218	0.176	0.173	0.184	0.303
Eu	0.080	0.083	0.079	0.073	0.078	0.080
Gd	0.262	0.30	0.243	0.237	0.254	0.317
Tb	0.050	0.055	0.045	0.045	0.047	0.059
Dy	0.337	0.378	0.306	0.303	0.323	0.372
Ho	0.075	0.084	0.069	0.068	0.073	0.089
Er	0.225	0.250	0.202	0.203	0.215	0.252
Tm			0.031			0.038
Yb	0.230	0.256	0.206	0.204	0.219	0.226
Lu	0.035	0.039	0.031	0.031	0.033	0.034
Hf	0.173	0.197	0.152	0.138	0.155	0.170
Ta	0.0253	0.0227	0.0216	0.0179	0.0174	0.021
Pb	0.0658	0.0336	0.0316	0.0171	0.0291	0.040
Th	0.065	0.045	0.034	0.035	0.036	0.042
U	0.0291	0.0128	0.0102	0.010	0.0094	0.015

Note: Data for Braunschweig, Renchen, Saint-Pierre-le-Viger (Saint-Pierre), and Antonin are from Bartoschewitz et al. (2017) and Bischoff, Barrat, et al. (2019); Bischoff et al. (2022, 2023), respectively. The data for mean L chondrites are taken from Lodders & Fegley (1998).
[a]Data in wt%; other data in $\mu g\ g^{-1}$ (ppm).

transition is proposed to be at 30–35 GPa (Stöffler et al., 1991). Taking these limits together, we propose that Drelów experienced an equilibrium shock pressure around 20 GPa. Since the mosaicism is inconclusive and only weakly pronounced, the shock pressure could be only slightly above 20 GPa.

The Surprising Occurrence of a Porphyritic Macrochondrule

The existence of the huge macrochondrule requires a short discussion. Porphyritic macrochondrules in chondrites are quite rare, and most have textures with

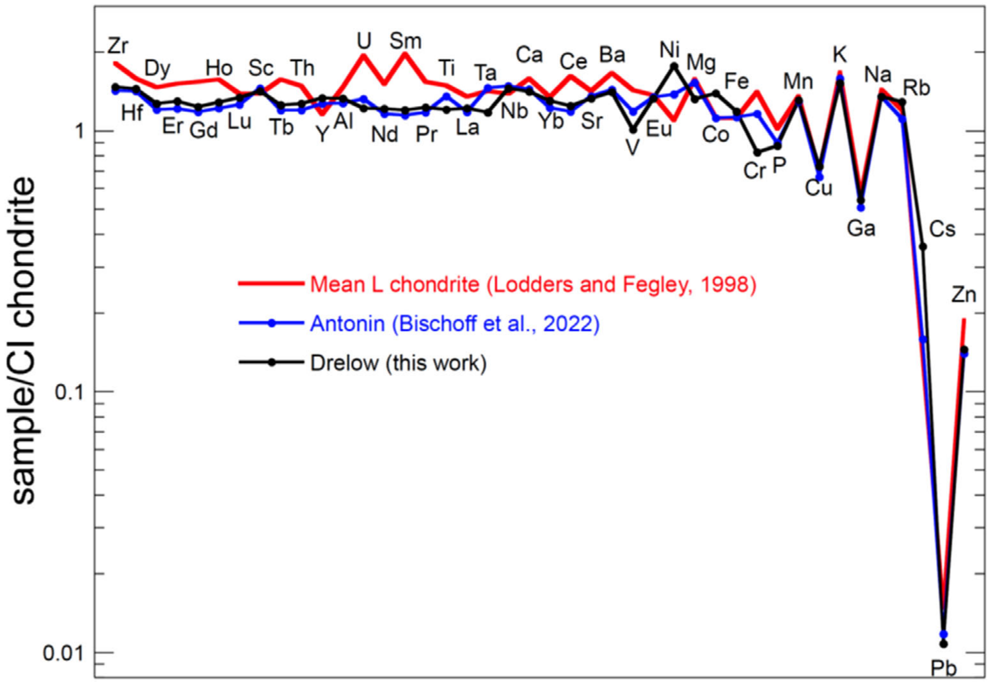

FIGURE 9. Bulk composition of Drelów in comparison with the L chondrite Antonin (Bischoff et al., 2022) and the average of other L chondrites (Lodders & Fegley, 1998). Elements are ordered with increasing volatility from left to right. For normalization, we used the CI values of Barrat et al. (2012). The Antonin chondrite was analyzed in the same laboratory as Drelów. (Color figure can be viewed at wileyonlinelibrary.com)

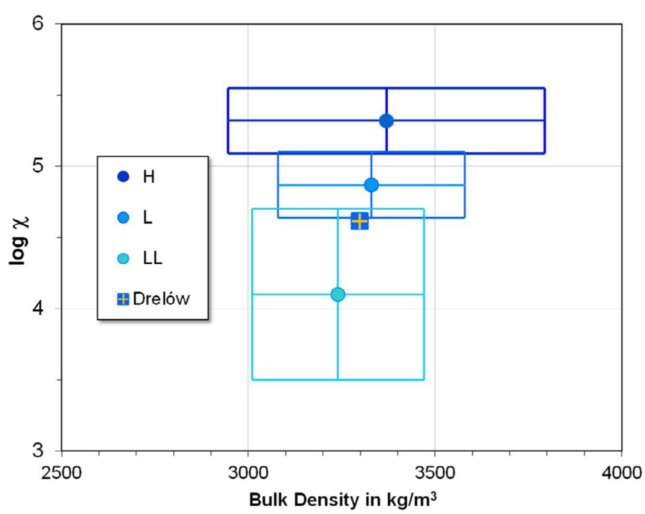

FIGURE 10. Magnetic susceptibility and density of Drelów plot at the border between L and LL chondrites (see also Rochette et al., 2003). (Color figure can be viewed at wileyonlinelibrary.com)

elongated pyroxene and olivine minerals (mostly RP or BO chondrules; Weyrauch & Bischoff, 2012a). Prior studies have suggested that macrochondrules may have formed by melting of mega-sized dust aggregates and/or are the result of melt droplet growth by rapid collisions at high temperatures. Since most macrochondrules are different in texture compared with normal-sized chondrules, Weyrauch and Bischoff (2012b) discussed the possibility that these unusually large chondrules have a different origin. The macrochondrule in Drelów, however, is an exception, as it still has a well-preserved porphyritic texture that survived strong recrystallization.

Drelów and the Shock Classification of L Chondrites

One of the most remarkable features of Drelów is its easily visible dark shock veins, which cross-cut the bulk rock; these are typical for L6 chondrites. As discussed above, the Münster group determined that Drelów has a shock degree of S4 (C-S4), and the shock degree of ordinary chondrites and their breccias has often been an aspect of discussion considering how to classify ordinary chondrites (e.g., Bischoff et al., 2006, 2018; Bischoff, Schleiting, & Patzek, 2019; Bischoff & Stöffler, 1992; Dodd & Jarosewich, 1979; Stöffler et al., 1988, 1991, 2018).

Recently, Bischoff, Schleiting, and Patzek (2019) published the results of shock degree investigations for 2280 ordinary chondrites. They concluded that a shock degree of S3 is most abundant for H and LL chondrites, while L chondrites (like Drelów) are, on average, more heavily shocked. Based on their statistics, more than 40% of all L chondrites (and more than 50% of L6 chondrites)

TABLE 5. Measured specific activities of selected radionuclides in the Drelów meteorite (L6) using gamma ray spectrometry, placed in context with analogous data from other recent L and LL chondrite falls of comparable chemical classification.

Specific activity (dpm kg^{-1})	Half-life	Haag VKTA Lab1	Haag TU Dresden Lab2	Drelów VKTA Lab1	Drelów TU Dresden Lab2	Renchen (R2)	Stubenberg (M1b)
	Cosmogenic						
^{7}Be	53.2 d	84 ± 25	73 ± 12	84 ± 24	80 ± 15	150 ± 6	74 ± 10
^{22}Na	2.60 a	96 ± 19	89 ± 18	82 ± 12	95 ± 18	106.7 ± 1.3	87 ± 9
^{26}Al	7.05 10^{5} a	45 ± 9	50 ± 10	59 ± 9	58 ± 10	65 ± 7	61 ± 5
^{46}Sc	83.8 d	<7.2	5.1 ± 1.3	7.4 ± 2.9	5.0 ± 1.0	11.1 ± 1.2	7.6 ± 0.8
^{51}Cr	27.7 d	<78	36 ± 14	<180	<79	59 ± 11	32 ± 9
^{54}Mn	312.2 d	63 ± 10	51 ± 5	51 ± 5	57 ± 6	85 ± 9	55 ± 6
^{57}Co	271.8 d	<5.3	<1.4	4.2 ± 0.9	5.2 ± 0.8	9.5 ± 1.3	4.9 ± 0.9
Chains (ch)	Primordial						
^{238}U-ch:	4.47 10^{9} a	13 ± 6	8.3 ± 2.2	10.8 ± 1.8	9.4 ± 2.0	11.9 ± 0.7	11.9 ± 1.5
^{232}Th-ch:	14.0 10^{9} a	23 ± 9	16 ± 4	<9.6	10 ± 3	10.7 ± 0.7	8.5 ± 0.7
^{40}K	1.25 10^{9} a	1380 ± 221	1573 ± 157	1596 ± 174	1815 ± 184	1923 ± 115	1540 ± 148

Note: Activity values are decay-corrected to the respective fall dates: Stubenberg (LL6; March 6, 2016; M1b; Bischoff et al., 2017), Renchen (L5-6; July 10, 2018; R2; Bischoff, Barrat, et al., 2019), Haag (LL4-6; October 24, 2024; Bischoff et al., 2025), and Drelów (L6; February 18, 2025). Nuclide half-lives are based on the Decay Nucléide—Lara Database of the C.E.A. Laboratoire National Henri Becquerel (www.lnhb.fr/Laraweb/index.php), except for ^{26}Al, which follows Norris et al. (1983). Secular equilibrium assumed for U and Th decay chains; the activity is based on gamma emitters from the lower chains. Uncertainties are given as 68% CL; limits given as 90% CL.

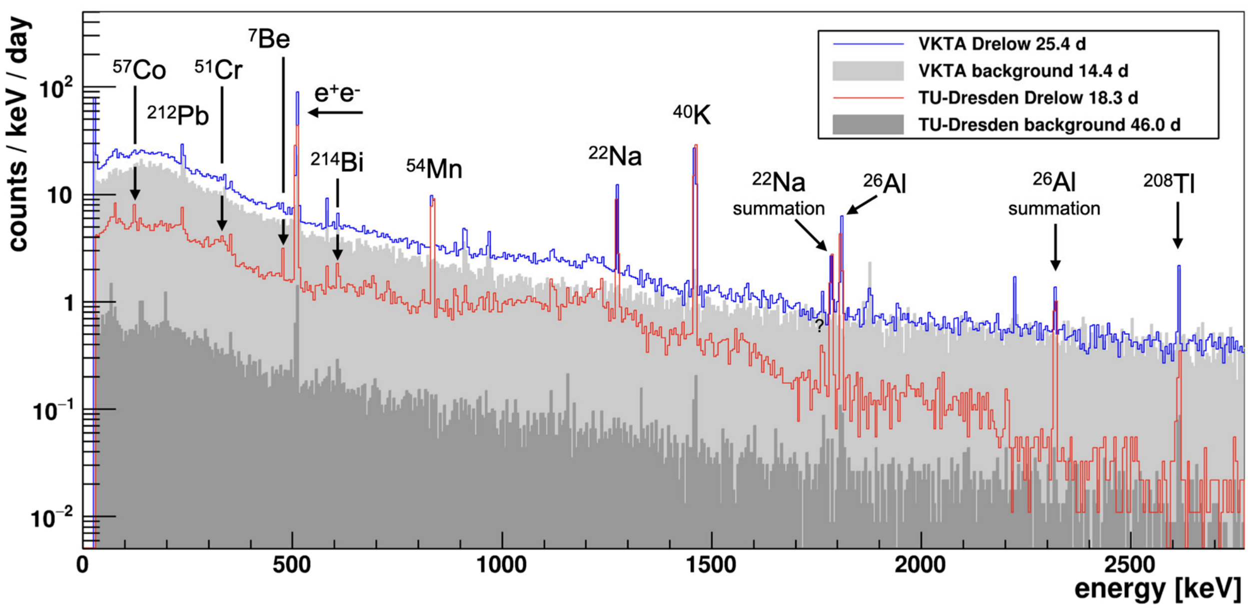

FIGURE 11. Gamma ray spectra acquired at VKTA (Lab1, shown in blue) and TU Dresden (Lab2, shown in red) for the ~15.2 g Drelów meteorite sample, with respective background spectra from each setup overlaid in varying shades of gray. Annotated peaks correspond to gamma emissions from radionuclides in the natural decay chains of primordial isotopes ^{238}U and ^{232}Th, ^{40}K (as listed in Table 5), as well as from both short-lived and long-lived cosmogenic nuclides. (Color figure can be viewed at wileyonlinelibrary.com)

are of shock stage S4 (Bischoff, Schleiting, & Patzek, 2019). In consequence, Drelów (L6), with a shock degree of S4 (suggested by the Münster group), lies in the same field in which most other L6 chondrites plot. Thus, considering the shock degree, Drelów is a very typical L6 chondrite.

To further clarify the shock degree differences among the L chondrites, we note that less than 20% of L chondrites (and only about 9% of L6 chondrites) are “unshocked” or “very weakly shocked,” but 40%–50% of H and LL chondrites show low shock degrees (S1 and S2; Bischoff, Schleiting, & Patzek, 2019). Drelów contains

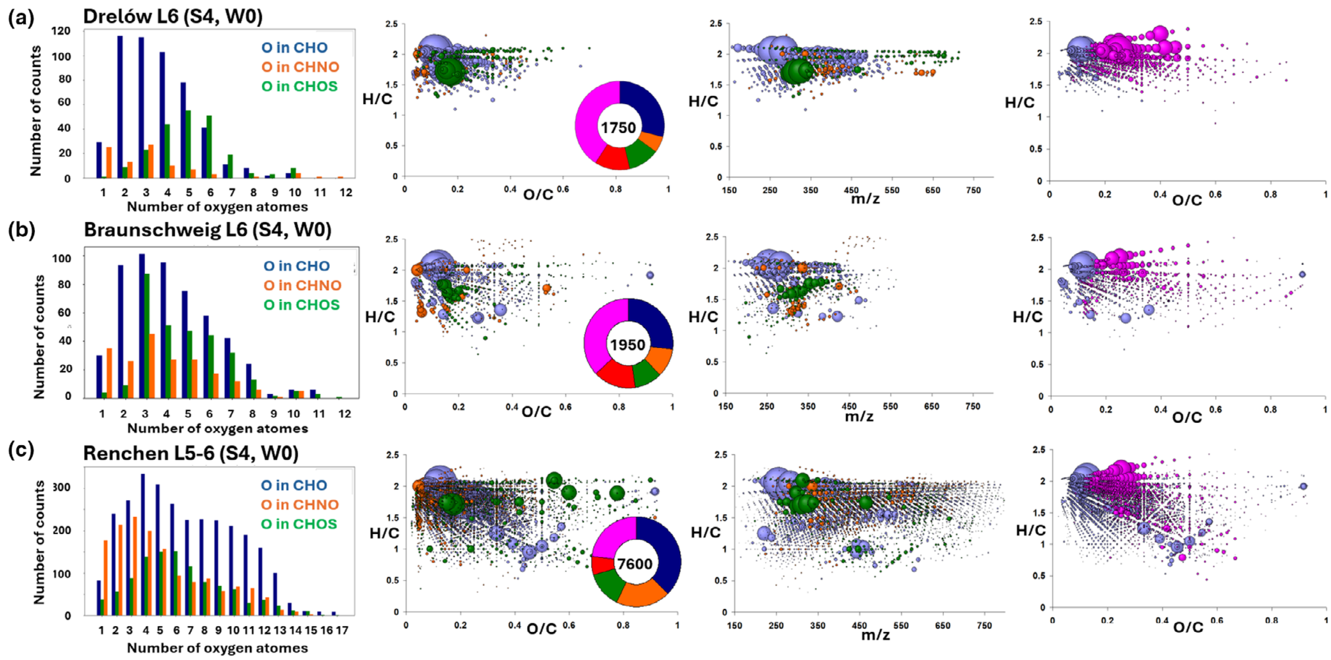

FIGURE 12. Representation of the direct injection ESI (−) FT-ICR MS compositional space of (a) Drelów compared with (b) Braunschweig, and (c) Renchen. The leftmost diagram shows the number of formulas with an increasing number of oxygen atoms (oxygenation of soluble organic material). Also presented are the van Krevelen diagrams of the three meteorites for the different color-coded chemical families (CHO in blue, CHNO in orange, CHOS in green, CHNOS in red, and CHOMg in pink; the bubble size in the diagrams is proportional to the intensity of the respective signals from mass spectrometry). The second and third columns show the chemical families of CHO, CHNO, CHOS, and CHNOS while the fourth column only depicts CHO and CHOMg annotations. (Color figure can be viewed at wileyonlinelibrary.com)

dark shock veins with minor abundances of the high-pressure phases wadsleyite and maskelynite (and perhaps majorite). The formation of wadsleyite, which is a high-pressure polymorph of olivine, must have happened under equilibrium shock pressures consistent with the beginning of the S4 classification of the bulk rock. The S3/S4 transition is defined by Stöffler et al. (1991) to be at an equilibrium shock pressure of about 20 GPa. Thus, the formation of a high-pressure mineral of olivine requires much less shock pressure than extreme shock (S6) as proposed by Stöffler et al. (1991). This finding is clearly confirming earlier results of Bischoff, Schleiting, and Patzek (2019), Hu and Sharp (2002), and Bischoff et al. (2026).

Significance of Spectroscopic Research

The bulk powder spectra of the Drelów meteorite are dominated by the bands for olivine and pyroxene, since these phases are the most abundant minerals in L chondrites (e.g., Dunn et al., 2010; Morlok et al., 2017, 2023; Weber et al., 2020, 2021). However, the plagioclase component, which is expected to be "oligoclasic" in composition, is not reflected in the shape of the RBs (Reitze et al., 2021). This observation has been made before with other meteorites (e.g., Haag, Bischoff et al., 2025).

However, the wavelength (wave number) of Drelów's CF is in accordance with those of other moderately shocked L-type meteorites like Antonin (Figure 13) (Bischoff et al., 2022; Salisbury et al., 1991). The change in the relative RB intensities between Antonin and Drelów might be due to a change of the modal compositions of the two meteorites. The same is true for the region of the TF, which is more influenced by the low-Ca pyroxene in the case of Drelów and more by olivine in the case of Antonin. The presence of high-pressure minerals and phases like wadsleyite and, most likely, some majorite and maskelynite back Drelów's classification as an L6 meteorite, since high-pressure phases are usually present within or close to the shock veins of L6 chondrites.

Considering the remote sensing of asteroids, the search for distinct parent bodies, and the spectral investigations of other solar system objects (like Mercury), our observation that the CF is not the global minimum, as is often expected (e.g., Hiesinger et al., 2020), is an important one. On the one hand, this observation can help identify a plagioclase component that is invisible in the region of RBs. On the other hand,

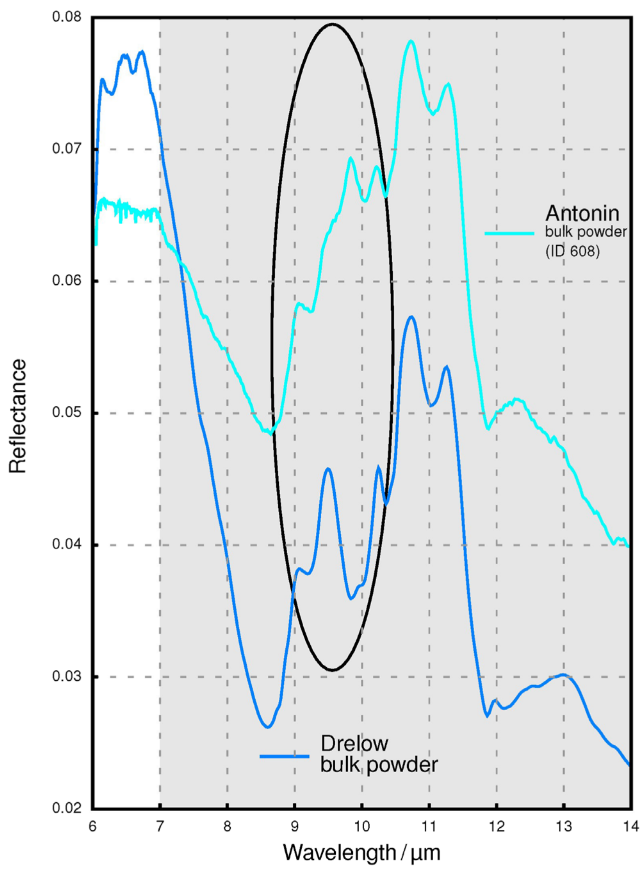

FIGURE 13. Comparison of the Drelów bulk powder spectrum with a spectrum of the L4-5 meteorite Antonin (Bischoff et al., 2022). Both meteorites' CFs are very similar, but the Reststrahlen bands (RBs) show different shapes, indicating a different modal composition, especially of olivine and pyroxene. The ellipse highlights the RB changes due to differences in the modal abundance of olivine and low-Ca pyroxene. The gray region indicates the measurement region of the MERTIS instrument onboard the BepiColombo spacecraft (Hiesinger et al., 2020). (Color figure can be viewed at wileyonlinelibrary.com)

it could lead to wrong spectral calibrations if researchers expect and use the assumption of a reflectance near zero (emissivity near unity) to derive absolute reflectance or emissivity data.

Significance of the Soluble Organic Compositions

The unbrecciated Drelów meteorite underwent very high thermal metamorphism and experienced moderate shock metamorphism, similar to that observed in Braunschweig. Thus, both meteorites have very similar profiles in composition, which are lower in number and abundance than samples of inferior and less-strained L chondrite types (Figure 11a,b), and are mainly driven by the numerous organomagnesium compounds that reflect these harsh conditions on the parent rock (Matzka et al., 2021; Ruf et al., 2017). In comparison, the brecciated Renchen chondrite (L5-6) is characterized by the presence of less metamorphosed components (e.g., L5 fragments) that show a higher number and abundance of signals, as documented in Figure 11c. This confirms that high temperatures during metamorphism, like in Drelów, induce the loss of higher molecular mass compounds and volatile nitrogen-containing compounds, leading to a population of less oxygenized and less aromatic thermostable chemical structures. As already pointed out in the study on Renchen, an increasing degree of metamorphism leads to a decreasing concentration of CHNOS and an increase in the number of different CHOMg species (see figure S6 in Bischoff, Barrat, et al. 2019).

CONCLUSIONS

Drelów is the 13th officially registered meteorite fall in Poland and, like the last meteorite fall in Poland, Antonin, it is an L-group ordinary chondrite. Drelów has dark shock veins that cross-cut the bulk rock, as often observed in L6 chondrites. The L6 classification is clearly supported by the occurrence of strongly equilibrated and recrystallized components, as well as by equilibrated mineral compositions and oxygen isotope data. Drelów is unbrecciated; officially the shock degree is S3 (C-S3) (Szopa et al., 2025), but the Münster group concluded that it has a shock degree of S4 (C-S4), based on Stöffler et al. (1991, 2018), since slightly more than 25% of the olivines of their sample show weak mosaicism. The results of IR spectroscopic studies reveal that maskelynite is present within and close to the dark shock veins. Since the maskelynite abundance is only very minor and completely restricted to areas close to the shock veins, an equilibrium shock degree of S5 and S6 can definitively be ruled out.

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Data Availability Statement—All infrared data are available free of charge without registration in the MERTIS IRIS Infrared database http://iris.uni-muenster.de. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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