

SIMS matrix effects in oxygen isotope analysis of olivine and pyroxene: Application to Acfer 094 chondrite chondrules and reconsideration of the primitive chondrule minerals (PCM) line

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ABSTRACT

The instrumental bias (here expressed as bias*, the difference relative to San Carlos Olivine, SC-Ol) of oxygen isotopes in secondary ion mass spectrometry (SIMS) analyses of olivine and pyroxene were investigated. Sixteen olivine (Fo₀₋₁₀₀), nine orthopyroxene (En₇₀₋₁₀₀Wo₀₋₃), and three clinopyroxene (En₂₈₋₄₉Wo₄₅₋₅₀) reference materials (RMs) were utilized. The values of bias* are nearly invariant (within 0 ± 0.5‰) among magnesian olivine (Fo ≥ 60) RMs but decrease systematically with increasing Fe molar fraction down to ~-10‰ (Fo₀). The session-to-session variability of bias* for Fo ≥ 60 olivines is ≤ 0.3‰ but becomes slightly larger for more Fe-rich compositions (≤ 1.5‰). Orthopyroxene RMs have a narrow range of bias* values (-1.7‰ to -2.6‰) that show session-to-session variability ≤ 0.3‰; correspondingly, the sputter rates are similarly low and resemble those of Fo ≥ 60 olivines. Clinopyroxene RMs bias* values (-0.2‰ to +1.2‰) are more variable and have larger session-to-session variability (≤ 0.8‰), which appear to be independent of sputter rates. Bias* of the same RMs change slightly from session to session with different analytical settings (≤ 0.6‰ for Fo ≥ 60 and as much as 2‰ for fayalite) so that equations of bias* as a function of Fo, En, and Wo should be determined for each SIMS session by the analyses of multiple RMs.

The new suite of olivine and pyroxene RMs with expanded composition range were used to correct the instrumental biases during oxygen three-isotope analysis of olivine and low-Ca pyroxene in chondrules of the ungrouped Acfer 094 chondrite, from which the primitive chondrule minerals (PCM, δ¹⁸O vs. δ¹⁷O) line was originally derived. The PCM line is considered to be a mixing trend of two extreme primary oxygen isotope reservoirs of solids in the early solar system. However, this new dataset, with better analytical precision and instrumental bias correction, allows two oxygen isotope trends to be clearly identified. One is represented by chondrules that plot on or above the PCM line, likely linked to ordinary chondrite (OC)-like materials. A second trend is represented by the major chondrule population in this chondrite that defines a regression line of δ¹⁷O = $(0.968 \pm 0.022) \times \delta^{18}\text{O} - (3.45 \pm 0.10)$ (MSWD = 2.0), consistent with recent oxygen isotope data of chondrules in carbonaceous chondrites (i.e., CV, CK, CO, and CM). We propose that this regression line represents a mixing of two oxygen isotope reservoirs (possibly ¹⁶O-rich solids and ¹⁶O-poor H₂O ice) in the outer solar system and likely resulting from the separate evolutions of isotope reservoirs after the “Jupiter divide” built up.

Keywords: reference materials (RM); secondary ion mass spectrometry (SIMS); matrix effect; oxygen isotopes; primitive chondrule mineral (PCM) line.

1. Introduction

Olivine and pyroxene are the most common rock-forming minerals in samples from the terrestrial mantle, differentiated and undifferentiated asteroids, and comets. Their oxygen isotope ratios provide key insights into the mass-dependent and mass-independent fractionation processes related to the formation of planets, rocks, and minerals. Secondary Ion Mass Spectrometry (SIMS) is an especially powerful technique for determining oxygen three-isotope ratios ($\delta^{18}\text{O}$, $\delta^{17}\text{O}$, and $\Delta^{17}\text{O} = \delta^{17}\text{O} - 0.52 \times \delta^{18}\text{O}$) of extraterrestrial materials where the sample size is limited, and isotopic variations are generally large (relative to the Earth-Moon system). SIMS can be optimized to detect oxygen isotope variations at the microscale with an analytical precision approaching $\pm 0.3\text{‰}$ (2SD = 2 standard deviations; 10-15 μm size spot) by using multi-collection Faraday cup (MCFC) detectors (Kita et al., 2009; Valley and Kita, 2009). However, oxygen isotope ratios of a target determined by SIMS as well as by other mass spectrometers deviate from the true values to different extents, that is, exhibit “instrumental bias” or “instrumental mass fractionation (IMF).” The instrumental bias of SIMS is principally caused by a combination of two factors in the ion sputtering processes. First, the SIMS settings themselves, i.e., instrumental architecture and configuration, and second, the matrix effect of the target materials, i.e., chemistry, crystal structure, and in rare cases, the crystal orientation of minerals relative to the primary beam (Eiler et al., 1997; Lyon et al., 1998; Riciputi et al., 1998; Valley and Kita, 2009; Huberty et al., 2010). Thus, to accurately determine the oxygen isotope ratios of olivine and pyroxene, a series of olivine and pyroxene reference materials (RMs) with both homogeneous chemical compositions and oxygen isotope ratios need to be analyzed under the same instrumental conditions as the samples, and the instrumental bias of unknowns is corrected with that determined from the RMs with matching crystal structure and compositions. Therefore, it is important that the RMs span the compositional variation of the samples to be analyzed by SIMS.

It has been known for some time that the SIMS instrumental bias in oxygen isotope analysis of olivine varies with their Mg molar fractions [Fo (forsterite) = $\text{Mg}/(\text{Fe} + \text{Mg})$] (e.g., Eiler et al., 1997; Riciputi et al., 1998; Valley and Kita, 2009; Kita et al., 2010). More recently, Isa et al. (2017) examined nine olivine RMs

covering the entire Fe-Mg compositional range and found that the instrumental bias values of iron-rich olivine have a stronger dependence on Fo mol% than magnesium-rich ones. Similar variations in instrumental bias among magnesium-rich olivine have been confirmed by Scicchitano et al. (2018) and Tang et al. (2019). On the other hand, the SIMS instrumental bias in oxygen isotope analysis of pyroxene is recognized to be more heavily dependent on their Ca molar fractions [Wo (wollastonite) = $\text{Ca}/(\text{Fe} + \text{Mg} + \text{Ca})$] than their Mg molar fractions [En (enstatite) = $\text{Mg}/(\text{Fe} + \text{Mg} + \text{Ca})$], although the number of existing low-Ca pyroxene RMs is limited (e.g., Valley and Kita, 2009; Kita et al., 2010). Several Ca-rich pyroxenes show similar instrumental biases nearly independent of En mol% (Ferry et al., 2014). To comprehensively understand the SIMS matrix effects in oxygen isotope analysis of olivine and pyroxene, 16 olivine, nine orthopyroxene, and three clinopyroxene RMs were studied here.

These olivine and pyroxene RMs cover the composition ranges of olivine and low-Ca pyroxene in chondrules of most chondritic meteorites and, therefore, are ideal for correcting their instrumental biases thoroughly and obtaining oxygen three-isotope ratios with improved accuracy. In addition, the analytical precision of stable isotopes and the aiming accuracy of target materials have been improved at the WiscSIMS (Wisconsin Secondary Ion Mass Spectrometer) laboratory thanks to (i) the improvement of the optical resolution of the reflected light microscope (from 3.5 μm down to 1.3 μm) by using a monochromatic UV light source (Kita et al., 2015); (ii) the design of large sample holders (external dimension of 32 mm in the y-direction and internal window diameter of 22 mm) that reduced the systematic bias on stable isotope analyses related to the sample stage X-Y coordinates ("X-Y effect," Peres et al., 2013); and (iii) the utilization of a $10^{12} \Omega$ feedback resistors in the FC amplifier boards for detecting relatively low secondary ions ($\leq 1 \times 10^6$ cps; cps = counts per second) that improved signal/noise ratios by the factor of 3 compared to original IMS-1280 FC amplifier boards with $10^{11} \Omega$ feedback resistors (Fukuda et al., 2021). Compared to the earlier oxygen three-isotope studies of chondrules in the WiscSIMS laboratory (e.g., Kita et al., 2010; Rudraswami et al., 2011; Ushikubo et al., 2012; Tenner et al., 2013), we can analyze chondrules with smaller beam spots and higher precisions (10-12 μm and $\leq 0.3 \text{ ‰}$ in 2SD) with less possibility of overlapping cracks and adjacent minerals.

A key observation from SIMS oxygen-three isotope analyses is the primitive chondrule minerals (PCM) line in the oxygen 3-isotope diagram, expressed as $\delta^{17}\text{O} = (0.987 \pm 0.013) \times \delta^{18}\text{O} - (2.7 \pm 0.11)$, that was

determined from chondrules in the pristine ungrouped carbonaceous chondrite Acfer 094 (Ushikubo et al., 2012). The PCM line crosses the oxygen isotope data from a wide range of solar system materials, such as calcium-aluminum-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), carbonaceous chondrite (CC, including CV, CK, CO, CM, CR, etc.) chondrules, enstatite chondrite (EC) chondrules, primitive achondrites, lunar rocks, the terrestrial mantle, and the extremely ^{16}O -poor cosmic symplectite that was also found in the Acfer 094 chondrite (e.g., Sakamoto et al., 2007; Ushikubo et al., 2017; Marrocchi et al., 2018, 2019; Tenner et al., 2018; Greenwood et al., 2020; Fukuda et al., 2021; Weisberg et al., 2021). Thus, the PCM line has been interpreted to represent a fundamental mixing trend of two extreme primary oxygen isotope reservoirs of solids in the early solar system (Ushikubo et al., 2012). However, the dataset (175 data from 31 individual chondrules) for constructing the PCM line shows a large scatter around the regression line with an MSWD value of 5.0 (Ushikubo et al., 2012). Several studies indicate that a small fraction of CC chondrules plot above the PCM line resembles ordinary chondrite (OC) chondrules in oxygen isotope ratios, Al-Mg relative ages, and nucleosynthetic $\epsilon^{50}\text{Ti}$ and $\epsilon^{54}\text{Cr}$ isotope anomaly (Ushikubo et al., 2013; Tenner et al., 2017; Hertwig et al., 2019a; Williams et al., 2020), possibly suggesting an exotic origin from the OC-forming region. In contrast, the majority of CC chondrules from recent analyses converge toward a linear trend parallel to and below the PCM line (Chaumard et al., 2018, 2021; Hertwig et al., 2018, 2019b; Williams et al., 2020; Fukuda et al., 2022). Recent analyses of minor FeO-rich (type II) chondrules in Acfer 094 by Hertwig et al. (2019a) mostly plot below the PCM line. These observations raise the possibility that the PCM line is a mixture of two trends, one represented by the typical CC chondrules and the other by those chondrules mixed with OC-like materials.

To further examine the possibility of two trends among CC chondrules, we re-analyze the same chondrules in Acfer 094 that were previously studied by Ushikubo et al. (2012). Ushikubo et al. (2012) used one olivine and one low-Ca pyroxene RMs, assuming small changes in the instrumental biases ($\leq 0.5\text{‰}$) for Mg-rich olivine (Fo_{60-100}) and Mg-rich low-Ca pyroxene (En_{85-97}), respectively (e.g., Kita et al., 2010). Results from chondrules with low Fo (< 60) were not reported in Ushikubo et al. (2012) except for $\Delta^{17}\text{O}$ due to lacking matrix-matched olivine RMs. Here we present a new oxygen isotope dataset of Acfer 094 chondrules with significantly improved precision and accuracy compared to the previous study, demonstrating improved data quality by applying a more robust instrumental bias correction scheme that we established in this study.

2. Materials

2.1 Reference materials

The 16 olivine and 12 pyroxene RMs are derived from terrestrial rocks (14 olivines and eight pyroxenes), meteorites (one olivine from pallasite and three pyroxenes from aubrite, diogenite, and Martian meteorite), and synthetic endmember crystals (forsterite and enstatite) (Table 1). The 16 olivine RMs cover the entire fayalite-forsterite series. Five were previously developed for oxygen isotope analysis (SC-OI, HN-OI, IG-OI, OR-OI, and Fa50278-OI) (Eiler et al., 1997; Valley and Kita, 2009; Kita et al., 2010). Four (FJ-OI, SW-OI, UW-OI-1, and HaK-OI) were newly developed for magnesium isotope analysis by Fukuda et al. (2020), who also reported their oxygen isotope ratios ($\delta^{18}\text{O}$) determined by laser fluorination. Here we developed seven new iron-rich olivine (Fo <60) RMs, corresponding to crystals separated and handpicked from medium-to-coarse grained (mm-cm) gabbroic rocks (SK90-6, 8, 9, 14, 21, and 22) of the Skaergaard layered mafic intrusion, Greenland, in the collection of Dr. Alan Boudreau currently housed in the Department of Geological Sciences at East Carolina University (ECU).

The 12 pyroxene RMs comprise nine orthopyroxenes (Opx, $\text{En}_{70-100}\text{Wo}_{0-3}$) and three clinopyroxenes (Cpx, $\text{En}_{28-49}\text{Wo}_{45-50}$, Table 1). Five (JE-En, IG-Opx, IG-Cpx, Sp79-11-En, and 95Ak-6-Di) were previously developed for oxygen isotope analysis (Eiler et al., 1997; Kita et al., 2010) and later used for magnesium isotopes (Fukuda et al., 2020). Enstatite grains of ALH 84001 (abbreviated as A84001-En), a Martian meteorite dominated by coarse-grained (up to 5 mm), cataclastic orthopyroxene crystals (Mittlefehldt, 1994; Valley et al., 1997), was also utilized as an RM in this study after Nakashima et al. (2013) and McDougal et al. (2017). Here we developed six new pyroxene RMs (five Opx and one Cpx), including (i) 7219A-En, 4-15-En, and 7244-Aug (Cpx), which were handpicked from three terrestrial rocks dominated by up to cm-sized pyroxene crystals in the collections of the Department of Geoscience at the University of Wisconsin-Madison (UW-Madison); (ii) SHW-En and JS-En, which were handpicked from two achondrites allocated from the meteorite collection of the Smithsonian National Museum of Natural History, i.e., the aubrite Shallowater (USNM 1206) and the diogenite Johnstown (USNM 6633), respectively; and (iii) ST-En, which are cm-size pure enstatite crystals synthesized by the Czochralski-pulling method by Dr. Shogo Tachibana at the University of Tokyo (Tachibana et al., 2002). Detailed petrographic descriptions of these new pyroxene RMs are in appendix EA1.

Table 1. Rock type and provenance of olivine and pyroxene reference materials (RMs) used in this study

Sample	Fo or En	Wo	Rock type & provenance	Reference
<i>Olivine</i>				
Fa50278-Ol	0.54		Unknown	Eiler et al. (1997)
SK90-14-Ol	20.8		Gabbro, Upper Zone b, Skaergaard, Greenland	This study
SK90-21-Ol	27.6		Gabbro, Upper Zone b, Skaergaard, Greenland	This study
SK90-22-Ol	29.4		Gabbro, Upper Zone b, Skaergaard, Greenland	This study
SK90-9-Ol	56.4		Gabbro, Lower Zone b, Skaergaard, Greenland	This study
SK90-6-Ol	57.3		Anorthosite, Lower Zone a, Skaergaard, Greenland	This study
SK90-8-Ol	57.3		Gabbro, Lower Zone a, Skaergaard, Greenland	This study
OR-Ol	59.3		Gabbro, Orikabe plutonic complex, Japan	Kita et al. (2010)
SK90-5-Ol	66.0		Gabbro, Lower Zone a, Skaergaard, Greenland	This study
FJ-Ol	73.4		Gabbro, Mount Fuji, Japan	Fukuda et al. (2020)
SW-Ol	81.8		Pallasite (Springwater), Meteorite Fall	Fukuda et al. (2020)
SC-Ol	89.0		Peridotite, San Carlos, USA	Kita et al. (2010)
UW-Ol-1	89.2		Peridotite, Kilbourne Hole, USA	Fukuda et al. (2020)
IG-Ol	89.6		Peridotite, Ichinome-gata, Japan	Kita et al. (2010)
HaK-Ol	91.9		Peridotite, Harrat al Kishb, Saudi Arabia	Fukuda et al. (2020)
HN-Ol	100		Synthetic Forsterite	Kita et al. (2010)
<i>Pyroxene</i>				
A84001-En	69.7	3.27	Orthopyroxenite, Martian Meteorite Found	Valley et al. (1997)
JS-En	74.9	2.36	Diogenite (Johnstown), Meteorite Fall	This study
7219A-En	85.8	0.49	Orthopyroxenite, Norway	This study
JE-En	85.5	0.40	Unknown	Eiler et al. (1997)
4-15-En	87.3	1.00	Harzburgite, Unknown	This study
IG-Opx	88.9	1.09	Peridotite, Ichinome-gata, Japan	Kita et al. (2010)
Sp79-11-En	96.3	0.82	Orthopyroxene gneiss, Adirondack Mts., USA	Kita et al. (2010)
SHW-En	99.8	0.16	Aubrite (Shallowater), Meteorite	This study
ST-En	100.0	0.00	Synthetic Enstatite	This study
7244-Aug	27.5	45.3	Clinopyroxenite, Norway	This study
IG-Cpx	48.6	47.1	Peridotite, Ichinome-gata, Japan	Kita et al. (2010)
95AK-6-Di	48.6	49.5	Marble, Adirondack Mts., USA	Edwards and Valley (1998)

2.2 Acfer 094 chondrite chondrules

33 out of 57 chondrules in the ungrouped Acfer 094 chondrite studied by Ushikubo et al. (2012) were selected. Because of the improvement in aiming accuracy (Kita et al., 2015), four chondrules (G48, G64, G75, and G87) that were previously analyzed at lower precisions ($2SD, \delta^{18}O > 1\%$) with 3 μm spots by Ushikubo et al. (2012) were reanalyzed with 10 μm spots for improved precision. High-Ca pyroxenes in these chondrules, which are small ($< 10 \mu m$) and have been measured with a 3 μm primary beam by Ushikubo et al. (2012), were not analyzed here. Most chondrules selected are porphyritic composed mainly of olivine phenocrysts (PO, 9/33), low-Ca pyroxene phenocrysts (PP, 2/33), or both (POP, 18/33). The remaining are olivine fragments (Ol-Frag, 3/33) and a non-porphyritic chondrule with barred-olivine texture (BO, 1/33). Five chondrules (G13, G56, G67, G100, and G113) contain refractory forsterite (RF) that show blue cathodoluminescence. The Mg# [mol% Mg/(Mg+Fe)] of the chondrules range from 42 to ~ 100 , with 19 having Mg# >98 (Type I), four having Mg# within 90-98 (Type I), and ten having Mg# <90 (Type II). Their olivine and low-Ca pyroxene display a compositional range within those of olivine and pyroxene RMs mentioned in section 2.1. Due to the addition of iron-rich olivine RMs, $\delta^{18}O$ and $\delta^{17}O$ of the FeO-rich chondrule G79 (Mg# = 42) were also determined accurately in addition to $\Delta^{17}O$ (Ushikubo et al., 2012).

3. Analytical methods

3.1 Reference material preparation

Nine new olivine RMs prepared from hand samples of gabbroic rocks from the Skaergaard layered mafic intrusion were first washed, cut, crushed, and finally pulverized to sand-size particles at ECU. Olivine grains were obtained after concentrating ferromagnesian minerals with a hand-magnet or a FRANTZ L-1 Isodynamic Magnetic Separator, then handpicking grains under a binocular microscope. Purity was checked via scanning electron microscope (SEM) with Energy Dispersive Spectroscopy (EDS, see section 3.2). Clean grains were embedded in the central 10 mm of a 25-mm diameter epoxy resin block, ground, and polished to a flat low-relief surface.

Five out of six new pyroxene RMs (except the synthetic enstatite crystal ST-En) were first examined for chemical and oxygen isotope homogeneity using SEM-EDS and SIMS (see sections 3.2 and 3.4), respectively.

This examination was carried out on four resin blocks (25 mm in diameter), of which three were mounted with rock cylinders drilled from terrestrial rock blocks, and one was mounted with fragments ($>425\ \mu\text{m}$) picked from the crushed and sieved fractions of two meteorites. Before handpicking, the Shallowater meteorite fragments were processed with 2N HCl for 24 h to remove terrestrial weathering products. After examination, the rock cylinders were removed from the resin blocks and then crushed, sieved ($>745\ \mu\text{m}$), and hand-picked. Clean pyroxene grains from the terrestrial rocks and meteorites were cast into a single 25-mm diameter resin block with five previously developed pyroxene RMs, A84001-En, and the synthetic crystal ST-En (crushed and mounted directly). A coarse grain ($>1\text{mm}$) of San Carlos olivine (SC-Ol) was placed at the mount center. All other grains were mounted within 5 mm of the center of the 25 mm resin block to minimize the “X-Y effect” (Kita et al., 2009).

3.2 Scanning Electron Microscope (SEM) and Electron Microprobe (EPMA) analysis

An FEI Quanta 200 Environmental SEM equipped with an Oxford Instruments EDS system housed at ECU and a variable pressure SEM (Hitachi S3400) with EDS at UW-Madison were used for preliminary petrographic observations and chemical homogeneity examinations in new RMs. The ECU-SEM operated at voltages from 15.0 to 30.0 kV and spot sizes of 3 to 7 nm in a low vacuum (0.45 torr) environment. The UW-Madison SEM operated at an accelerating voltage of 15.0 kV and a beam current of 50-80 μA . Quantitative major element compositions of olivine and pyroxene RMs were acquired using a field emission electron probe micro-analyzer (EPMA, CAMECA SXFive FE) at UW-Madison. Eight olivine and seven pyroxene RMs (6 new plus A84001-En) were analyzed in the Feb. 2019 and Feb. 2020 sessions, respectively. To better evaluate the grain-scale homogeneity, each grain of an RM was analyzed 3-5 times. The analytical conditions of the two sessions are nearly identical, with an accelerating voltage of 15 kV, a beam current of 20 nA, and a beam size of 3 μm . Natural minerals and synthetic crystals were used as calibration standards, including Burma jadeite (Na), NMNH 122142 Kakanui augite (Ca), Grass Valley anorthite (Al), synthetic enstatite (Mg, Si), TiO_2 (Ti), Cr_2O_3 (Cr), Mn_2SiO_4 (Mn), fayalite (Fe), and Ni_2SiO_4 (Ni). The element peaks and the off-peak backgrounds were counted for 10s. Data reduction was performed using the “Probe for Windows” software (Donovan et al., 2007). Typical detection limits are: 0.02 wt.% for CaO, MgO and Na_2O ; 0.03 wt.% for Al_2O_3 and SiO_2 ; 0.05 wt.% for TiO_2 and MnO; 0.06 wt.% for Cr_2O_3 and FeO; and 0.08 wt.% for NiO.

3.3 Oxygen two-isotope analysis by laser fluorination

Laser fluorination and gas-source mass spectrometry analysis of oxygen isotope ratios in new olivine and pyroxene RMs were conducted at the Stable Isotope Laboratory, Department of Geoscience, UW-Madison. Two or three aliquots, 2-3 mg/ea, of clean grains for each RM were pretreated overnight at room temperature in the sample chamber with BrF_5 and then individually heated with a CO_2 laser ($\lambda = 10.6 \mu\text{m}$) in the atmosphere of BrF_5 to release O_2 , which was cryogenically purified, converted into CO_2 by reaction with hot graphite, and analyzed on a Finnigan MAT 251 gas-source mass spectrometer (Valley et al., 1995; Page et al., 2010). The measured oxygen isotope ratios are reported in permil (‰) units using standard $\delta^{18}\text{O}$ notation relative to the Vienna Standard Mean Ocean Water (VSMOW) (Baertschi, 1976; Coplen, 1995). Aliquots of UWG-2 garnet ($\delta^{18}\text{O} = 5.80\text{‰}$) were run in the same sessions as samples, and RM values were corrected by the difference of UWG-2 from 5.80‰ (Valley et al., 1995; Page et al., 2010). Multiple analyses on UWG-2 in each session gave a typical analytical precision of $\pm 0.1\text{‰}$ (2SD) and average corrections of $< 0.15\text{‰}$.

3.4 Oxygen two- and three-isotope analysis by SIMS

In situ oxygen two-isotope analysis of olivine and pyroxene RMs was performed with a CAMECA IMS-1280 at the WiscSIMS laboratory. Preliminary examination of oxygen isotope homogeneity in new pyroxene RMs was performed in two sessions: Nov. 2019 for 7219A-En, 4-15-En, and 7244-Aug and Jan. 2020 for SHW-En and JS-En. In addition, the SIMS matrix effect was determined from all olivine and pyroxene RMs in Oct. 2018 and Mar. 2020, respectively. The analytical conditions of the four sessions are similar to those described in Kita et al. (2009). A focused $^{133}\text{Cs}^+$ primary ion beam with a diameter of $\sim 10 \mu\text{m}$, a beam current of $\sim 2.0 \text{ nA}$, and a total accelerating voltage of 20 kV was utilized. A conductive coating (20 nm carbon) and a normal incidence electron gun were used to compensate for the positive charging on the sample surface during sputtering. The entrance slit was set to $120 \mu\text{m}$; transfer optics was set to $200\times$ magnification from the sample to the field aperture set to $4000 \mu\text{m}^2$. Secondary ions $^{16}\text{O}^-$ ($\sim 3 \times 10^9 \text{ cps}$) and $^{18}\text{O}^-$ ($\sim 6 \times 10^6 \text{ cps}$) were detected simultaneously using two FCs on the multicollection system with the slit widths of $500 \mu\text{m}$ and mass resolving power (MRP) of 2200. Each analysis takes $\sim 3 \text{ min}$, including 10 s of presputtering, 60 s of automated centering of secondary ions, and 80 s of ion signal integration. Except for the Nov. 2019 session (bracketed by Sp79-11-En), each 10-20 analyses on the olivine and pyroxene RMs were bracketed by eight analyses on the running

standard SC-OI, giving a spot-to-spot reproducibility (2SD) in $\delta^{18}\text{O}$ of $\pm 0.2\%$. Each grain of an RM was analyzed once or twice to evaluate the grain-scale homogeneity better. The instrumental biases of olivine and pyroxene RMs are expressed as differences relative to that of SC-OI (Bias*), which is calculated as:

$$\text{Bias}^*(\text{RM}) = \left[\frac{\alpha^{18}\text{O}_{\text{SIMS}}(\text{RM})}{\alpha^{18}\text{O}_{\text{SIMS}}(\text{SC-OI})} - 1 \right] \times 1000(\text{‰})$$

where

$$\alpha^{18}\text{O}_{\text{SIMS}} = \frac{(^{18}\text{O}/^{16}\text{O})_{\text{SIMS}}}{(^{18}\text{O}/^{16}\text{O})_{\text{LF}}}$$

is the instrumental mass fractionation defined as $\delta^{18}\text{O}$ determined by SIMS relative to that determined by laser fluorination, as described in appendix EA1 of Kita et al. (2010).

In situ oxygen three-isotope analysis of olivine and low-Ca pyroxene in chondrules of the Acfer 094 chondrite was performed in two sessions (Nov. 2020: 3O-S1 and Dec. 2020: 3O-S2) on the CAMECA IMS-1280. Seventeen olivine and 12 pyroxene RMs were analyzed under the same instrumental conditions to fully correct the instrumental biases of unknowns. The analytical conditions of the two sessions are almost identical and follow that of Kita et al. (2010). We used a primary beam with a diameter of $\sim 10\ \mu\text{m}$ and an intensity of $\sim 2\ \text{nA}$ for analysis. In addition, we prepared a lower intensity beam ($< 0.1\ \text{nA}$, with a diameter of $\sim 3\text{--}4\ \mu\text{m}$) for presputtering. The typical count rate of $^{16}\text{O}^-$ under the $1.8\ \text{nA}$ analysis condition was $2\text{--}3 \times 10^9\ \text{cps}$. Secondary ions $^{16}\text{O}^-$, $^{17}\text{O}^-$, and $^{18}\text{O}^-$ were detected simultaneously using three FCs, in which $^{17}\text{O}^-$ was counted by an axial FC with a $10^{12}\ \Omega$ resistor for improved precision, while $^{16}\text{O}^-$ and $^{18}\text{O}^-$ were counted by two multicollection FCs with resistors of $10^{10}\ \Omega$ and $10^{11}\ \Omega$, respectively (Goodrich et al., 2019; Siron et al., 2021). The entrance slit was reduced to $75\ \mu\text{m}$, and the exit slit width of the axial FC was set to $240\ \mu\text{m}$, resulting in an MRP of ~ 5000 for $^{17}\text{O}^-$ to separate the molecular interference $^{16}\text{O}^1\text{H}^-$. The contribution of the $^{16}\text{O}^1\text{H}^-$ tailing effect on $^{17}\text{O}^-$ counts, though always minor (typically $< 0.1\%$ correction), was further corrected using the method described in Heck et al. (2010). Each measurement takes $\sim 7\ \text{min}$, including 100s of presputtering for monitoring the FC baseline, 120s of secondary ions centering, and 200s of ion signals integration. The low-intensity beam ($< 0.1\ \text{nA}$) was rastered over $10\ \mu\text{m}$ areas during the presputtering to minimize the sample consumption before ion signal

integrations. The FC baseline was averaged over eight consecutive analyses (Kita et al., 2010). Typical analytical precisions for $\delta^{18}\text{O}$, $\delta^{17}\text{O}$, and $\Delta^{17}\text{O}$, represented by spot-to-spot reproducibility (2SD) of the eight bracketing SC-OI standard analyses, are 0.2‰, 0.3‰, and 0.3‰, respectively. The locations and morphology of the analysis pits were checked using an SEM, and data from pits that went through the target mineral (hit other phases beneath) and overlapped other minerals or weathering products were rejected (EA2). The instrumental biases in chondrule olivine were corrected using two equations, one linear equation for olivine with $\text{Fo} \geq 60$ and one quadratic equation for those with $\text{Fo} < 60$ (EA2 Table S7). The instrumental biases in chondrule low-Ca pyroxene were corrected using a combination function of a linear function of bias* (Opx) vs. En mol% and a linear function of bias* (Cpx) vs. Wo mol% to reduce the residuals of the fit (EA2 Table S7).

3.5 Determination of SIMS sputter rates

The SIMS sputter rates of all olivine and pyroxene RMs were determined using the Kohler illumination mode of the CAMECA IMS-1280 instrument. Compared to a Gaussian beam, the Kohler beam typically makes craters with better bottom flatness (EA2 Fig. S1), allowing accurate sputter volume estimates. The primary Cs^+ beam was nearly round, with a size of $\sim 22 \mu\text{m} \times 22 \mu\text{m}$ and an intensity of $\sim 0.5 \text{ nA}$ (corrected for the offset of E-beam emission). Each RM was sputtered for 18 min. The depth and morphology of the Kohler pits were inspected with a Zygo NewView™ 9000 interferometer at the Nanoscale Imaging and Analysis Center, UW-Madison. With the coherence scanning interferometry technology of the interferometer, nanometer precision can be achieved. The SIMS sputter rate was defined as sputtering volume (μm^3) per beam intensity (nA) and time (s) and thus, expressed in units of $\mu\text{m}^3/\text{nA}/\text{s}$.

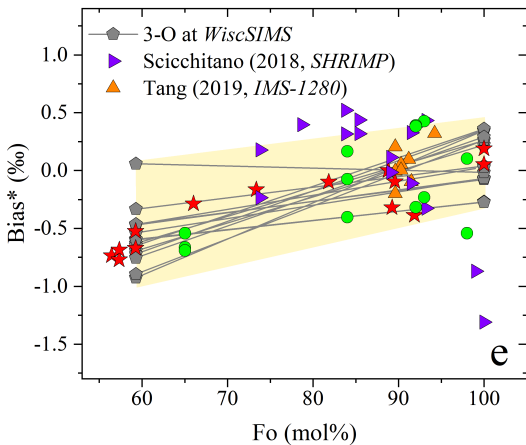
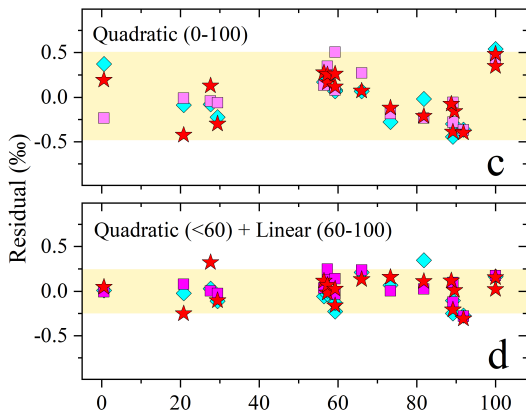
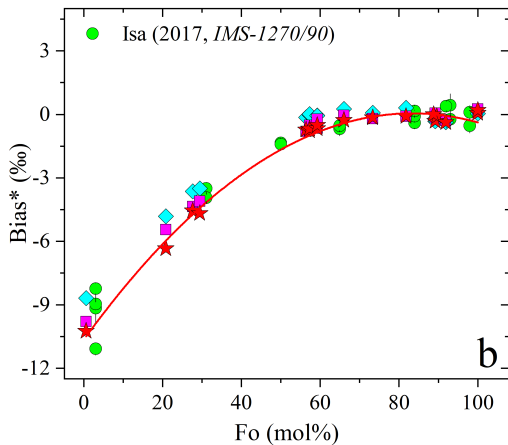
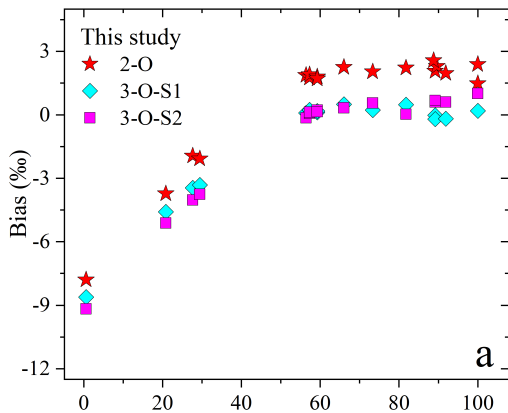
4. Results

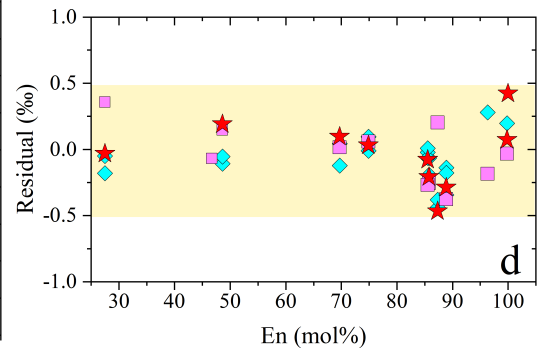
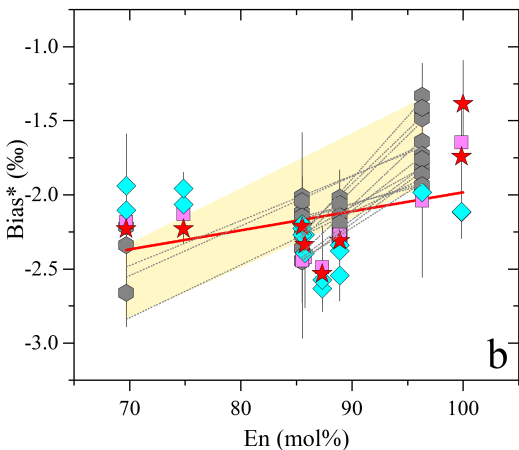
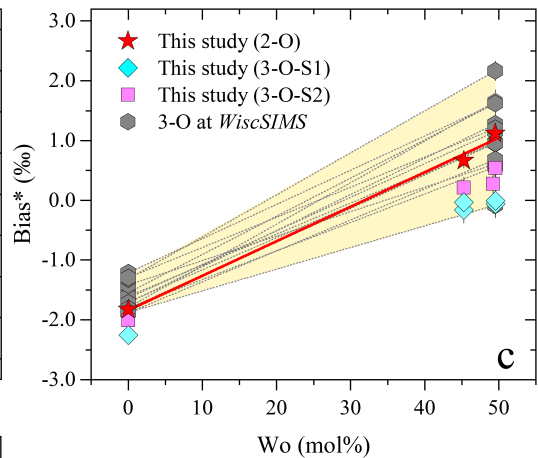
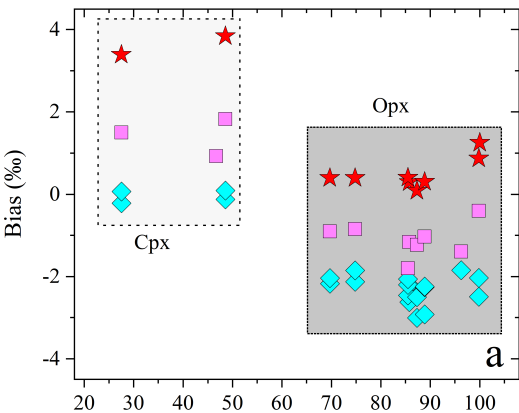
4.1 Chemical and oxygen isotope homogeneity of new olivine and pyroxene RMs

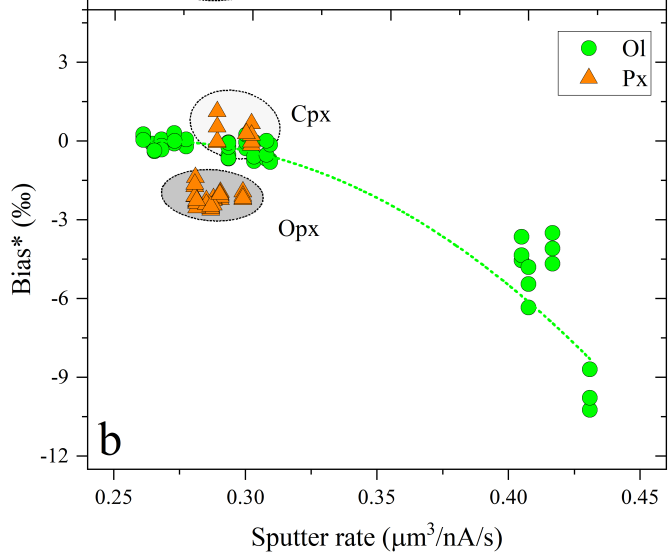
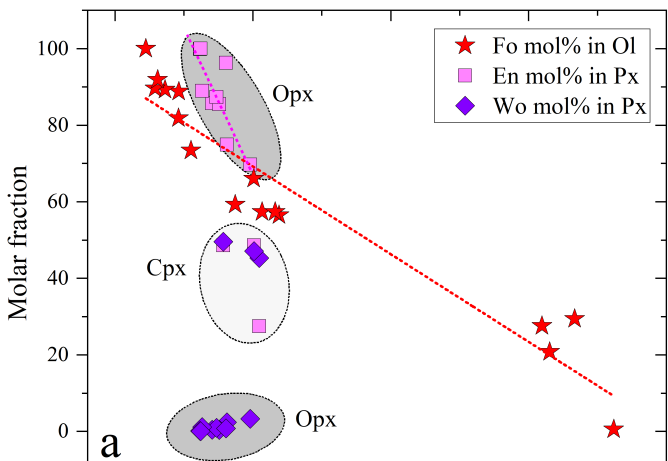
SEM observations show that most selected grains of new olivine and pyroxene RMs are $>99 \text{ vol\%}$ of a single-phase; a few pyroxene RMs have minor amounts ($<1 \text{ vol\%}$) of inclusions of metal, sulfide, silica, olivine, and plagioclase, and diopside lamellae (EA1). Chemical zoning was not observed. EDS analysis shows that variations in the Mg molar fractions are $<1.2\%$ (2SD). Quantitative EPMA measurements determined that 2SD of Fo mol% in olivine RMs and En mol% and Wo mol% in pyroxene RMs are typically $<1.4\%$ (Table 2, EA2

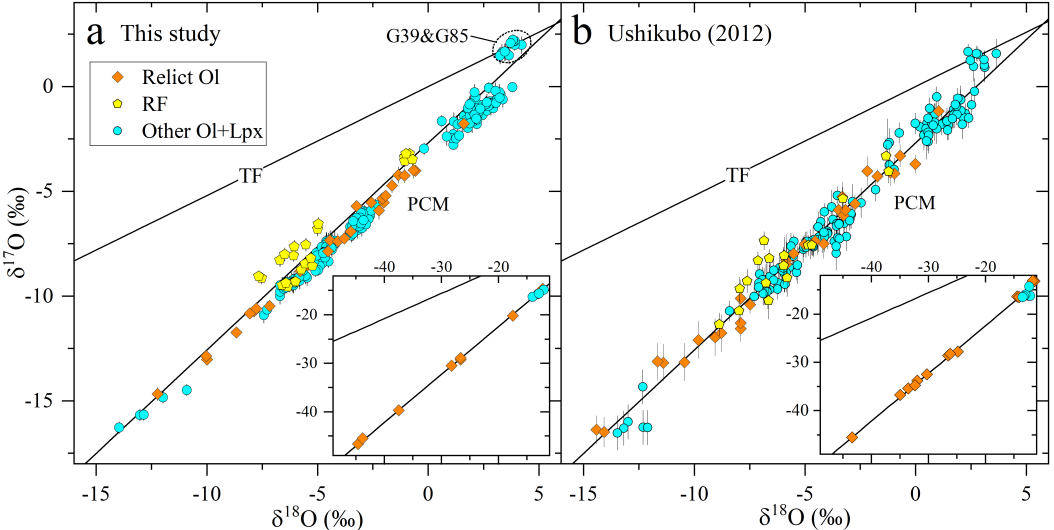
S2), suggesting homogeneous chemical compositions. One exception is the RM SK90-21-Ol which has 2SD of Fo mol% $\sim 7.3\%$ (2SD). The new olivine RMs have a minor abundance of MnO (<1 wt.%) and are nearly free of Cr_2O_3 (<0.2 wt.%). The new orthopyroxene RMs are poor in CaO (<1.2 wt.%; Wo mol% <2.4) and Al_2O_3 (<1.1 wt.%), with trace amounts of MnO (<0.6 wt.%) and Cr_2O_3 (<0.7 wt.%), while the clinopyroxene (augite) RM 7244-Aug has ~ 20 wt.% CaO, ~ 2 wt.% Na_2O , and ~ 15 wt.% FeO. Major element compositions of previously developed olivine and pyroxene RMs are taken from Fukuda et al. (2020) and tabulated in Table 2.

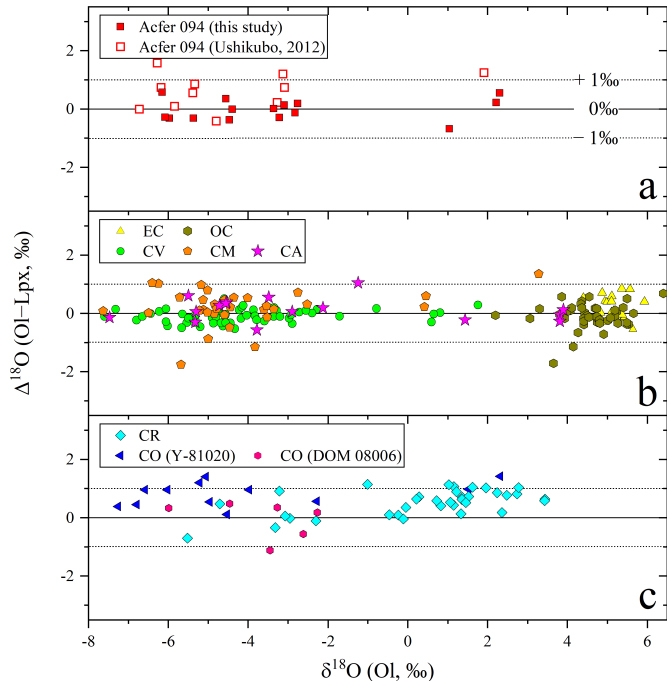
SIMS oxygen-isotope analyses on multiple grains of new olivine and pyroxene RMs showed homogeneous oxygen isotope ratios in $\delta^{18}\text{O}$ with 2SD typically $<0.3\text{‰}$ (Table 3, EA2 S3-S5) for both preliminary homogeneity examination (five pyroxene RMs) and/or final SIMS matrix effect evaluations. The laser fluorination results show nearly identical $\delta^{18}\text{O}$ values among two or three measurements (2SD typically $<0.15\text{‰}$) for each RM. As exceptions, SK90-21-Ol and ST-En have 2SD of $\delta^{18}\text{O}$ equal to 1.32‰ and 0.95‰ as determined by SIMS and 0.48‰ and 0.34‰ as determined by laser fluorination, suggestive of oxygen isotope heterogeneity. Thus, the two samples are not qualified as reference materials and were not included in the following discussions. In addition, internal errors (2SE) of individual SIMS analyses on all olivine and orthopyroxene RMs are positively correlated with their Mg molar fractions. Considering the Nov. 2020 oxygen three-isotope session as an example, 2SE of individual analysis increases from $\sim 0.1\text{‰}$ to $\sim 0.6\text{‰}$ on olivine RMs as Fo mol% increases from 0 to 100 and increases from $\sim 0.4\text{‰}$ to $\sim 0.7\text{‰}$ on orthopyroxene RMs as En mol% increases from 70 to 100. In contrast, individual analyses on clinopyroxene RMs in the same session typically have higher 2SE than orthopyroxene RMs, i.e., $0.7\text{--}0.8\text{‰}$ vs. $0.4\text{--}0.7\text{‰}$.

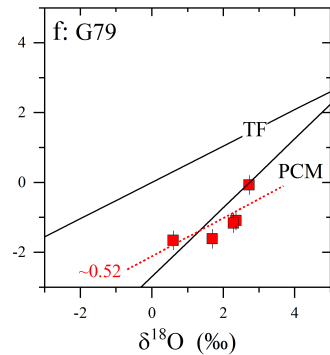
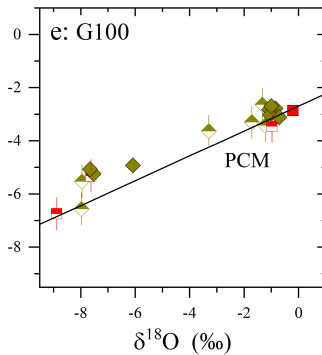
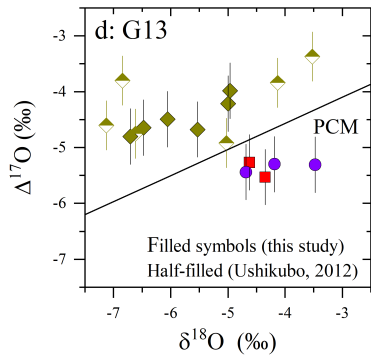
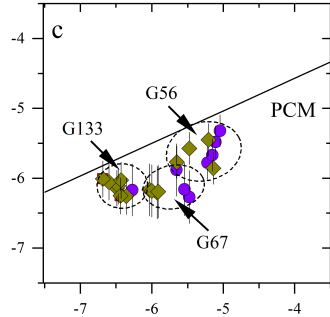
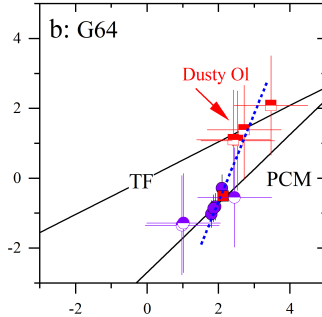
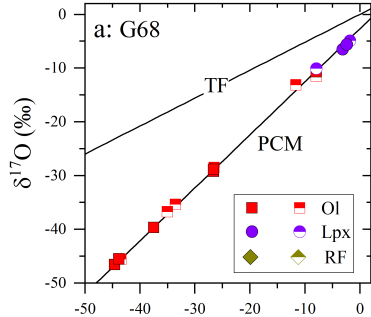






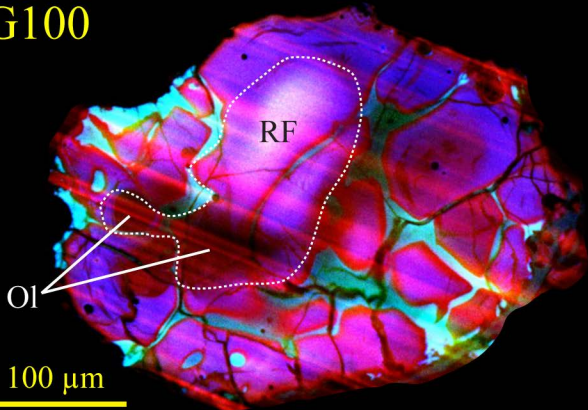






G100

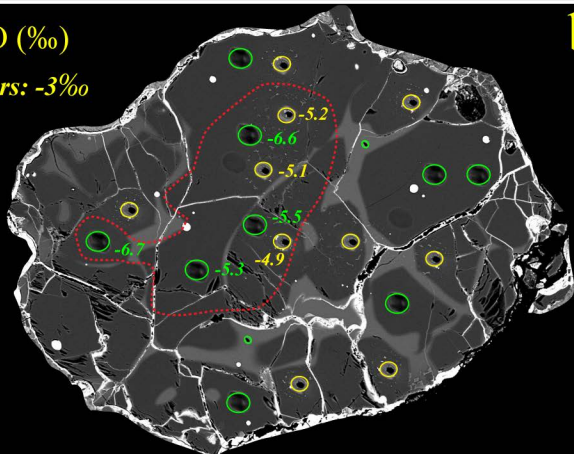
a

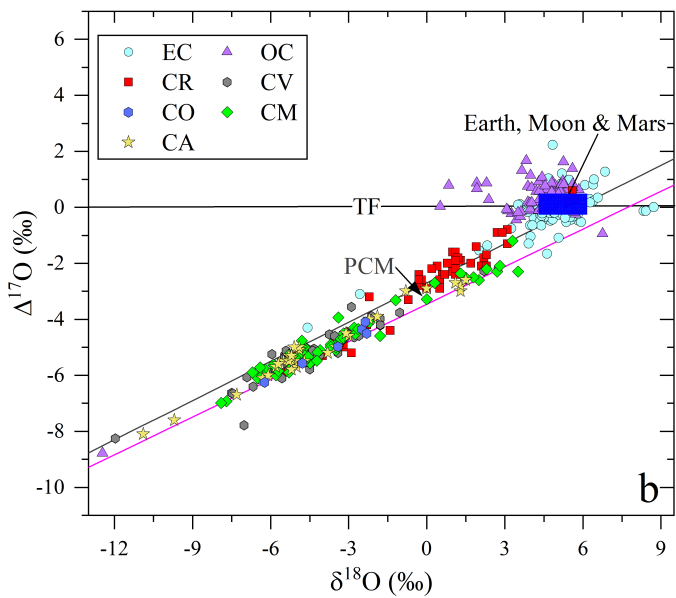
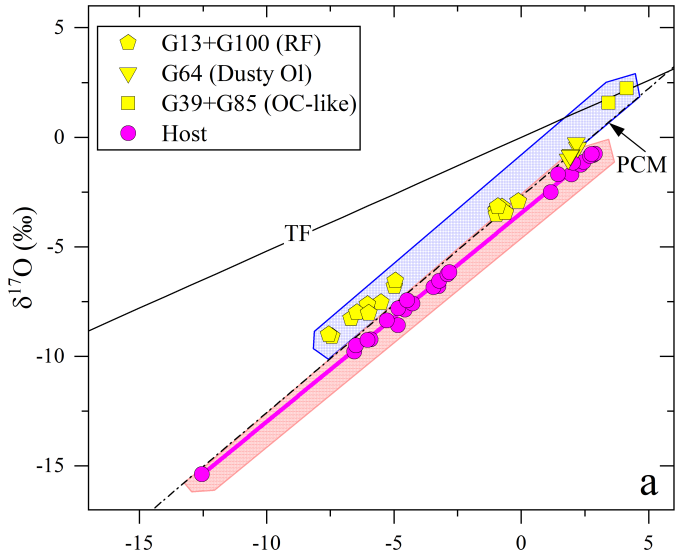


$\Delta^{17}\text{O}$ (‰)

b

Others: -3‰

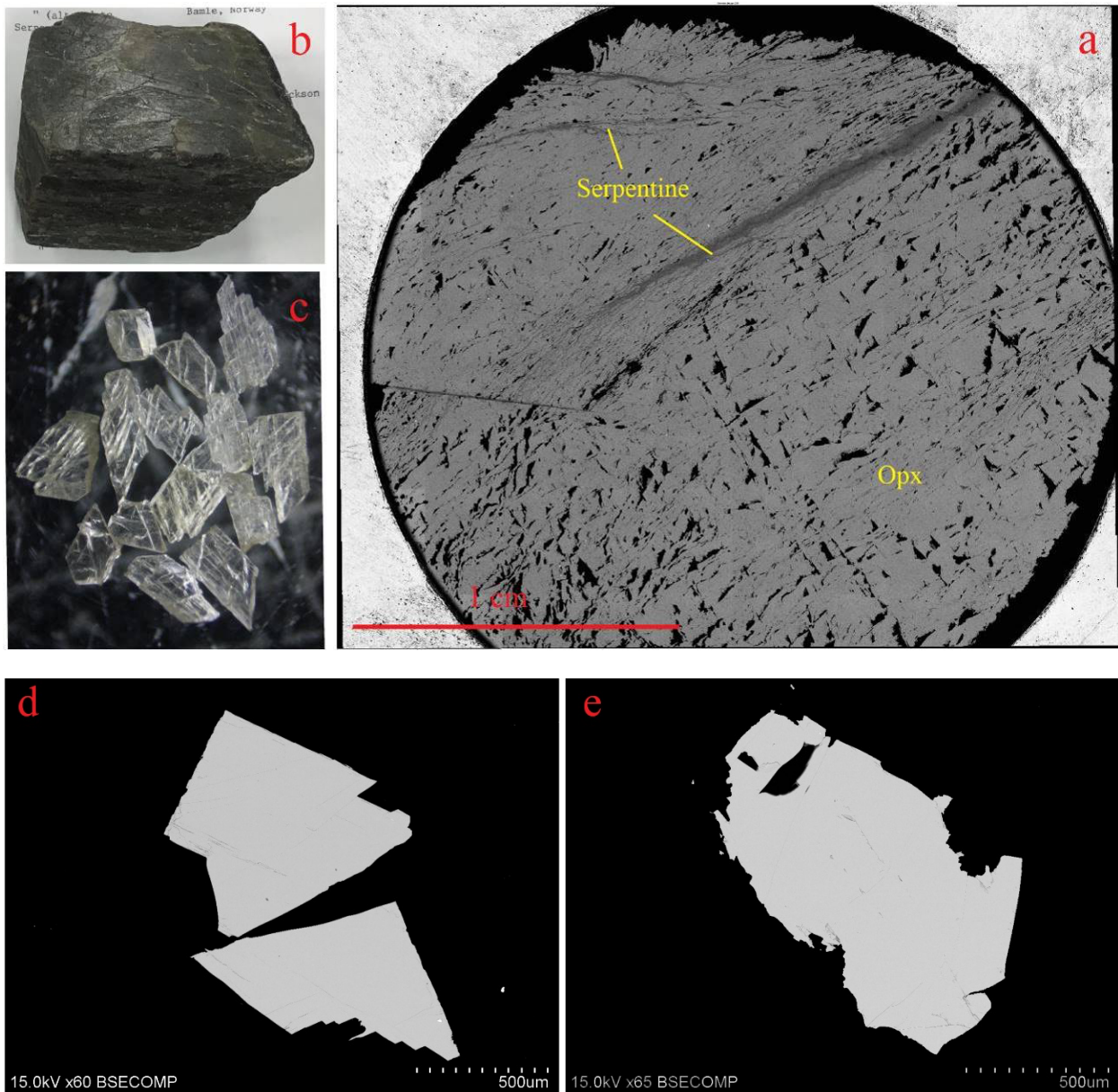




Appendix 1: sample descriptions

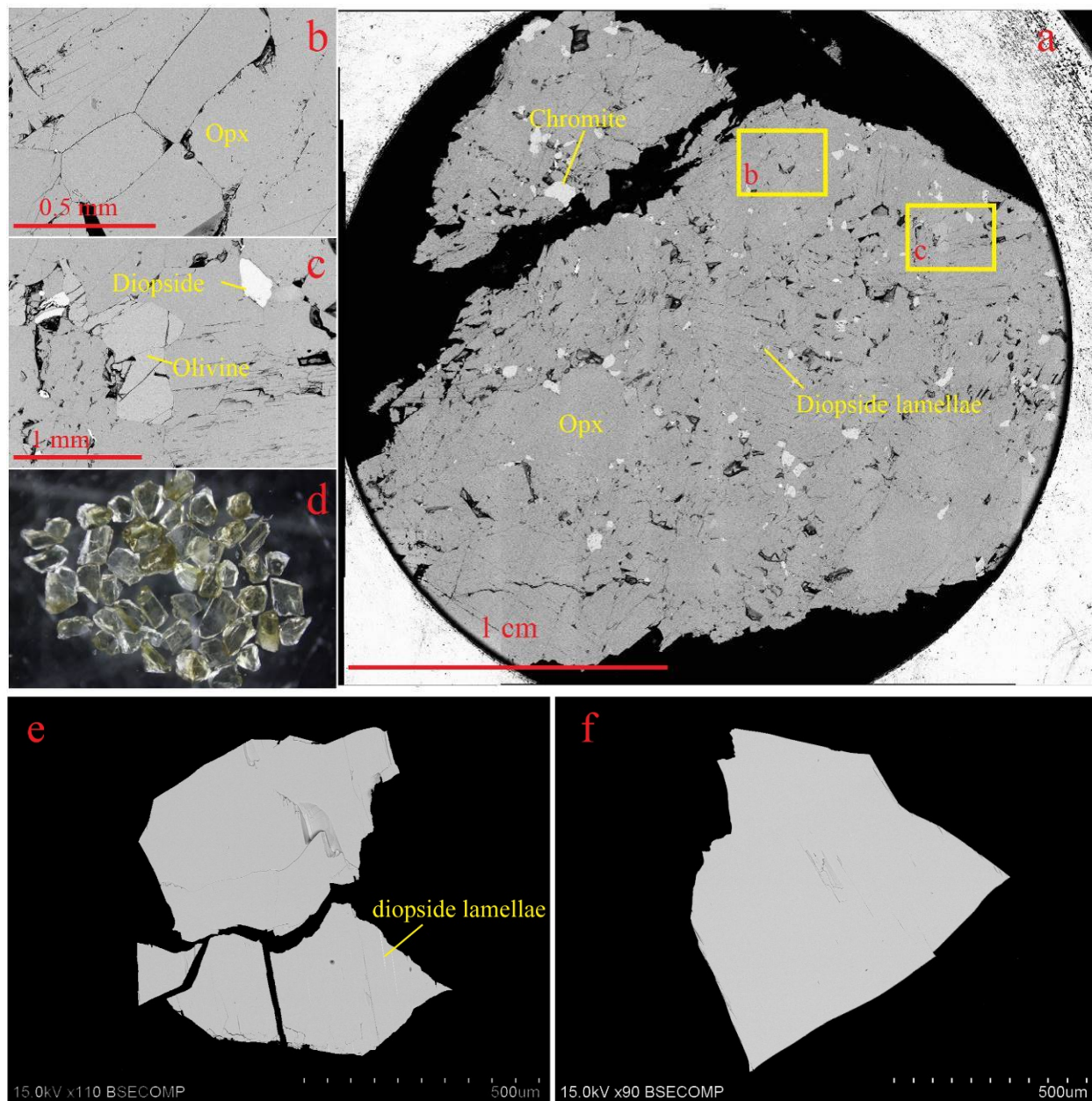
7219A-En ($\text{En}_{85.8}\text{Wo}_{0.4}$); Orthopyroxenite from Norway; Rock collection of Department of Geosciences, UW-Madison.

7219A is an orthopyroxenite composed exclusively of orthopyroxene with minor serpentinization (a, b). Preliminary petrology and oxygen isotope homogeneity examination were done on this resin block, showing SD of Mg# is 0.6 at% (checked by EDS), and 2SD of $\delta^{18}\text{O}$ is 0.29‰ (checked by SIMS). The block was later crashed for handpicking. Clean and transparent grains with size $>745\text{ }\mu\text{m}$ were picked out for laser fluorination analysis and were mounted with other pyroxene standards for in situ oxygen isotope analysis (c). The picked grains are free of inclusions (d, e).



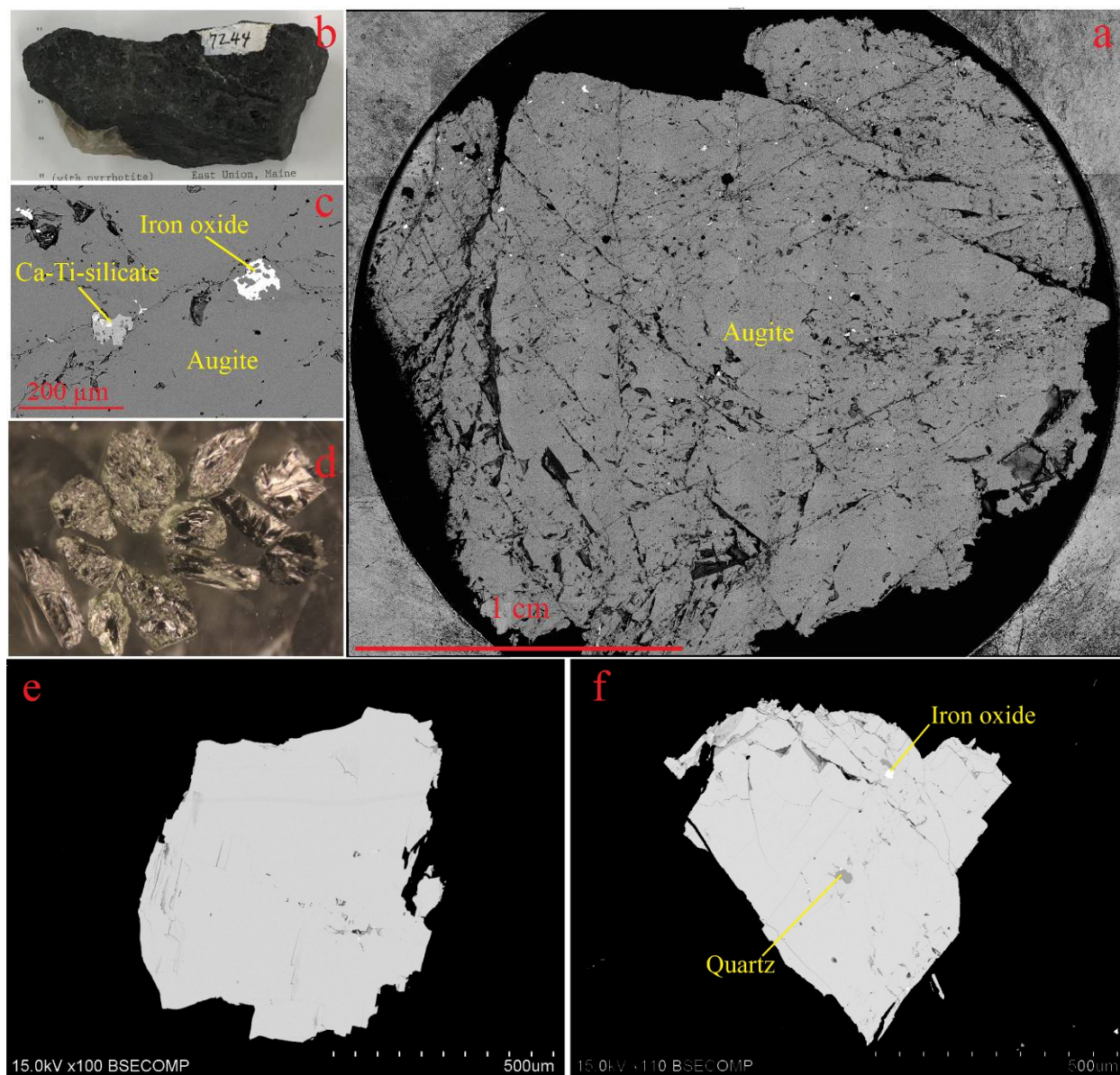
4-15-En ($\text{En}_{87.3}\text{Wo}_{1.0}$); Harzburgite of unknown provenance; Rock collection of Department of Geosciences, UW-Madison.

4-15 is a harzburgite composed of orthopyroxene, diopside, chromite, and olivine (a, b, c). Preliminary petrology and oxygen isotope homogeneity examination were done on this resin block, showing SD of Mg# is 0.23 at% (checked by EDS), and 2SD of $\delta^{18}\text{O}$ is 0.21‰ (checked by SIMS). The block was later crashed for handpicking. Clean and transparent grains with size $>425\text{ }\mu\text{m}$ were picked for laser fluorination analysis and were mounted with other pyroxene standards for in situ oxygen isotope analysis (d). A small portion of picked grains contains $<1\text{ vol\%}$ of diopside lamellae (e, f).



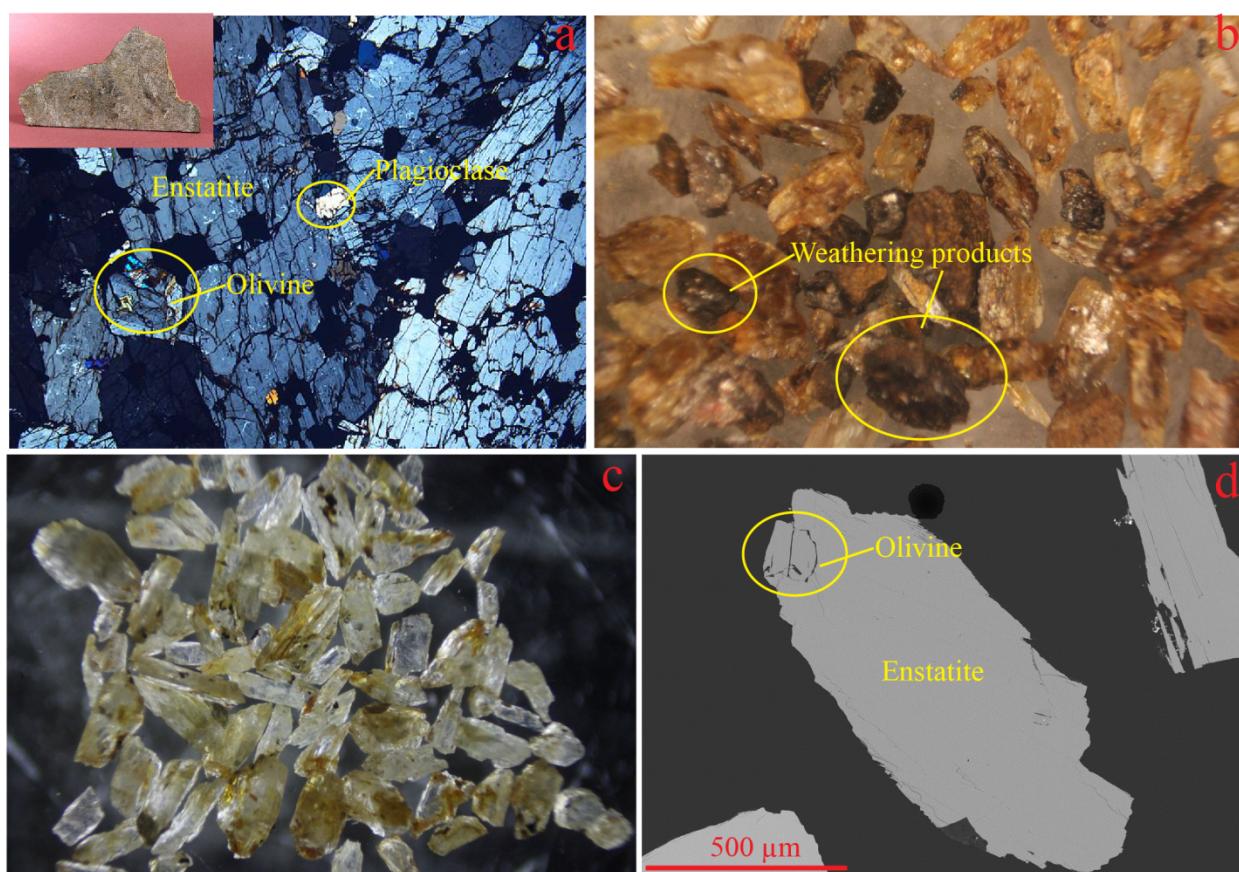
7244-Aug (En_{27.5}Wo_{45.3}); Clinopyroxenite from Norway; Rock collection of Department of Geosciences, UW-Madison.

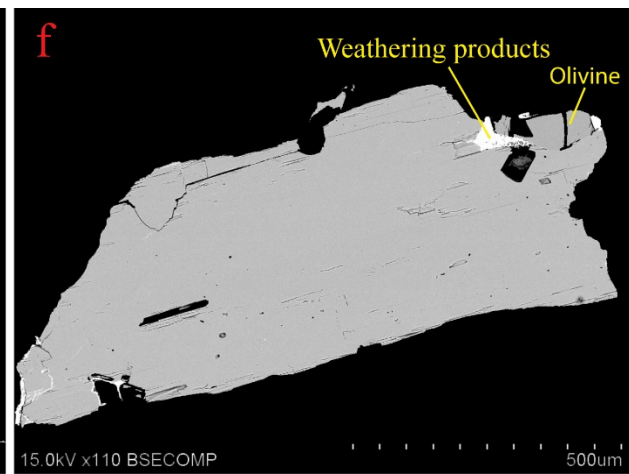
7244 is a clinopyroxenite composed predominantly of augite with a minor amount of iron oxide, Ca-Ti-silicate, and quartz (a, b, c). Preliminary petrology and oxygen isotope homogeneity examination were done on this resin block, showing SD of Mg at% is 0.25 at% (checked by EDS) and 2SD of $\delta^{18}\text{O}$ is 0.25‰ (checked by SIMS). The block was later crashed for handpicking. >745 μm grains without rust stains were picked out for laser fluorination analysis and were mounted with other pyroxene standards for in situ oxygen isotope analysis (d). The picked grains contain <1 vol% quartz and iron oxides (e, f).



SW-En (En_{99.8}Wo_{0.16}); Shallowater aubrite; Meteorite collection of Smithsonian National Museum of Natural History (NMNH)

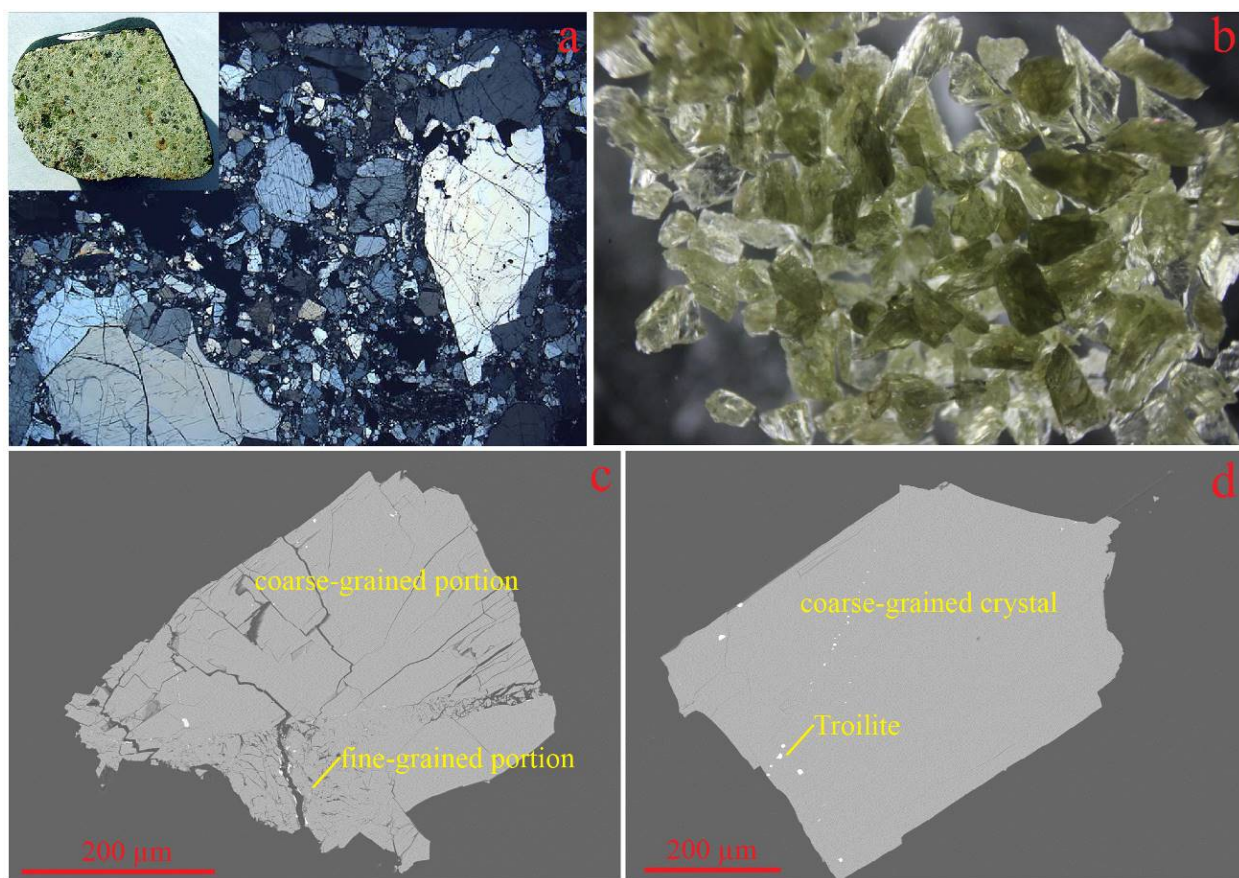
Shallowater is an unbrecciated igneous aubrite (enstatite achondrite) found in Texas, 1936. It is a coarse-grained orthopyroxenite consisting of poikilitic enstatite crystals (80 vol%) up to 4.5 cm in size, which contain, as inclusions and in the interstices, xenoliths of an assemblage of forsterite (2.9 vol%), Fe-Ni metal (3.3 vol%), and weathered opaques (8 vol%) (a) (Keil et al., 1989). **0.54 g** sample allocated from NMNH has been gently crushed and processed with 2N HCl for 24 hours to dissolve weathering products, resulting in a large portion of transparent grains with/without iron oxide coating (<1 vol%), as well as a small quantity of dark weathered products (b). **100-500 μm** transparent grains with/without iron oxide coating were handpicked. Ten picked grains were mounted into a resin block with San Carlos olivine standard for chemical and oxygen isotopic homogeneity examination (c). The results show both the coated and uncoated grains are homogenous with SD of Mg at% is ≤ 0.32 at% (checked by EDS), and 2SD of $\delta^{18}\text{O}$ is $\leq 0.29\text{‰}$ (checked by SIMS). The clean grains without oxide coatings were used for laser fluorination analysis, while the others were used for in situ oxygen isotope analysis (c). Some grains contain olivine and plagioclase inclusions (d, e), which cannot be distinguished from enstatite under an optical microscope.

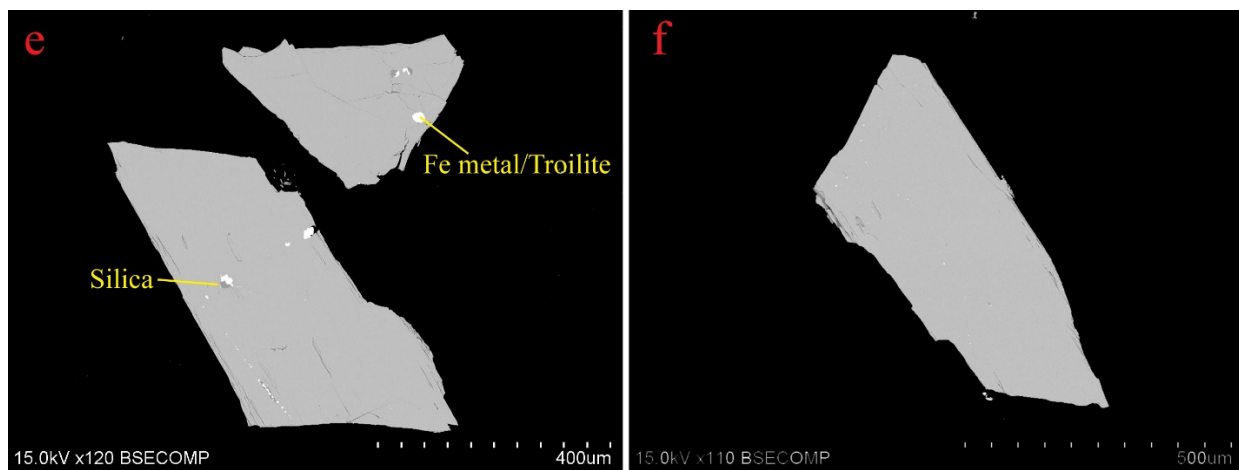




JS-En (En_{74.9}Wo_{2.36}); Johnstown Diogenite; Meteorite collection of Smithsonian National Museum of Natural History (NMNH)

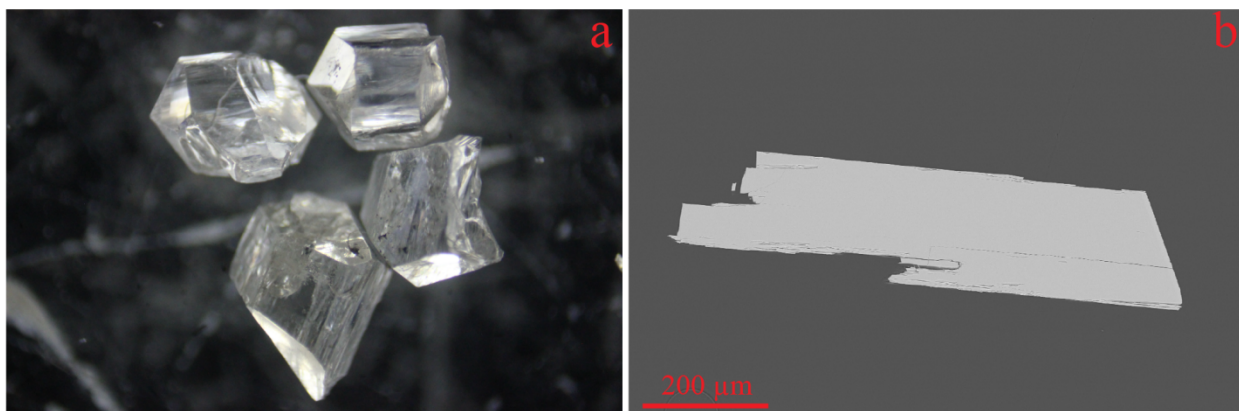
Johnstown is a brecciated igneous diogenite (HED achondrite) found in Texas, 1936. It is a monomictic breccia composed exclusively of orthopyroxene (95-96 vol%) with a minor amount of high-Ca pyroxene (0.5 vol%), troilite (2.3-2.8 vol%), and silica (0.4-0.6 vol%), and chromite (0.1 vol%) (a) (Bowman et al., 1997). **0.463 g** sample allocated from NMNH has been gently crushed, and the **coarse-grained (100-500 μm)** and the fine-grained portions were manually separated. Five coarse-grained and five fine-grained fragments were mounted into a resin block with the Johnstown meteorite fragments for chemical and oxygen isotopic homogeneity examination (c, d). The results show both the coarse-grained and fine-grained fragments are homogenous with SD of Mg at% is ≤ 0.25 at% (checked by EDS), and 2SD of $\delta^{18}\text{O}$ is $\leq 0.4\text{‰}$ (checked by SIMS). Furthermore, the coarse-grained crystals (2SD=0.21‰) seem more homogeneous in oxygen isotopes than the fine-grained counterparts (2SD=0.4‰) (c). Thus, only the coarse-grained crystals were used for laser fluorination analysis and in situ oxygen isotope analysis (b, d), containing trace amounts of Fe metal, troilite, and silica (e, f).





ST-En (En₁₀₀); Synthetic pure enstatite crystals; Made by Dr. Shogo Tachibana, University of Tokyo.

Four pure enstatite crystals with a weight range from **6.5 mg to 8.7 mg** were provided by Dr. Shogo Tachibana, synthesized using the Czochralski-pulling method described by Morioka and Nagasawa (1991). The crystals were directly crushed and used for laser fluorination analysis. The large fragments (**100-500 μm**) were mounted with other standard grains into the final grain mount. Chemical compositions and oxygen isotope homogeneity were determined on the grain mount using EPMA and SIMS, respectively.



References

- Bowman L. E., Spide M. N. and Papike J. J. (1997) Automated energy dispersive spectrometer modal analysis applied to the diogenites. *Meteorit. Planet. Sci* **32**, 869-875.
- Keil K., Ntaflos T., Taylor G. J., Brearley A. J., Newsom H. E. and Romig A. D. (1989) The Shallowater aubrite: Evidence for origin by planetesimal impacts. *Geochim. Cosmochim. Acta* **53**, 3291-3307.
- Morioka M. and Nagasawa H. (1991) Diffusion in single crystals of melilite: II. Cations. *Geochim. Cosmochim. Acta* **55**, 751-759.

Table S1. Major elements of the eight new olivine RMs and the fayalite RM Fa50278

Sample	MgO	SiO ₂	CaO	Cr ₂ O ₃	FeO	NiO	MnO	Total
Fa50278-Ol	0.18	28.28	0.04	b.d.	66.34	b.d.	3.30	98.04
Fa50278-Ol	0.21	28.40	0.04	b.d.	66.56	b.d.	3.26	98.47
Fa50278-Ol	0.19	28.26	0.04	b.d.	66.55	b.d.	3.14	98.24
Fa50278-Ol	0.20	28.36	0.07	b.d.	66.96	b.d.	2.92	98.44
Fa50278-Ol	0.22	28.12	0.08	b.d.	66.51	b.d.	2.77	97.70
Fa50278-Ol	0.21	27.87	0.07	b.d.	66.44	0.09	2.88	97.53
Fa50278-Ol	0.21	29.00	0.04	b.d.	66.30	b.d.	2.95	98.45
Fa50278-Ol	0.19	28.95	0.04	b.d.	66.86	b.d.	3.02	99.08
Fa50278-Ol	0.22	29.05	0.03	b.d.	66.70	b.d.	2.96	99.01
Average (N=9)	0.20	28.48	0.05		66.58		3.02	98.33
SD	0.01	0.42	0.02		0.22		0.18	0.53
SK90-14-Ol	8.66	30.89	b.d.	b.d.	58.91	b.d.	0.93	99.44
SK90-14-Ol	8.39	30.62	b.d.	b.d.	58.90	b.d.	0.98	98.84
SK90-14-Ol	8.98	31.10	b.d.	b.d.	58.82	b.d.	0.97	99.98
SK90-14-Ol	8.85	30.92	b.d.	b.d.	58.61	b.d.	0.85	99.32
SK90-14-Ol	8.89	31.31	b.d.	b.d.	58.02	b.d.	0.90	99.19
SK90-14-Ol	8.75	30.98	b.d.	b.d.	58.30	b.d.	1.08	99.21
SK90-14-Ol	8.74	30.96	b.d.	b.d.	58.64	b.d.	1.01	99.43
SK90-14-Ol	8.14	30.78	b.d.	b.d.	59.38	b.d.	0.94	99.31
SK90-14-Ol	8.97	30.95	b.d.	b.d.	58.32	b.d.	0.98	99.29
SK90-14-Ol	8.18	30.63	b.d.	b.d.	58.83	b.d.	0.91	98.59
SK90-14-Ol	8.55	30.88	0.03	b.d.	58.97	b.d.	0.94	99.42
SK90-14-Ol	8.63	30.89	0.04	b.d.	58.39	b.d.	1.06	98.99
SK90-14-Ol	8.80	31.07	b.d.	b.d.	57.68	b.d.	0.99	98.59
SK90-14-Ol	8.58	30.37	0.03	b.d.	58.30	b.d.	0.85	98.14
SK90-14-Ol	8.47	30.10	0.03	b.d.	59.00	b.d.	0.90	98.47
SK90-14-Ol	8.02	30.24	b.d.	b.d.	59.48	b.d.	0.90	98.70
SK90-14-Ol	8.49	30.83	b.d.	b.d.	58.75	b.d.	1.01	99.14
SK90-14-Ol	8.83	30.65	b.d.	b.d.	57.83	b.d.	0.95	98.23
SK90-14-Ol	8.93	30.45	0.03	b.d.	58.24	b.d.	0.94	98.68
SK90-14-Ol	8.69	30.61	b.d.	b.d.	58.44	b.d.	0.90	98.65
Average (N=20)	8.63	30.76	0.03		58.59		0.95	98.98
SD	0.28	0.30	0.00		0.47		0.06	0.47
SK90-21-Ol	16.16	32.47	b.d.	b.d.	50.13	b.d.	0.75	99.54
SK90-21-Ol	11.81	31.45	0.05	b.d.	55.26	b.d.	0.77	99.28
SK90-21-Ol	11.70	31.65	0.07	b.d.	54.90	0.09	0.80	99.17
SK90-21-Ol	11.27	31.53	0.04	b.d.	55.40	b.d.	0.82	99.08
SK90-21-Ol	11.72	31.51	0.07	b.d.	54.73	b.d.	0.78	98.80
SK90-21-Ol	11.91	31.31	0.07	b.d.	54.35	b.d.	0.76	98.51
SK90-21-Ol	11.65	31.59	0.07	b.d.	54.09	b.d.	0.79	98.20
SK90-21-Ol	11.78	31.62	0.06	b.d.	54.47	b.d.	0.79	98.76
SK90-21-Ol	11.69	31.15	0.06	b.d.	54.06	b.d.	0.81	97.80
SK90-21-Ol	11.49	31.68	0.07	b.d.	54.70	b.d.	0.77	98.76
SK90-21-Ol	11.73	31.44	0.05	b.d.	54.21	b.d.	0.76	98.13
SK90-21-Ol	11.74	31.35	0.06	b.d.	54.87	b.d.	0.82	98.77
SK90-21-Ol	15.98	32.32	0.03	b.d.	49.44	b.d.	0.74	98.50

SK90-21-OI	11.89	31.72	0.07	b.d.	54.73	b.d.	0.76	99.08
SK90-21-OI	11.79	31.50	0.05	b.d.	54.32	b.d.	0.83	98.49
SK90-21-OI	11.82	31.87	0.04	b.d.	54.23	b.d.	0.86	98.89
SK90-21-OI	15.86	32.53	b.d.	b.d.	49.97	b.d.	0.63	98.90
SK90-21-OI	11.19	30.81	0.06	b.d.	55.48	b.d.	0.87	98.38
SK90-21-OI	15.48	32.48	b.d.	b.d.	50.06	b.d.	0.63	98.76
SK90-21-OI	16.16	32.73	b.d.	b.d.	49.39	b.d.	0.74	99.10
<i>Average (N=15)</i>	12.56	31.70	0.06		53.61		0.78	98.70
SD	1.77	0.49	0.01		2.11		0.06	0.39
SK90-22-OI	12.06	31.76	0.07	b.d.	54.35	b.d.	0.91	99.09
SK90-22-OI	12.15	31.80	0.06	b.d.	53.98	b.d.	0.69	98.77
SK90-22-OI	12.05	31.84	0.07	b.d.	53.64	b.d.	0.85	98.34
SK90-22-OI	11.93	31.46	0.07	b.d.	54.24	b.d.	0.81	98.59
SK90-22-OI	11.91	31.55	0.08	b.d.	53.96	b.d.	0.83	98.29
SK90-22-OI	12.95	31.55	0.05	b.d.	53.42	b.d.	0.82	98.85
SK90-22-OI	12.02	32.03	0.07	b.d.	54.24	b.d.	0.76	99.13
SK90-22-OI	11.83	31.65	0.06	b.d.	54.70	b.d.	0.83	99.12
SK90-22-OI	11.93	31.46	0.06	b.d.	54.19	b.d.	0.88	98.55
SK90-22-OI	12.18	31.55	0.06	b.d.	54.12	b.d.	0.72	98.66
SK90-22-OI	12.26	31.94	0.06	b.d.	54.04	0.09	0.74	99.14
SK90-22-OI	12.37	31.73	0.06	b.d.	53.58	b.d.	0.77	98.56
SK90-22-OI	12.03	31.20	0.07	b.d.	54.49	b.d.	0.77	98.60
SK90-22-OI	11.86	31.65	0.05	b.d.	54.74	b.d.	0.92	99.25
SK90-22-OI	11.85	31.22	0.06	b.d.	53.96	b.d.	0.76	97.96
SK90-22-OI	12.05	31.57	0.06	b.d.	53.75	b.d.	0.83	98.25
SK90-22-OI	11.96	31.54	0.07	b.d.	54.65	b.d.	0.89	99.16
SK90-22-OI	12.53	31.75	0.06	b.d.	53.59	b.d.	0.78	98.77
SK90-22-OI	12.40	31.61	0.06	b.d.	53.81	b.d.	0.75	98.64
SK90-22-OI	11.91	31.84	0.06	b.d.	53.97	b.d.	0.88	98.62
<i>Average (N=20)</i>	12.11	31.64	0.06		54.07		0.81	98.72
SD	0.28	0.21	0.01		0.38		0.07	0.35
SK90-9-OI	26.62	34.96	b.d.	b.d.	37.03	0.10	0.52	99.26
SK90-9-OI	26.89	35.14	b.d.	b.d.	36.80	b.d.	0.49	99.41
SK90-9-OI	26.94	35.15	b.d.	b.d.	35.93	0.11	0.46	98.64
SK90-9-OI	26.72	35.40	b.d.	b.d.	36.78	b.d.	0.57	99.50
SK90-9-OI	26.28	35.10	b.d.	b.d.	37.15	0.12	0.55	99.21
SK90-9-OI	26.42	35.14	b.d.	b.d.	36.32	0.11	0.48	98.50
SK90-9-OI	27.20	35.30	b.d.	0.08	35.90	0.12	0.47	99.08
SK90-9-OI	26.46	35.04	b.d.	b.d.	36.69	0.19	0.49	98.87
SK90-9-OI	26.55	35.19	b.d.	b.d.	36.66	0.14	0.48	99.04
SK90-9-OI	26.83	35.15	b.d.	b.d.	36.56	0.20	0.44	99.20
SK90-9-OI	26.84	35.31	b.d.	b.d.	36.50	0.09	0.58	99.35
SK90-9-OI	26.80	35.16	b.d.	b.d.	36.62	0.18	0.54	99.31
SK90-9-OI	26.50	35.34	b.d.	b.d.	36.91	0.14	0.63	99.55
SK90-9-OI	26.35	35.31	b.d.	b.d.	37.06	b.d.	0.48	99.29
SK90-9-OI	26.60	34.75	b.d.	b.d.	36.25	0.10	0.51	98.22
SK90-9-OI	26.55	35.10	b.d.	b.d.	36.62	0.16	0.51	98.95
SK90-9-OI	26.54	35.08	b.d.	b.d.	37.32	0.24	0.41	99.58

SK90-9-OI	26.68	34.74	b.d.	b.d.	36.63	0.17	0.48	98.76
SK90-9-OI	26.46	35.31	b.d.	b.d.	36.73	0.13	0.43	99.08
SK90-9-OI	26.61	34.80	b.d.	b.d.	36.59	0.15	0.54	98.72
<i>Average (N=20)</i>	26.64	35.12			36.65	0.14	0.50	99.08
<i>SD</i>	0.22	0.19			0.36	0.04	0.05	0.37
SK90-6-OI	27.35	35.51	b.d.	b.d.	35.80	0.11	0.45	99.25
SK90-6-OI	26.97	35.28	b.d.	b.d.	35.89	0.15	0.47	98.79
SK90-6-OI	28.25	35.35	b.d.	b.d.	35.04	b.d.	0.51	99.24
SK90-6-OI	27.24	35.22	b.d.	b.d.	36.13	0.19	0.50	99.31
SK90-6-OI	27.26	35.21	b.d.	b.d.	35.94	0.11	0.46	98.99
SK90-6-OI	27.19	35.34	b.d.	b.d.	36.21	0.14	0.48	99.41
SK90-6-OI	27.35	35.43	b.d.	b.d.	35.80	b.d.	0.46	99.20
SK90-6-OI	26.69	35.13	b.d.	b.d.	36.50	0.21	0.41	98.94
SK90-6-OI	27.19	35.27	b.d.	b.d.	36.33	0.10	0.52	99.42
SK90-6-OI	27.21	35.61	b.d.	b.d.	36.39	b.d.	0.55	99.84
SK90-6-OI	27.23	35.42	b.d.	b.d.	35.83	b.d.	0.54	99.12
SK90-6-OI	27.66	35.37	b.d.	b.d.	35.16	0.15	0.48	98.85
SK90-6-OI	26.83	35.23	b.d.	b.d.	36.25	0.13	0.58	99.02
SK90-6-OI	27.13	35.34	b.d.	b.d.	35.88	b.d.	0.52	98.94
SK90-6-OI	27.19	34.81	b.d.	b.d.	35.57	0.13	0.45	98.15
SK90-6-OI	27.21	35.24	b.d.	b.d.	35.94	0.12	0.51	99.04
SK90-6-OI	26.63	35.14	b.d.	b.d.	36.94	0.20	0.45	99.41
SK90-6-OI	26.59	35.29	b.d.	b.d.	36.02	0.13	0.44	98.45
SK90-6-OI	26.68	35.07	b.d.	b.d.	36.47	b.d.	0.39	98.67
<i>Average (N=19)</i>	27.15	35.28			36.01	0.14	0.48	99.05
<i>SD</i>	0.39	0.17			0.45	0.03	0.05	0.38
SK90-8-OI	27.01	35.04	b.d.	b.d.	36.18	0.17	0.53	98.98
SK90-8-OI	27.02	35.34	b.d.	b.d.	36.17	0.14	0.49	99.15
SK90-8-OI	26.87	35.16	b.d.	b.d.	35.77	b.d.	0.49	98.29
SK90-8-OI	26.89	35.39	b.d.	b.d.	36.24	0.10	0.46	99.09
SK90-8-OI	27.25	35.17	b.d.	b.d.	36.44	0.13	0.43	99.39
SK90-8-OI	27.11	35.25	b.d.	b.d.	35.59	b.d.	0.52	98.50
SK90-8-OI	27.16	35.19	b.d.	b.d.	35.67	b.d.	0.45	98.58
SK90-8-OI	27.14	35.36	b.d.	b.d.	36.35	0.15	0.49	99.48
SK90-8-OI	26.60	34.85	b.d.	b.d.	36.71	b.d.	0.53	98.80
SK90-8-OI	27.47	35.33	b.d.	b.d.	36.06	0.16	0.51	99.51
SK90-8-OI	27.60	35.21	b.d.	b.d.	35.94	0.14	0.38	99.25
SK90-8-OI*	25.04	34.82	b.d.	b.d.	39.17	0.12	0.53	99.73
SK90-8-OI	27.54	35.47	b.d.	b.d.	35.82	0.12	0.45	99.44
SK90-8-OI	27.63	35.05	b.d.	b.d.	35.90	b.d.	0.53	99.13
SK90-8-OI*	22.21	52.64	0.25	b.d.	21.93	b.d.	0.40	97.47
SK90-8-OI	27.24	35.38	b.d.	b.d.	35.93	b.d.	0.50	99.14
SK90-8-OI	26.91	35.09	b.d.	b.d.	36.18	0.11	0.43	98.71
SK90-8-OI	27.59	35.54	b.d.	b.d.	35.93	0.11	0.49	99.65
SK90-8-OI	26.96	35.68	b.d.	b.d.	35.85	0.10	0.49	99.14
SK90-8-OI	27.25	35.39	b.d.	b.d.	36.21	0.12	0.57	99.57
<i>Average (N=18)</i>	27.18	35.27			36.05	0.13	0.49	99.10
<i>SD</i>	0.30	0.20			0.28	0.02	0.05	0.39

SK90-5-OI	32.55	36.24	b.d.	b.d.	29.52	0.14	0.33	98.84
SK90-5-OI	31.98	36.61	b.d.	b.d.	29.90	0.15	0.34	99.01
SK90-5-OI	32.28	36.43	b.d.	b.d.	29.86	b.d.	0.36	98.97
SK90-5-OI	32.60	36.43	b.d.	b.d.	29.26	0.28	0.46	99.04
SK90-5-OI	32.27	36.60	b.d.	b.d.	29.55	0.19	0.37	98.99
SK90-5-OI	32.21	36.51	b.d.	b.d.	29.68	0.15	0.44	99.01
SK90-5-OI	32.32	36.38	b.d.	b.d.	29.30	0.14	0.43	98.59
SK90-5-OI	32.31	36.56	b.d.	b.d.	29.96	0.17	0.44	99.45
SK90-5-OI	31.91	36.57	b.d.	b.d.	29.62	0.23	0.36	98.68
SK90-5-OI	32.88	36.80	b.d.	b.d.	28.92	0.26	0.37	99.20
SK90-5-OI	32.23	36.50	b.d.	b.d.	29.51	0.16	0.50	98.90
SK90-5-OI	31.97	36.50	b.d.	b.d.	29.85	0.18	0.36	98.91
SK90-5-OI*	14.46	50.75	4.99	b.d.	7.98	b.d.	0.20	78.52
SK90-5-OI	32.25	36.36	b.d.	b.d.	30.49	0.19	0.45	99.70
SK90-5-OI	32.68	36.73	b.d.	b.d.	29.22	0.18	0.40	99.25
SK90-5-OI	32.40	36.51	b.d.	b.d.	29.65	0.21	0.35	99.11
SK90-5-OI	31.92	36.46	b.d.	b.d.	29.65	0.14	0.38	98.60
SK90-5-OI	32.25	36.26	b.d.	b.d.	29.67	0.19	0.38	98.76
SK90-5-OI	32.34	36.40	b.d.	b.d.	29.99	0.13	0.44	99.32
<i>Average (N=18)</i>	32.30	36.49			29.65	0.18	0.40	99.02
<i>SD</i>	0.26	0.14			0.35	0.04	0.05	0.29

Mg#
0.48
0.56
0.52
0.53
0.60
0.56
0.55
0.51
0.57
0.54
0.03
20.77
20.25
21.40
21.21
21.46
21.12
21.00
19.64
21.53
19.86
20.53
20.85
21.38
20.79
20.38
19.37
20.49
21.40
21.46
20.95
20.79
0.64
36.49
27.59
27.52
26.62
27.63
28.09
27.74
27.82
27.83
27.24
27.83
27.62
36.56

27.92
27.89
27.99
36.14
26.45
35.54
36.84
29.41
3.67
28.34
28.64
28.59
28.16
28.23
30.17
28.33
27.82
28.18
28.63
28.80
29.16
28.25
27.86
28.14
28.55
28.06
29.42
29.12
28.23
28.53
0.57
56.17
56.57
57.20
56.43
55.77
56.46
57.45
56.25
56.35
56.68
56.73
56.61
56.14
55.90
56.67
56.37
55.91

56.49
56.22
56.46
56.44
0.41
57.66
57.26
58.97
57.34
57.49
57.24
57.66
56.59
57.16
57.13
57.53
58.38
56.88
57.41
57.67
57.44
56.24
56.82
56.60
57.34
0.62
57.09
57.11
57.25
56.94
57.14
57.58
57.58
57.10
56.36
57.59
57.79
53.26
57.82
57.85
64.36
57.48
57.01
57.78
57.28
57.29
57.34
0.39

66.28
65.60
65.84
66.51
66.06
65.93
66.28
65.78
65.76
66.97
66.06
65.63
76.35
65.34
66.60
66.08
65.75
65.96
65.78
66.01
0.40

Table S2. Major elements of the six new pyroxene RMs and the A84001-En RM

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	Cr ₂ O ₃	MnO
A84001-En	0.08	25.00	0.70	53.23	1.76	0.16	0.40	0.50
A84001-En	0.05	25.09	0.57	53.05	1.69	0.16	0.44	0.54
A84001-En	0.04	25.21	0.60	53.54	1.43	0.15	0.30	0.50
A84001-En	0.04	24.85	0.59	52.84	1.84	0.17	0.43	0.48
A84001-En	0.06	24.85	0.65	53.29	1.82	0.22	0.42	0.45
A84001-En	0.06	24.96	0.74	53.14	1.63	0.15	0.39	0.52
A84001-En	0.03	24.86	0.63	53.58	1.67	0.16	0.38	0.46
A84001-En	b.d.	25.00	0.64	53.49	1.72	0.18	0.32	0.50
A84001-En	0.05	25.08	0.61	53.56	1.63	0.15	0.27	0.52
A84001-En	b.d.	25.25	0.70	52.97	1.57	0.14	0.37	0.46
A84001-En	0.03	24.90	0.82	52.84	1.69	0.17	0.56	0.46
A84001-En	0.04	25.10	0.64	53.31	1.50	0.10	0.28	0.53
A84001-En	0.05	25.28	0.64	54.04	1.59	0.14	0.37	0.46
A84001-En	0.03	25.10	0.62	53.20	1.67	0.14	0.44	0.45
A84001-En	0.05	25.09	0.63	53.06	1.60	0.13	0.51	0.51
A84001-En	0.03	24.97	0.57	53.18	1.63	0.13	0.36	0.49
A84001-En	0.06	25.11	0.63	53.35	1.63	0.12	0.40	0.55
A84001-En*	b.d.	7.33	0.23	20.43	0.82	0.08	0.19	0.31
A84001-En	0.03	25.33	0.84	53.56	1.52	0.18	0.73	0.55
A84001-En	b.d.	24.91	0.53	52.94	1.70	0.19	0.29	0.43
A84001-En*	5.60	0.04	23.21	64.90	5.34	b.d.	b.d.	b.d.
A84001-En*	0.03	20.55	0.53	45.76	1.26	0.15	0.23	0.47
A84001-En	0.06	24.44	0.62	52.96	1.82	0.16	0.42	0.44
Average (N=20)		25.02	0.65	53.26	1.66	0.16	0.40	0.49
SD		0.20	0.08	0.31	0.11	0.03	0.11	0.04
JS-En	b.d.	27.04	0.88	54.05	1.18	0.08	0.74	0.39
JS-En	b.d.	27.09	0.87	53.87	1.22	0.09	0.87	0.50
JS-En	0.04	27.07	0.95	53.62	1.13	0.10	0.71	0.42
JS-En	b.d.	26.95	0.96	53.18	1.24	0.11	0.83	0.45
JS-En	b.d.	27.22	0.85	53.43	1.15	0.10	0.72	0.53
JS-En	b.d.	27.34	0.89	53.65	1.19	0.11	0.71	0.53
JS-En	b.d.	27.26	0.91	53.57	1.15	0.10	0.65	0.44
JS-En	b.d.	27.36	0.93	53.89	1.12	0.10	0.74	0.52
JS-En	b.d.	27.27	0.85	53.35	1.14	0.11	0.60	0.55
JS-En	b.d.	27.12	0.87	53.76	1.17	0.10	0.67	0.45
JS-En	b.d.	27.07	0.85	54.03	1.18	0.10	0.57	0.53
JS-En	b.d.	27.36	0.88	53.76	1.15	0.09	0.61	0.54
JS-En	b.d.	27.19	0.86	53.78	1.20	0.10	0.73	0.47
JS-En	b.d.	27.20	0.84	53.47	1.20	0.11	0.83	0.57
JS-En	b.d.	27.27	0.84	53.85	1.14	0.09	0.72	0.48
JS-En	b.d.	27.21	0.84	54.04	1.15	0.10	0.84	0.43
JS-En	b.d.	27.11	0.88	53.97	1.13	0.09	0.79	0.45
JS-En	b.d.	27.21	0.78	53.68	1.17	0.09	0.81	0.51
JS-En	b.d.	27.40	0.87	53.39	1.13	0.09	0.76	0.53
JS-En	b.d.	27.21	0.86	53.71	1.16	0.09	0.67	0.42
JS-En	b.d.	27.16	0.84	53.31	1.21	0.12	0.83	0.50

JS-En	b.d.	26.92	0.88	53.21	1.27	0.09	0.87	0.51
JS-En	b.d.	27.17	0.88	53.64	1.17	0.08	0.77	0.45
JS-En	b.d.	27.20	0.85	53.79	1.17	0.10	0.71	0.45
JS-En	b.d.	27.26	0.87	53.46	1.17	0.11	0.78	0.50
JS-En	b.d.	27.34	0.91	53.69	1.18	0.09	0.72	0.44
JS-En	b.d.	27.16	0.93	53.27	1.16	0.08	0.75	0.40
JS-En	b.d.	27.33	0.87	53.68	1.15	0.10	0.74	0.53
JS-En	0.03	27.02	0.88	53.58	1.22	0.09	0.71	0.55
JS-En	b.d.	27.23	0.91	53.95	1.19	0.08	0.67	0.46
JS-En	b.d.	27.21	0.89	53.76	1.18	0.10	0.78	0.52
JS-En	b.d.	27.09	0.92	53.77	1.18	0.09	0.69	0.47
JS-En	b.d.	27.10	0.83	53.77	1.17	0.11	0.72	0.44
JS-En	b.d.	27.20	0.83	53.67	1.22	0.13	0.79	0.54
JS-En	b.d.	27.19	0.90	53.23	1.14	0.14	0.81	0.50
JS-En	b.d.	27.25	1.01	53.29	1.08	0.11	0.74	0.49
JS-En	b.d.	27.27	0.95	53.82	1.19	0.09	0.86	0.62
JS-En	b.d.	27.08	0.93	53.63	1.14	0.09	0.71	0.52
Average (N=42)		27.19	0.88	53.65	1.17	0.10	0.74	0.49
SD		0.11	0.04	0.24	0.04	0.01	0.07	0.05
7219A-En	0.03	33.13	0.16	56.79	0.28	b.d.	b.d.	b.d.
7219A-En	0.03	33.04	0.14	56.01	0.27	0.06	b.d.	b.d.
7219A-En	b.d.	33.09	0.17	56.32	0.24	b.d.	b.d.	b.d.
7219A-En	b.d.	33.03	0.15	56.47	0.26	b.d.	b.d.	0.11
7219A-En	b.d.	33.32	0.13	57.06	0.26	0.06	b.d.	b.d.
7219A-En	b.d.	33.21	0.14	56.32	0.24	b.d.	b.d.	0.09
7219A-En	b.d.	33.08	0.14	56.55	0.26	b.d.	b.d.	b.d.
7219A-En	b.d.	33.16	0.14	56.62	0.25	0.06	b.d.	0.09
7219A-En	b.d.	33.21	0.15	56.94	0.26	b.d.	b.d.	b.d.
7219A-En	b.d.	33.28	0.11	56.48	0.26	b.d.	b.d.	0.06
7219A-En	b.d.	33.02	0.14	56.50	0.26	b.d.	b.d.	b.d.
7219A-En	b.d.	33.05	0.15	56.49	0.26	b.d.	b.d.	b.d.
7219A-En	b.d.	33.22	0.16	56.57	0.25	b.d.	b.d.	b.d.
7219A-En	b.d.	33.22	0.16	56.25	0.27	0.06	b.d.	b.d.
7219A-En	0.03	33.22	0.12	56.87	0.25	b.d.	b.d.	b.d.
7219A-En	0.03	33.14	0.14	56.67	0.27	b.d.	b.d.	b.d.
7219A-En	b.d.	33.01	0.14	56.57	0.26	0.06	b.d.	b.d.
7219A-En	b.d.	32.97	0.15	56.35	0.26	b.d.	b.d.	0.08
7219A-En	b.d.	33.26	0.16	56.42	0.23	b.d.	b.d.	0.12
7219A-En	b.d.	33.40	0.11	56.84	0.23	0.07	b.d.	0.06
7219A-En	b.d.	33.26	0.12	56.57	0.26	b.d.	b.d.	0.06
7219A-En	b.d.	33.29	0.14	56.59	0.25	b.d.	b.d.	0.07
7219A-En	b.d.	33.22	0.12	56.47	0.24	b.d.	b.d.	b.d.
7219A-En	b.d.	33.14	0.11	56.35	0.23	b.d.	b.d.	0.12
7219A-En	0.03	32.74	0.17	56.04	0.34	b.d.	b.d.	0.10
7219A-En	0.03	32.93	0.18	56.24	0.35	b.d.	b.d.	b.d.
7219A-En	b.d.	32.75	0.19	56.63	0.34	0.07	b.d.	0.16
7219A-En	b.d.	32.84	0.20	56.17	0.38	b.d.	b.d.	b.d.
7219A-En	0.04	32.83	0.20	56.27	0.38	0.06	b.d.	b.d.

7219A-En	0.04	32.84	0.21	56.34	0.34	b.d.	b.d.	0.06
7219A-En	0.03	32.73	0.20	56.12	0.35	b.d.	b.d.	b.d.
7219A-En	b.d.	33.11	0.13	56.77	0.27	b.d.	b.d.	b.d.
7219A-En	b.d.	33.27	0.11	56.65	0.25	b.d.	b.d.	0.06
7219A-En	b.d.	33.12	0.13	56.74	0.22	b.d.	b.d.	0.09
7219A-En	b.d.	33.26	0.16	56.49	0.25	b.d.	b.d.	0.06
7219A-En	b.d.	33.18	0.13	56.66	0.25	b.d.	b.d.	b.d.
7219A-En	b.d.	32.97	0.13	56.29	0.25	b.d.	b.d.	0.10
7219A-En	b.d.	32.80	0.15	56.02	0.26	b.d.	b.d.	0.10
7219A-En	b.d.	32.94	0.12	56.14	0.26	b.d.	b.d.	0.06
7219A-En	b.d.	32.91	0.12	56.16	0.24	b.d.	b.d.	b.d.
Average (N=40)		33.08	0.15	56.48	0.27	0.06		0.09
SD		0.19	0.03	0.26	0.04	0.00		0.03
4-15-En	b.d.	33.73	1.03	56.05	0.47	b.d.	0.38	0.24
4-15-En	0.03	33.81	1.10	55.66	0.41	b.d.	0.35	0.23
4-15-En	b.d.	32.98	1.07	56.35	1.58	b.d.	0.40	0.16
4-15-En	b.d.	33.34	1.07	56.46	0.93	b.d.	0.39	0.22
4-15-En	b.d.	33.43	0.99	56.21	0.43	b.d.	0.35	0.14
4-15-En	b.d.	33.49	1.10	56.21	0.45	b.d.	0.29	0.25
4-15-En	b.d.	33.50	1.01	56.21	0.35	b.d.	0.32	0.19
4-15-En	0.04	33.63	1.03	56.19	0.42	b.d.	0.29	0.18
4-15-En	b.d.	33.67	1.18	56.01	0.28	b.d.	0.45	0.14
4-15-En	b.d.	33.67	1.13	56.17	0.31	b.d.	0.48	0.17
4-15-En	b.d.	33.48	1.10	55.90	0.34	b.d.	0.46	0.15
4-15-En	b.d.	33.56	1.06	55.73	0.37	b.d.	0.40	0.20
4-15-En	b.d.	33.42	1.07	56.20	0.46	b.d.	0.40	0.15
4-15-En	b.d.	33.26	1.10	55.95	0.49	b.d.	0.49	0.20
4-15-En	b.d.	33.51	1.07	56.23	0.45	b.d.	0.36	0.18
4-15-En	b.d.	33.32	1.19	56.00	0.44	b.d.	0.48	0.24
4-15-En	b.d.	33.31	1.01	56.24	0.42	b.d.	0.38	0.18
4-15-En	b.d.	33.58	0.90	56.27	0.40	b.d.	0.32	0.17
4-15-En	0.04	33.68	0.93	56.37	0.40	b.d.	0.32	0.22
4-15-En	b.d.	33.48	1.07	55.97	0.38	b.d.	0.33	0.13
4-15-En	b.d.	33.50	1.04	55.85	0.42	b.d.	0.35	0.13
4-15-En	b.d.	33.54	0.94	56.04	0.41	b.d.	0.32	0.16
4-15-En	b.d.	33.50	1.00	56.14	0.60	b.d.	0.34	0.18
4-15-En	b.d.	33.64	0.92	56.33	0.41	b.d.	0.30	0.18
4-15-En	b.d.	32.77	0.99	56.11	1.38	b.d.	0.36	0.16
4-15-En	b.d.	32.98	1.01	56.45	1.40	b.d.	0.42	0.15
4-15-En	b.d.	33.51	1.10	56.32	0.31	b.d.	0.42	0.22
4-15-En	b.d.	33.44	1.07	56.17	0.34	b.d.	0.42	0.24
4-15-En	b.d.	33.50	0.56	56.49	0.21	b.d.	0.16	0.20
4-15-En	b.d.	33.41	0.96	55.89	0.31	b.d.	0.28	0.18
Average (N=30)		33.45	1.03	56.14	0.52		0.37	0.18
SD		0.23	0.11	0.21	0.34		0.07	0.04
SHW-En	b.d.	40.61	0.15	59.67	0.33	b.d.	b.d.	b.d.
SHW-En	0.05	40.30	0.09	59.21	0.41	b.d.	b.d.	b.d.
SHW-En	0.03	40.27	0.23	59.06	0.35	b.d.	b.d.	b.d.

SHW-En	b.d.	40.43	0.16	59.26	0.28	b.d.	b.d.	b.d.
SHW-En	b.d.	40.59	0.17	59.35	0.08	b.d.	b.d.	b.d.
SHW-En	0.03	40.61	0.14	59.48	0.09	b.d.	b.d.	0.09
SHW-En	b.d.	40.72	0.16	59.41	0.09	b.d.	b.d.	b.d.
SHW-En	b.d.	40.72	0.13	59.89	0.08	b.d.	b.d.	b.d.
SHW-En	b.d.	40.88	0.18	59.88	0.11	b.d.	b.d.	0.07
SHW-En	b.d.	40.71	0.09	59.76	0.06	b.d.	b.d.	b.d.
SHW-En	b.d.	40.85	0.14	59.51	0.08	b.d.	b.d.	b.d.
SHW-En	b.d.	40.77	0.20	59.25	0.07	b.d.	b.d.	b.d.
SHW-En	b.d.	40.74	0.18	59.41	0.10	b.d.	b.d.	b.d.
SHW-En	b.d.	40.72	0.19	59.43	0.10	b.d.	b.d.	b.d.
SHW-En	b.d.	40.69	0.18	59.28	0.10	b.d.	b.d.	b.d.
SHW-En	b.d.	40.48	0.14	59.30	0.08	b.d.	b.d.	b.d.
SHW-En	b.d.	40.56	0.18	59.33	0.35	b.d.	b.d.	b.d.
SHW-En	b.d.	40.50	0.18	59.40	0.24	b.d.	b.d.	b.d.
SHW-En	b.d.	40.53	0.16	59.09	0.34	b.d.	b.d.	b.d.
SHW-En	b.d.	40.27	0.18	59.65	0.38	b.d.	b.d.	b.d.
SHW-En	b.d.	40.55	0.07	59.65	0.15	b.d.	b.d.	b.d.
SHW-En	b.d.	40.51	0.05	59.39	0.14	b.d.	b.d.	b.d.
SHW-En	b.d.	40.58	0.11	59.29	0.15	b.d.	b.d.	b.d.
SHW-En	b.d.	40.48	0.17	59.46	0.11	b.d.	b.d.	b.d.
SHW-En	b.d.	40.65	0.13	59.32	0.07	b.d.	b.d.	0.07
SHW-En	b.d.	40.59	0.09	59.56	0.06	b.d.	b.d.	b.d.
SHW-En	b.d.	40.83	0.11	59.53	0.09	b.d.	b.d.	b.d.
SHW-En	b.d.	40.65	0.12	59.58	0.09	b.d.	b.d.	b.d.
SHW-En	b.d.	40.80	0.16	59.69	0.14	b.d.	b.d.	b.d.
SHW-En	b.d.	40.69	0.08	59.76	0.09	b.d.	b.d.	b.d.
SHW-En	b.d.	40.69	0.21	59.68	0.10	b.d.	b.d.	0.06
SHW-En	b.d.	40.74	0.12	59.60	0.08	b.d.	b.d.	b.d.
SHW-En	b.d.	40.75	0.16	59.21	0.09	b.d.	b.d.	b.d.
SHW-En	b.d.	40.87	0.17	59.63	0.07	b.d.	b.d.	b.d.
SHW-En	b.d.	40.55	0.20	59.27	0.09	b.d.	b.d.	b.d.
SHW-En	b.d.	40.74	0.12	58.86	0.07	b.d.	0.07	b.d.
SHW-En	b.d.	40.72	0.11	59.56	0.06	b.d.	b.d.	b.d.
SHW-En	b.d.	40.74	0.12	60.06	0.07	b.d.	b.d.	b.d.
SHW-En	b.d.	40.70	0.14	59.69	0.06	b.d.	b.d.	b.d.
SHW-En	b.d.	40.57	0.18	59.25	0.06	b.d.	b.d.	b.d.
SHW-En	b.d.	40.71	0.11	59.50	0.35	b.d.	b.d.	b.d.
SHW-En	b.d.	40.86	0.09	59.70	0.11	b.d.	b.d.	b.d.
SHW-En	b.d.	40.40	0.13	59.12	0.49	b.d.	b.d.	0.06
SHW-En	0.04	40.38	0.22	59.32	0.31	b.d.	b.d.	b.d.
Average (N=44)		40.63	0.15	59.46	0.16			0.07
SD		0.16	0.04	0.24	0.12			0.01
ST-En	b.d.	40.66	0.07	59.34	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.78	0.08	59.46	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.67	0.07	59.28	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.82	0.07	59.44	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.79	0.04	59.48	b.d.	b.d.	b.d.	b.d.

ST-En	b.d.	40.75	0.05	59.64	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.36	b.d.	58.91	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.51	0.07	59.47	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.62	0.13	59.26	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.42	0.07	59.06	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.43	0.06	59.37	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.69	0.04	59.60	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.50	0.07	59.61	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.50	0.06	59.08	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.58	0.07	59.63	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.31	0.10	60.23	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.39	0.12	59.78	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.23	0.06	59.85	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.46	0.10	59.74	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.58	0.10	59.66	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.57	0.07	59.61	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.75	0.07	59.87	b.d.	b.d.	0.07	b.d.
ST-En	b.d.	40.37	0.05	58.82	b.d.	b.d.	0.09	b.d.
ST-En	b.d.	40.52	0.05	59.51	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.30	0.08	59.32	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.43	0.09	59.58	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.49	0.11	59.42	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.48	0.11	59.98	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.48	0.10	59.65	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.65	0.08	59.74	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.51	0.08	59.56	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.59	b.d.	59.58	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.67	0.04	59.75	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.48	0.11	59.67	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.35	0.09	59.51	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.46	0.12	59.18	b.d.	b.d.	b.d.	b.d.
ST-En	b.d.	40.52	0.11	59.23	b.d.	b.d.	b.d.	b.d.
<i>Average (N=37)</i>		40.53	0.08	59.51			0.08	
<i>SD</i>		0.15	0.02	0.29			0.01	
7244-Aug	2.02	8.86	1.01	51.08	20.11	b.d.	b.d.	0.68
7244-Aug	2.02	8.70	1.04	50.99	20.05	0.07	b.d.	0.61
7244-Aug	2.05	8.85	1.01	50.99	20.30	b.d.	b.d.	0.60
7244-Aug	2.20	8.79	1.09	50.76	20.08	b.d.	b.d.	0.68
7244-Aug	2.01	8.90	1.06	51.30	20.16	b.d.	b.d.	0.64
7244-Aug	2.35	8.35	1.29	50.72	19.58	0.08	b.d.	0.65
7244-Aug	2.26	8.39	1.30	50.66	19.60	b.d.	b.d.	0.65
7244-Aug	2.18	8.32	1.30	50.76	19.55	0.06	b.d.	0.69
7244-Aug	2.28	8.40	1.32	50.54	19.66	0.07	b.d.	0.69
7244-Aug	2.02	8.88	0.88	51.06	20.17	b.d.	b.d.	0.58
7244-Aug	1.83	9.06	0.79	50.96	20.32	b.d.	b.d.	0.66
7244-Aug	1.75	9.07	0.80	51.13	20.43	b.d.	b.d.	0.68
7244-Aug	1.80	9.04	0.87	51.23	20.20	b.d.	b.d.	0.66
7244-Aug	2.37	8.34	1.30	50.44	19.57	0.07	b.d.	0.60

7244-Aug	2.31	8.36	1.26	50.56	19.57	0.06	b.d.	0.62
7244-Aug	2.22	8.34	1.12	50.50	19.87	b.d.	b.d.	0.63
7244-Aug	2.25	8.38	1.28	50.88	19.51	b.d.	b.d.	0.60
7244-Aug	2.36	8.44	1.30	50.33	19.57	0.07	b.d.	0.65
7244-Aug	2.28	8.32	1.31	50.67	19.61	0.07	b.d.	0.67
7244-Aug	2.30	8.35	1.29	50.73	19.44	0.09	b.d.	0.64
7244-Aug	2.24	8.30	1.29	50.66	19.62	0.06	b.d.	0.69
7244-Aug	1.79	9.03	0.80	51.03	20.29	b.d.	b.d.	0.62
7244-Aug	1.92	8.95	0.86	50.92	20.27	b.d.	b.d.	0.58
7244-Aug	1.81	9.04	0.77	50.68	20.38	b.d.	b.d.	0.58
7244-Aug	1.81	8.97	0.79	50.92	20.26	b.d.	b.d.	0.66
7244-Aug	2.25	8.34	1.33	50.40	19.67	b.d.	b.d.	0.50
7244-Aug	2.35	8.29	1.31	50.35	19.66	0.07	b.d.	0.64
7244-Aug	2.26	8.36	1.29	50.42	19.44	0.06	b.d.	0.66
7244-Aug	2.28	8.64	1.21	51.34	19.99	b.d.	b.d.	0.60
7244-Aug	2.38	8.37	1.31	50.78	19.61	0.09	b.d.	0.60
7244-Aug	2.16	8.34	1.33	50.59	19.65	0.07	0.09	0.67
7244-Aug	2.25	8.59	1.19	50.80	20.18	b.d.	b.d.	0.67
7244-Aug	1.99	8.89	0.92	51.03	20.21	b.d.	b.d.	0.67
7244-Aug	2.21	8.92	0.97	50.98	20.18	b.d.	b.d.	0.63
7244-Aug	2.06	8.77	1.06	51.25	20.02	0.07	b.d.	0.64
7244-Aug	2.23	8.65	1.12	50.96	19.89	0.07	b.d.	0.64
<i>Average (N=36)</i>	2.13	8.63	1.12	50.82	19.91	0.07		0.64
<i>SD</i>	0.19	0.29	0.20	0.28	0.32	0.01		0.04

FeO	NiO	Total	En	Wo
17.66	b.d.	99.53	69.35	3.52
17.57	b.d.	99.17	69.50	3.50
17.61	b.d.	99.42	69.85	3.02
17.33	b.d.	98.60	69.35	3.52
17.51	b.d.	99.27	69.19	3.54
17.45	b.d.	99.04	69.70	3.03
17.56	b.d.	99.33	69.19	3.54
17.36	b.d.	99.27	69.70	3.54
17.63	b.d.	99.60	69.70	3.03
17.78	b.d.	99.27	69.65	2.99
17.34	b.d.	98.80	69.70	3.54
17.62	b.d.	99.12	69.85	3.02
17.37	b.d.	99.96	70.05	3.05
17.09	b.d.	98.74	69.85	3.52
17.35	b.d.	98.99	70.20	3.03
17.52	b.d.	98.91	69.85	3.02
17.40	b.d.	99.28	70.20	3.03
9.05	b.d.	38.48	59.29	4.71
17.39	b.d.	100.19	70.20	3.03
17.39	b.d.	98.39	69.50	3.50
0.28	b.d.	99.40	19.28	95.00
15.56	b.d.	84.57	70.39	3.08
17.14	b.d.	98.06	69.54	3.55
17.45		99.15	69.71	3.27
0.17		0.50	0.31	0.26
14.64	b.d.	99.00	75.00	2.55
15.28	b.d.	99.81	74.24	2.53
14.93	b.d.	98.96	75.13	2.03
14.43	b.d.	98.16	75.13	2.54
15.02	b.d.	99.10	74.50	2.50
14.92	b.d.	99.35	74.87	2.51
15.02	b.d.	99.11	74.50	2.50
14.88	b.d.	99.56	75.25	2.02
14.77	b.d.	98.64	75.38	2.01
15.19	b.d.	99.37	74.37	2.51
14.87	b.d.	99.20	74.75	2.53
15.25	b.d.	99.64	74.87	2.01
15.03	b.d.	99.35	74.37	2.51
14.87	b.d.	99.11	74.87	2.51
14.79	b.d.	99.21	75.25	2.02
14.92	b.d.	99.55	75.13	2.03
15.08	b.d.	99.50	74.75	2.02
14.84	b.d.	99.09	74.87	2.51
14.95	b.d.	99.12	75.38	2.01
14.99	b.d.	99.11	74.87	2.51
14.87	b.d.	98.84	74.87	2.51

14.52	b.d.	98.26	75.13	2.54
14.96	b.d.	99.14	74.75	2.53
14.64	b.d.	98.92	75.25	2.53
15.16	b.d.	99.32	74.50	2.50
14.98	b.d.	99.37	74.87	2.51
14.80	b.d.	98.56	74.87	2.51
14.97	b.d.	99.45	75.25	2.02
14.76	b.d.	98.83	74.75	2.53
14.84	b.d.	99.36	74.75	2.53
14.79	b.d.	99.24	74.75	2.53
14.89	0.10	99.20	74.75	2.53
15.10	b.d.	99.25	74.37	2.51
14.86	b.d.	99.24	74.75	2.53
15.08	b.d.	99.01	74.87	2.01
14.76	b.d.	98.79	75.25	2.02
15.12	b.d.	99.95	74.37	2.51
15.09	b.d.	99.21	74.75	2.02
14.92		99.15	74.85	2.36
0.19		0.37	0.31	0.24
9.54	b.d.	100.07	85.64	0.50
9.52	b.d.	99.08	85.78	0.49
9.34	b.d.	99.36	86.14	0.50
9.37	b.d.	99.47	86.14	0.50
9.54	b.d.	100.42	85.71	0.49
9.60	b.d.	99.63	85.78	0.49
9.47	b.d.	99.65	85.71	0.49
9.25	b.d.	99.57	86.14	0.50
9.57	b.d.	100.30	85.64	0.50
9.60	b.d.	99.85	85.78	0.49
9.49	b.d.	99.57	85.71	0.49
9.41	b.d.	99.43	86.14	0.50
9.80	b.d.	100.02	85.29	0.49
9.46	b.d.	99.46	85.78	0.49
9.75	b.d.	100.35	85.64	0.50
9.45	b.d.	99.78	85.71	0.49
9.64	b.d.	99.74	85.64	0.50
9.68	b.d.	99.55	85.71	0.49
9.64	b.d.	99.95	85.71	0.49
9.73	b.d.	100.47	85.71	0.49
9.43	b.d.	99.79	86.21	0.49
9.44	b.d.	99.86	85.78	0.49
9.57	b.d.	99.70	85.78	0.49
9.37	b.d.	99.37	86.21	0.49
9.75	b.d.	99.28	85.22	0.49
9.70	b.d.	99.49	85.71	0.49
9.61	b.d.	99.84	85.57	0.50
9.61	b.d.	99.28	85.64	0.50
9.86	b.d.	99.70	85.22	0.49

9.69	b.d.	99.64	85.64	0.50
9.52	b.d.	99.12	85.64	0.50
9.50	b.d.	99.83	85.71	0.49
9.44	b.d.	99.86	85.71	0.49
9.29	b.d.	99.63	86.14	0.50
9.10	b.d.	99.41	86.21	0.49
9.33	b.d.	99.67	86.14	0.50
9.64	b.d.	99.49	85.71	0.49
9.83	b.d.	99.25	85.22	0.49
9.55	b.d.	99.12	85.71	0.49
9.85	b.d.	99.38	85.29	0.49
9.56		99.68	85.73	0.49
0.17		0.34	0.27	0.00
8.31	b.d.	100.34	87.13	0.99
8.30	0.12	100.04	87.19	0.99
7.66	b.d.	100.28	86.00	3.00
7.99	b.d.	100.46	86.93	1.51
8.00	b.d.	99.66	87.50	1.00
8.05	b.d.	99.95	87.50	1.00
8.10	0.13	99.84	87.50	0.50
8.16	b.d.	100.05	87.06	1.00
8.07	0.13	99.98	88.00	0.50
8.16	0.11	100.20	87.50	0.50
7.82	b.d.	99.31	88.00	0.50
8.17	b.d.	99.56	87.56	0.50
7.93	b.d.	99.68	87.50	1.00
8.04	0.14	99.68	87.44	1.01
8.00	b.d.	99.87	87.50	1.00
8.29	b.d.	100.01	87.00	1.00
8.03	b.d.	99.58	87.44	1.01
8.24	0.15	100.02	87.50	0.50
8.07	b.d.	100.12	87.94	0.50
8.01	0.10	99.49	87.94	0.50
8.00	b.d.	99.37	87.56	1.00
8.03	b.d.	99.53	87.56	1.00
7.90	b.d.	99.74	87.50	1.00
8.06	0.11	99.98	87.50	1.00
7.80	b.d.	99.67	86.00	2.50
7.83	b.d.	100.33	86.00	2.50
8.18	b.d.	100.15	87.50	0.50
8.15	b.d.	99.93	87.50	0.50
8.44	b.d.	99.60	87.06	0.50
8.29	b.d.	99.38	87.50	0.50
8.07		99.86	87.33	0.98
0.17		0.31	0.52	0.64
b.d.	b.d.	100.80	99.51	0.49
b.d.	b.d.	100.11	99.51	0.49
b.d.	b.d.	99.99	99.51	0.49

b.d.	b.d.	100.18	99.51	0.49
b.d.	b.d.	100.27	100.00	0.00
b.d.	b.d.	100.52	100.00	0.00
b.d.	b.d.	100.38	100.00	0.00
b.d.	b.d.	100.96	100.00	0.00
b.d.	b.d.	101.17	100.00	0.00
b.d.	b.d.	100.69	100.00	0.00
b.d.	b.d.	100.58	100.00	0.00
b.d.	b.d.	100.32	100.00	0.00
b.d.	0.09	100.53	100.00	0.00
b.d.	b.d.	100.50	100.00	0.00
b.d.	b.d.	100.29	100.00	0.00
b.d.	b.d.	100.09	100.00	0.00
b.d.	b.d.	100.50	99.51	0.49
b.d.	b.d.	100.40	99.51	0.49
b.d.	b.d.	100.17	99.51	0.49
b.d.	b.d.	100.59	99.50	0.50
b.d.	b.d.	100.42	99.51	0.49
b.d.	b.d.	100.10	100.00	0.00
b.d.	b.d.	100.22	99.51	0.49
b.d.	b.d.	100.26	100.00	0.00
b.d.	b.d.	100.25	100.00	0.00
b.d.	b.d.	100.33	100.00	0.00
b.d.	b.d.	100.58	100.00	0.00
b.d.	b.d.	100.46	100.00	0.00
b.d.	b.d.	100.83	100.00	0.00
b.d.	b.d.	100.72	100.00	0.00
b.d.	b.d.	100.76	100.00	0.00
b.d.	b.d.	100.61	100.00	0.00
b.d.	b.d.	100.26	100.00	0.00
b.d.	b.d.	100.84	100.00	0.00
b.d.	b.d.	100.23	100.00	0.00
b.d.	b.d.	99.87	100.00	0.00
b.d.	b.d.	100.49	100.00	0.00
b.d.	b.d.	101.02	100.00	0.00
b.d.	b.d.	100.60	100.00	0.00
b.d.	b.d.	100.16	100.00	0.00
b.d.	b.d.	100.72	99.51	0.49
b.d.	b.d.	100.81	100.00	0.00
b.d.	b.d.	100.26	99.02	0.98
b.d.	b.d.	100.28	99.51	0.49
		100.46	99.84	0.16
		0.29	0.25	0.25
b.d.	b.d.	100.19	100.00	0.00
b.d.	b.d.	100.41	100.00	0.00
b.d.	b.d.	100.12	100.00	0.00
b.d.	b.d.	100.38	100.00	0.00
b.d.	b.d.	100.36	100.00	0.00

b.d.	b.d.	100.49	100.00	0.00
b.d.	b.d.	99.35	100.00	0.00
b.d.	b.d.	100.06	100.00	0.00
b.d.	b.d.	100.10	100.00	0.00
b.d.	b.d.	99.64	100.00	0.00
b.d.	b.d.	99.97	100.00	0.00
0.07	b.d.	100.58	100.00	0.00
b.d.	b.d.	100.27	100.00	0.00
b.d.	b.d.	99.81	100.00	0.00
b.d.	b.d.	100.41	100.00	0.00
0.07	b.d.	100.73	100.00	0.00
b.d.	b.d.	100.32	100.00	0.00
b.d.	b.d.	100.27	100.00	0.00
b.d.	b.d.	100.39	100.00	0.00
b.d.	b.d.	100.46	100.00	0.00
0.08	b.d.	100.36	100.00	0.00
b.d.	b.d.	100.80	100.00	0.00
b.d.	b.d.	99.36	100.00	0.00
b.d.	b.d.	100.14	100.00	0.00
b.d.	b.d.	99.80	100.00	0.00
0.08	b.d.	100.19	100.00	0.00
0.07	b.d.	100.13	100.00	0.00
0.09	b.d.	100.69	100.00	0.00
b.d.	b.d.	100.35	100.00	0.00
b.d.	b.d.	100.54	100.00	0.00
b.d.	b.d.	100.22	100.00	0.00
0.07	b.d.	100.27	100.00	0.00
0.08	b.d.	100.62	100.00	0.00
b.d.	b.d.	100.32	100.00	0.00
b.d.	b.d.	100.07	100.00	0.00
0.13	b.d.	99.96	100.00	0.00
0.09	b.d.	100.03	100.00	0.00
0.08		100.22	100.00	0.00
0.02		0.33	0.00	0.00
15.08	b.d.	98.88	28.11	45.41
15.15	b.d.	98.66	27.72	45.65
15.18	b.d.	99.01	27.96	45.70
14.77	b.d.	98.47	28.26	45.65
15.11	b.d.	99.24	28.11	45.41
15.56	b.d.	98.59	26.92	45.05
15.84	b.d.	98.79	26.78	44.81
15.76	b.d.	98.66	26.92	45.05
15.88	b.d.	98.86	26.78	44.81
14.79	b.d.	98.41	28.11	45.95
14.86	b.d.	98.57	28.49	45.70
14.86	b.d.	98.78	28.49	45.70
15.16	b.d.	99.04	28.49	45.16
15.73	b.d.	98.48	26.78	44.81

15.58	b.d.	98.33	26.92	45.05
15.53	b.d.	98.22	26.63	45.65
15.45	b.d.	98.43	27.07	45.30
15.75	b.d.	98.46	27.17	44.57
15.84	b.d.	98.78	26.78	44.81
15.75	b.d.	98.59	26.92	45.05
15.99	b.d.	98.95	26.78	44.81
14.94	b.d.	98.54	28.34	45.45
14.93	b.d.	98.53	28.34	45.45
14.98	b.d.	98.30	28.19	45.74
14.22	b.d.	97.69	28.65	45.95
15.73	b.d.	98.32	26.63	45.11
15.81	b.d.	98.53	26.63	45.11
15.90	b.d.	98.40	26.78	44.81
15.29	b.d.	99.41	27.47	45.60
15.76	b.d.	98.88	26.92	45.05
15.84	b.d.	98.75	26.78	44.81
15.16	b.d.	98.92	27.32	45.90
15.19	b.d.	98.95	28.11	45.41
14.86	b.d.	98.79	28.26	45.65
15.32	b.d.	99.19	27.72	45.11
15.49	b.d.	99.04	27.72	45.11
15.36		98.68	27.50	45.29
0.43		0.33	0.70	0.39

Table S3. Oxygen isotope ratios of eighteen olivine RMs measured by S

Filename	Comment	$\delta^{18}\text{O}$ ‰ _{Raw}	2SE/2SD
<i>Mount WI-STD-91</i>			
20181030@316	SC-OI	7.36	0.14
20181030@317	SC-OI	7.50	0.11
20181030@318	SC-OI	7.43	0.13
20181030@319	SC-OI	7.49	0.13
20181030@320	FJ-OI	6.85	0.13
20181030@321	FJ-OI	6.88	0.15
20181030@322	FJ-OI	6.80	0.18
20181030@323	FJ-OI	6.90	0.17
20181030@324	FJ-OI	6.86	0.12
20181030@325	FJ-OI	6.93	0.13
20181030@326	FJ-OI	6.98	0.14
20181030@327	FJ-OI	7.49	0.12
20181030@328	FJ-OI	6.65	0.17
20181030@329	FJ-OI	6.85	0.11
20181030@330	FJ-OI	7.00	0.14
20181030@331	FJ-OI	6.93	0.11
20181030@332	FJ-OI	6.85	0.09
20181030@333	FJ-OI	6.76	0.14
20181030@334	FJ-OI	6.91	0.11
20181030@335	FJ-OI	7.06	0.15
20181030@336	FJ-OI	6.89	0.13
20181030@337	FJ-OI	7.01	0.16
20181030@338	FJ-OI	7.03	0.12
20181030@339	FJ-OI	6.96	0.17
20181030@340	FJ-OI	7.37	0.15
20181030@341	FJ-OI	6.77	0.16
20181030@342	SC-OI	7.65	0.17
20181030@343	SC-OI	7.70	0.18
20181030@344	SC-OI	7.62	0.19
20181030@345	SC-OI	7.57	0.11
<i>Average&2SD (FJ-OI, N=22)</i>		6.94	0.37
<i>Average&2SD (SC-OI, N=8)</i>		7.54	0.23
<i>$\delta^{18}\text{O}_{\text{LF}}$ (FJ-OI, N=3)</i>		4.89	
<i>$\delta^{18}\text{O}_{\text{LF}}$ (SC-OI, N=3)</i>		5.32	0.08
<i>Instrumental Bias(FJ-OI)</i>		2.04	0.08
<i>Instrumental Bias(SC-OI)</i>		2.21	0.09
<i>Bias(FJ-OI)-Bias(SC-OI)</i>		-0.16	0.12
20181030@346	SW-OI	5.76	0.13
20181030@347	SW-OI	5.50	0.18
20181030@348	SW-OI	5.69	0.18
20181030@349	SW-OI	5.80	0.16
20181030@350	SW-OI	5.78	0.14
20181030@351	SW-OI	5.65	0.16
20181030@352	SW-OI	5.67	0.15

20181030@353	SW-OI	5.73	0.15
20181030@354	SW-OI	5.72	0.18
20181030@355	SW-OI	5.71	0.18
20181030@356	SC-OI	7.58	0.16
20181030@357	SC-OI	7.69	0.17
20181030@358	SC-OI	7.55	0.17
20181030@359	SC-OI	7.66	0.15
20181030@360	SW-OI	5.89	0.14
20181030@361	SW-OI	5.80	0.14
20181030@362	SW-OI	5.89	0.11
20181030@363	SW-OI	5.74	0.13
20181030@364	SW-OI	5.68	0.16
20181030@365	SW-OI	5.76	0.14
20181030@366	SW-OI	5.77	0.16
20181030@367	SW-OI	5.75	0.13
20181030@368	SW-OI	5.58	0.16
20181030@369	SW-OI	5.79	0.15
20181030@370	SW-OI	5.80	0.17
20181030@371	SC-OI	7.71	0.17
20181030@372	SC-OI	7.70	0.16
20181030@373	SC-OI	7.75	0.20
20181030@374	SC-OI	7.66	0.20
Average&2SD (SW-OI, N=21)		5.74	0.18
Average&2SD (SC-OI, N=12)		7.65	0.12
$\delta^{18} O_{LF}$ (SW-OI, N=3)		3.51	
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(SW-OI)		2.22	0.04
Instrumental Bias(SC-OI)		2.32	0.06
Bias(SW-OI)-Bias(SC-OI)		-0.10	0.07
20181030@375	HaK-OI	7.22	0.20
20181030@376	HaK-OI	7.48	0.18
20181030@377	HaK-OI	7.12	0.18
20181030@378	HaK-OI	7.20	0.19
20181030@379	HaK-OI	7.19	0.17
20181030@380	HaK-OI	7.17	0.20
20181030@381	HaK-OI	7.20	0.22
20181030@382	SC-OI	7.60	0.15
20181030@383	SC-OI	7.67	0.18
20181030@384	SC-OI	7.60	0.19
20181030@385	SC-OI	7.66	0.14
20181030@386	HaK-OI	7.24	0.18
20181030@387	HaK-OI	7.20	0.16
20181030@388	HaK-OI	7.14	0.20
20181030@389	HaK-OI	7.09	0.18
20181030@390	HaK-OI	7.21	0.20
20181030@391	HaK-OI	7.20	0.16
20181030@392	HaK-OI	7.14	0.20

20181030@393	SC-OI	7.65	0.16
20181030@394	SC-OI	8.65	0.19
20181030@395	SC-OI	7.71	0.18
20181030@396	SC-OI	7.62	0.18
20181030@397	SC-OI	7.63	0.21
20181030@398	HaK-OI	7.20	0.13
20181030@399	HaK-OI	7.19	0.24
20181030@400	HaK-OI	7.46	0.19
20181030@401	HaK-OI	7.28	0.16
20181030@402	HaK-OI	7.25	0.20
20181030@403	HaK-OI	7.20	0.17
20181030@404	HaK-OI	7.18	0.17
20181030@405	SC-OI	7.79	0.17
20181030@406	SC-OI	7.51	0.14
20181030@407	SC-OI	7.73	0.13
20181030@408	SC-OI	7.68	0.18
Average&2SD (HaK-OI, N=21)		7.22	0.19
Average&2SD (SC-OI, N=12)		7.68	0.15
$\delta^{18} O_{LF}$ (HaK-OI, N=3)		5.25	
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(HaK-OI)		1.96	0.04
Instrumental Bias(SC-OI)		2.35	0.06
Bias(HaK-OI)-Bias(SC-OI)		-0.39	0.07
20181030@409	HN-OI	11.34	0.16
20181030@410	HN-OI	11.30	0.17
20181030@411	HN-OI	11.28	0.22
20181030@412	HN-OI	11.26	0.21
20181030@413	OR-OI	7.54	0.12
20181030@414	OR-OI	7.76	0.11
20181030@415	OR-OI	7.68	0.13
20181030@416	OR-OI	7.77	0.13
20181030@417	SC-OI	7.63	0.15
20181030@418	SC-OI	7.74	0.15
20181030@419	SC-OI	7.64	0.19
20181030@420	SC-OI	7.70	0.22
20181030@421	WK-OI	7.67	0.22
20181030@422	WK-OI	7.59	0.16
20181030@423	WK-OI	7.71	0.21
20181030@424	WK-OI	7.57	0.18
20181030@425	WN-OI	6.55	0.19
20181030@426	WN-OI	6.61	0.20
20181030@427	WN-OI	6.63	0.19
20181030@428	WN-OI	6.75	0.24
20181030@429	SC-OI	7.53	0.19
20181030@430	SC-OI	7.61	0.18
20181030@431	SC-OI	7.66	0.22
20181030@432	SC-OI	7.66	0.18

<i>Average&2SD (HN-OI, N=4)</i>	11.30	0.07
<i>Average&2SD (OR-OI, N=4)</i>	7.69	0.21
<i>Average&2SD (WK-OI, N=4)</i>	7.64	0.13
<i>Average&2SD (WN-OI, N=4)</i>	6.63	0.16
<i>Average&2SD (SC-OI, N=12)</i>	7.66	0.16
$\delta^{18} O_{LF}$ (HN-OI, N=3)	8.90	0.08
$\delta^{18} O_{LF}$ (OR-OI, N=3)	5.88	0.02
$\delta^{18} O_{LF}$ (WK-OI, N=3)		
$\delta^{18} O_{LF}$ (WN-OI, N=3)	5.15	
$\delta^{18} O_{LF}$ (SC-OI, N=3)	5.32	0.08
<i>Instrumental Bias(HN-OI)</i>	2.38	0.06
<i>Instrumental Bias(OR-OI)</i>	1.80	0.11
<i>Instrumental Bias(WK-OI)</i>		
<i>Instrumental Bias(WN-OI)</i>	1.48	0.08
<i>Instrumental Bias(SC-OI)</i>	2.32	0.07
<i>Bias(HN-OI)-Bias(SC-OI)</i>	0.05	0.09
<i>Bias(OR-OI)-Bias(SC-OI)</i>	-0.53	0.13
<i>Bias(WK-OI)-Bias(SC-OI)</i>		
<i>Bias(WN-OI)-Bias(SC-OI)</i>	-0.85	0.10

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20181101@1	SC-OI	7.79	0.18
20181101@2	SC-OI	7.94	0.22
20181101@3	SC-OI	7.91	0.14
20181101@4	SC-OI	7.86	0.16
20181101@5	SC-OI	7.77	0.23
20181101@6	SC-OI	7.80	0.19
20181101@7	SC-OI	7.87	0.18
20181101@8	SK90-5	5.81	0.16
20181101@9	SK90-5	6.92	0.15
20181101@10	SK90-5	7.07	0.08
20181101@11	SK90-5	6.98	0.09
20181101@12	SK90-5	7.02	0.15
20181101@13	SK90-5	7.05	0.13
20181101@14	SK90-5	6.83	0.13
20181101@15	SK90-5	6.74	0.11
20181101@16	SK90-5	6.72	0.10
20181101@17	SK90-5	6.91	0.12
20181101@18	SC-OI	7.93	0.16
20181101@19	SC-OI	7.78	0.17
20181101@20	SC-OI	7.86	0.20
20181101@21	SC-OI	7.95	0.15
20181101@22	SK90-5	6.95	0.12
20181101@23	SK90-5	6.75	0.15
20181101@24	SK90-5	6.70	0.11
20181101@25	SK90-5	5.27	0.33
20181101@26	SK90-5	6.77	0.17
20181101@27	SK90-5	6.88	0.16

20181101@28	SK90-5	6.69	0.14
20181101@29	SK90-5	6.67	0.16
20181101@30	SK90-5	7.07	0.12
20181101@31	SK90-5	6.78	0.14
20181101@32	SC-OI	7.97	0.25
20181101@33	SC-OI	7.75	0.13
20181101@34	SC-OI	7.94	0.17
20181101@35	SC-OI	7.80	0.19
Average&2SD (SK90-5, N=18)		6.86	0.28
Average&2SD (SC-OI, N=15)		7.86	0.15
$\delta^{18} O_{LF}$ (SK90-5, N=3)		4.61	0.16
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(SK90-5)		2.24	0.11
Instrumental Bias(SC-OI)		2.53	0.06
Bias(SK90-5)-Bias(SC-OI)		-0.29	0.13
20181101@36	SK90-6	5.56	0.15
20181101@37	SK90-6	6.47	0.13
20181101@38	SK90-6	6.62	0.12
20181101@39	SK90-6	6.49	0.12
20181101@40	SK90-6	6.39	0.14
20181101@41	SK90-6	6.65	0.12
20181101@42	SK90-6	6.53	0.15
20181101@43	SK90-6	6.53	0.14
20181101@44	SK90-6	6.44	0.12
20181101@45	SK90-6	6.52	0.10
20181101@46	SC-OI	7.83	0.17
20181101@47	SC-OI	7.79	0.19
20181101@48	SC-OI	7.80	0.17
20181101@49	SC-OI	8.34	0.21
20181101@50	SK90-6	6.30	0.15
20181101@51	SK90-6	6.48	0.13
20181101@52	SK90-6	-40.39	3.88
20181101@53	SK90-6	6.42	0.11
20181101@54	SK90-6	6.48	0.14
20181101@55	SK90-6	6.35	0.12
20181101@56	SK90-6	6.59	0.11
20181101@57	SK90-6	6.50	0.12
20181101@58	SK90-6	6.51	0.11
20181101@59	SK90-6	6.24	0.13
20181101@60	SC-OI	7.84	0.19
20181101@61	SC-OI	7.86	0.15
20181101@62	SC-OI	7.87	0.18
20181101@63	SC-OI	7.93	0.17
Average&2SD (SK90-6, N=19)		6.42	0.47
Average&2SD (SC-OI, N=11)		7.85	0.14
$\delta^{18} O_{LF}$ (SK90-6, N=3)		4.67	0.20
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08

<i>Instrumental Bias(SK90-6)</i>	<i>1.75</i>	<i>0.16</i>
<i>Instrumental Bias(SC-OI)</i>	<i>2.52</i>	<i>0.06</i>
<i>Bias(SK90-6)-Bias(SC-OI)</i>	<i>-0.77</i>	<i>0.17</i>

20181101@64	SK90-8	6.67	0.13
20181101@65	SK90-8	6.38	0.11
20181101@66	SK90-8	6.06	0.09
20181101@67	SK90-8	6.55	0.10
20181101@68	SK90-8	6.62	0.11
20181101@69	SK90-8	6.60	0.17
20181101@70	SK90-8	6.59	0.10
20181101@71	SK90-8	6.52	0.11
20181101@72	SK90-8	6.46	0.12
20181101@73	SK90-8	6.50	0.09
20181101@74	SC-OI	7.91	0.16
20181101@75	SC-OI	7.96	0.16
20181101@76	SC-OI	8.04	0.18
20181101@77	SC-OI	7.80	0.17
20181101@78	SK90-8	6.37	0.11
20181101@79	SK90-8	6.55	0.16
20181101@80	SK90-8	6.15	0.14
20181101@81	SK90-8	6.70	0.12
20181101@82	SK90-8	5.18	0.15
20181101@83	SK90-8	6.72	0.13
20181101@84	SK90-8	6.57	0.13
20181101@85	SK90-8	6.59	0.10
20181101@86	SK90-8	6.67	0.13
20181101@87	SK90-8	6.41	0.11
20181101@88	SC-OI	7.85	0.18
20181101@89	SC-OI	7.97	0.23
20181101@90	SC-OI	7.89	0.14
20181101@91	SC-OI	8.12	0.17

<i>Average&2SD (SK90-8, N=19)</i>	<i>6.51</i>	<i>0.35</i>
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<i>Average&2SD (SC-OI, N=12)</i>	<i>7.92</i>	<i>0.18</i>
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<i>$\delta^{18}O_{LF}$ (SK90-8, N=3)</i>	<i>4.60</i>	<i>0.11</i>
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<i>$\delta^{18}O_{LF}$ (SC-OI, N=3)</i>	<i>5.32</i>	<i>0.08</i>
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<i>Instrumental Bias(SK90-8)</i>	<i>1.90</i>	<i>0.10</i>
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<i>Instrumental Bias(SC-OI)</i>	<i>2.59</i>	<i>0.07</i>
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<i>Bias(SK90-8)-Bias(SC-OI)</i>	<i>-0.68</i>	<i>0.12</i>
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20181101@92	SK90-9	6.44	0.11
20181101@93	SK90-9	6.49	0.13
20181101@94	SK90-9	6.76	0.13
20181101@95	SK90-9	6.60	0.18
20181101@96	SK90-9	6.27	0.12
20181101@97	SK90-9	6.25	0.13
20181101@98	SK90-9	6.68	0.14
20181101@99	SK90-9	6.56	0.12

20181101@100	SK90-9	6.28	0.12
20181101@101	SK90-9	6.52	0.09
20181101@102	SC-OI	7.90	0.21
20181101@103	SC-OI	7.92	0.15
20181101@104	SC-OI	8.03	0.15
20181101@105	SC-OI	7.92	0.16
20181101@106	SK90-9	6.59	0.11
20181101@107	SK90-9	6.51	0.12
20181101@108	SK90-9	6.55	0.09
20181101@109	SK90-9	6.26	0.11
20181101@110	SK90-9	6.53	0.15
20181101@111	SK90-9	6.51	0.16
20181101@112	SK90-9	6.67	0.13
20181101@113	SK90-9	6.54	0.09
20181101@114	SK90-9	6.56	0.10
20181101@115	SK90-9	6.64	0.12
20181101@116	SC-OI	7.96	0.16
20181101@117	SC-OI	7.76	0.18
20181101@118	SC-OI	8.04	0.16
20181101@119	SC-OI	7.96	0.18
Average&2SD (SK90-9, N=20)		6.51	0.29
Average&2SD (SC-OI, N=12)		7.94	0.19
$\delta^{18} O_{LF}$ (SK90-9, N=3)		4.63	0.40
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(SK90-9)		1.87	0.24
Instrumental Bias(SC-OI)		2.61	0.07
Bias(SK90-9)-Bias(SC-OI)		-0.74	0.25
20181101@120	SK90-14	0.59	0.11
20181101@121	SK90-14	0.65	0.08
20181101@122	SK90-14	0.81	0.13
20181101@123	SK90-14	0.87	0.16
20181101@124	SK90-14	0.92	0.12
20181101@125	SK90-14	0.77	0.15
20181101@126	SK90-14	0.90	0.11
20181101@127	SK90-14	0.44	0.09
20181101@128	SK90-14	0.90	0.11
20181101@129	SK90-14	0.34	0.13
20181101@130	Fo60Std1	7.93	0.17
20181101@131	Fo60Std1	7.88	0.12
20181101@132	Fo60Std2	7.88	0.10
20181101@133	Fo60Std2	7.86	0.15
20181101@134	SC-OI	7.94	0.22
20181101@135	SC-OI	7.99	0.16
20181101@136	SC-OI	7.98	0.19
20181101@137	SC-OI	5.69	0.21
20181101@138	SK90-14	0.50	0.12
20181101@139	SK90-14	0.83	0.14

20181101@140	SK90-14	0.73	0.13
20181101@141	SK90-14	0.53	0.15
20181101@142	SK90-14	0.81	0.12
20181101@143	SK90-14	0.64	0.12
20181101@144	SK90-14	0.58	0.13
20181101@145	SK90-14	0.76	0.10
20181101@146	SK90-14	0.90	0.13
20181101@147	SK90-14	0.58	0.11
20181101@148	SC-OI	7.91	0.20
20181101@149	SC-OI	5.52	0.19
20181101@150	SC-OI	7.98	0.17
20181101@151	SC-OI	8.06	0.21
Average&2SD (SK90-14, N=20)		0.70	0.34
Average&2SD (SC-OI, N=10)		7.96	0.16
$\delta^{18} O_{LF}$ (SK90-14, N=2)		4.45	0.09
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(SK90-14)		-3.73	0.09
Instrumental Bias(SC-OI)		2.62	0.07
Bias(SK90-14)-Bias(SC-OI)		-6.34	0.12
20181101@152	SK90-21	3.95	0.12
20181101@153	SK90-21	2.32	0.12
20181101@154	SK90-21	2.17	0.11
20181101@155	SK90-21	1.83	0.12
20181101@156	SK90-21	2.19	0.10
20181101@157	SK90-21	2.43	0.10
20181101@158	SK90-21	2.30	0.13
20181101@159	SK90-21	2.41	0.09
20181101@160	SK90-21	2.21	0.10
20181101@161	SK90-21	2.25	0.11
20181101@162	Fa60Std1	8.10	0.11
20181101@163	Fa60Std1	7.92	0.09
20181101@164	Fa60Std2	7.72	0.12
20181101@165	Fa60Std2	7.95	0.14
20181101@166	SC-OI	8.25	0.16
20181101@167	SC-OI	7.88	0.15
20181101@168	SC-OI	7.92	0.19
20181101@169	SC-OI	7.95	0.14
20181101@170	SK90-21	2.33	0.11
20181101@171	SK90-21	2.39	0.12
20181101@172	SK90-21	2.22	0.15
20181101@173	SK90-21	3.91	0.14
20181101@174	SK90-21	2.19	0.11
20181101@175	SK90-21	2.30	0.11
20181101@176	SK90-21	2.21	0.12
20181101@177	SK90-21	3.67	0.12
20181101@178	SK90-21	3.64	0.11
20181101@179	SC-OI	7.86	0.17

20181101@180	SC-OI	7.87	0.17
20181101@181	SC-OI	7.90	0.17
20181101@182	SC-OI	7.93	0.19
20181101@381	SC-OI	7.65	0.17
20181101@382	SC-OI	8.31	0.19
20181101@383	SC-OI	7.55	0.62
20181101@384	SC-OI	8.02	0.14
20181101@385	SC-OI	8.05	0.13
20181101@386	SC-OI	8.11	0.20
20181101@387	SC-OI	8.11	0.28
Average&2SD (SK90-21, N=19)		2.57	1.32
Average&2SD (SC-OI, N=18)		7.96	0.37
$\delta^{18} O_{LF}$ (SK90-21, N=2)		4.52	0.48
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(SK90-21)		-1.94	0.46
Instrumental Bias(SC-OI)		2.63	0.13
Bias(SK90-21)-Bias(SC-OI)		-4.55	0.47
20181101@388	SK90-22	2.44	0.14
20181101@389	SK90-22	2.58	0.08
20181101@390	SK90-22	2.64	0.13
20181101@391	SK90-22	2.40	0.15
20181101@392	SK90-22	2.49	0.18
20181101@393	SK90-22	2.48	0.10
20181101@394	SK90-22	2.60	0.13
20181101@395	SK90-22	2.49	0.14
20181101@396	SK90-22	2.40	0.13
20181101@397	SK90-22	2.26	0.13
20181101@398	SC-OI	7.93	0.14
20181101@399	SC-OI	8.01	0.19
20181101@400	SC-OI	7.99	0.23
20181101@401	SC-OI	7.96	0.10
20181101@402	SK90-22	2.71	0.12
20181101@403	SK90-22	2.61	0.13
20181101@404	SK90-22	2.36	0.10
20181101@405	SK90-22	2.17	0.13
20181101@406	SK90-22	2.27	0.12
20181101@407	SK90-22	2.47	0.12
20181101@408	SK90-22	2.13	0.12
20181101@409	SK90-22	2.63	0.14
20181101@410	SK90-22	2.71	0.11
20181101@411	SK90-22	2.42	0.12
20181101@412	Fo60Std1	8.07	0.11
20181101@413	Fo60Std1	8.04	0.12
20181101@414	Fo60Std2	7.86	0.11
20181101@415	Fo60Std2	8.02	0.13
20181101@416	SC-OI	7.95	0.15
20181101@417	SC-OI	5.61	0.17

20181101@418	SC-OI	7.87	0.14
20181101@419	SC-OI	7.91	0.16
Average&2SD (SK90-22, N=19)		2.46	0.33
Average&2SD (SC-OI, N=18)		7.94	0.34
$\delta^{18} O_{LF}$ (SK90-22, N=3)		4.55	0.14
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(SK90-22)		-2.08	0.11
Instrumental Bias(SC-OI)		2.61	0.09
Bias(SK90-22)-Bias(SC-OI)		-4.68	0.14

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20181101@450	SC-OI	7.79	0.15
20181101@451	SC-OI	7.70	0.16
20181101@452	SC-OI	7.70	0.15
20181101@453	SC-OI	7.76	0.15
20181101@454	IG-OI	7.45	0.18
20181101@455	IG-OI	7.52	0.17
20181101@456	IG-OI	7.70	0.15
20181101@457	IG-OI	7.67	0.20
20181101@458	IG-OI	7.51	0.21
20181101@459	IG-OI	7.57	0.14
20181101@460	IG-OI	7.37	0.15
20181101@461	IG-OI	7.46	0.21
20181101@462	IG-OI	7.47	0.14
20181101@463	IG-OI	7.57	0.18
20181101@464	SC-OI	7.76	0.14
20181101@465	SC-OI	7.72	0.22
20181101@466	SC-OI	7.66	0.18
20181101@467	SC-OI	7.63	0.18
20181101@468	SC-OI	7.71	0.14
Average&2SD (IG-OI, N=10)		7.53	0.20
Average&2SD (SC-OI, N=9)		7.72	0.10
$\delta^{18} O_{LF}$ (IG-OI, N=3)		5.23	0.03
$\delta^{18} O_{LF}$ (SC-OI, N=3)		5.32	0.08
Instrumental Bias(IG-OI)		2.29	0.07
Instrumental Bias(SC-OI)		2.38	0.06
Bias(IG-OI)-Bias(SC-OI)		-0.10	0.09
20181101@469	UW-OI-1	7.52	0.17
20181101@470	UW-OI-1	7.51	0.15
20181101@471	UW-OI-1	7.55	0.17
20181101@472	UW-OI-1	7.56	0.16
20181101@473	UW-OI-1	7.52	0.18
20181101@474	UW-OI-1	7.63	0.15
20181101@475	UW-OI-1	7.51	0.15
20181101@476	UW-OI-1	7.52	0.15
20181101@477	UW-OI-1	7.72	0.15
20181101@478	UW-OI-1	7.54	0.16

20181101@479	SC-OI	7.78	0.17
20181101@480	SC-OI	7.78	0.18
20181101@481	SC-OI	7.67	0.17
20181101@482	SC-OI	7.78	0.17
<i>Average&2SD (UW-OI-1, N=10)</i>		7.56	0.14
<i>Average&2SD (SC-OI, N=9)</i>		7.72	0.11
<i>$\delta^{18}\text{OLF}(\text{UW-OI-1}, N=3)$</i>		5.48	
<i>$\delta^{18}\text{O}_{\text{LF}}(\text{SC-OI}, N=3)$</i>		5.32	0.08
<i>Instrumental Bias(UW-OI-1)</i>		2.07	0.04
<i>Instrumental Bias(SC-OI)</i>		2.39	0.06
<i>Bias(UW-OI-1-1)-Bias(SC-OI)</i>		-0.32	0.07

20181101@483	HN-OI	11.51	0.22
20181101@484	HN-OI	11.31	0.18
20181101@485	HN-OI	11.61	0.24
20181101@486	HN-OI	11.50	0.24
20181101@487	OR-OI	7.56	0.09
20181101@488	OR-OI	7.62	0.11
20181101@489	OR-OI	7.60	0.10
20181101@490	OR-OI	7.57	0.12
20181101@491	SC-OI	7.49	0.15
20181101@492	SC-OI	7.77	0.17
20181101@493	SC-OI	7.67	0.15
20181101@494	SC-OI	7.70	0.19
<i>Average&2SD (HN-OI, N=4)</i>		11.48	0.25
<i>Average&2SD (OR-OI, N=4)</i>		7.59	0.06
<i>Average&2SD (SC-OI, N=8)</i>		7.70	0.20
<i>$\delta^{18}\text{O}_{\text{LF}}(\text{HN-OI}, N=3)$</i>		8.90	0.08
<i>$\delta^{18}\text{O}_{\text{LF}}(\text{OR-OI}, N=3)$</i>		5.88	0.02
<i>$\delta^{18}\text{O}_{\text{LF}}(\text{SC-OI}, N=3)$</i>		5.32	0.08
<i>Instrumental Bias(HN-OI)</i>		2.56	0.13
<i>Instrumental Bias(OR-OI)</i>		1.70	0.03
<i>Instrumental Bias(SC-OI)</i>		2.37	0.08
<i>Bias(HN-OI)-Bias(SC-OI)</i>		0.19	0.16
<i>Bias(OR-OI)-Bias(SC-OI)</i>		-0.67	0.09

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20181101@495	UW-OI-1	7.57	0.20
20181101@496	UW-OI-1	7.52	0.20
20181101@497	UW-OI-1	7.64	0.16
20181101@498	UW-OI-1	7.59	0.16
20181101@499	Fa50278	-3.17	0.12
20181101@500	Fa50278	-5.85	0.21
20181101@501	UW-OI-1	7.64	0.17
20181101@502	Fa50278	-3.37	0.14
20181101@503	Fa50278	-3.13	0.16
20181101@504	Fa50278	-3.36	0.17
20181101@505	Fa50278	-3.19	0.16

20181101@506	Fa50278	-3.52	0.16
20181101@507	Fa50278	-3.56	0.15
20181101@508	UW-Ol-1	7.71	0.16
20181101@509	UW-Ol-1	7.65	0.13
20181101@510	UW-Ol-1	7.72	0.15
20181101@511	UW-Ol-1	7.70	0.18
<i>Average&2SD (Fa50278, N=7)</i>		-3.33	0.34
<i>Average&2SD (UW-Ol-1, N=9)</i>		7.64	0.13
<i>$\delta^{18}\text{O}_{\text{LF}}$ (Fa50278, N=3)</i>		4.50	
<i>$\delta^{18}\text{OLF}$ (UW-Ol-1, N=3)</i>		5.48	
<i>Instrumental Bias (Fa50278)</i>		-7.79	0.13
<i>Instrumental Bias (UW-Ol-1)</i>		2.15	0.04
<i>Bias (UW-Ol-1)-Bias (SC-Ol)</i>		-0.32	0.07
<i>Instrumental Bias (SC-Ol)</i>		2.47	0.09
<i>Bias (Fa50278)-Bias (SC-Ol)</i>		-10.24	0.16

Table S4. Oxygen isotope ratios of nine pyroxene RMs measured by SIM

Filename	Comment	$\delta^{18}\text{O} \text{‰}_{\text{Raw}}$	2SE/2SD
20200306@1	SC-Ol	8.12	0.16
20200306@2	SC-Ol	8.00	0.15
20200306@3	SC-Ol	8.03	0.18
20200306@4	SC-Ol	7.94	0.16
20200306@5	SC-Ol	7.95	0.14
20200306@6	SC-Ol	8.06	0.14
20200306@7	ST-En	11.86	0.17
20200306@8	ST-En	12.09	0.17
20200306@9	ST-En	11.95	0.20
20200306@10	ST-En	11.24	0.15
20200306@11	ST-En	11.28	0.20
20200306@12	ST-En	11.31	0.18
20200306@13	ST-En	11.98	0.18
20200306@14	ST-En	11.80	0.14
20200306@15	ST-En	12.84	0.21
20200306@16	ST-En	12.53	0.17
20200306@17	ST-En	12.72	0.15
20200306@18	ST-En	12.52	0.15
20200306@19	ST-En	12.67	0.17
20200306@20	ST-En	12.07	0.16
20200306@21	ST-En	12.28	0.21
20200306@22	ST-En	12.06	0.18
20200306@23	ST-En	12.37	0.17
20200306@24	ST-En	12.41	0.17
20200306@25	ST-En	12.43	0.14
20200306@26	ST-En	12.48	0.22
20200306@27	SC Ol	7.86	0.16
20200306@28	SC Ol	7.91	0.15
20200306@29	SC Ol	7.87	0.12
20200306@30	SC Ol	8.00	0.16
<i>Average&2SD (ST-En, N=20)</i>		<i>12.14</i>	<i>0.95</i>
<i>Average&2SD (SC-Ol, N=10)</i>		<i>7.98</i>	<i>0.17</i>
<i>$\delta^{18}\text{O}_{\text{LF}}$ (ST-En, N=3)</i>		<i>10.88</i>	<i>0.34</i>
<i>$\delta^{18}\text{O}_{\text{LF}}$ (SC-Ol, N=3)</i>		<i>5.32</i>	<i>0.08</i>
<i>Instrumental Bias(ST-En)</i>		<i>1.25</i>	<i>0.29</i>
<i>Instrumental Bias(SC-Ol)</i>		<i>2.64</i>	<i>0.07</i>
<i>Bias(ST-En)-Bias(SC-Ol)</i>		<i>-1.39</i>	<i>0.30</i>
20200306@31	SHW-En	6.63	0.15
20200306@32	SHW-En	6.62	0.14
20200306@34	SHW-En	6.63	0.17
20200306@35	SHW-En	6.53	0.16
20200306@36	SHW-En	6.49	0.15
20200306@37	SHW-En	6.52	0.22
20200306@38	SHW-En	6.64	0.15
20200306@39	SHW-En	6.57	0.18

20200306@40	SHW-En	6.43	0.15
20200306@41	SHW-En	6.68	0.16
20200306@50	SC Ol	8.13	0.11
20200306@51	SC Ol	7.94	0.15
20200306@52	SC Ol	7.96	0.17
20200306@53	SC Ol	7.96	0.14
Average&2SD (SHW-En, N=10)		6.58	0.16
Average&2SD (SC-Ol , N=8)		7.95	0.17
$\delta^{18}\text{OLF}(\text{SHW-En}, N=3)$		5.69	0.14
$\delta^{18}\text{O}_{\text{LF}}(\text{SC-Ol}, N=3)$		5.32	0.08
Instrumental Bias(SHW-En)		0.88	0.10
Instrumental Bias(SC-Ol)		2.62	0.08
Bias(SHW-En)-Bias(SC-Ol)		-1.74	0.12
20200306@54	IG-Opx	6.28	0.15
20200306@55	IG-Opx	6.19	0.19
20200306@56	IG-Opx	6.30	0.15
20200306@57	IG-Opx	6.10	0.23
20200306@58	IG-Opx	6.27	0.16
20200306@59	IG-Opx	6.01	0.14
20200306@60	IG-Opx	6.21	0.21
20200306@61	IG-Opx	6.19	0.18
20200306@62	4-15-En	6.14	0.16
20200306@63	4-15-En	6.06	0.19
20200306@64	4-15-En	5.86	0.16
20200306@65	4-15-En	6.10	0.14
20200306@66	4-15-En	5.96	0.20
20200306@67	4-15-En	5.86	0.18
20200306@68	4-15-En	5.80	0.14
20200306@69	JE-En	9.58	0.14
20200306@70	JE-En	9.69	0.14
20200306@71	JE-En	9.53	0.14
20200306@72	JE-En	9.58	0.19
20200306@73	JE-En	9.58	0.13
20200306@74	JE-En	9.64	0.18
20200306@75	SC Ol	7.85	0.12
20200306@76	SC Ol	7.93	0.14
20200306@77	SC Ol	7.89	0.12
20200306@78	SC Ol	7.95	0.13
Average&2SD (IG-Opx , N=8)		6.19	0.20
Average&2SD (4-15-En , N=7)		5.97	0.27
Average&2SD (JE-En , N=6)		9.60	0.11
Average&2SD (SC-Ol , N=8)		7.95	0.16
$\delta^{18}\text{O}_{\text{LF}}(\text{IG-Opx}, N=3)$		5.89	0.13
$\delta^{18}\text{OLF}(4-15-En, N=3)$		5.89	0.15
$\delta^{18}\text{O}_{\text{LF}}(\text{JE-En}, N=3)$		9.2	
$\delta^{18}\text{O}_{\text{LF}}(\text{SC-Ol}, N=3)$		5.32	0.08
Instrumental Bias(IG-Opx)		0.30	0.10

<i>Instrumental Bias(4-15-En)</i>	<i>0.08</i>	<i>0.13</i>
<i>Instrumental Bias(JE-En)</i>	<i>0.40</i>	<i>0.04</i>
<i>Instrumental Bias(SC-Ol)</i>	<i>2.62</i>	<i>0.07</i>
<i>Bias(IG-Opx)-Bias(SC-Ol)</i>	<i>-2.31</i>	<i>0.13</i>
<i>Bias(4-15-En)-Bias(SC-Ol)</i>	<i>-2.53</i>	<i>0.15</i>
<i>Bias(JE-En)-Bias(SC-Ol)</i>	<i>-2.21</i>	<i>0.09</i>
20200306@79 7219A_En	9.73	0.20
20200306@80 7219A_En	9.85	0.19
20200306@81 7219A_En	9.71	0.18
20200306@82 7219A_En	9.82	0.19
20200306@83 7219A_En	9.72	0.15
20200306@84 7219A_En	9.95	0.16
20200306@85 7219A_En	9.94	0.21
20200306@86 7219A_En	9.75	0.13
20200306@87 JS-En	4.01	0.17
20200306@88 JS-En	4.03	0.10
20200306@89 JS-En	4.07	0.14
20200306@90 JS-En	4.20	0.19
20200306@91 JS-En	4.14	0.19
20200306@92 JS-En	4.21	0.26
20200306@93 JS-En	4.16	0.19
20200306@94 JS-En	4.08	0.15
20200306@95 JS-En	4.17	0.16
20200306@96 JS-En	4.34	0.14
20200306@97 A84001-En	5.41	0.17
20200306@98 A84001-En	5.49	0.11
20200306@99 A84001-En	5.50	0.13
20200306@100 A84001-En	5.37	0.14
20200306@101 A84001-En	5.30	0.16
20200306@102 A84001-En	5.23	0.17
20200306@103 SC Ol	7.98	0.15
20200306@104 SC Ol	8.00	0.12
20200306@105 SC Ol	8.08	0.21
20200306@106 SC Ol	8.02	0.19
<i>Average&2SD (7219A-En, N=8)</i>	<i>9.81</i>	<i>0.19</i>
<i>Average&2SD (JS-En, N=10)</i>	<i>4.14</i>	<i>0.20</i>
<i>Average&2SD (A84001-En, N=6)</i>	<i>5.38</i>	<i>0.21</i>
<i>Average&2SD (SC-Ol , N=8)</i>	<i>7.96</i>	<i>0.15</i>
<i>δ18OLF(7219A-En, N=3)</i>	<i>9.52</i>	<i>0.19</i>
<i>δ18OLF(JS-En, N=3)</i>	<i>3.75</i>	<i>0.04</i>
<i>δ18OLF(A84001-En, N=3)</i>	<i>4.99</i>	
<i>δ¹⁸ O_{LF} (SC-Ol, N=3)</i>	<i>5.32</i>	<i>0.08</i>
<i>Instrumental Bias(7219A-En)</i>	<i>0.29</i>	<i>0.13</i>
<i>Instrumental Bias(JS-En)</i>	<i>0.39</i>	<i>0.07</i>
<i>Instrumental Bias(A84001-En)</i>	<i>0.39</i>	<i>0.09</i>
<i>Instrumental Bias(SC-Ol)</i>	<i>2.63</i>	<i>0.07</i>
<i>Bias(7219A-En)-Bias(SC-Ol)</i>	<i>-2.34</i>	<i>0.15</i>

<i>Bias(JS-En)-Bias(SC-OL)</i>		<i>-2.23</i>	<i>0.10</i>
<i>Bias(A84001-En)-Bias(SC-OL)</i>		<i>-2.23</i>	<i>0.11</i>
20200306@107	7244-Aug	10.60	0.22
20200306@108	7244-Aug	10.38	0.18
20200306@109	7244-Aug	10.85	0.21
20200306@110	7244-Aug	10.63	0.24
20200306@111	7244-Aug	10.59	0.22
20200306@112	7244-Aug	10.62	0.24
20200306@113	7244-Aug	10.45	0.24
20200306@114	7244-Aug	10.55	0.25
20200306@115	7244-Aug	10.48	0.22
20200306@116	7244-Aug	10.45	0.26
20200306@117	95 AK-6_Di	28.09	0.19
20200306@118	96 AK-6_Di	28.07	0.24
20200306@119	97 AK-6_Di	28.08	0.25
20200306@120	98 AK-6_Di	28.13	0.29
20200306@121	99 AK-6_Di	28.00	0.27
20200306@122	SC OL	8.12	0.10
20200306@123	SC OL	8.16	0.15
20200306@124	SC OL	8.03	0.13
20200306@125	SC OL	8.05	0.16
<i>Average&2SD (7244-Aug , N=10)</i>		<i>10.56</i>	<i>0.27</i>
<i>Average&2SD (95 AK-6-Di, N=5)</i>		<i>28.08</i>	<i>0.10</i>
<i>Average&2SD (SC-OL , N=8)</i>		<i>8.05</i>	<i>0.12</i>
<i>$\delta^{18} O_{LF}$ (7244-Aug, N=3)</i>		<i>7.15</i>	<i>0.12</i>
<i>$\delta^{18} O_{LF}$ (95Ak-6-Di, N=3)</i>		<i>24.14</i>	
<i>$\delta^{18} O_{LF}$ (SC-OL, N=3)</i>		<i>5.32</i>	<i>0.08</i>
<i>Instrumental Bias(7244-Aug)</i>		<i>3.39</i>	<i>0.11</i>
<i>Instrumental Bias(95Ak-6-Di)</i>		<i>3.84</i>	<i>0.04</i>
<i>Instrumental Bias(SC-OL)</i>		<i>2.72</i>	<i>0.06</i>
<i>Bias(7244-Aug)-Bias(SC-OL)</i>		<i>0.66</i>	<i>0.13</i>
<i>Bias(95Ak-6-Di)-Bias(SC-OL)</i>		<i>1.12</i>	<i>0.08</i>

Table S5. Oxygen isotope homogeneity examination of the four new pyroxene RMs

Filename	Comment	$\delta^{18}\text{O}$ ‰ _{Raw}	2SE/2SD
Session 1 (11/7/2019)			
20191107@2	Sp79-11-En	15.24	0.16
20191107@3	Sp79-11-En	15.42	0.21
20191107@4	Sp79-11-En	15.20	0.14
20191107@5	Sp79-11-En	15.31	0.15
20191107@6	4-15-En	6.64	0.14
20191107@7	4-15-En	6.48	0.12
20191107@8	4-15-En	6.41	0.12
20191107@9	4-15-En	6.55	0.15
20191107@10	4-15-En	6.66	0.10
20191107@11	4-15-En	6.64	0.12
20191107@12	4-15-En	6.67	0.12
20191107@13	4-15-En	6.56	0.14
20191107@14	4-15-En	6.63	0.12
20191107@15	4-15-En	6.59	0.14
20191107@16	4-15-En	6.49	0.14
20191107@17	4-15-En	6.67	0.11
20191107@18	4-15-En	6.69	0.14
20191107@19	4-15-En	6.57	0.10
20191107@20	4-15-En	6.57	0.14
20191107@21	4-15-En	6.52	0.08
20191107@22	4-15-En	6.57	0.20
20191107@23	4-15-En	6.67	0.12
20191107@24	4-15-En	6.77	0.17
20191107@25	4-15-En	6.59	0.13
20191107@26	4-15-En	6.68	0.16
20191107@27	4-15-En	6.80	0.14
20191107@28	4-15-En	6.80	0.14
20191107@29	4-15-En	6.80	0.10
20191107@30	Sp79-11-En	15.20	0.16
20191107@31	Sp79-11-En	15.44	0.17
20191107@32	Sp79-11-En	15.16	0.14
20191107@33	Sp79-11-En	15.18	0.15
Average&2SD (4-15-En, N=24)		6.63	0.21
Average&2SD (Sp 79-11, N=8)		15.25	0.26
20191107@34	7219A-En	10.52	0.13
20191107@35	7219A-En	10.68	0.16
20191107@36	7219A-En	10.93	0.11
20191107@37	7219A-En	10.61	0.13
20191107@38	7219A-En	10.90	0.14
20191107@39	7219A-En	10.70	0.13
20191107@40	7219A-En	10.71	0.11
20191107@41	7219A-En	10.53	0.14
20191107@42	7219A-En	10.76	0.16
20191107@43	7219A-En	10.59	0.14

20191107@44	7219A-En	10.68	0.13
20191107@45	7219A-En	10.65	0.14
20191107@46	7219A-En	10.68	0.13
20191107@47	7219A-En	10.37	0.16
20191107@48	7219A-En	10.92	0.15
20191107@49	7219A-En	10.79	0.14
20191107@50	7219A-En	10.72	0.09
20191107@51	7219A-En	10.50	0.13
20191107@52	7219A-En	10.59	0.15
20191107@53	7219A-En	10.54	0.22
20191107@54	7219A-En	10.81	0.10
Average&2SD (7219A-En, N=21)		10.68	0.29

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20200121@12	UWQ-1	5.11	0.18
20200121@13	UWQ-1	5.06	0.26
20200121@14	UWQ-1	5.03	0.27
20200121@15	UWQ-1	5.01	0.27
20200121@16	UWQ-1	5.00	0.21
20200121@17	UWQ-1	5.05	0.29
20200121@18	UWQ-1	4.86	0.19
20200121@19	UWQ-1	4.82	0.23
20200121@20	SC-OI	8.09	0.12
20200121@21	SC-OI	8.21	0.16
20200121@22	SC-OI	8.23	0.19
20200121@23	SC-OI	8.25	0.17
20200121@24	95Ak-6-Di	28.25	0.25
20200121@25	95Ak-6-Di	28.13	0.28
20200121@26	95Ak-6-Di	28.50	0.27
20200121@27	95Ak-6-Di	28.34	0.24
20200121@28	Sp 79-11	14.55	0.19
20200121@29	Sp 79-11	14.52	0.14
20200121@30	Sp 79-11	14.61	0.22
20200121@31	Sp 79-11	14.57	0.19
20200121@32	SC-OI	8.30	0.16
20200121@33	SC-OI	8.34	0.18
20200121@34	SC-OI	8.35	0.21
20200121@35	SC-OI	8.16	0.15
20200121@36	UWQ-1	4.59	0.38
20200121@37	UWQ-1	4.71	0.32
20200121@38	UWQ-1	4.52	0.40
20200121@39	UWQ-1	4.54	0.40
20200121@40	UWQ-1	4.87	0.23
20200121@41	UWQ-1	4.69	0.21
20200121@42	UWQ-1	4.71	0.24
20200121@43	UWQ-1	4.68	0.25
20200121@44	SC-OI	7.95	0.11

20200121@45	SC-OI	8.11	0.17
20200121@46	SC-OI	7.86	0.14
20200121@47	SC-OI	8.01	0.18
20200121@48	SHW Fe-rich En	6.50	0.14
20200121@49	SHW Fe-rich En	6.29	0.20
20200121@50	SHW Fe-rich En	6.15	0.20
20200121@51	SHW Fe-rich En	6.28	0.21
20200121@52	SHW Fe-rich En	6.18	0.12
20200121@53	SHW OI	8.42	0.17
20200121@54	SHW OI	8.32	0.20
20200121@55	SHW OI	8.13	0.19
20200121@56	SHW OI	7.81	0.19
20200121@70	SHW OI	7.88	0.16
20200121@57	SHW OI	8.62	0.14
20200121@58	SHW OI	8.41	0.24
20200121@59	SHW OI	8.54	0.16
20200121@60	SHW OI	8.19	0.21
Average&2SD (SHW Fe-rich En, N=4)		6.23	0.14
Average&2SD (SHW OI, N=13)		8.17	0.54
20200121@61	SHW PI	3.15	0.27
20200121@62	SHW PI	3.74	0.19
20200121@63	SHW PI	3.19	0.24
20200121@64	SHW PI	3.50	0.24
20200121@65	SHW PI	3.13	0.22
20200121@66	SHW PI	3.50	0.19
20200121@67	SHW PI	3.50	0.27
20200121@68	SHW PI	3.56	0.24
20200121@69	SHW PI	3.37	0.22
Average&2SD (SHW PI, N=9)		3.40	0.42
20200121@71	SC-OI	8.05	0.17
20200121@72	SC-OI	8.01	0.11
20200121@73	SC-OI	8.07	0.14
Average&2SD (SHW OI, N=12)		8.20	0.52
20200121@74	SHW-En (clean)	6.96	0.20
20200121@75	SHW-En (clean)	7.17	0.17
20200121@76	SHW-En (clean)	6.80	0.19
20200121@77	SHW-En (clean)	6.88	0.16
20200121@78	SHW-En (clean)	7.11	0.21
20200121@79	SHW-En (clean)	6.95	0.19
20200121@80	SHW-En (clean)	6.93	0.16
20200121@81	SHW-En (clean)	6.83	0.18
20200121@82	SHW-En (clean)	6.80	0.17
20200121@83	SHW-En (clean)	6.96	0.21
20200121@84	SHW-En (clean)	6.94	0.15
20200121@85	SHW-En (clean)	6.89	0.22

20200121@86	SHW-En (clean)	6.88	0.17
20200121@87	SHW-En (clean)	6.95	0.20
20200121@88	SHW-En (clean)	6.96	0.17
20200121@89	SHW-En (clean)	6.79	0.20
20200121@90	SHW-En (clean)	6.83	0.18
20200121@91	SHW-En (clean)	6.80	0.24
20200121@92	SHW-En (clean)	6.80	0.23
20200121@93	SHW-En (clean)	6.97	0.20
20200121@94	SHW-En (rusty)	6.77	0.21
20200121@95	SHW-En (rusty)	7.00	0.19
20200121@96	SHW-En (rusty)	7.03	0.16
20200121@97	SHW-En (rusty)	7.25	0.15
20200121@98	SHW-En (rusty)	7.01	0.20
20200121@129	SHW-En (rusty)	6.75	0.19
20200121@130	SHW-En (rusty)	6.98	0.15
20200121@131	SHW-En (rusty)	7.23	0.19
20200121@132	SHW-En (rusty)	6.94	0.18
20200121@99	SHW-En (rusty)	7.12	0.18
20200121@100	SHW-En (rusty)	7.02	0.21
20200121@101	SHW-En (rusty)	6.91	0.19
20200121@102	SHW-En (rusty)	7.13	0.21
20200121@103	SHW-En (rusty)	6.97	0.21
20200121@104	SHW-En (rusty)	6.92	0.25
Average&2SD (SHW-En, N=35)		6.95	0.26

20200121@105	JS-En CG3	4.21	0.11
20200121@106	JS-En CG3	4.53	0.18
20200121@107	JS-En CG3	4.42	0.16
20200121@108	JS-En CG5	4.36	0.15
20200121@109	JS-En CG5	4.20	0.20
20200121@110	JS-En CG5	4.22	0.12
20200121@111	JS-En CG4	4.39	0.17
20200121@112	JS-En CG4	4.25	0.17
20200121@113	JS-En CG4	4.51	0.15
Average&2SD (JS-En CG, N=9)		4.34	0.26

20200121@114	JS-En FG1	4.36	0.15
20200121@115	JS-En FG1	4.42	0.17
20200121@116	JS-En FG1	4.35	0.16
20200121@117	JS-En FG2	3.98	0.17
20200121@118	JS-En FG2	3.92	0.12
20200121@119	JS-En FG2	4.09	0.08
20200121@120	JS-En FG2	4.34	0.16
20200121@121	JS-En FG2	4.28	0.13
20200121@122	JS-En FG2	4.56	0.13
20200121@123	JS-En FG2	4.31	0.15
20200121@124	JS-En FG3	4.43	0.19
20200121@125	JS-En FG3	4.24	0.15

20200121@126	JS-En FG4	4.04	0.15
20200121@127	JS-En FG4	3.89	0.17
20200121@128	JS-En FG4	4.31	0.12
Average&2SD (JS-En FG, N=15)		4.23	0.40
20200121@133	SC-OI	8.07	0.17
20200121@134	SC-OI	8.05	0.15
20200121@135	SC-OI	8.23	0.13
20200121@136	SC-OI	7.93	0.15
Average&2SD (SC-OI, N=7)		8.07	0.25

Table S6. Instrumental biases of olivine and pyroxene RMs used in oxygen three-isotope sessions

RMs	Fo/En	Wo	$\delta^{18}\text{O}_{\text{LF}}$	2SD	No.	$\delta^{18}\text{O}_{\text{SIMS}}$	2SD	No.
Nov. 2020 Session								
Olivine								
Fa50278	0.54		4.50			-4.16	0.40	4
SK90-14-O	20.8		4.45	0.09	3	-0.16	0.16	4
SK90-21-O	27.6		4.52	0.48	2	1.05	0.21	4
SK90-22-O	29.4		4.55	0.14	3	1.22	0.04	4
SK90-9-Ol	56.4		4.63	0.40	3	4.72	0.17	4
SK90-6-Ol	57.3		4.67	0.20	3	4.89	0.21	4
SK90-8-Ol	57.3		4.60	0.11	3	4.83	0.06	4
OR-Ol ¹	59.3		5.88	0.02	3	6.00	0.02	4
OR-Ol ²	59.3		5.88	0.02	3	6.06	0.16	4
SK90-5-Ol	66.0		4.61	0.16	3	5.10	0.02	4
FJ-Ol	73.4		4.89	0.28	3	5.11	0.45	4
SC-Ol	88.8		5.32		3			
SW-Ol	81.8		3.51	0.03	2	3.99	0.29	4
UW-Ol-1 ¹	89.2		5.48	0.11	5	5.45	0.14	4
UW-Ol-1 ²	89.2		5.48	0.11	5	5.28	0.20	4
HaK-Ol	91.9		5.25			5.06	0.08	4
HN-Ol	100.0		8.90	0.08	3	9.09	0.10	4
Pyroxene								
A84001-En	69.7	3.27	4.99			2.81	0.13	4
A84001-En	69.7	3.27	4.99			2.94	0.38	4
JS-En ¹	74.9	2.36	3.75	0.04	3	1.61	0.08	4
JS-En ²	74.9	2.36	3.75	0.04	3	1.89	0.14	4
7219A-En ¹	85.7	0.49	9.52	0.19	3	6.87	0.11	4
7219A-En ²	85.7	0.49	9.52	0.19	3	7.29	0.22	4
JE-En ¹	85.5	0.40	9.2			6.72	0.10	4
JE-En ²	85.5	0.40	9.2			6.97	0.62	4
JE-En ³	85.5	0.40	9.2			7.12	0.05	4
4-15-En ¹	87.3	1.00	5.89	0.15	3	2.86	0.22	4
4-15-En ²	87.3	1.00	5.89	0.15	3	3.38	0.14	4
IG-Opx ¹	88.9	1.09	5.89	0.13	3	2.95	0.04	4
IG-Opx ²	88.9	1.09	5.89	0.13	3	3.61	0.28	4
IG-Opx ³	88.9	1.09	5.89	0.13	3	3.63	0.10	4
Sp79-11-En	96.3	0.82	113.31	0.12	3	11.44	0.19	4
SHW-En ¹	99.8	0.16	5.69	0.14	3	3.18	0.16	4
SHW-En ²	99.8	0.16	5.69	0.14	3	3.64	0.21	4
7244-Aug ¹	27.5	45.3	7.15	0.12	3	6.92	0.08	4
7244-Aug ²	27.5	45.3	7.15	0.12	3	7.22	0.32	4
95 Ak/6-Di	48.6	49.5	24.14			24.01	0.23	4
95 Ak/6-Di	48.6	49.5	24.14			24.23	0.40	4
Dec. 2020 Session								
Olivine								
Fa50278	0.5		4.50			-4.72	0.52	4
SK90-14-O	20.8		4.45	0.09	3	-0.69	0.65	4

SK90-21-O	27.6		4.52	0.48	2	0.48	0.60	4
SK90-22-O	29.4		4.55	0.14	3	0.77	0.17	4
SK90-9-Ol	56.4		4.63	0.40	3	4.48	0.16	4
SK90-6-Ol	57.3		4.67	0.20	3	4.74	0.56	4
SK90-8-Ol	57.3		4.60	0.11	3	4.74	0.13	4
OR-Ol ¹	59.3		5.88	0.02	3	6.11	0.15	4
OR-Ol ²	59.3		5.88	0.02	3	6.03	0.28	4
SK90-5-Ol	66.0		4.61	0.16	3	4.94	0.21	4
FJ-Ol	73.4		4.89	0.28	3	5.44	0.18	4
SC-Ol	88.8		5.32		3			
SW-Ol	81.8		3.51	0.03	2	3.34	0.26	4
UW-Ol-1 ¹	89.2		5.48	0.11	5	6.08	0.06	4
UW-Ol-1 ²	89.2		5.48	0.11	5	6.16	0.46	4
HaK-Ol	91.9		5.25			5.85	0.25	4
HN-Ol	100.0		8.90	0.08	3	9.92	0.19	4
Pyroxene								
A84001-En	69.7	3.27	4.99			4.08	0.39	4
JS-En	74.9	2.36	3.75	0.04	3	2.90	0.02	4
7219A-En	85.7	0.49	9.52	0.19	3	8.34	0.22	4
JE-En ¹	85.5	0.40	9.2			7.38	0.38	4
JE-En ²	85.5	0.40	9.2			8.48	0.39	4
4-15-En	87.3	1.00	5.89	0.15	3	4.65	0.13	4
IG-Opx	88.9	1.09	5.89	0.13	3	4.85	0.29	4
Sp79-11-En	96.3	0.82	113.31	0.12	3	11.89	0.32	4
SHW-En	99.8	0.16	5.69	0.14	3	5.28	0.23	4
7244-Aug	27.5	45.3	7.15	0.12	3	8.66	0.16	4
IG-Cpx	46.7	49.2	5.15	0.16	3	6.08	0.20	4
95Ak-6-Di	48.6	49.5	24.14			26.01	0.41	4

Residuals* refer to the residual of the regression functions (listed in Table S7), which were used for correc

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Bias	Unc.	Bias/SC-OI	Unc.	Residuals*	Yield (10 ⁹ cps/nA)
-8.62	0.20	-8.70	0.28	0.07	1.72
-4.59	0.10	-4.81	0.18	-0.07	1.65
-3.45	0.36	-3.64	0.36	-0.01	1.66
-3.31	0.08	-3.50	0.11	-0.15	1.66
0.09	0.25	-0.14	0.29	0.12	1.55
0.22	0.16	-0.03	0.20	0.16	1.52
0.23	0.07	0.01	0.17	0.20	1.55
0.12	0.02	-0.05	0.13	-0.02	1.52
0.18	0.08	-0.07	0.15	-0.03	1.53
0.49	0.09	0.24	0.15	0.03	1.47
0.22	0.28	0.07	0.30	-0.05	1.42
		0.00		-0.08	1.28-1.31
0.48	0.15	0.31	0.20	0.29	1.33
-0.03	0.08	-0.18	0.15	-0.10	1.26
-0.20	0.11	-0.33	0.20	-0.25	1.28
-0.19	0.04	-0.37	0.14	-0.25	1.26
0.19	0.07	0.03	0.14	0.25	1.17
-2.17	0.07	-1.94	0.35	0.04	1.36
-2.04	0.19	-2.10	0.22	-0.12	1.37
-2.13	0.05	-2.07	0.21	-0.01	1.35
-1.86	0.07	-1.96	0.11	0.10	1.35
-2.63	0.12	-2.39	0.37	-0.19	1.28
-2.21	0.15	-2.27	0.19	-0.07	1.29
-2.46	0.05	-2.23	0.35	-0.02	1.27
-2.21	0.31	-2.27	0.33	-0.07	1.30
-2.07	0.02	-2.20	0.23	0.01	1.29
-3.01	0.14	-2.63	0.15	-0.44	1.26
-2.50	0.11	-2.57	0.16	-0.38	1.28
-2.92	0.08	-2.54	0.10	-0.34	1.24
-2.26	0.16	-2.34	0.20	-0.14	1.26
-2.25	0.09	-2.38	0.25	-0.18	1.24
-1.85	0.12	-1.98	0.26	0.28	1.21
-2.49	0.11	-2.12	0.13	0.20	1.18
-2.04	0.13	-2.11	0.18	0.20	1.19
-0.22	0.08	-0.16	0.22	-0.18	1.30
0.07	0.18	-0.03	0.19	-0.05	1.30
-0.12	0.11	-0.06	0.23	-0.11	1.16
0.09	0.20	-0.01	0.22	-0.05	1.16
-9.18	0.26	-9.79	0.57	0.02	1.42
-5.12	0.33	-5.45	0.41	0.04	1.39

-4.02	0.45	-4.36	0.51	-0.05	1.38
-3.76	0.12	-4.10	0.27	-0.09	1.39
-0.15	0.25	-0.80	0.77	-0.10	1.27
0.06	0.30	-0.59	0.79	0.04	1.28
0.13	0.09	-0.52	0.74	0.11	1.31
0.23	0.08	-0.65	0.33	-0.18	1.26
0.15	0.14	-0.23	0.41	0.25	1.27
0.32	0.14	-0.05	0.41	-0.08	1.23
0.55	0.18	-0.21	0.27	-0.07	1.18
		0.00		0.04	1.08-1.12
0.02	0.13	-0.12	0.29	-0.03	1.13
0.60	0.06	-0.16	0.20	-0.12	1.08
0.68	0.24	0.06	0.56	0.10	1.11
0.59	0.13	-0.29	0.35	-0.27	1.05
1.01	0.11	0.26	0.22	0.23	1.00
-0.90	0.20	-2.18	0.24	0.02	1.07
-0.85	0.02	-2.13	0.14	0.06	1.07
-1.17	0.15	-2.42	0.30	-0.26	1.01
-1.80	0.19	-2.44	0.52	-0.27	1.09
-0.71	0.39	-1.97	0.41	0.20	0.99
-1.23	0.11	-2.49	0.28	-0.38	0.98
-1.03	0.16	-2.27	0.31	-0.18	0.96
-1.40	0.18	-2.04	0.52	-0.03	1.01
-0.41	0.14	-1.65	0.30	0.35	0.91
1.50	0.11	0.21	0.18	0.36	1.08
0.92	0.14	0.28	0.51	-0.07	1.07
1.83	0.20	0.54	0.25	0.15	0.97

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Table S7. SIMS oxygen isotope ratios of chondrules in Acfer 094 chondrite

Chondrule	Analysis point	Mineral	Fo/En	Wo	Notes
Nov. 2020 Session	Olivine (Fo≥60): Bias/SC-Ol = -0.0048*Fo+0.3503				
	Olivine (Fo<60): Bias/SC-Ol = -0.0011*Fo^2+0.217*Fo-8.8224				
	Pyroxene: Bias/SC-Ol = -2.32+0.0068*Fs+0.0475*Wo				
G74 IAB Mg#=94.5	#1	Ol	94.6		Relict
	#2	Ol	94.6		Relict
	#3	Ol	94.6		
	#5	Ol	94.6		
	#6	Lpx	91.2	3.5	
	#8	Lpx	91.2	3.5	
	#9	Lpx	91.2	3.5	
	Average and 2SD_Ol				
	Average and 2SD_Lpx				
	Average and 2SD_Host				
	#4 _Rejected	Ol			Overlap another p
	#7 _Rejected	Lpx			Overlap another p
G77 RF-IAB Mg#=99.3	#1	Ol	99.2		
	#2	Ol	99.2		
	#3	Ol	99.2		
	#4	Ol	99.2		
	#5	Lpx	98.3	0.8	
	#6	Lpx	98.3	0.8	
	#7	Lpx	98.3	0.8	
	#8	Lpx	98.3	0.8	
	Average and 2SD_Ol				
Average and 2SD_Lpx					
Average and 2SD_Host					
G52 IA Mg#=94.6	#1	Ol	94.6		
	#2	Ol	94.6		
	#3	Ol	94.6		Relict
	#4	Ol	94.6		
	#5	Ol	94.6		
	#6	Ol	94.6		
	#7	Ol	94.6		
	Average and 2SD_Host				
G73 IAB Mg#=99.1 Slightly heterogeneous (Uncertainty of Δ ¹⁷ O > 3SD)	#1	Ol	99.2		
	#2	Ol	99.2		
	#3	Ol	99.2		
	#4	Ol	99.2		
	#5	Lpx	97.3	1.3	
	#6	Lpx	97.3	1.3	
	#7	Lpx	97.3	1.3	

#8	Lpx	97.3	1.3
#9	Lpx	97.3	1.3
Average and 2SD_Ol			
Average and 2SD_Lpx			
Average and 2SD_Host			

G67	#1	Ol	99.4	
RF-IAB	#2	Ol	99.4	
Mg#=99.2	#3	Ol	99.4	
	#4	Ol	99.4	
	#5	Lpx	97.2	1.7
	#6	Lpx	97.2	1.7
	#7	Lpx	97.2	1.7
	#8	Lpx	97.2	1.7
Average and 2SD_Ol				
Average and 2SD_Lpx				
Average and 2SD_Host				

G79	#1	Ol	36.2
IIAB	#2	Ol	40.4
Mg#=42.2	#3	Ol	40.1
	#4	Ol	35.6
	#5	Ol	35.6

Heterogeneous

G68	#4	Ol	98.7	Relict
IAB	#5	Ol	98.7	Relict
Mg#=98	#6	Ol	98.7	Relict
	#8	Ol	98.7	Relict
	#9	Ol	98.7	Relict
	#10	Ol	98.7	Relict
	#12	Lpx	96.9	1
	#13	Lpx	96.9	1

Heterogeneous

#1_Rejected	Ol	98.7	Mixture of ¹⁶ O-ri
#2_Rejected	Ol	98.7	Mixture of ¹⁶ O-ri
#3_Rejected	Ol	98.7	Mixture of ¹⁶ O-ri
#7_Rejected	Ol	98.7	Mixture of ¹⁶ O-ri
#11_Rejected	Lpx	96.9	1 Mixture of ¹⁶ O-ri

G6	#1	Ol	59.4
IIA	#2	Ol	55.9
Mg#=49.7	#4	Ol	57.4
	#5	Ol	57.9
	#6	Ol	55.4
	#7	Ol	51.1
	#8	Ol	51.2

	#9	Ol	57.4	
	Average and 2SD_Host			
	#3_Rejected	Ol	46.3	Overlap a crack
G10	#1	Ol	72.7	
IAB	#2	Ol	71.9	
Mg#=67.8	#3	Ol	72.6	
	#4	Ol	72.4	
	Average and 2SD_Host			
	#5_Rejected	Ol	68.1	Slightly charging
G70	#1	Ol	99.1	
IAB	#3	Ol	99.1	
Mg#=99	#4	Ol	99.1	
	#5	Ol	99.1	
	#6	Lpx	97.8	1
	#7	Lpx	97.8	1
	#8	Lpx	97.8	1
	Average and 2SD_Ol			
	Average and 2SD_Lpx			
	Average and 2SD_Host			
	#2_Rejected	Ol	99.1	Mixture of ¹⁶ O-ri
G45	#1	Ol	95.6	Relict
IAB	#2	Ol	95.6	
Mg#=95.2	#3	Ol	95.6	Relict
	#4	Ol	95.6	Relict
	#5	Ol	95.6	
	#6	Lpx	92.5	2.9
	#7	Lpx	92.5	2.9
	#8	Lpx	92.5	2.9
	#9	Lpx	92.5	2.9
	Average and 2SD_Ol			
	Average and 2SD_Lpx			
	Average and 2SD_Host			
G46	#1	Ol	98.8	Relict
IAB	#2	Ol	98.8	
Mg#=98.9	#3	Ol	98.8	
	#4	Ol	98.8	Relict
	#5	Ol	98.8	Relict

#6	Lpx	97.9	0.8
#7	Lpx	97.9	0.8
#8	Lpx	97.9	0.8
#9	Lpx	97.9	0.8

Average and 2SD_OI
Average and 2SD_Lpx
Average and 2SD_Host

G48 IA-BO Mg#=99.4	#1	Ol	99.4	
	#2	Ol	99.4	
	#3	Ol	99.4	
	#5	Lpx	93.1	6

Average and 2SD_OI
Average and 2SD_Lpx
Average and 2SD_Host

#4_Rejected	Ol	99.4		Overlap mesostas
#6_Rejected	Lpx	93.1	6	Overlap mesostas

G64 IB-Dusty Ol Mg#=99	#1	Ol	98.6	
	#2	Lpx	98.3	0.6
	#3	Lpx	98.3	0.6
	#4	Lpx	98.3	0.6
	#5	Lpx	98.3	0.6

Average and 2SD_OI
Average and 2SD_Lpx
Average and 2SD_Host

G81 IAB Mg#=99.1	#1	Ol	99.1		Relict
	#2	Ol	99.1		
	#3	Ol	99.1		
	#4	Ol	99.1		Relict
	#5	Lpx	98.1	1	
	#6	Lpx	98.1	1	
	#7	Lpx	98.1	1	

Average and 2SD_OI
Average and 2SD_Lpx
Average and 2SD_Host

#8_Rejected	Lpx	98.1	1	Overlap another 1
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G87 IAB Mg#=99.1 Slightly heterogeneous (Uncertainty of $\Delta^{17}\text{O} > 3\text{SD}$)	#1	Ol	99.2	
	#4	Ol	99.2	
	#5	Lpx	97.5	0.9
	#6	Lpx	97.5	0.9
	#7	Lpx	97.5	0.9

Average and 2SD_OI

Average and 2SD_Lpx		Average and 2SD_Host			
	#2_Rejected	Ol	99.2		Mixture of ¹⁶ O-ri
	#3_Rejected	Ol	99.2		Mixture of ¹⁶ O-ri
	#8_Rejected	Lpx	97.5	0.9	Overlap another p
	#9_Rejected	Ol	99.2		Mixture of ¹⁶ O-ri
G32	#1	Ol	44.6		
IIA	#2	Ol	75.5		
Mg#=60.7	#3	Ol	75.5		
	#4	Ol	70		
	#5	Ol	69.6		
Average and 2SD_Host					
G63	#1	Ol	71.5		
IIA	#2	Ol	76.8		Relict
Mg#=62.1	#3	Ol	64.6		Relict
Slightly heterogeneous (Uncertainty of Δ ¹⁷ O > 3SD)	#4	Ol	67.9		
	#5	Ol	68.4		
	#6	Ol	65		
	#7	Ol	68.2		
	#8	Ol	72.2		Relict
	#9	Ol	68.8		
Average and 2SD_Host					
G113	#1	Ol	99.3		
RF-I-Ol Frag	#2	Ol	99.3		
Mg#=99.5	#3	Ol	99.3		
	#4	Ol	99.3		
	#5	Ol	99.3		
	#6	Ol	99.3		
	#7	Ol	99.3		
Average and 2SD_Host					
G56	#1	Ol	99.4		
RF-IAB	#2	Ol	99.4		
Mg#=99.5	#3	Ol	99.4		
	#4	Ol	99.4		
	#5	Lpx	98.2	0.7	
	#6	Lpx	98.2	0.7	
	#7	Lpx	98.2	0.7	
	#8	Lpx	98.2	0.7	
Average and 2SD_Ol					
Average and 2SD_Lpx					
Average and 2SD_Host					
G84	#1	Ol	99.2		Relict

IAB Mg#=99	#3	Ol	99.2		Relict
	#4	Ol	99.2		Relict
	#5	Ol	99.2		Relict
	#6	Ol	99.2		Relict
	#9	Ol	99.2		Relict
	#10	Lpx	97.9	1.3	
	#11	Lpx	97.9	1.3	
	#12	Lpx	97.9	1.3	

Average and 2SD_Host

#2_Rejected	Ol	99.2		Mixture of ¹⁶ O-ri
#7_Rejected	Ol	99.2		Mixture of ¹⁶ O-ri
#8_Rejected	Ol	99.2		Mixture of ¹⁶ O-ri
#13_Rejected	Ol	99.2		Mixture of ¹⁶ O-ri

G95	#1	Ol	98.7		
IAB Mg#=98.7	#2	Ol	98.7		
	#3	Ol	98.7		
	#6	Lpx	97.8	0.9	
	#7	Lpx	97.8	0.9	
	#8	Lpx	97.8	0.9	
	#9	Lpx	97.8	0.9	

Average and 2SD_Ol

Average and 2SD_Lpx

Average and 2SD_Host

#4_Rejected	Ol	98.7		Beam intensity in
#5_Rejected	Ol	98.7		Overlap another p

G100	#1	Ol	99.5		
RF-IA Mg#=99.5	#2	Ol	99.5		
	#3	Ol	99.5		Relict
	#4	Ol	99.5		
	#5	Ol	99.5		
	#6	Ol	99.5		Relict
	#7	Ol	99.5		
	#8	Ol	99.5		
	#9	Ol	99.5		Relict
	#10	Ol	99.5		

Average and 2SD_Host

G71	#1	Ol	61.6		
IIA Mg#=67.6	#2	Ol	75.4		
	#3	Ol	61.9		
	#4	Ol	59.7		
	#5	Ol	60.9		

	#6	Ol	64.5		Relict
	#7	Ol	65.7		
	#8	Ol	64.3		
Average and 2SD_Host					
G75	#1	Ol	87.5		Relict
IIA	#2	Ol	82.4		Relict
Mg#=75.4	#3	Ol	58.3		
	#4	Ol	84.2		Relict
	#5	Ol	59.4		Relict
Average and 2SD_Host					
G39	#1	Ol	90.3		
I-Ol Frag	#2	Ol	90.3		
Mg#=92.3	#3	Ol	90.3		
	#4	Ol	90.3		
	#5	Ol	90.3		
	#6	Ol	90.3		
	#7	Ol	90.3		
Average and 2SD_Host					
G85	#1	Lpx	85.6	1.51	
IIB	#2	Lpx	85.2	1.67	
Mg#=87.1	#3	Lpx	83.4	0.67	
	#4	Lpx	82.8	0.61	
	#5	Lpx	80.9	1.11	
	#6	Lpx	82.7	1.5	
Average and 2SD_Host					
Dec. 2020 Session	Olivine (Fo≥60): Bias/SC-Ol = 0.011*Fo-1.0176				
	Olivine (Fo<60): Bias/SC-Ol = -0.00134*Fo^2+0.2376*Fo-9.8985				
	Pyroxene: Bias/SC-Ol = 2.009-0.013*Fs+0.049*Wo				
G13	#1	Ol	91.7		Relict
RF-IAB	#2	Ol	91.7		Relict
Mg#=98.8	#3	Ol	91.7		Relict
	#4	Ol	91.7		Relict
	#5	Ol	91.7		Relict
	#6	Ol	91.7		Relict
	#7	Ol	91.7		
	#8	Ol	91.7		
	#9	Lpx	96.3	2.3	
	#10	Lpx	96.3	2.3	
	#11	Lpx	96.3	2.3	
Average and 2SD_Ol					
Average and 2SD_Lpx					
Average and 2SD_Host					
G7	#1	Ol	98.8		Relict
IAB	#2	Ol	98.8		

Mg#=98.5	#3	Ol	98.8	
	#4	Ol	98.8	
	#5	Ol	98.8	
	#6	Lpx	97.7	0.9
	#7	Lpx	97.7	0.9
	#9	Lpx	97.7	0.9

Average and 2SD_Ol
Average and 2SD_Lpx
Average and 2SD_Host

#8_Rejected	Lpx	97.7	0.9	Overlap weatheri
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G26	#1	Lpx	98	0.9
IAB	#2	Lpx	98	0.9
Mg#=98.9	#3	Lpx	98	0.9
	#4	Lpx	98	0.9
	#5	Lpx	98	0.9
	#6	Ol	99	Relict
	#7	Ol	99	Relict

Average and 2SD_Host

G38	#2	Ol	99.1	
IAB	#3	Ol	99.1	
Mg#=99.1	#4	Ol	99.1	
	#5	Lpx	95.9	3
	#6	Lpx	95.9	3
	#7	Lpx	95.9	3
	#8	Lpx	95.9	3

Average and 2SD_Ol
Average and 2SD_Lpx
Average and 2SD_Host

#1_Rejected	Ol	99.1	Overlap another 1
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G34	#2	Ol	73.4
IIA	#3	Ol	73.4
Mg#=77.1	#4	Ol	67.6
	#5	Ol	73.4
	#6	Ol	73.2
	#7	Ol	67.2

Average and 2SD_Host

#1_Rejected	Ol	64.5	Overlap another 1
#8_Rejected	Ol	64.7	Overlap another 1

G86	#1	Ol	60.3	Relict
IIA	#2	Ol	61.3	Relict
Mg#=60	#3	Ol	57.2	

Slightly heterogeneous (Uncertainty of $\Delta^{17}\text{O} > 3\text{SD}$)	#4	Ol	58.2
	#5	Ol	59.2
	#6	Ol	60.2
	Average and 2SD Host		

Note: Major element chemistries of olivine and low-Ca pyroxene in Type I chondrules were taken f

No. of Mean	$\delta^{18}\text{O}$	2SE	Unc.	$\delta^{17}\text{O}$	2SE	Unc.	$\Delta^{17}\text{O}$
	-5.77	0.19		-8.81	0.45		-5.81
	-5.67	0.19		-8.68	0.45		-5.73
	2.25	0.19		-0.86	0.45		-2.03
	2.29	0.19		-1.31	0.45		-2.50
	2.24	0.19		-1.11	0.45		-2.27
	1.62	0.19		-1.42	0.45		-2.26
	1.80	0.19		-1.10	0.45		-2.03
3	2.26	0.05	0.33	-1.09	0.46	0.34	-2.27
2	1.71	0.25	0.35	-1.26	0.45	0.39	-2.14
5	2.04	0.62	0.41	-1.16	0.43	0.29	-2.22
phase beneath	1.26	0.42		-2.03	0.54		-2.69
phase beneath	1.45	0.63		-0.52	1.63		-1.27
	-4.35	0.19		-7.37	0.45		-5.11
	-4.47	0.19		-7.70	0.45		-5.37
	-4.61	0.19		-7.40	0.45		-5.00
	-4.51	0.19		-7.44	0.45		-5.10
	-4.59	0.19		-7.45	0.45		-5.06
	-4.23	0.19		-7.36	0.45		-5.16
	-4.43	0.19		-7.31	0.45		-5.01
	-4.65	0.19		-7.57	0.45		-5.15
4	-4.48	0.22	0.33	-7.48	0.30	0.31	-5.15
4	-4.48	0.38	0.36	-7.42	0.22	0.31	-5.09
8	-4.48	0.29	0.32	-7.45	0.25	0.27	-5.12
	2.57	0.26		-0.90	0.40		-2.24
	2.83	0.26		-0.99	0.40		-2.46
	-2.24	0.26		-5.93	0.40		-4.76
	2.19	0.26		-1.35	0.40		-2.49
	1.98	1.02		-1.48	0.72		-2.51
	2.54	0.26		-1.01	0.40		-2.34
	2.58	0.26		-1.03	0.40		-2.37
6	2.45	0.62	0.40	-1.13	0.46	0.28	-2.40
	-5.81	0.14		-9.28	0.39		-6.26
	-6.08	0.14		-9.48	0.39		-6.32
	-6.70	0.14		-10.00	0.39		-6.52
	-6.36	0.14		-9.33	0.39		-6.02
	-6.60	0.14		-9.47	0.39		-6.04
	-6.69	0.14		-9.79	0.39		-6.32
	-7.43	0.14		-10.90	0.39		-7.04

	-6.06	0.14		-9.19	0.39		-6.04
	-7.28	0.14		-10.64	0.39		-6.86
4	-6.24	0.73	0.48	-9.52	0.58	0.35	-6.28
5	-6.81	1.10	0.58	-10.00	1.48	0.69	-6.46
9	-6.56	1.09	0.47	-9.79	1.23	0.46	-6.38
	-6.12	0.14		-9.35	0.39		-6.17
	-6.01	0.14		-9.33	0.39		-6.21
	-6.08	0.14		-9.34	0.39		-6.18
	-6.00	0.14		-9.31	0.39		-6.19
	-6.27	0.14		-9.43	0.39		-6.17
	-5.66	0.14		-8.82	0.39		-5.88
	-5.48	0.14		-9.12	0.39		-6.27
	-5.54	0.14		-9.04	0.39		-6.16
4	-6.05	0.12	0.31	-9.33	0.03	0.28	-6.19
4	-5.74	0.73	0.47	-9.10	0.50	0.32	-6.12
8	-5.91	0.56	0.36	-9.23	0.39	0.25	-6.16
	0.61	0.12		-1.66	0.28		-1.98
	2.36	0.12		-1.09	0.28		-2.32
	2.29	0.12		-1.16	0.28		-2.35
	2.73	0.12		-0.07	0.28		-1.49
	1.69	0.12		-1.61	0.28		-2.49
	-44.59	0.12		-46.60	0.28		-23.41
	-37.46	0.12		-39.68	0.28		-20.20
	-43.84	0.12		-45.51	0.28		-22.72
	-7.87	0.12		-10.73	0.28		-6.63
	-26.61	0.12		-29.22	0.28		-15.38
	-26.60	0.12		-28.89	0.28		-15.06
	-3.14	0.12		-6.56	0.28		-4.92
	-2.37	0.12		-5.65	0.28		-4.42
	-2.75	1.08	0.82	-6.10	1.28	0.92	-4.67
ch & ¹⁶ O-poor Ol	-40.49	0.12		-43.44	0.28		-22.39
ch & ¹⁶ O-poor Ol	-27.62	0.98		-29.77	1.26		-15.41
ch & ¹⁶ O-poor Ol	-15.51	2.50		-18.39	2.95		-10.33
ch & ¹⁶ O-poor Ol	-16.91	1.20		-19.50	1.54		-10.71
ch & ¹⁶ O-poor Ol	-9.30	0.33		-12.60	0.57		-7.77
	2.22	0.16		-1.05	0.22		-2.21
	2.44	0.16		-0.94	0.22		-2.21
	2.45	0.16		-1.37	0.22		-2.64
	2.37	0.16		-1.11	0.22		-2.35
	2.20	0.16		-1.34	0.22		-2.49
	2.20	0.16		-1.80	0.22		-2.94
	2.64	0.16		-1.15	0.22		-2.52

8	2.22	0.16		-1.38	0.22		-2.54
	2.34	0.32	0.33	-1.27	0.54	0.25	-2.49
	1.98	0.48		-1.08	0.38		-2.11
	1.13	0.16		-2.78	0.22		-3.37
	1.12	0.16		-2.29	0.22		-2.87
	1.09	0.16		-2.46	0.22		-3.03
	1.26	0.16		-2.48	0.22		-3.13
4	1.15	0.15	0.32	-2.50	0.41	0.27	-3.10
	1.58	0.48		-1.77	0.33		-2.59
	-6.52	0.12		-9.65	0.43		-6.26
	-5.93	0.12		-9.17	0.43		-6.09
	-6.12	0.12		-9.39	0.43		-6.20
	-6.09	0.12		-9.39	0.43		-6.22
	-5.81	0.12		-9.09	0.43		-6.07
	-5.64	0.12		-8.78	0.43		-5.84
	-6.17	0.12		-9.31	0.43		-6.10
4	-6.16	0.51	0.39	-9.40	0.39	0.30	-6.19
3	-5.88	0.54	0.43	-9.06	0.54	0.38	-6.00
7	-6.04	0.53	0.36	-9.25	0.52	0.29	-6.11
ch & ¹⁶ O-poor Ol	-18.04	1.42		-19.77	1.24		-10.39
	-28.23	0.12		-30.51	0.43		-15.83
	0.83	0.12		-2.38	0.43		-2.81
	-17.49	0.12		-20.20	0.43		-11.11
	-4.45	0.12		-7.35	0.43		-5.03
	1.15	0.12		-1.67	0.43		-2.27
	1.33	0.12		-1.80	0.43		-2.49
	1.53	0.12		-1.75	0.43		-2.55
	1.88	0.12		-1.38	0.43		-2.36
	1.96	0.12		-1.12	0.43		-2.14
2	0.99	0.46	0.44	-2.03	1.01	0.74	-2.54
4	1.67	0.59	0.42	-1.51	0.64	0.39	-2.38
6	1.44	0.86	0.46	-1.69	0.82	0.40	-2.44
	-1.43	0.16		-4.27	0.39		-3.53
	-3.39	0.16		-6.65	0.39		-4.89
	-3.50	0.16		-7.01	0.39		-5.19
	-4.16	0.16		-7.43	0.39		-5.27
	-4.61	0.16		-7.91	0.39		-5.51

	-3.39	0.16		-6.91	0.39		-5.15
	-3.53	0.16		-6.94	0.39		-5.11
	-3.52	0.16		-6.68	0.39		-4.86
	-3.37	0.16		-6.90	0.39		-5.14
2	-3.44	0.16	0.33	-6.83	0.51	0.41	-5.04
4	-3.45	0.17	0.32	-6.86	0.24	0.28	-5.06
6	-3.45	0.15	0.31	-6.85	0.29	0.26	-5.06
	-3.46	0.16		-6.94	0.39		-5.14
	-3.21	0.16		-6.85	0.39		-5.19
	-3.27	0.16		-6.76	0.39		-5.06
	-3.00	0.16		-6.76	0.39		-5.19
4	-3.30	0.22	0.32	-6.81	0.22	0.28	-5.09
1	-3.00	0.16		-6.76	0.39		-5.19
5	-3.24	0.33	0.34	-6.80	0.20	0.27	-5.11
is	-3.28	0.56		-6.68	0.59		-4.98
is	-2.99	0.56		-6.48	0.48		-4.92
	2.14	0.16		-0.51	0.39		-1.62
	1.80	0.16		-1.03	0.39		-1.96
	2.10	0.16		-0.28	0.39		-1.37
	1.91	0.16		-0.82	0.39		-1.81
	1.86	0.16		-0.86	0.39		-1.83
1	2.14	0.16		-0.51	0.39		-1.62
4	1.92	0.26	0.33	-0.75	0.65	0.38	-1.74
5	1.96	0.30	0.33	-0.70	0.60	0.34	-1.72
	-3.52	0.19		-6.93	0.28		-5.10
	-4.50	0.19		-8.36	0.28		-6.02
	-4.78	0.19		-8.44	0.28		-5.95
	-3.79	0.19		-7.25	0.28		-5.28
	-4.89	0.19		-8.56	0.28		-6.02
	-4.98	0.19		-8.76	0.28		-6.17
	-5.09	0.19		-8.80	0.28		-6.15
2	-4.64	0.40	0.42	-8.40	0.12	0.27	-5.99
3	-4.99	0.20	0.33	-8.71	0.25	0.24	-6.11
5	-4.85	0.45	0.37	-8.58	0.38	0.25	-6.06
phase beneath	-4.70	0.52		-9.50	0.40		-7.05
	-13.03	0.19		-15.67	0.28		-8.90
	-13.97	0.19		-16.28	0.28		-9.01
	-10.91	0.19		-14.48	0.28		-8.81
	-11.99	0.19		-14.83	0.28		-8.60
	-12.85	0.19		-15.66	0.28		-8.98
2	-13.50	1.33	0.99	-15.97	0.85	0.63	-8.96

3	-11.92	1.94	1.16	-14.99	1.21	0.72	-8.79
5	-12.55	2.31	1.08	-15.38	1.44	0.67	-8.86
ch & ¹⁶ O-poor Ol	-26.22	2.14		-28.93	2.35		-15.30
ch & ¹⁶ O-poor Ol	-31.97	3.41		-32.53	3.28		-15.90
phase beneath	-7.18	1.31		-1.51	5.31		2.23
ch & ¹⁶ O-poor Ol	-10.24	1.69		-13.15	5.69		-7.83
	2.94	0.14		-1.04	0.20		-2.57
	3.05	0.14		-0.64	0.20		-2.23
	2.79	0.14		-0.70	0.20		-2.15
	2.58	0.14		-0.87	0.20		-2.21
	2.76	0.14		-0.79	0.20		-2.23
5	2.82	0.36	0.34	-0.81	0.31	0.22	-2.28
	1.79	0.14		-1.97	0.20		-2.90
	-5.46	0.14		-8.54	0.20		-5.70
	-0.58	0.14		-4.03	0.20		-3.73
	2.07	0.14		-1.63	0.20		-2.71
	1.39	0.14		-2.34	0.20		-3.07
	1.86	0.14		-1.76	0.20		-2.72
	2.20	0.14		-1.58	0.20		-2.73
	-3.50	0.14		-6.92	0.20		-5.10
	2.50	0.14		-0.96	0.20		-2.26
6	1.97	0.76	0.43	-1.71	0.92	0.41	-2.73
	-6.49	0.14		-9.52	0.20		-6.14
	-6.47	0.14		-9.48	0.20		-6.11
	-6.36	0.14		-9.56	0.20		-6.26
	-6.44	0.14		-9.60	0.20		-6.25
	-6.60	0.14		-9.49	0.20		-6.05
	-6.68	0.14		-9.49	0.20		-6.01
	-6.43	0.14		-9.37	0.20		-6.03
7	-6.50	0.22	0.32	-9.50	0.14	0.18	-6.12
	-5.74	0.26		-8.75	0.27		-5.77
	-5.56	0.26		-8.46	0.27		-5.57
	-5.22	0.26		-8.57	0.27		-5.86
	-5.29	0.26		-8.20	0.27		-5.45
	-5.11	0.26		-8.14	0.27		-5.48
	-5.22	0.26		-8.50	0.27		-5.78
	-5.04	0.26		-7.94	0.27		-5.32
	-5.15	0.26		-8.35	0.27		-5.67
4	-5.45	0.48	0.39	-8.50	0.46	0.29	-5.66
4	-5.13	0.15	0.34	-8.23	0.48	0.30	-5.56
8	-5.29	0.47	0.36	-8.37	0.52	0.26	-5.61
	-10.00	0.26		-13.04	0.27		-7.84

	-10.02	0.26		-12.86	0.27		-7.65
	-7.16	0.26		-10.47	0.27		-6.75
	-7.77	0.26		-10.61	0.27		-6.57
	-8.05	0.26		-10.84	0.27		-6.65
	-8.67	0.26		-11.74	0.27		-7.23
	-4.66	0.26		-7.71	0.27		-5.28
	-5.02	0.26		-8.07	0.27		-5.46
	-4.81	0.26		-7.65	0.27		-5.15
3	-4.83	0.36	0.37	-7.81	0.45	0.32	-5.30
ch & ¹⁶ O-poor Ol	-15.37	2.37		-18.12	1.90		-10.12
ch & ¹⁶ O-poor Ol	-12.97	2.01		-15.61	1.60		-8.87
ch & ¹⁶ O-poor Ol	-14.26	2.16		-17.12	1.98		-9.71
ch & ¹⁶ O-poor Ol	-29.42	4.31		-31.76	3.89		-16.46
	-2.95	0.14		-6.29	0.30		-4.76
	-2.86	0.14		-6.18	0.30		-4.69
	-2.90	0.14		-5.96	0.30		-4.45
	-2.64	0.19		-6.18	0.27		-4.81
	-2.93	0.19		-6.37	0.27		-4.84
	-2.86	0.19		-6.01	0.27		-4.52
	-2.64	0.19		-6.10	0.27		-4.73
3	-2.90	0.09	0.33	-6.14	0.34	0.26	-4.63
4	-2.77	0.30	0.34	-6.17	0.30	0.23	-4.73
7	-2.83	0.26	0.32	-6.16	0.29	0.21	-4.69
stable	-3.29	0.75		-4.75	5.30		-3.04
phase beneath	-2.87	0.19		-6.63	0.27		-5.14
	-1.03	0.19		-3.33	0.27		-2.80
	-0.84	0.19		-3.22	0.27		-2.78
	-7.53	0.19		-9.15	0.27		-5.23
	-1.08	0.19		-3.39	0.27		-2.83
	-1.06	0.19		-3.57	0.27		-3.02
	-7.65	0.19		-9.05	0.27		-5.07
	-0.71	0.19		-3.48	0.27		-3.12
	-1.00	0.19		-3.21	0.27		-2.69
	-6.08	0.19		-8.08	0.27		-4.92
	-0.20	0.19		-2.97	0.27		-2.87
7	-0.84	0.63	0.39	-3.31	0.40	0.23	-2.87
	2.30	0.21		-1.18	0.11		-2.38
	3.12	0.21		-0.60	0.11		-2.22
	2.47	0.21		-0.88	0.11		-2.16
	2.09	0.21		-1.35	0.11		-2.43
	3.26	0.21		-0.38	0.11		-2.07

7	-3.25	0.21		-5.70	0.11		-4.01
	2.86	0.21		-0.81	0.11		-2.30
	2.81	0.21		-0.83	0.11		-2.29
	2.70	0.86	0.45	-0.86	0.66	0.29	-2.27
1	-2.58	0.21		-5.55	0.11		-4.21
	-2.02	0.21		-5.54	0.11		-4.49
	3.81	0.21		-0.04	0.11		-2.02
	-2.07	0.21		-5.34	0.11		-4.26
	-1.93	0.21		-5.22	0.11		-4.22
	3.81	0.21		-0.04	0.11		-2.02
6	3.46	0.26		1.64	0.40		-0.16
	3.33	0.26		1.61	0.40		-0.12
	4.22	0.26		1.97	0.40		-0.22
	3.32	0.26		1.55	0.40		-0.17
	3.50	0.26		1.65	0.40		-0.17
	3.64	0.26		1.47	0.40		-0.42
	3.24	0.26		1.47	0.40		-0.22
	3.42	0.29	0.34	1.57	0.17	0.26	-0.21
6	3.91	0.19		1.98	0.27		-0.05
	3.91	0.19		2.16	0.27		0.12
	3.45	0.19		1.67	0.27		-0.13
	3.84	0.19		2.15	0.27		0.15
	3.82	0.19		2.22	0.27		0.24
	3.72	0.19		2.08	0.27		0.15
	3.78	0.35	0.34	2.04	0.40	0.24	0.08
2	-5.00	0.64		-6.81	0.31		-4.21
	-5.53	0.64		-7.55	0.31		-4.68
	-4.96	0.64		-6.57	0.31		-3.99
	-6.70	0.64		-8.29	0.31		-4.81
	-6.06	0.64		-7.64	0.31		-4.50
	-6.48	0.64		-8.01	0.31		-4.64
	-4.62	0.64		-7.67	0.31		-5.27
	-4.35	0.64		-7.79	0.31		-5.53
	-3.48	0.64		-7.12	0.31		-5.31
	-4.19	0.64		-7.48	0.31		-5.30
	-4.69	0.64		-7.88	0.31		-5.44
	-4.49	0.38	0.59	-7.73	0.18	0.29	-5.40
	-4.12	1.22	0.80	-7.49	0.76	0.48	-5.35
	-4.26	0.97	0.57	-7.59	0.61	0.33	-5.37
	-12.23	0.64		-14.67	0.31		-8.31
	-2.69	0.64		-6.34	0.31		-4.94

	-2.58	0.64		-5.93	0.31		-4.59
	-2.94	0.64		-6.07	0.31		-4.54
	-3.05	0.64		-6.04	0.31		-4.45
	-3.06	0.64		-6.26	0.31		-4.66
	-3.13	0.64		-6.66	0.31		-5.04
	-2.81	0.64		-6.57	0.31		-5.11
4	-2.81	0.43	0.49	-6.09	0.35	0.26	-4.63
3	-3.00	0.34	0.53	-6.50	0.43	0.31	-4.94
7	-2.89	0.42	0.45	-6.27	0.56	0.28	-4.76
ng products	-1.43	0.70		-5.92	0.49		-5.18
	-4.65	0.41		-8.15	0.34		-5.73
	-4.39	0.41		-7.58	0.34		-5.30
	-4.70	0.41		-7.91	0.34		-5.47
	-4.74	0.41		-7.95	0.34		-5.48
	-4.36	0.41		-7.70	0.34		-5.43
	-1.07	0.41		-4.26	0.34		-3.70
	-1.64	0.41		-4.73	0.34		-3.88
5	-4.57	0.36	0.38	-7.86	0.45	0.28	-5.48
	-3.25	0.41		-6.28	0.34		-4.59
	-3.17	0.41		-6.54	0.34		-4.89
	-3.03	0.41		-6.53	0.34		-4.96
	-3.40	0.41		-7.02	0.34		-5.25
	-3.43	0.41		-6.65	0.34		-4.87
	-3.38	0.41		-6.43	0.34		-4.67
	-2.93	0.41		-6.38	0.34		-4.86
3	-3.15	0.23	0.41	-6.45	0.29	0.27	-4.81
4	-3.29	0.47	0.41	-6.62	0.58	0.35	-4.91
7	-3.23	0.39	0.37	-6.55	0.48	0.26	-4.87
phase beneath	-4.05	0.63		-6.72	0.46		-4.61
	2.71	0.48		-0.93	0.39		-2.34
	2.62	0.48		-0.84	0.39		-2.21
	2.36	0.48		-1.07	0.39		-2.29
	3.37	0.48		-0.62	0.39		-2.37
	3.07	0.48		-0.79	0.39		-2.38
	3.22	0.48		-0.28	0.39		-1.96
6	2.89	0.78	0.47	-0.75	0.55	0.30	-2.26
phase beneath	3.32	0.61		-0.43	0.54		-2.16
phase beneath	1.87	0.76		-1.39	0.62		-2.36
	1.61	0.48		-1.78	0.39		-2.62
	-0.66	0.48		-4.00	0.39		-3.66
	3.03	0.48		-0.20	0.39		-1.78

	2.64	0.48		-0.76	0.39		-2.13
	3.22	0.48		-0.55	0.39		-2.22
	2.16	0.48		-1.53	0.39		-2.66
4	2.76	0.93	0.58	-0.76	1.13	0.60	-2.20

rom Ushikubo et al (2012) and mean values for each mineral were used. In addition, Fo mol% cont

SIMS oxygen isotope ratios of chondrules in Acfer 09

2SE	Unc.	Analysis point	Mineral	Fo/En	Wo	Notes
0.39		a	Ol	94.1		
0.39		b	Ol	93.4		
0.39		d	Ol	95.0		
0.39		e	Ol	94.5		
0.39		f	LPx	91.2	3.5	
0.39		g	LPx	90.5	3.6	
0.39		c	Ol	95.4		Relict
0.48	0.31	Average and 2SD_Ol				
0.33	0.31	Average and 2SD_Lpx				
0.40	0.27	Average and 2SD_Host				
0.53						
1.65						
0.39		a	Ol	99.3		
0.39		b	Ol	99.2		
0.39		c	Ol	99.3		
0.39		d	Ol	99.2		
0.39		e	Ol	99.1		
0.39		f	Ol	99.1		
0.39		g	Ol	99.5		
0.39		h	Ol	98.9		
		i	Ol	99.4		
0.32	0.24	Average and 2SD_Ol				
0.14	0.24					
0.24	0.20					
0.31		a	Ol	94.9		
0.31		c	Ol	94.5		
0.31		b	Ol	94.3		Relict
0.31						
0.31						
0.31						
0.31						
0.21	0.17	Average and 2SD_Ol				
0.37		a	Ol	99.2		
0.37		b	Ol	99.1		
0.37		c	Ol	99.2		
0.37		d	Ol	99.4		
0.37		e	LPx	97.7	1.1	
0.37		f	LPx	97.1	1.4	
0.37						

0.37

0.37

0.41 0.25**Average and 2SD_OI****0.93 0.44****Average and 2SD_Lpx****0.73 0.28****Average and 2SD_Host**

0.37

a

OI

99.6

0.37

b

OI

99.2

0.37

c

OI

99.5

0.37

d

OI

99.4

0.37

e

LPx

97.8

1.0

0.37

0.37

0.37

0.37

0.03 0.23**Average and 2SD_OI****0.33 0.23****Average and 2SD_Lpx****0.22 0.19****Average and 2SD_Host**

0.29

a

OI

48.5

0.29

b

OI

42.1

0.29

c

LPx

49.9

2.3

0.29

d

LPx

47.3

1.1

0.29

e

LPx

46.7

1.2

Heterogeneous

0.29

a

OI

98.6

0.29

b

OI

98.8

0.29

c

OI

98.6

0.29

d

OI

98.5

0.29

e

OI

98.6

0.29

f

OI

98.6

0.29

g

LPx

95.1

1.0

0.29

h

LPx

96.1

1.0

0.72 0.52**Heterogeneous**

0.29

1.36

3.23

1.66

0.60

0.22

a

OI

61.1

0.22

b

OI

63.1

0.22

c

OI

44.3

0.22

d

OI

59.0

0.22

e

OI

42.2

0.22

f

OI

59.6

0.22

g

OI

46.8

0.22		h	Ol	41.4	
0.48	0.19	Average and 2SD_OI			
0.45					
0.22		b	Ol	61.2	
0.22		c	Ol	68.0	
0.22		f	Ol	66.1	
0.22		a	Ol	77.3	Relict
		d	Ol	80.5	Relict
		e	Ol	84.4	Relict
0.42	0.22	Average and 2SD_OI			
0.41					
0.40		a	Ol	98.9	
0.40		b	Ol	99.2	
0.40		d	Ol	98.9	
0.40		e	Ol	98.7	
0.40		f	LPx	97.8	1.0
0.40		g	LPx	98.0	1.1
0.40		h	LPx	97.9	1.0
		i	LPx	94.7	2.3
		c	Ol	99.2	Relict
0.14	0.25	Average and 2SD_OI			
0.28	0.27	Average and 2SD_Lpx			
0.27	0.21	Average and 2SD_Host			
1.43					
0.40		c	LPx	93.1	2.6
0.40		d	LPx	95.3	0.9
0.40		e	LPx	93.3	2.8
0.40		f	LPx	90.3	4.1
0.40		a	Ol	95.5	Relict
0.40		b	Ol	95.8	Relict
0.40					
0.40					
0.77	0.56				
0.36	0.25	Average and 2SD_Lpx			
0.44	0.23	Average and 2SD_Host			
0.38		b	Ol	98.9	
0.38		c	Ol	99.0	
0.38		f	Ol	98.7	
0.38		g	LPx	97.6	0.7
0.38		h	LPx	98.2	0.8

0.38		i	LPx	98.2	0.9	
0.38		a	Ol	98.6		Relict
0.38		d	Ol	99.0		Relict
0.38		e	Ol	98.8		Relict
0.42	0.33	Average and 2SD_Ol				
0.28	0.23	Average and 2SD_Lpx				
0.29	0.21	Average and 2SD_Host				
0.38						
0.38						
0.38						
0.38						
0.18	0.23					
0.38						
0.18	0.22					
0.65						
0.56						
0.38						
0.38						
0.38						
0.38						
0.38						
0.38						
0.51	0.29					
0.46	0.24					
0.33		a	Ol	99.1		
0.33		d	LPx	98.0	1.0	
0.33		e	LPx	98.0	1.0	
0.33		f	LPx	97.9	0.9	
0.33		b	Ol	99.0		Relict
0.33		c	Ol	99.2		Relict
0.33						
0.09	0.26	Average and 2SD_Ol				
0.16	0.22	Average and 2SD_Lpx				
0.19	0.19	Average and 2SD_Host				
0.51						
0.33		a	Ol	99.3		
0.33		b	Ol	99.3		
0.33		c	Ol	99.3		
0.33		d	Ol	99.3		
0.33		e	LPx	96.0	1.0	
		f	LPx	97.9	0.9	
0.16	0.26	Average and 2SD_Ol				

0.38	0.25		Average and 2SD_Lpx			
0.33	0.19		Average and 2SD_Host			
2.61						
3.73						
5.36						
5.76						
0.26			a	Ol	74.1	
0.26			b	Ol	74.2	
0.26			c	Ol	76.2	
0.26			d	Ol	51.5	
0.26						
0.33	0.17		Average and 2SD_Host			
0.26			a	Ol	69.6	
0.26			b	Ol	71.5	
0.26			e	Ol	57.7	
0.26			c	Ol	86.3	Relict
0.26			d	Ol	79.8	Relict
0.26						
0.26						
0.26						
0.26						
0.54	0.24		Average and 2SD_Host			
0.26			a	Ol	99.6	
0.26			b	Ol	99.2	
0.26			c	Ol	99.0	
0.26			d	Ol	99.5	
0.26			e	Ol	99.5	
0.26						
0.26						
0.20	0.13		Average and 2SD_Host			
0.23			a	Ol	99.7	
0.23			b	Ol	99.5	
0.23			c	Ol	99.5	
0.23			d	Ol	99.5	
0.23			e	Ol	99.1	
0.23			f	LPx	98.5	0.7
0.23						
0.23						
0.37	0.20		Average and 2SD_Ol			
0.41	0.22	Average and 2SD_Lpx				
0.38	0.16		Average and 2SD_Host			
0.23			a	Ol	99.0	Relict

0.23			b	Ol	99.1		Relict
0.23			c	Ol	99.4		Relict
0.23			d	Ol	99.0		Relict
0.23			e	Ol	99.4		Relict
0.23			f	Ol	99.3		Relict
0.23			g	Ol	99.2		Relict
0.23			h	Ol	97.5		Relict
0.23			i	Ol	99.3		Relict
			j	LPx	98.0	1.3	
			k	LPx	98.0	1.2	

0.31 0.20 Average and 2SD_Lpx

2.26
1.90
2.27
4.49

0.26			a	Ol	98.7		
0.26			b	Ol	98.6		
0.26			c	LPx	98.2	0.8	
0.22			d	LPx	98.2	0.7	
0.22			e	LPx	98.0	0.8	

0.22
0.22
0.32 0.20 Average and 2SD_Ol
0.29 0.16 Average and 2SD_Lpx
0.29 0.13 Average and 2SD_Host

5.31
0.22

0.22			a	Ol	99.5		
0.22			b	Ol	99.1		
0.22			c	Ol	99.8		
0.22			d	Ol	99.5		
0.22			e	Ol	99.6		
0.22			f	Ol	99.5		
0.22			g	Ol	99.7		
0.22			h	Ol	99.6		
0.22			i	Ol	99.1		

0.22
0.30 0.14 Heterogeneous

0.22			a	Ol	63.5		
0.22			c	Ol	78.9		
0.22			d	Ol	79.0		
0.22			e	Ol	61.5		
0.22			f	Ol	69.7		

0.22			g	Ol	73.0	
0.22			b	Ol	76.0	Relict
0.22						
0.25	0.12		Average and 2SD_Host			
0.22						
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0.50			d	Ol	98.7		
0.50			e	LPx	97.6	0.8	
0.50			f	LPx	97.8	0.9	
0.50			b	Ol	98.9		Relict
0.50							
0.50							
0.43	0.30		Average and 2SD_Ol				
0.48	0.34		Average and 2SD_Lpx				
0.53	0.27		Average and 2SD_Host				
0.64							
0.23			c	LPx	98.1	0.9	
0.23			d	LPx	97.8	1.1	
0.23			e	LPx	98.3	0.7	
0.23			a	Ol	99.2		Relict
0.23			b	Ol	98.8		Relict
0.23							
0.23							
0.32	0.16		Average and 2SD_Host				
0.23			a	Ol	99.2		
0.23			b	Ol	99.0		
0.23			c	Ol	99.1		
0.23			d	LPx	99.1	3.9	
0.23			e	LPx	95.1	4.0	
0.23			f	LPx	95.0	1.2	
0.23							
0.39	0.24		Average and 2SD_Ol				
0.49	0.26		Average and 2SD_Lpx				
0.42	0.18		Average and 2SD_Host				
0.47							
0.28			b	Ol	78.0		
0.28			c	Ol	67.1		
0.28			a	Ol	96.2		Relict
0.28			d	Ol	68.1		Relict
0.28							
0.28							
0.32	0.16		Average and 2SD_Host				
0.50							
0.64							
0.28			c	Ol	62.2		
0.28			d	Ol	63.5		
0.28			e	Ol	63.1		

0.28			a	Ol	63.2	Relict
0.28			b	Ol	70.7	Relict
0.28						
0.72	0.37		Average and 2SD_Host			

ents for iron-rich olivine in Type II chondrules were determiend by EDS in this study.

¹⁴ chondrite determined by Ushikubo et al. (2012)

						Difference between two studies		
$\delta^{18}\text{O}$	Unc.	$\delta^{17}\text{O}$	Unc.	$\Delta^{17}\text{O}$	Unc.	Ol dif	Lpx Diff	Host diff
2.04	0.16	-0.64	0.50	-1.70	0.53			
1.91	0.16	-0.58	0.50	-1.57	0.53			
1.86	0.16	-1.34	0.50	-2.31	0.53			
1.85	0.16	-0.95	0.50	-1.91	0.53			
0.56	0.16	-1.52	0.50	-1.81	0.53			
0.79	0.16	-1.85	0.50	-2.26	0.53			
-5.84	0.16	-8.50	0.50	-5.46	0.53			
1.91	0.17	-0.88	0.70	-1.87	0.65	0.34		
0.68	0.32	-1.69	0.47	-2.04	0.64		1.03	
1.50	0.61	-1.15	0.44	-1.93	0.25			0.54
-5.05	0.25	-7.66	0.48	-5.03	0.58			
-4.95	0.25	-7.68	0.48	-5.11	0.58			
-4.62	0.25	-7.66	0.48	-5.26	0.58			
-4.97	0.25	-7.42	0.48	-4.83	0.58			
-4.65	0.25	-7.60	0.48	-5.18	0.58			
-4.85	0.25	-7.58	0.48	-5.06	0.58			
-4.69	0.25	-7.57	0.48	-5.13	0.58			
-3.74	0.25	-6.35	0.48	-4.41	0.58			
-4.91	0.25	-7.39	0.48	-4.84	0.58			
-4.71	0.79	-7.43	0.84	-4.98	0.52	0.23		
2.0	0.23	-1.2	0.71	-2.2	0.72			
1.8	0.23	-1.3	0.71	-2.2	0.72			
-3.3	0.23	-5.3	0.71	-3.5	0.72			
1.88	0.28	-1.22	0.17	-2.19	0.02	0.57		
-6.24	0.25	-9.67	0.48	-6.42	0.58			
-6.42	0.25	-9.24	0.48	-5.91	0.58			
-6.60	0.25	-9.70	0.48	-6.26	0.58			
-5.85	0.25	-8.87	0.48	-5.82	0.58			
-7.29	0.25	-10.02	0.48	-6.23	0.58			
-8.41	0.25	-10.70	0.48	-6.33	0.58			

-6.28	0.64	-9.37	0.79	-6.10	0.57	0.04	1.04	0.25
-7.85	1.58	-10.36	0.97	-6.28	0.15			
-6.80	0.81	-9.70	0.54	-6.16	0.24			
-6.64	0.32	-10.22	0.88	-6.77	0.87			
-6.67	0.32	-9.74	0.88	-6.27	0.87			
-6.75	0.32	-9.37	0.88	-5.86	0.87			
-6.84	0.32	-9.55	0.88	-6.00	0.87			
-6.71	0.32	-9.21	0.88	-5.72	0.87			
-6.72	0.18	-9.72	0.73	-6.22	0.80	0.67	0.97	0.81
-6.71	0.32	-9.21	0.88	-5.72	0.87			
-6.72	0.33	-9.62	0.42	-6.12	0.39			
-0.02	0.16	-1.77	0.50	-1.76	0.53			
-0.75	0.16	-2.22	0.50	-1.83	0.53			
0.95	0.16	-0.50	0.50	-0.99	0.53			
0.88	0.16	-1.30	0.50	-1.76	0.53			
0.63	0.16	-1.04	0.50	-1.37	0.53			
-11.65	0.32	-13.12	0.88	-7.06	0.87			
-26.50	0.32	-28.55	0.88	-14.77	0.87			
-33.55	0.32	-35.40	0.88	-17.95	0.87			
-34.96	0.32	-36.74	0.88	-18.56	0.87			
-43.39	0.30	-45.57	0.54	-23.00	0.63			
-7.91	0.30	-11.55	0.54	-7.44	0.63			
-7.90	0.32	-10.11	0.88	-6.00	0.87			
-1.81	0.30	-4.93	0.54	-3.99	0.63			
1.37	0.31	-1.69	0.50	-2.40	0.41			
1.77	0.31	-1.33	0.50	-2.25	0.41			
0.61	0.22	-1.81	0.67	-2.12	0.68			
1.19	0.31	-1.81	0.50	-2.43	0.41			
0.65	0.22	-1.89	0.67	-2.23	0.68			
1.72	0.22	-1.09	0.67	-1.99	0.68			
-1.19	0.22	-2.68	0.67	-2.06	0.68			

0.61	0.22	-1.90	0.67	-2.22	0.68		0.77		
1.57	0.50	-1.51	0.50	-2.27	0.19				
0.5	0.20	-2.0	0.43	-2.3	0.44				
0.6	0.20	-2.6	0.43	-2.9	0.44				
-1.2	0.20	-3.8	0.43	-3.1	0.44				
-0.01	0.20	-3.71	0.43	-3.70	0.44				
-2.73	0.20	-5.59	0.43	-4.18	0.44				3.88
-7.48	0.20	-10.41	0.43	-6.52	0.44				
-0.03	2.02	-2.79	1.80	-2.78	0.92				
							1.18		
-6.2	0.30	-9.4	0.54	-6.1	0.63				
-5.8	0.23	-9.2	0.63	-6.1	0.61				
-6.5	0.23	-9.0	0.63	-5.7	0.61				
-6.1	0.30	-8.6	0.54	-5.5	0.63				
-7.0	0.23	-9.0	0.63	-5.3	0.61				
-6.9	0.23	-9.2	0.63	-5.6	0.61				
-6.6	0.30	-9.1	0.54	-5.6	0.63				
-7.1	0.30	-9.4	0.54	-5.7	0.63				
-31.95	0.23	-33.84	0.63	-17.23	0.61				
-6.18	0.57	-9.06	0.61	-5.84	0.69				
-6.91	0.44	-9.16	0.38	-5.57	0.37				
-6.54	0.44	-9.11	0.27	-5.70	0.22				
							0.01		
1.0	0.23	-2.0	0.71	-2.5	0.72				
0.7	0.23	-1.8	0.71	-2.2	0.72				
0.4	0.23	-2.3	0.71	-2.5	0.72				
0.6	0.23	-2.2	0.71	-2.5	0.72				
-24.80	0.23	-27.81	0.71	-14.92	0.72				
-14.08	0.23	-16.49	0.71	-9.17	0.72				
0.66	0.50	-2.08	0.47	-2.42	0.34				
0.66	0.39	-2.08	0.38	-2.42	0.36				
							1.01		
-4.7	0.23	-7.5	0.71	-5.1	0.72				
-4.1	0.23	-7.2	0.71	-5.0	0.72				
-5.6	0.23	-7.9	0.71	-5.1	0.72				
-4.4	0.23	-6.7	0.71	-4.4	0.72				
-4.6	0.23	-7.3	0.71	-4.9	0.72				

-4.1	0.30	-7.0	0.54	-4.8	0.63	1.36	0.93	1.14
-2.18	0.23	-4.04	0.71	-2.91	0.72			
1.04	0.30	-1.18	0.54	-1.72	0.63			
-0.70	0.30	-3.31	0.54	-2.94	0.63			
-4.80	1.47	-7.55	0.78	-5.05	0.03			
-4.38	0.49	-6.99	0.63	-4.71	0.53			
-4.59	0.53	-7.27	0.39	-4.88	0.29			
-5.38	0.33	-8.88	0.36	-6.08	0.34	0.74	0.95	0.95
-5.90	0.33	-9.44	0.36	-6.37	0.34			
-6.00	0.33	-8.80	0.36	-5.68	0.34			
-5.90	0.33	-8.49	0.36	-5.42	0.34			
-4.54	0.33	-7.38	0.36	-5.02	0.34			
-3.17	0.33	-5.89	0.36	-4.24	0.34			
-5.38	0.33	-8.88	0.36	-6.08	0.34			
-5.93	0.12	-8.91	0.97	-5.83	0.98	-0.85		
-5.80	0.41	-8.90	0.43	-5.89	0.42			
-12.3	0.63	-16.3	0.82	-9.9	0.95			
-12.1	0.63	-16.3	0.82	-10.0	0.95			
-13.0	0.63	-16.0	0.82	-9.2	0.95			
-13.2	0.63	-16.3	0.82	-9.4	0.95			
-13.5	0.63	-16.5	0.82	-9.5	0.95			
-12.3	0.63	-14.3	0.82	-7.9	0.95			
-12.65	1.04	-16.21	0.28	-9.63	0.69			

-12.89	1.62	-15.43	3.10	-8.73	2.26		0.97	
-12.73	0.54	-15.95	0.68	-9.33	0.60			0.18
2.25	0.35	-1.29	0.48	-2.45	0.58			
2.13	0.35	-1.44	0.48	-2.55	0.58			
2.40	0.35	-1.50	0.48	-2.75	0.58			
1.47	0.35	-1.64	0.48	-2.40	0.58			
2.26	0.36	-1.41	0.31	-2.54	0.29		0.57	
0.8	0.32	-1.7	0.88	-2.1	0.87			
0.6	0.32	-2.3	0.88	-2.6	0.87			
0.5	0.32	-2.6	0.88	-2.9	0.87			
-11.39	0.32	-13.18	0.88	-7.26	0.87			
-3.26	0.32	-6.15	0.88	-4.45	0.87			
0.72	0.39	-2.01	0.64	-2.54	0.50		1.25	
-6.7	0.24	-9.7	0.55	-6.2	0.61			
-6.7	0.24	-9.8	0.55	-6.3	0.61			
-6.9	0.24	-9.9	0.55	-6.3	0.61			
-7.1	0.24	-9.6	0.55	-5.9	0.61			
-6.7	0.24	-10.1	0.55	-6.6	0.61			
-6.82	0.33	-9.82	0.29	-6.27	0.27		0.33	
-5.93	0.26	-8.06	0.89	-4.98	0.90			
-5.96	0.26	-8.56	0.89	-5.46	0.90			
-5.83	0.26	-8.30	0.89	-5.26	0.90			
-5.80	0.26	-9.13	0.89	-6.12	0.90			
-5.71	0.26	-8.63	0.89	-5.66	0.90			
-5.94	0.26	-8.93	0.89	-5.84	0.90			
-5.85	0.21	-8.54	0.80	-5.50	0.86		0.39	
-5.94	0.26	-8.93	0.89	-5.84	0.90			0.81
-5.86	0.32	-8.60	0.39	-5.55	0.37			0.57
-7.90	0.26	-11.29	0.89	-7.18	0.90			

-9.06	0.26	-11.97	0.89	-7.26	0.90
-10.45	0.26	-13.15	0.89	-7.72	0.90
-30.30	0.26	-32.51	0.89	-16.76	0.90
-32.34	0.26	-34.71	0.89	-17.90	0.90
-9.80	0.26	-12.09	0.89	-6.99	0.90
-8.78	0.26	-11.77	0.89	-7.20	0.90
-5.34	0.26	-8.52	0.89	-5.74	0.90
-26.18	0.30	-28.22	0.54	-14.61	0.63
-5.98	0.26	-8.66	0.89	-5.55	0.90
-6.41	0.30	-8.77	0.54	-5.44	0.63
-6.19	0.61	-8.71	0.16	-5.49	0.16

1.36

-3.6	0.35	-6.6	0.48	-4.7	0.58
-3.0	0.35	-6.4	0.48	-4.8	0.58
-3.6	0.35	-6.6	0.48	-4.8	0.58
-3.4	0.35	-6.5	0.48	-4.7	0.58
-3.5	0.35	-6.6	0.48	-4.8	0.58

-3.27	0.82	-6.48	0.22	-4.78	0.21
-3.50	0.15	-6.58	0.12	-4.77	0.04
-3.41	0.37	-6.54	0.26	-4.77	0.26

0.37

0.73

0.58

-1.0	0.24	-4.0	0.55	-3.5	0.61
-1.3	0.24	-3.3	0.55	-2.6	0.61
-8.0	0.24	-10.7	0.55	-6.6	0.61
-3.3	0.24	-5.4	0.55	-3.6	0.61
-7.6	0.24	-9.3	0.55	-5.3	0.61
-1.2	0.24	-4.1	0.55	-3.4	0.61
-7.9	0.24	-9.7	0.55	-5.5	0.61
-8.9	0.24	-11.4	0.55	-6.7	0.61
-1.7	0.24	-4.2	0.55	-3.3	0.61

1.4	0.23	-1.7	0.63	-2.4	0.61
2.7	0.23	-0.2	0.63	-1.6	0.61
2.5	0.23	-0.9	0.63	-2.2	0.61
1.7	0.23	-1.4	0.63	-2.3	0.61
2.1	0.23	-1.2	0.63	-2.2	0.61

2.0	0.23	-0.6	0.63	-1.6	0.61
-1.15	0.23	-4.10	0.63	-3.50	0.61

2.07	0.49	-0.98	0.45	-2.05	0.27	0.63
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3.1	0.19	0.9	0.71	-0.7	0.75
3.1	0.19	1.0	0.71	-0.6	0.75
2.6	0.19	1.0	0.71	-0.4	0.75
3.6	0.19	1.6	0.71	-0.3	0.75

3.12	0.51	1.12	0.39	-0.51	0.37	0.29
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2.8	0.33	1.5	0.36	0.1	0.34
2.4	0.33	1.7	0.36	0.4	0.34
3.1	0.33	1.3	0.36	-0.3	0.34
2.5	0.33	1.2	0.36	0.0	0.34
2.8	0.33	1.6	0.36	0.1	0.34

2.70	0.39	1.46	0.22	0.06	0.25	1.08
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-4.1	0.20	-6.0	0.43	-3.8	0.44
-7.1	0.20	-8.3	0.43	-4.6	0.44
-5.0	0.20	-7.5	0.43	-4.9	0.44
-6.8	0.20	-7.4	0.43	-3.8	0.44
-6.6	0.20	-8.2	0.43	-4.8	0.44
-3.5	0.20	-5.2	0.43	-3.4	0.44

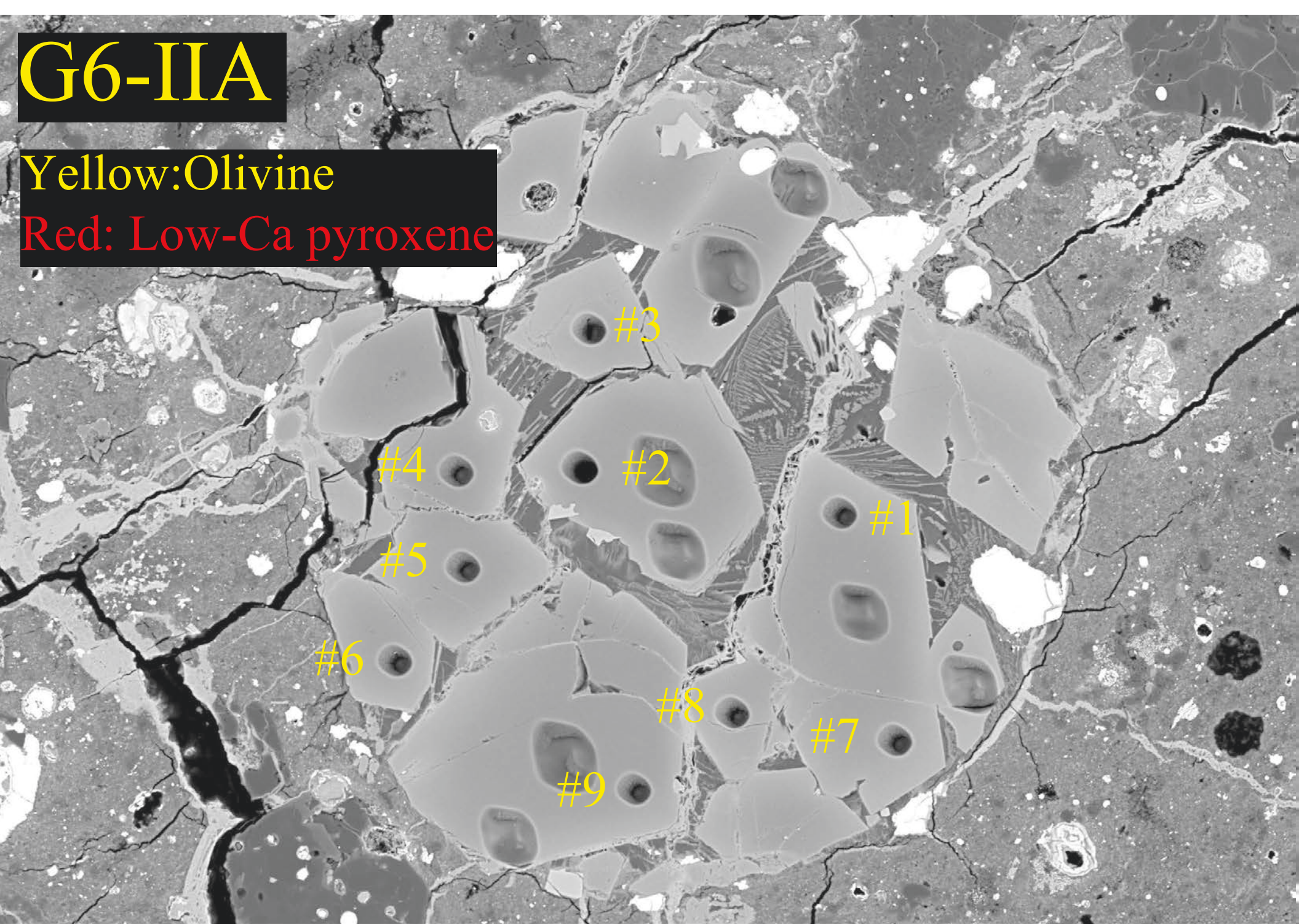
-2.9	0.22	-6.1	0.67	-4.6	0.68
-3.2	0.22	-6.5	0.67	-4.8	0.68

-3.1	0.22	-7.2	0.67	-5.5	0.68						
-4.0	0.22	-6.9	0.67	-4.8	0.68						
-3.7	0.22	-7.4	0.67	-5.5	0.68						
-14.42	0.22	-16.38	0.67	-8.88	0.68						
-3.09	0.32	-6.60	1.08	-4.99	0.99						
-3.83	0.43	-7.14	0.69	-5.15	0.92						
-3.39	0.49	-6.82	0.48	-5.06	0.38						
-5.6	0.16	-8.1	0.34	-5.2	0.39						
-5.5	0.16	-8.1	0.34	-5.2	0.39						
-5.5	0.16	-7.4	0.34	-4.5	0.39						
-1.72	0.16	-4.28	0.34	-3.39	0.39						
-3.48	0.16	-5.90	0.34	-4.09	0.39						
-5.53	0.31	-7.87	0.50	-4.99	0.46						
-4.0	0.19	-7.0	0.71	-5.0	0.75						
-2.5	0.19	-5.6	0.71	-4.3	0.75						
-2.9	0.19	-6.1	0.71	-4.5	0.75						
-4.4	0.19	-7.2	0.71	-4.9	0.75						
-4.4	0.19	-7.3	0.71	-5.0	0.75						
-4.2	0.19	-7.2	0.71	-5.0	0.75						
-3.13	1.55	-6.21	1.49	-4.59	0.69						
-4.33	0.24	-7.24	0.12	-4.99	0.13						
-3.73	0.74	-6.73	0.62	-4.79	0.31						
2.1	0.19	-1.8	0.71	-2.9	0.75						
1.5	0.19	-1.8	0.71	-2.6	0.75						
-5.52	0.19	-7.97	0.71	-5.10	0.75						
-4.15	0.19	-7.50	0.71	-5.34	0.75						
1.79	0.90	-1.83	0.07	-2.75	0.40						
1.7	0.35	-1.5	0.48	-2.4	0.58						
1.4	0.35	-2.1	0.48	-2.8	0.58						
1.8	0.35	-0.9	0.48	-1.8	0.58						

G6-IIA

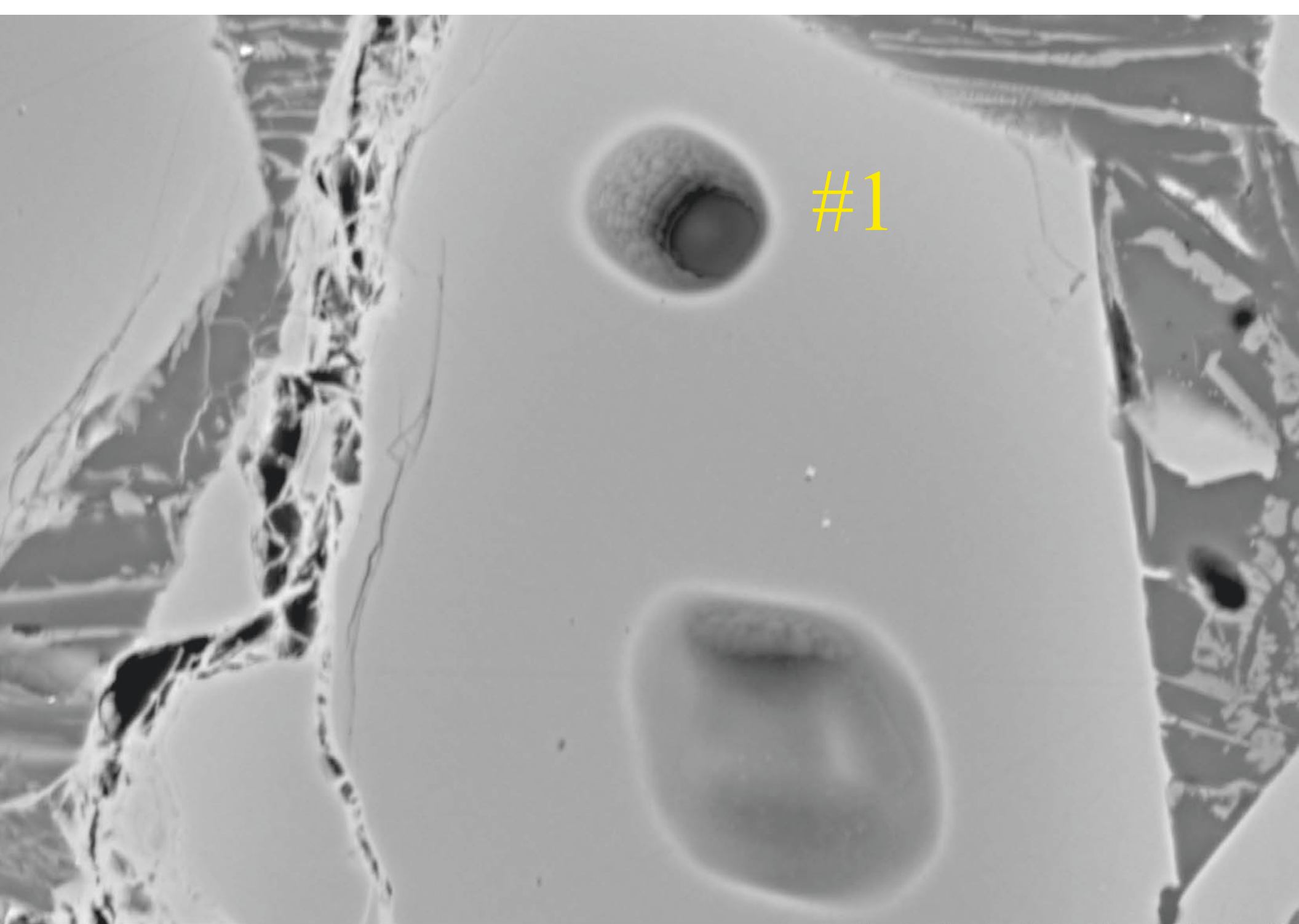
Yellow: Olivine

Red: Low-Ca pyroxene



15.0kV x370 BSECOMP

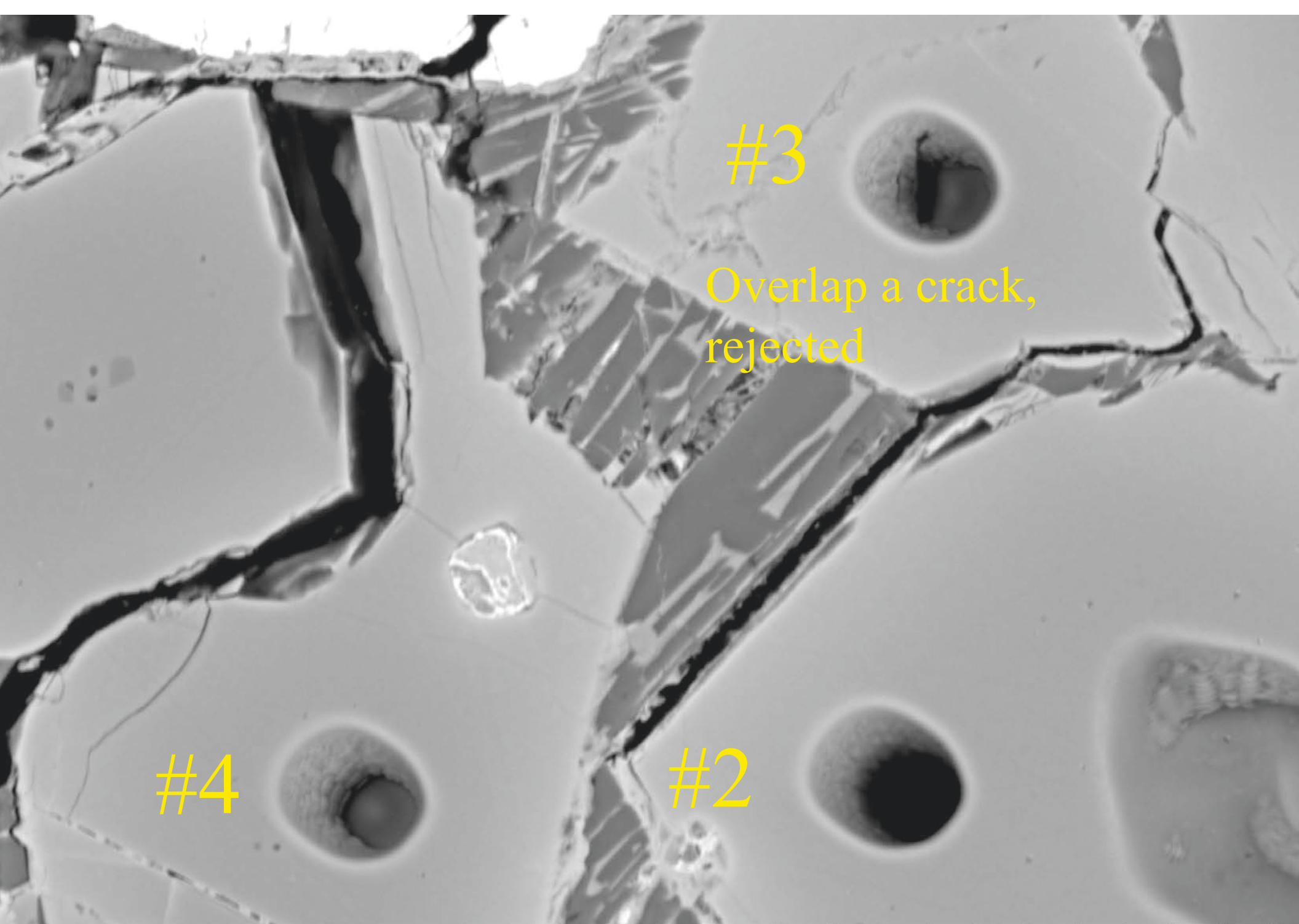
100um



#1

15.0kV x2.00k BSECOMP

20.0um

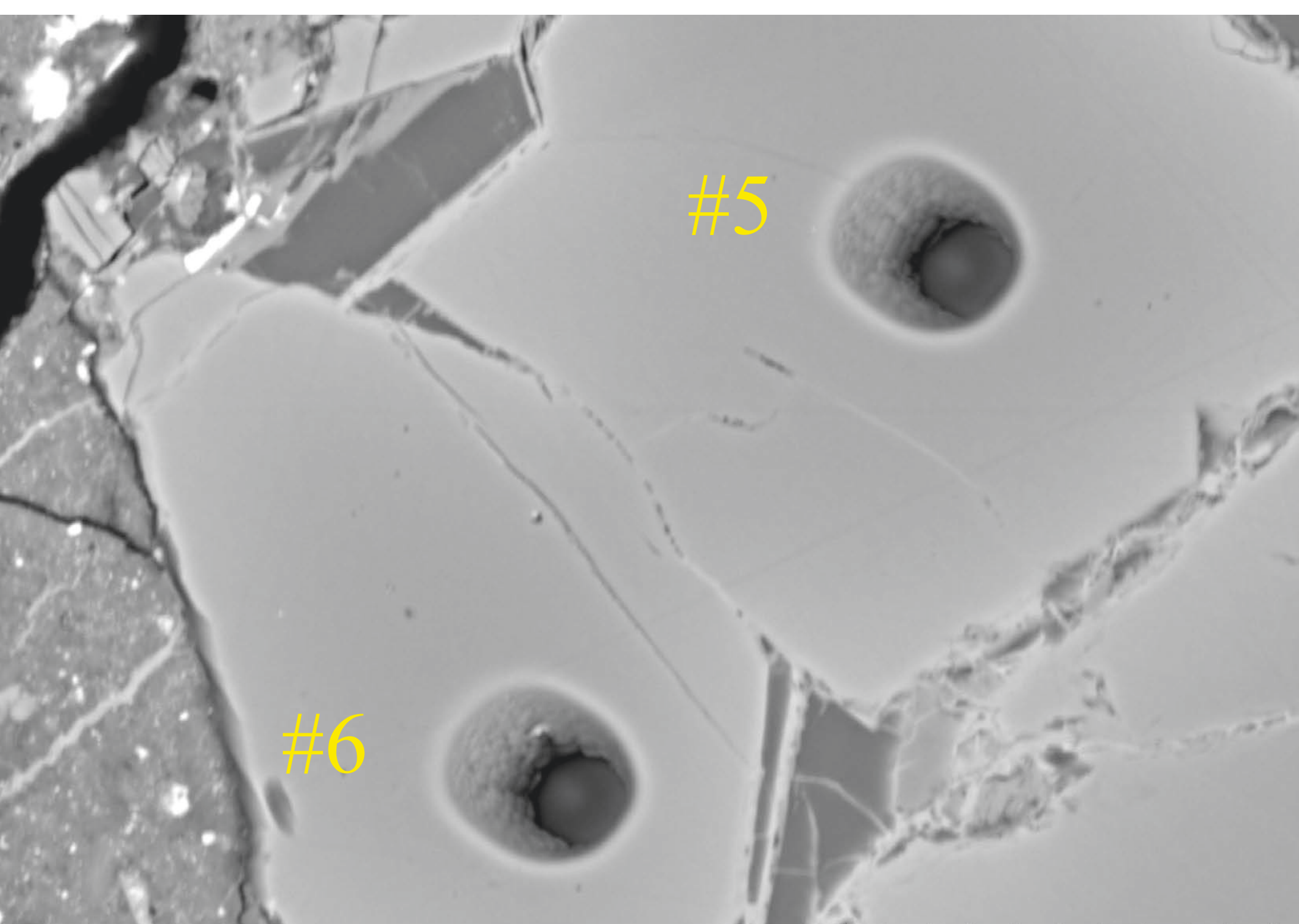


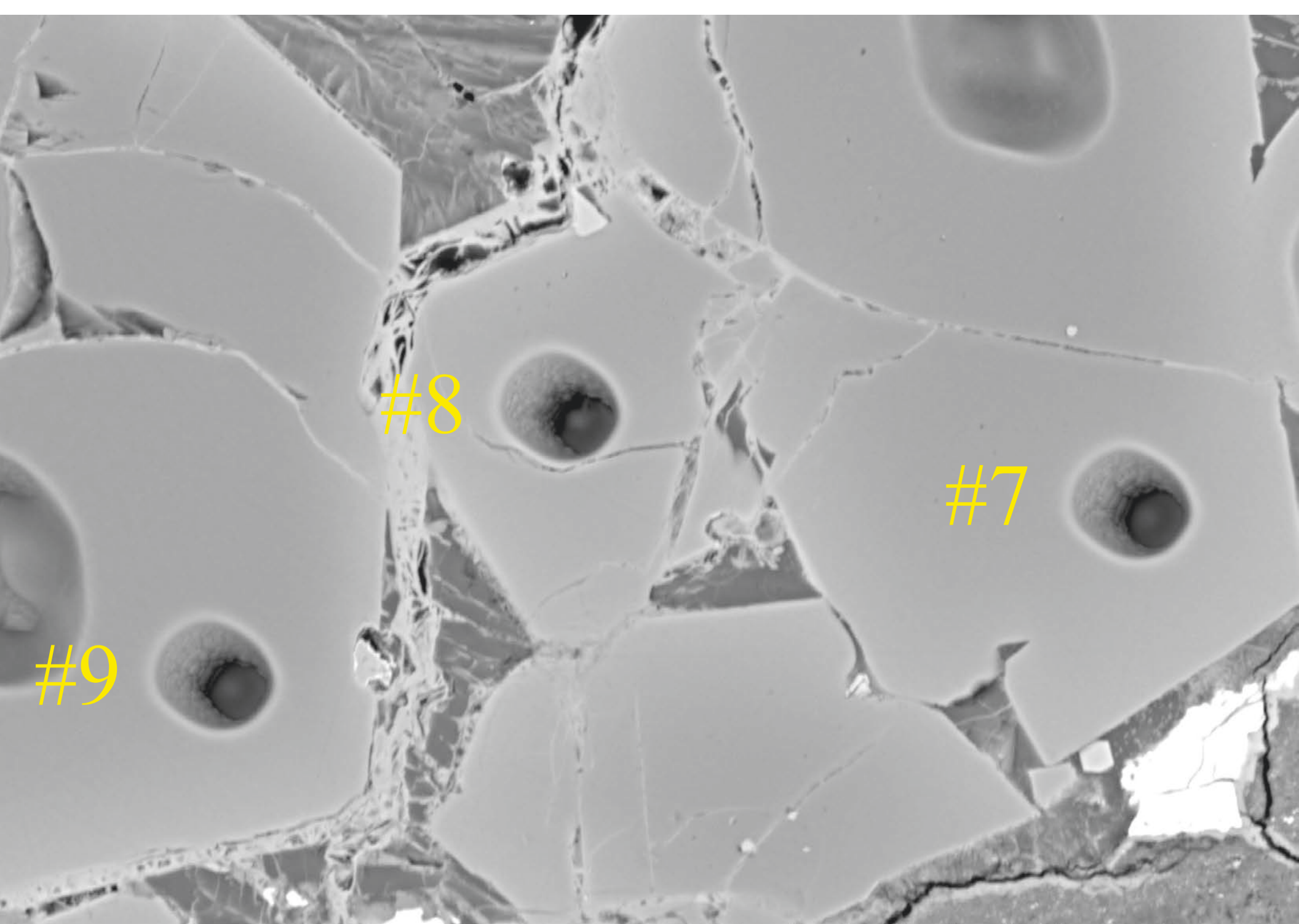
#3

Overlap a crack,
rejected

#4

#2



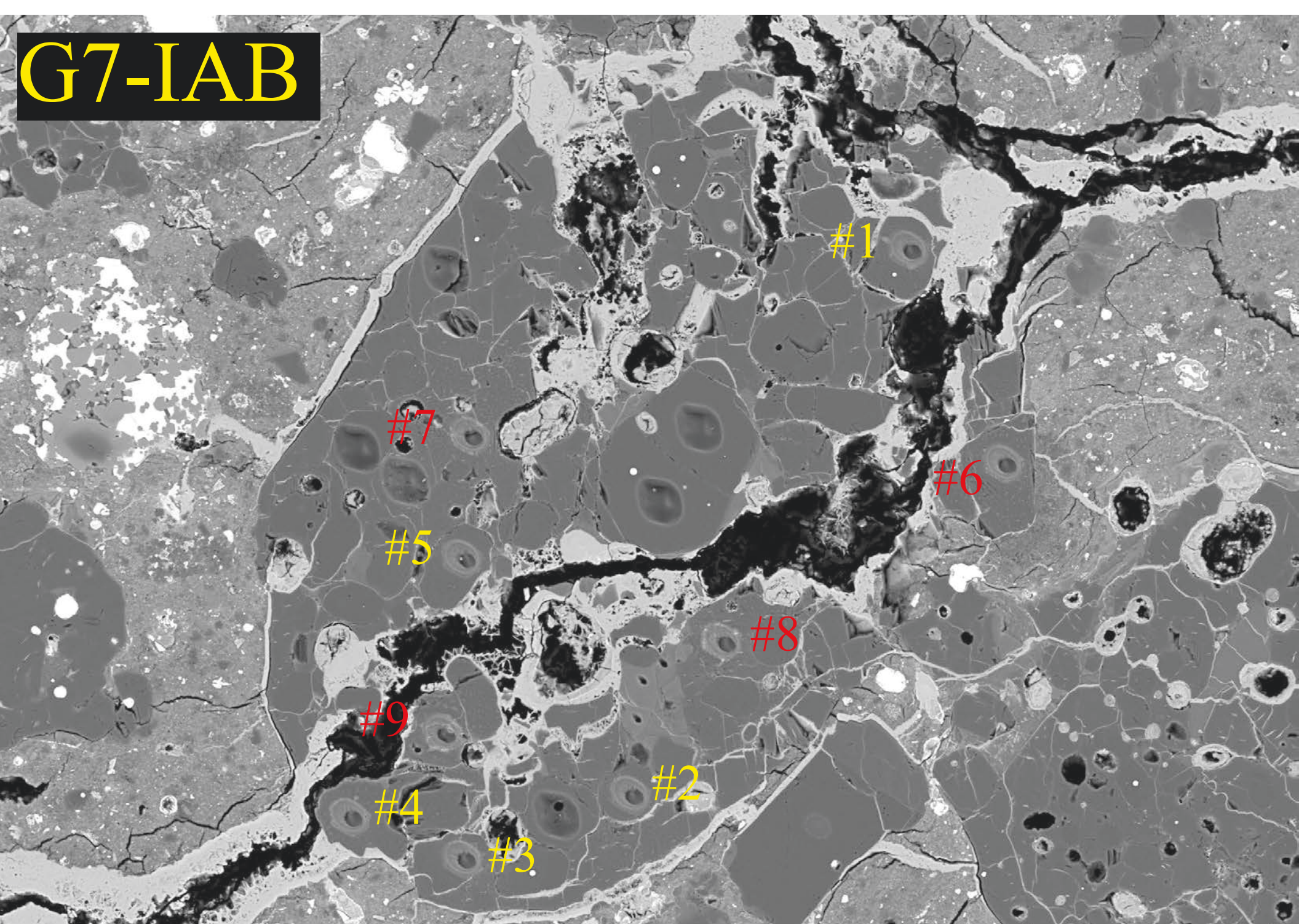


#8

#7

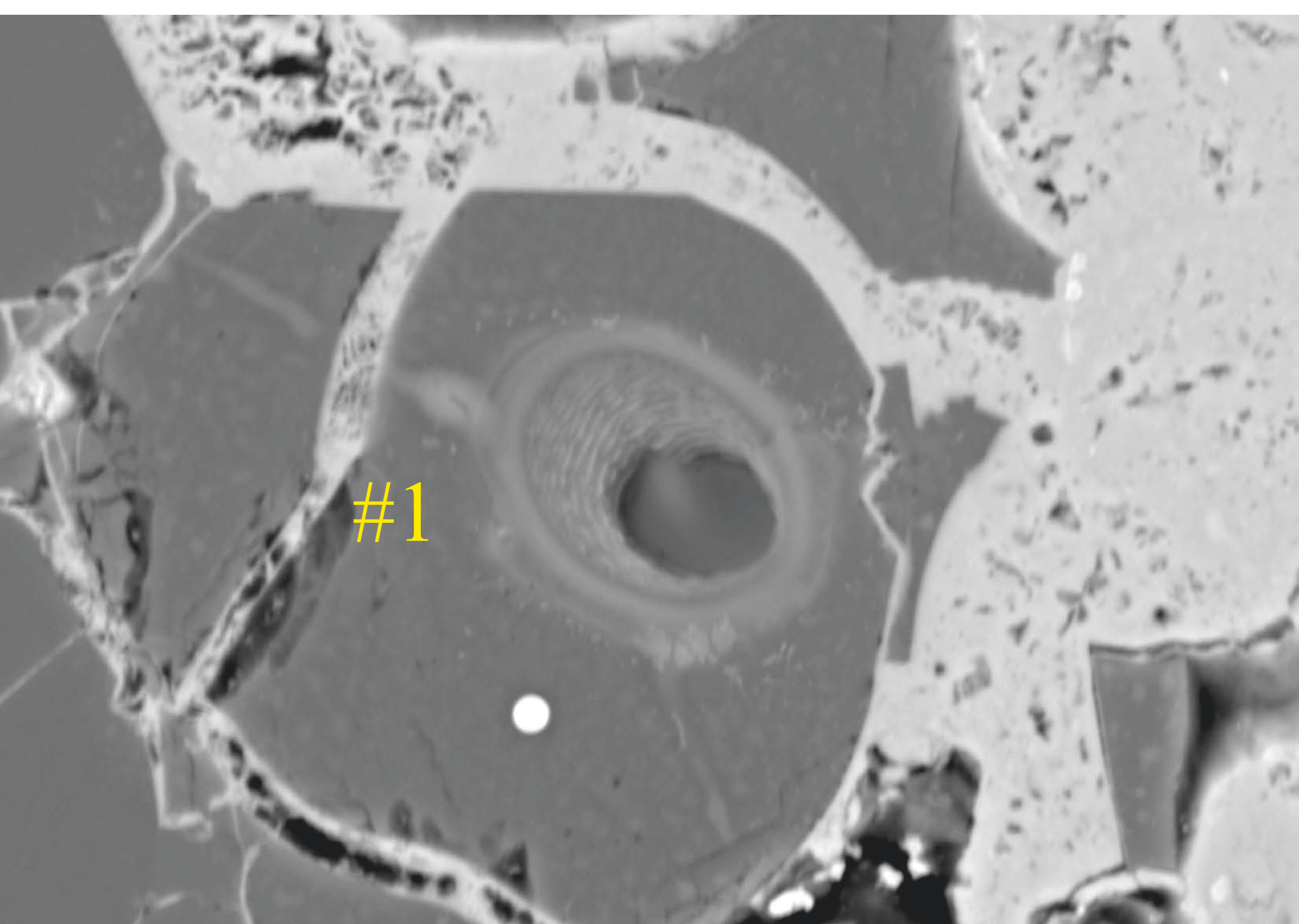
#9

G7-IAB

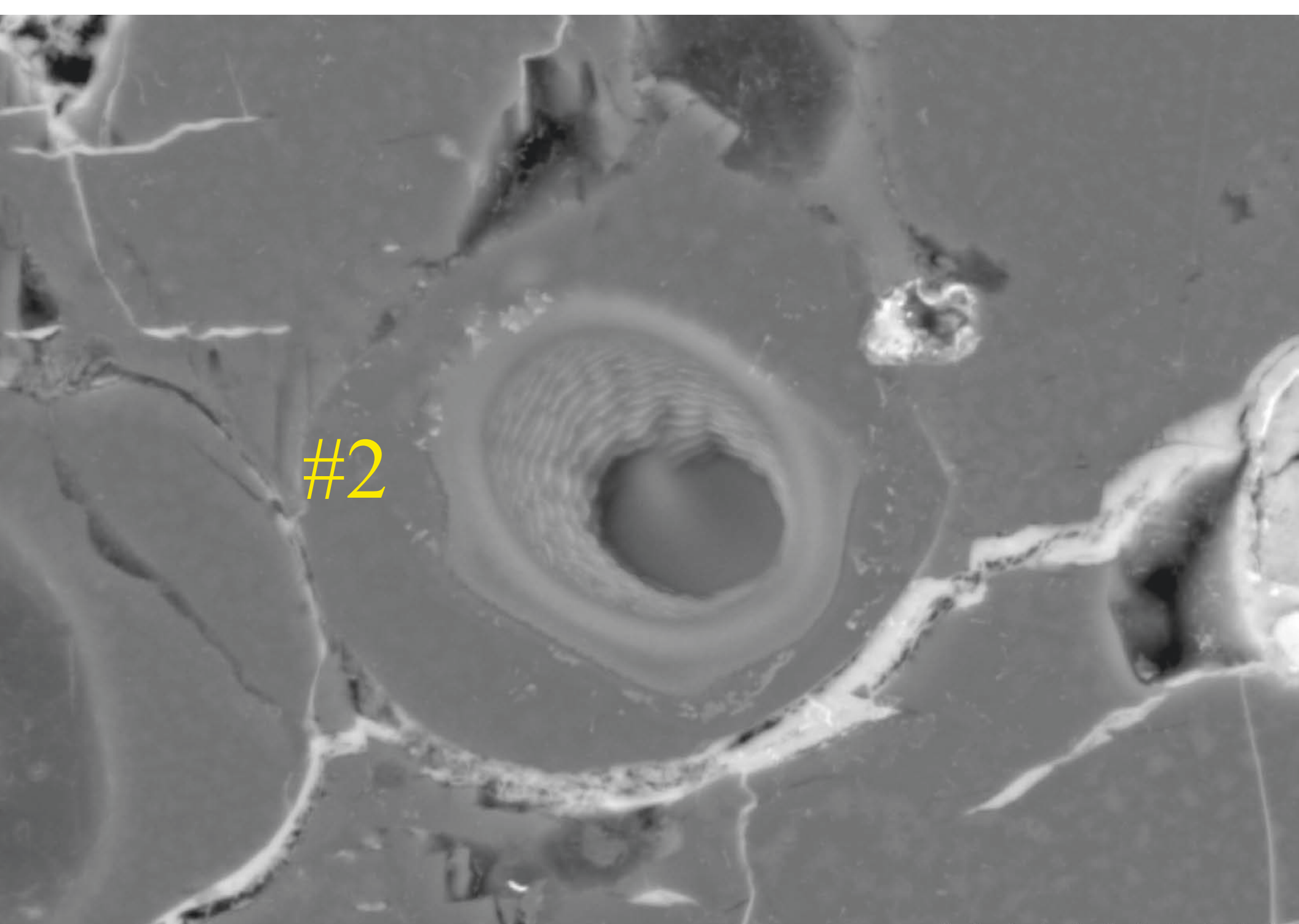


15.0kV x300 BSECOMP

100um



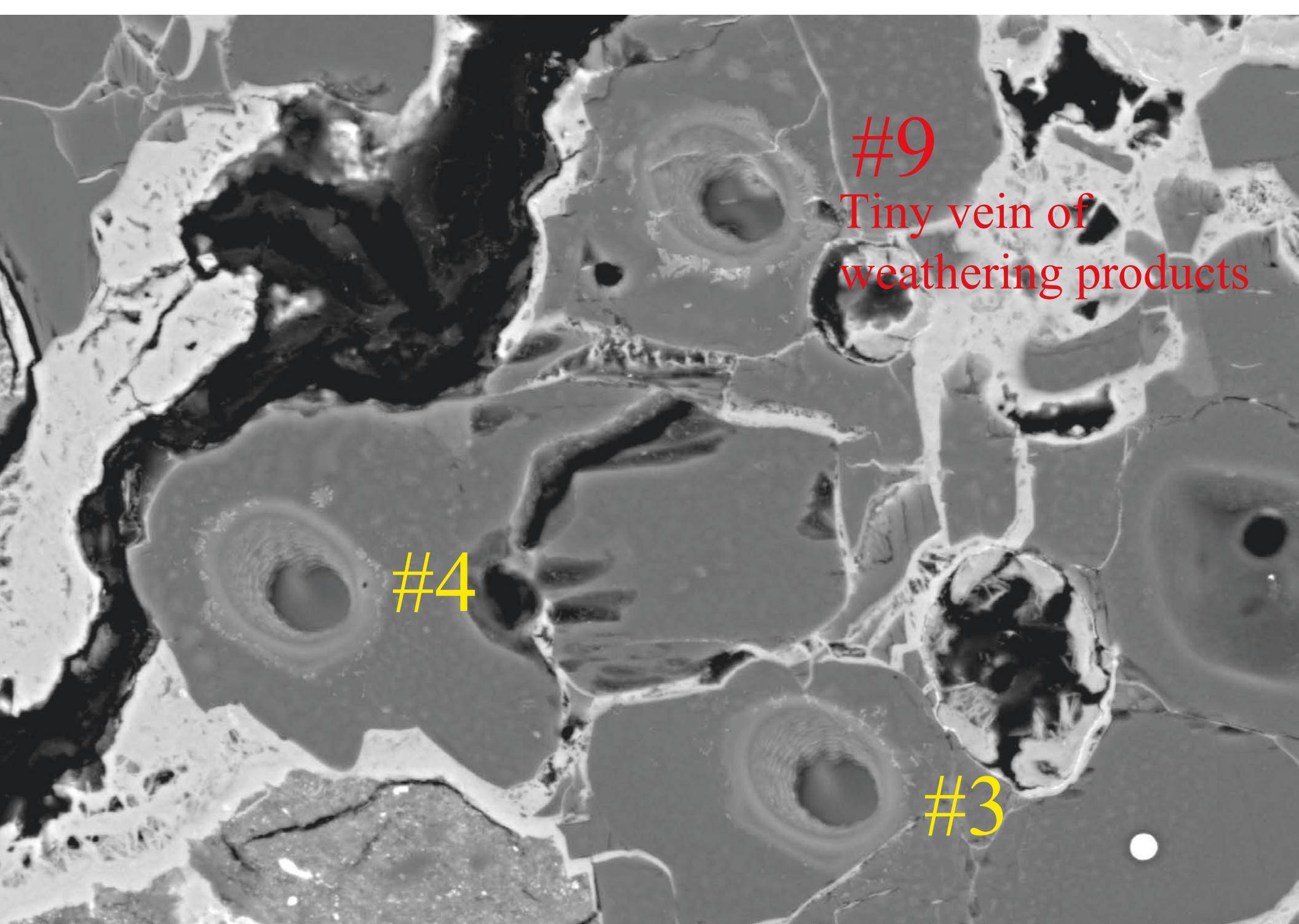
#1



#2

15.0kV x3.20k BSECOMP

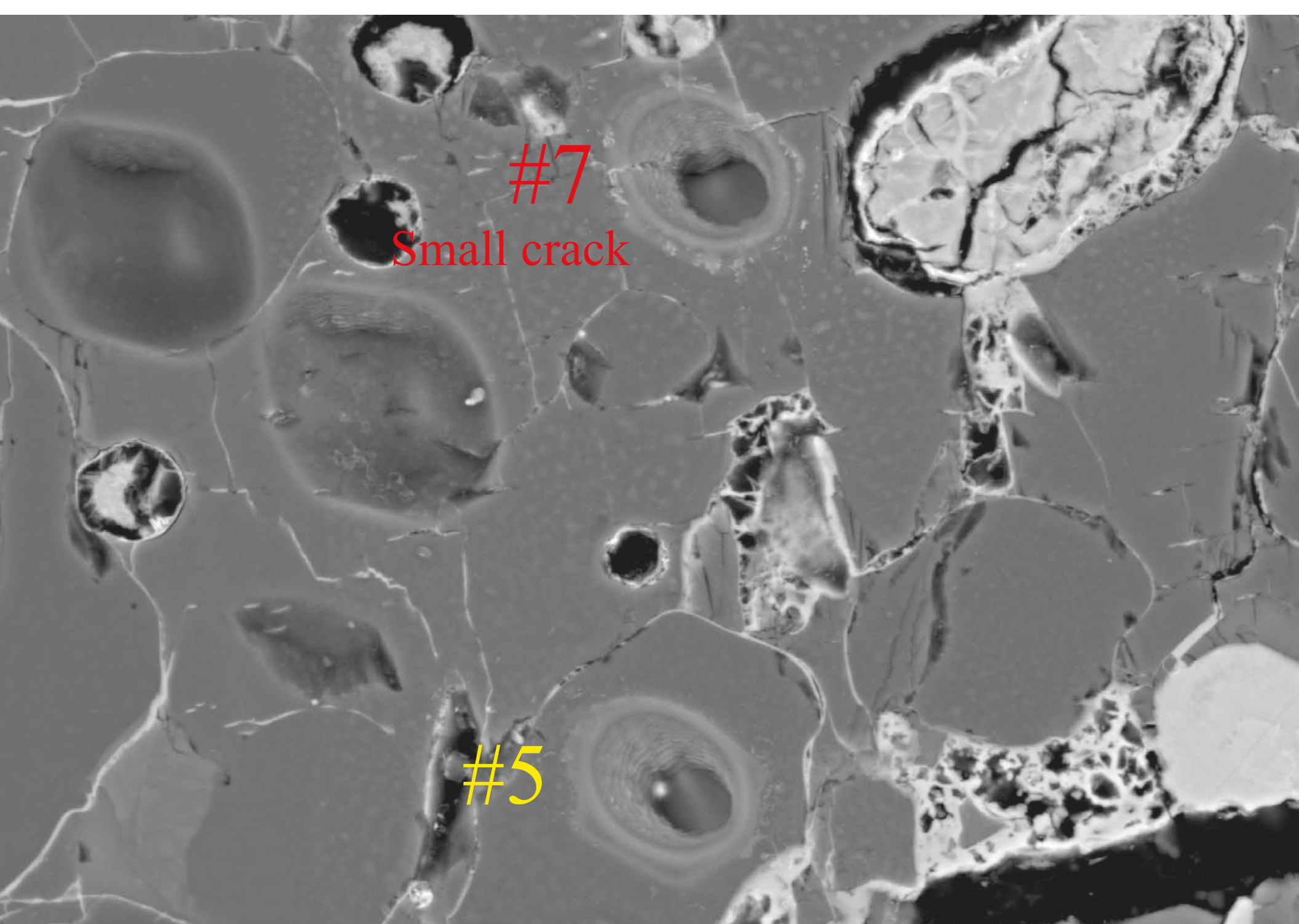
10.0um

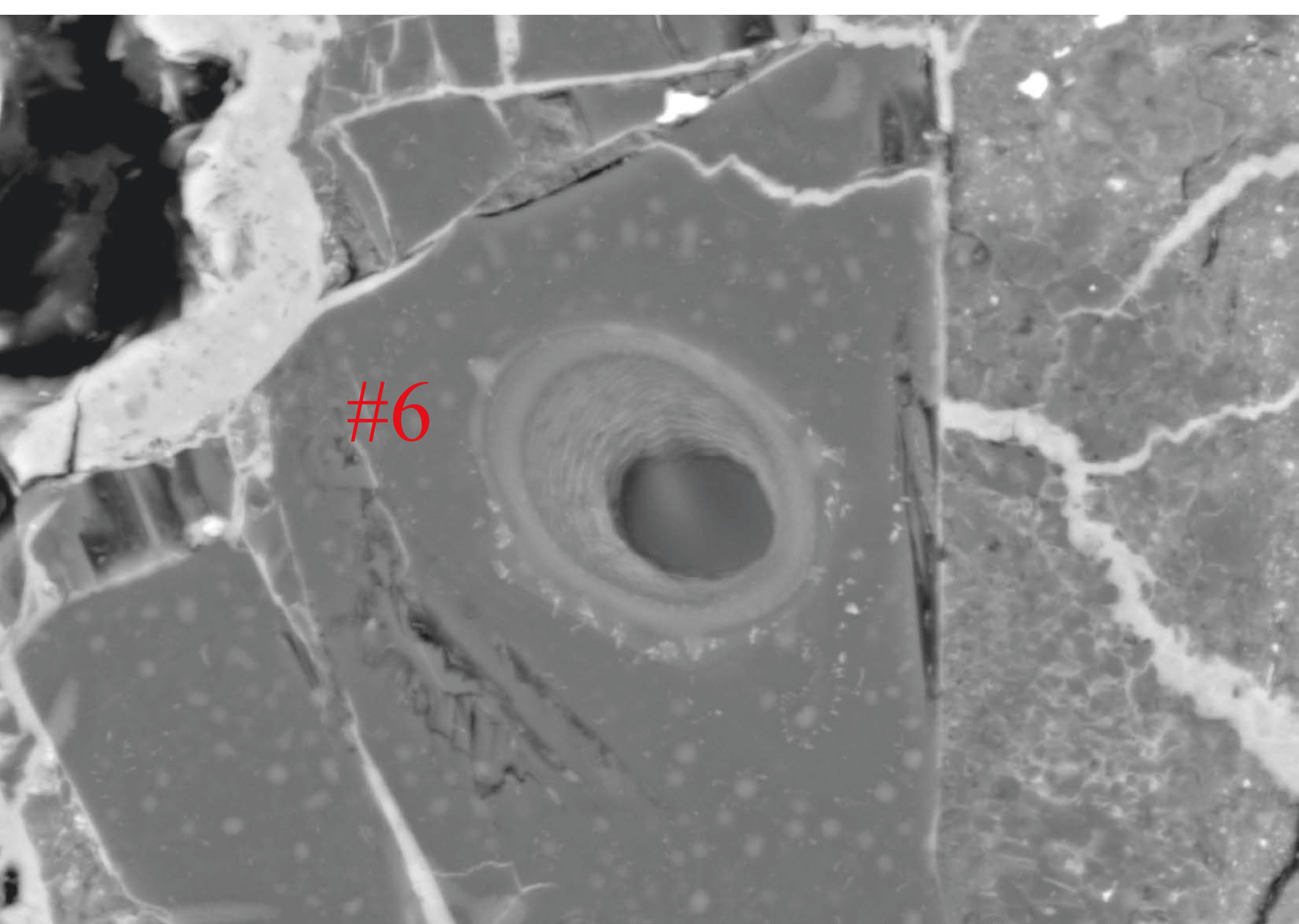


#9
Tiny vein of
weathering products

#4

#3

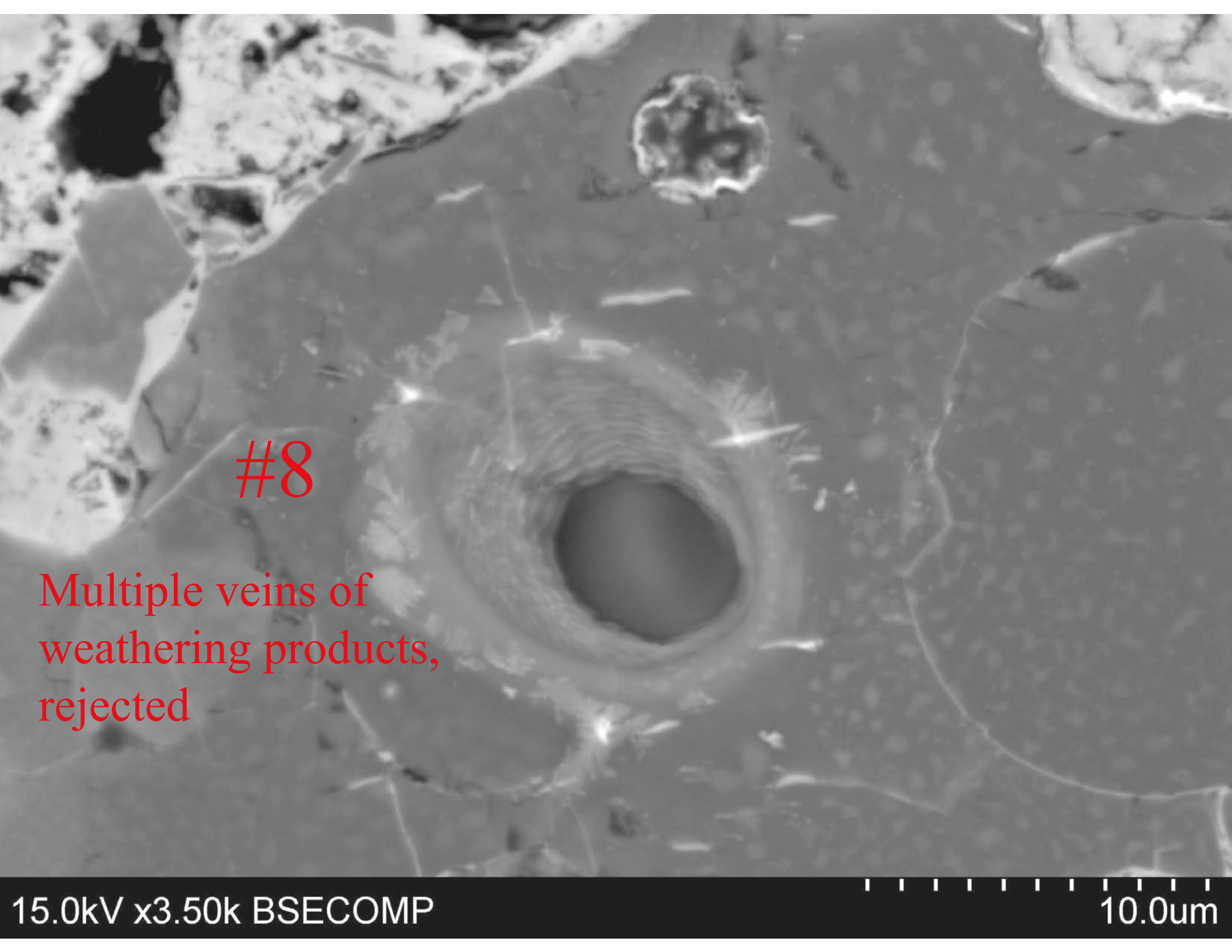




#6

15.0kV x2.70k BSECOMP

20.0um

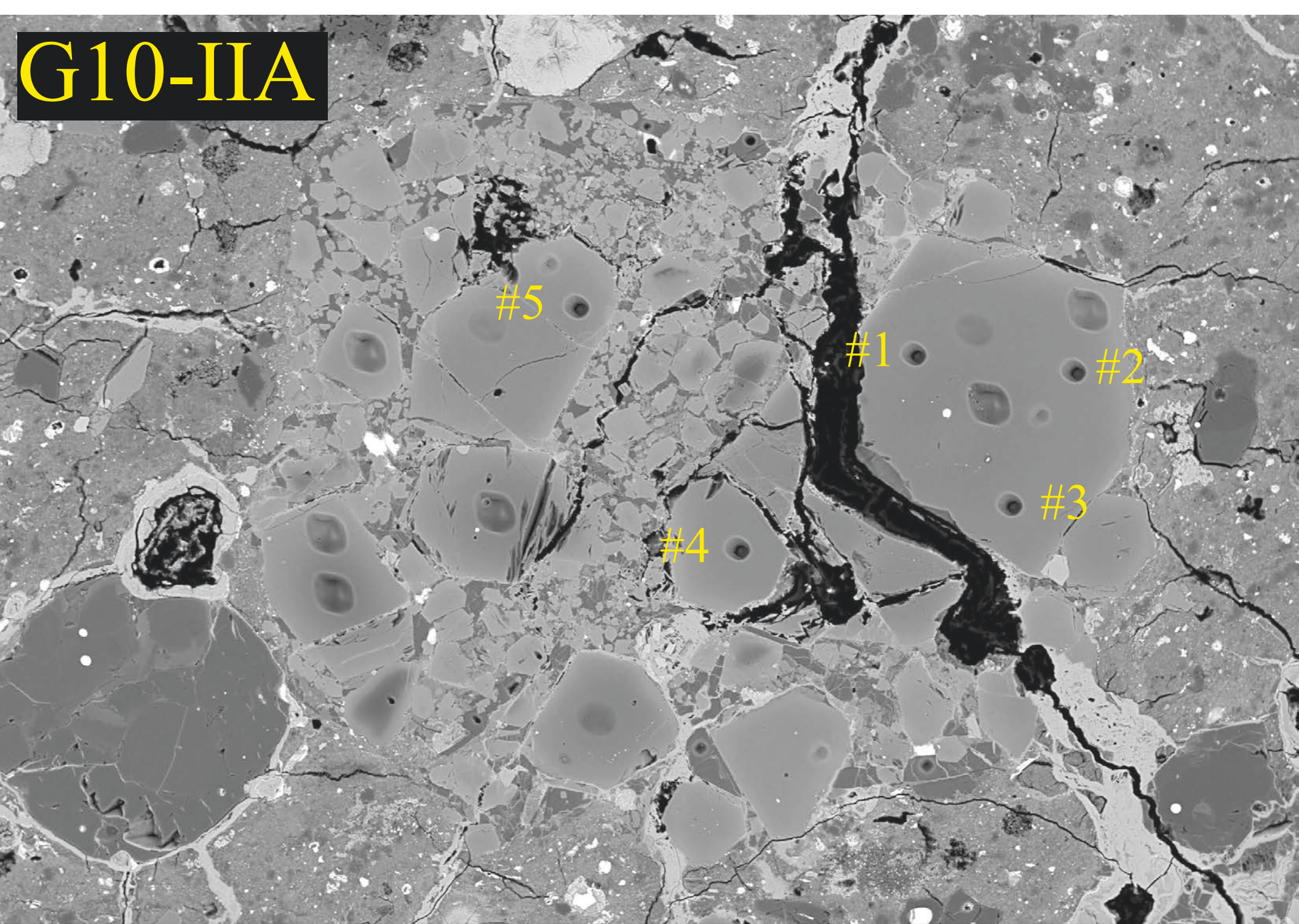


#8

This scanning electron micrograph (SEM) shows a mineral grain with a central dark core and concentric rings of lighter material, indicating multiple veins of weathering products. The grain is surrounded by a matrix of smaller, darker particles. The image is labeled with a red '#8' and a red text description.

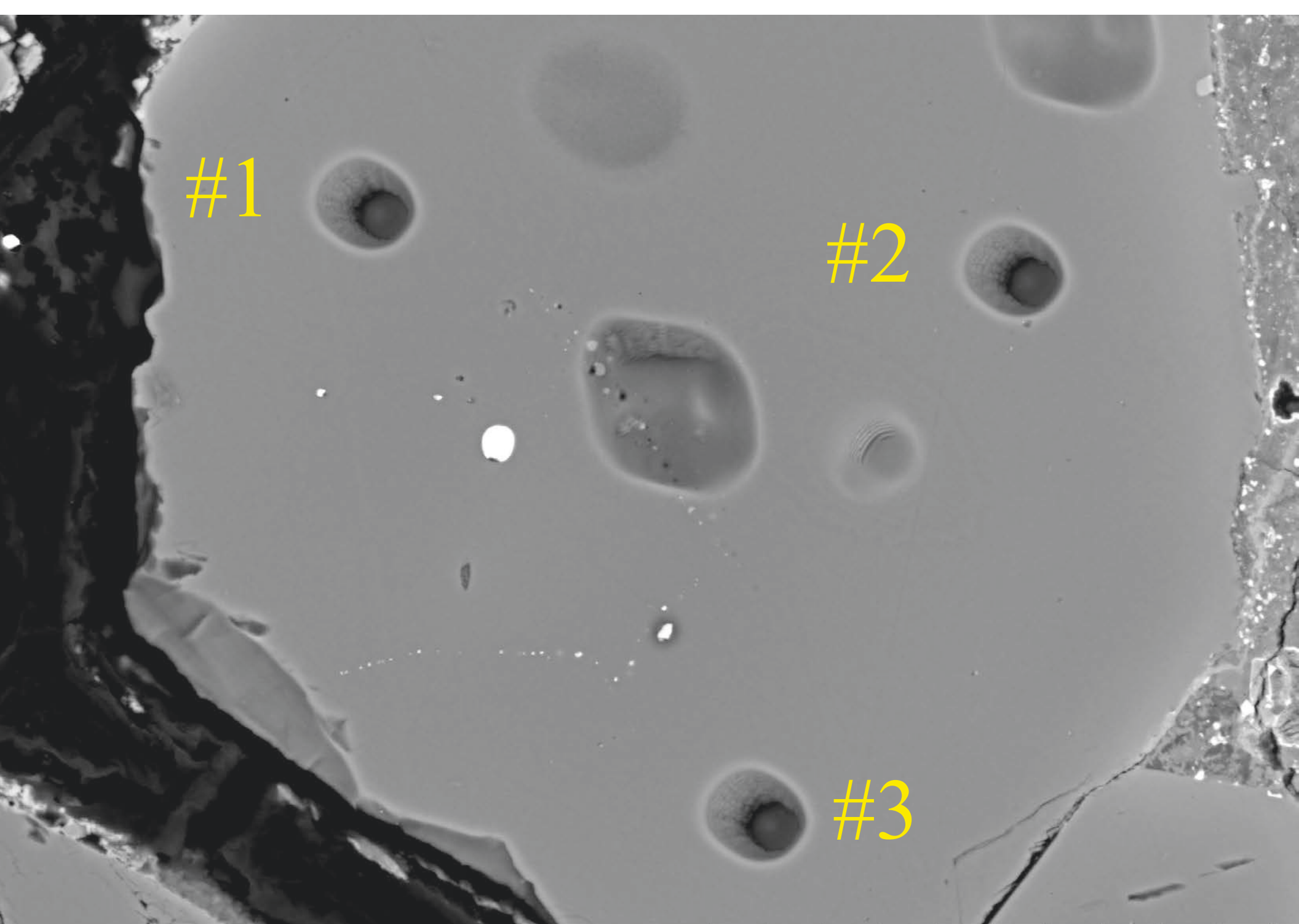
Multiple veins of
weathering products,
rejected

G10-IIA



15.0kV x270 BSECOMP

200um



#1

#2

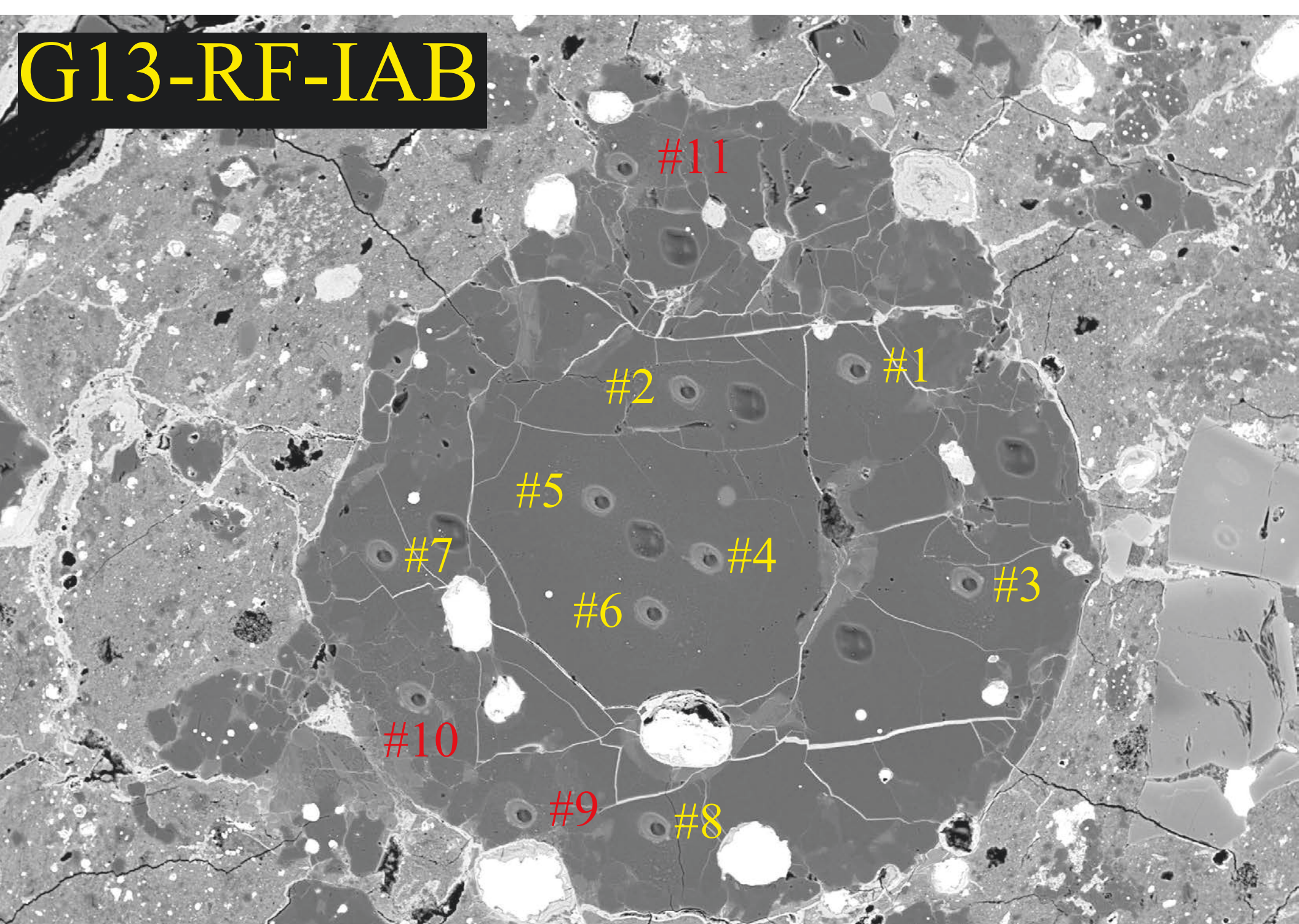
#3

#4

#5

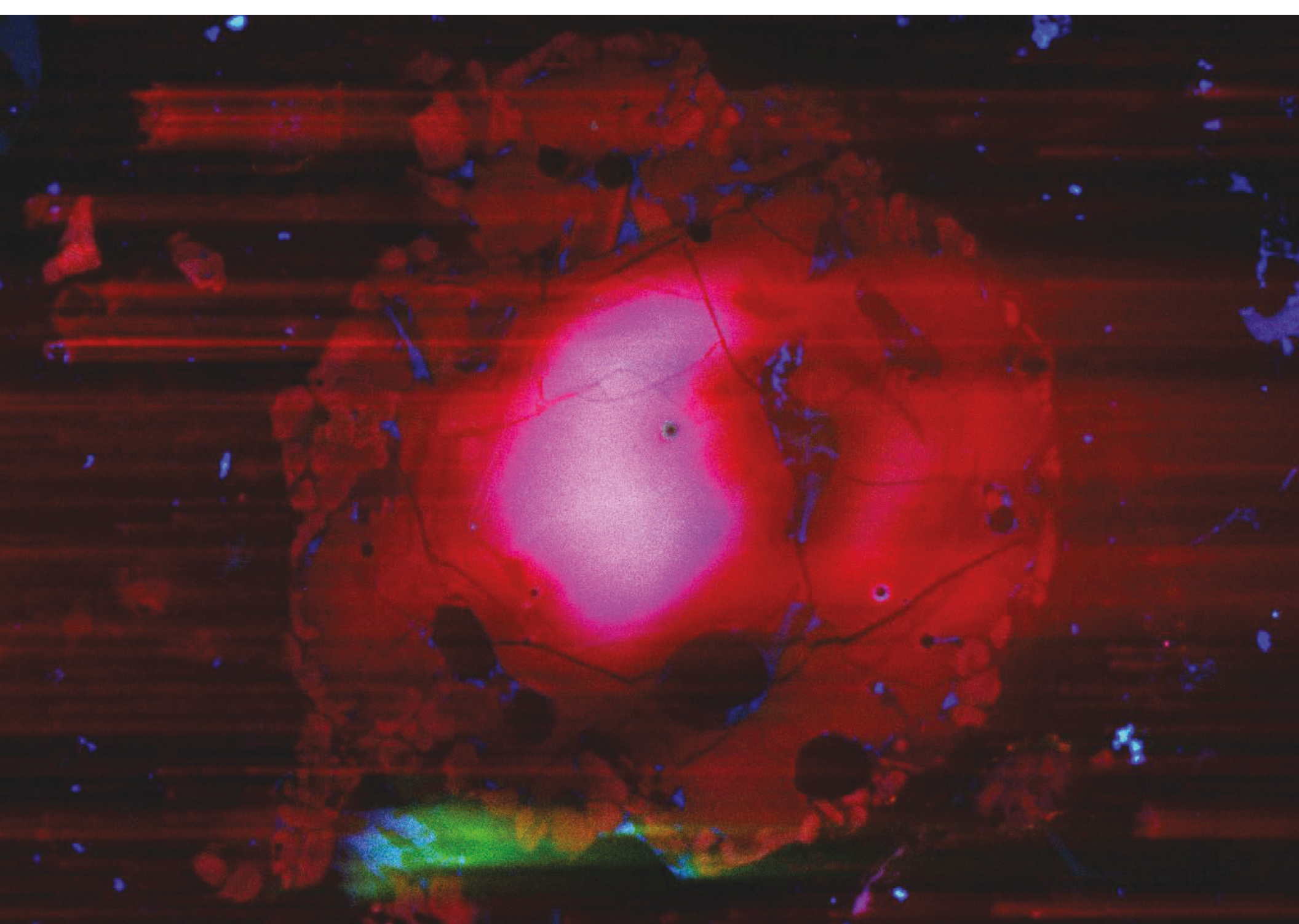
Slightly charging,
rejected

G13-RF-IAB



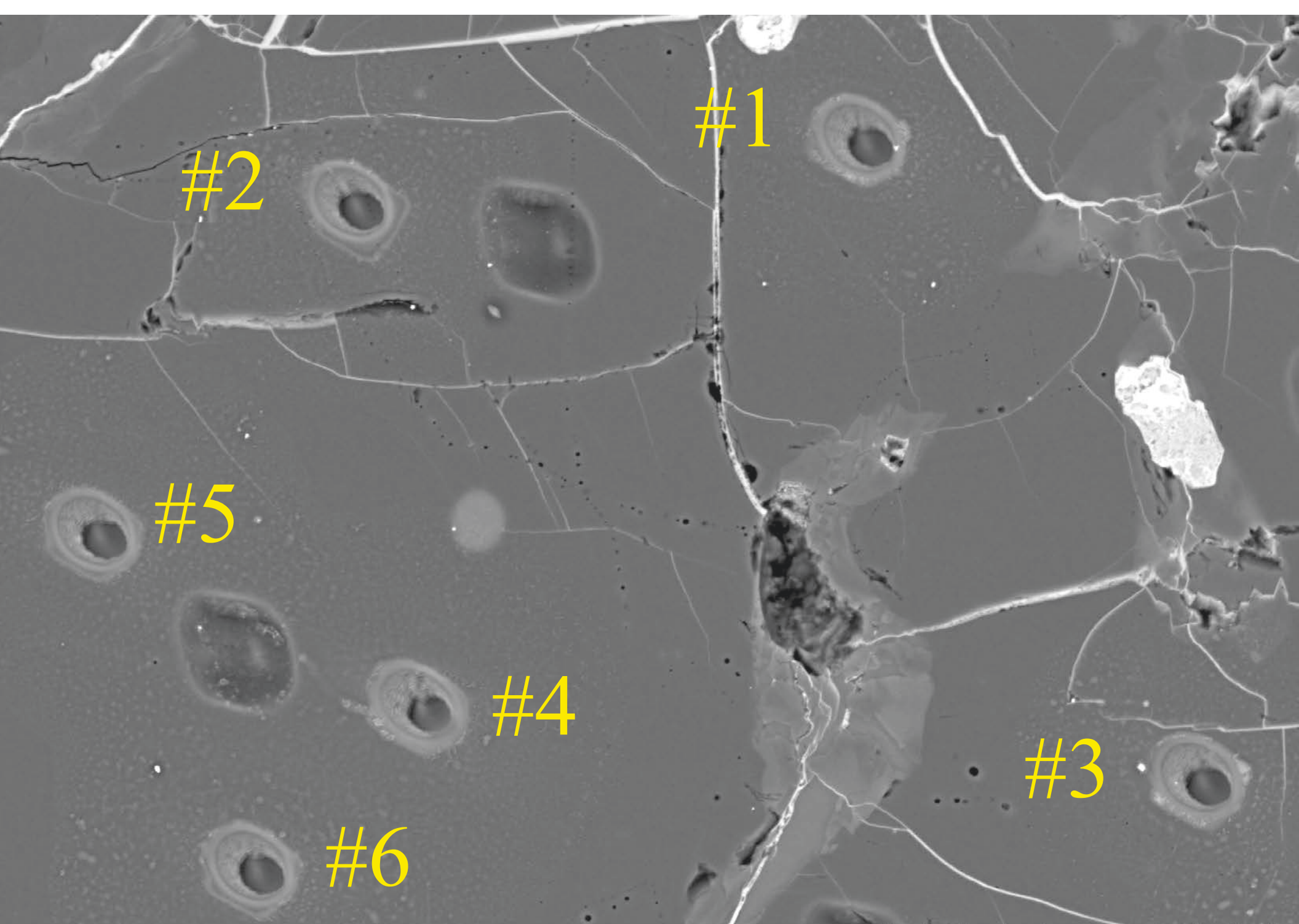
15.0kV x250 BSECOMP

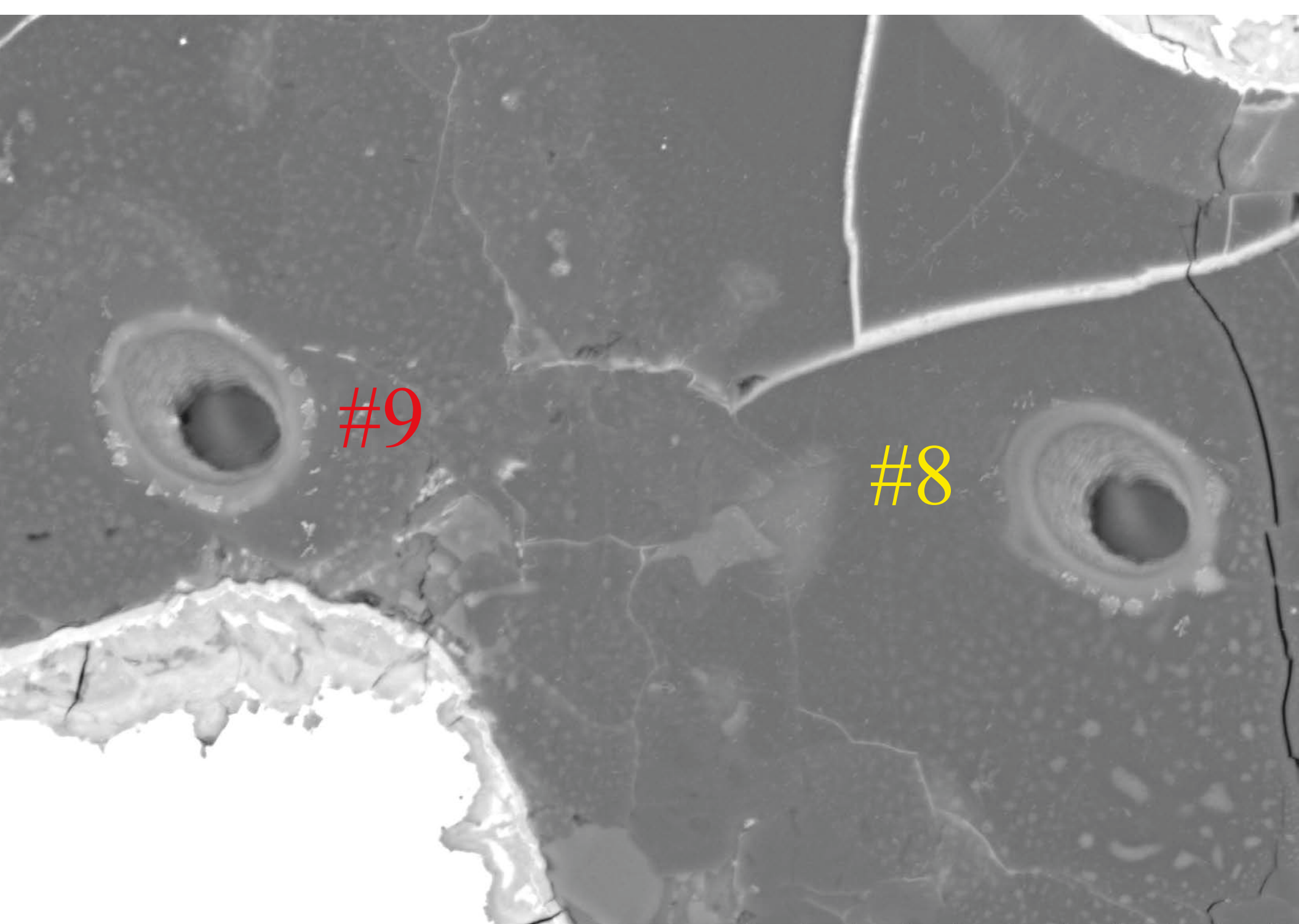
200um



15.0kV x250 OTHER2 10/22/2008

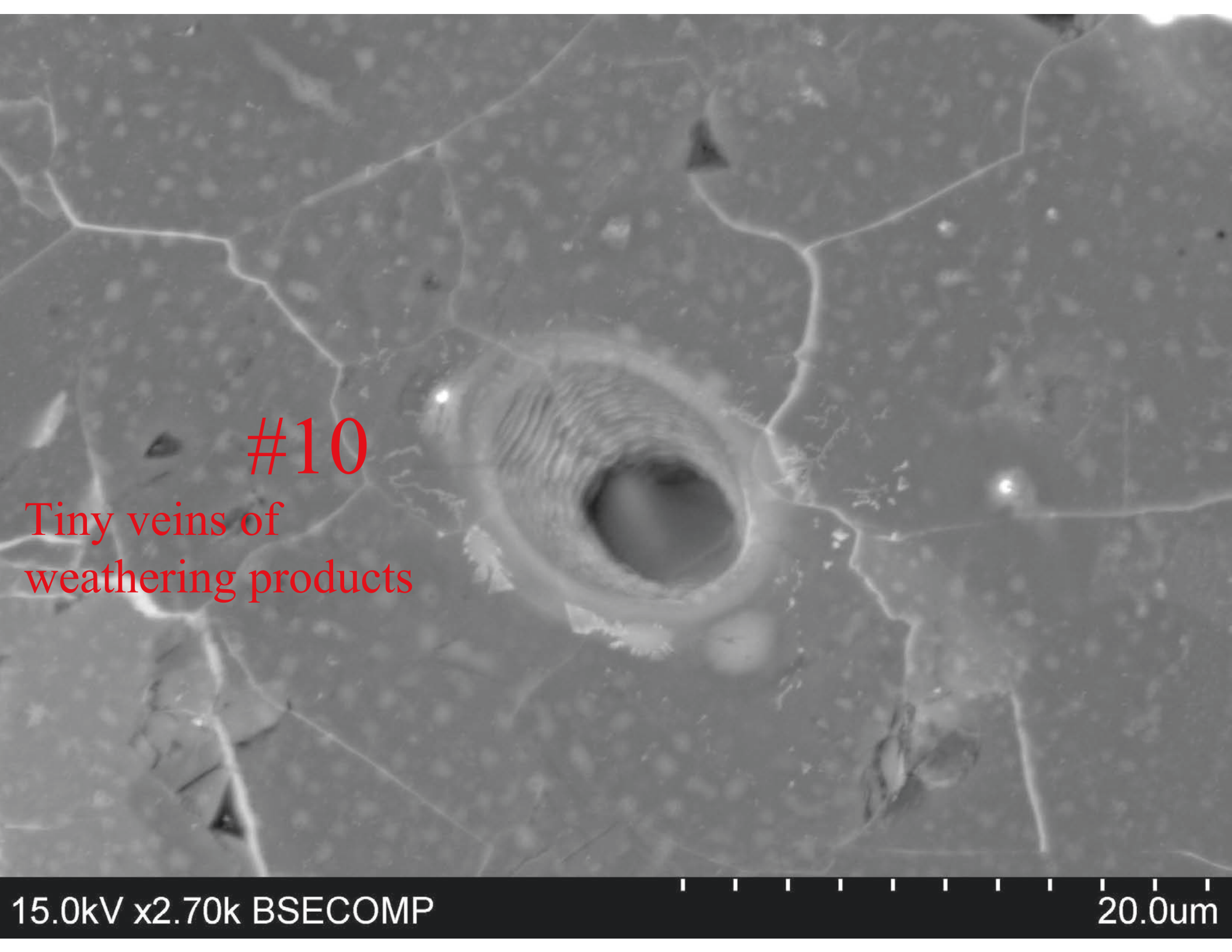
200um





#9

#8



This scanning electron micrograph (SEM) shows a mineral grain with a complex internal structure. A central, dark, circular inclusion is surrounded by concentric, wavy lines, suggesting a core-and-rim growth pattern. The grain is embedded in a matrix of smaller, more irregularly shaped mineral grains. Fine, light-colored veins are visible throughout the matrix, particularly around the central grain. The image is labeled with a red '#10' and a description of the veins. Technical SEM data and a scale bar are at the bottom.

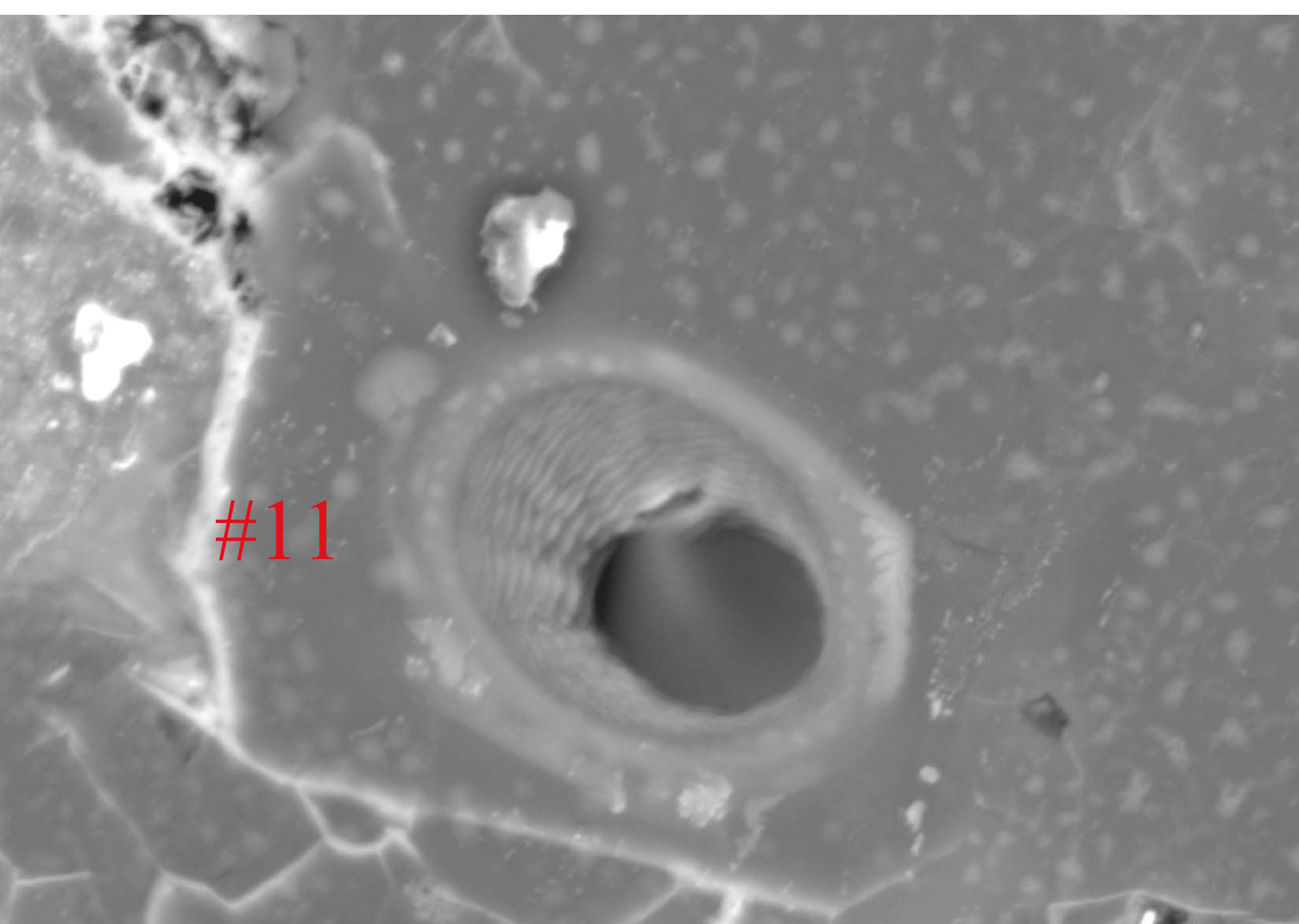
#10

Tiny veins of
weathering products

15.0kV x2.70k BSECOMP

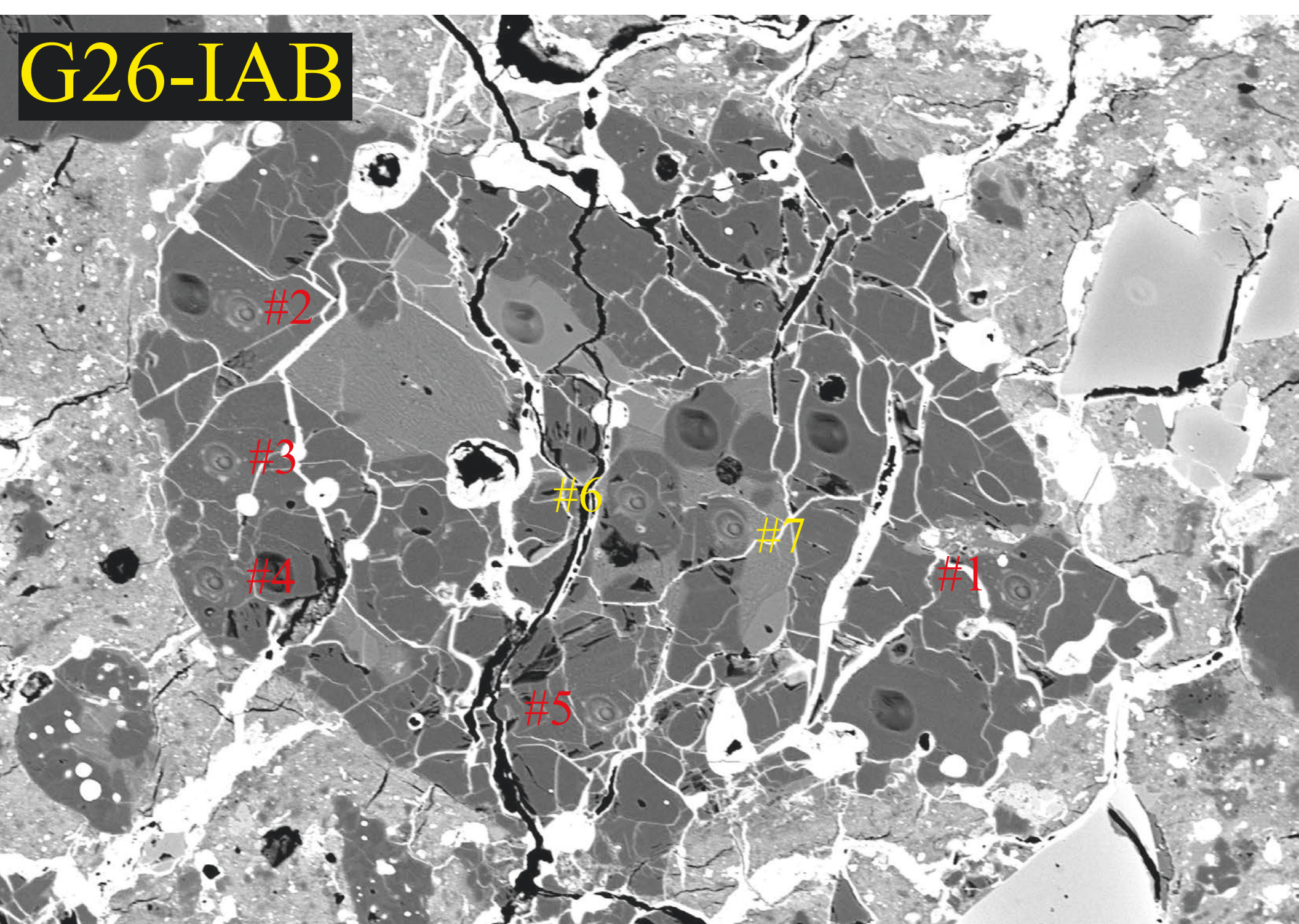
20.0um

#7



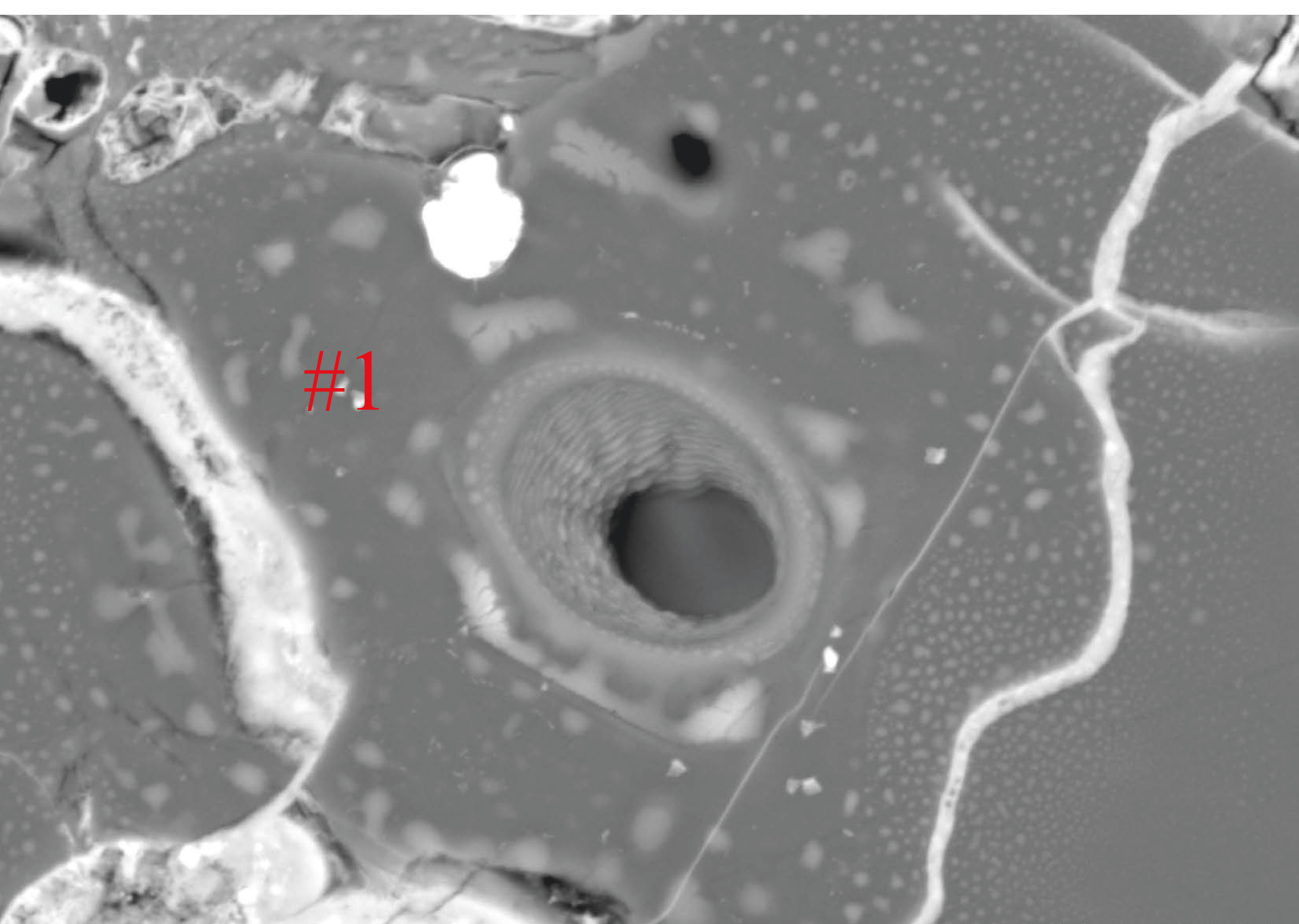
#11

G26-IAB



15.0kV x270 BSECOMP

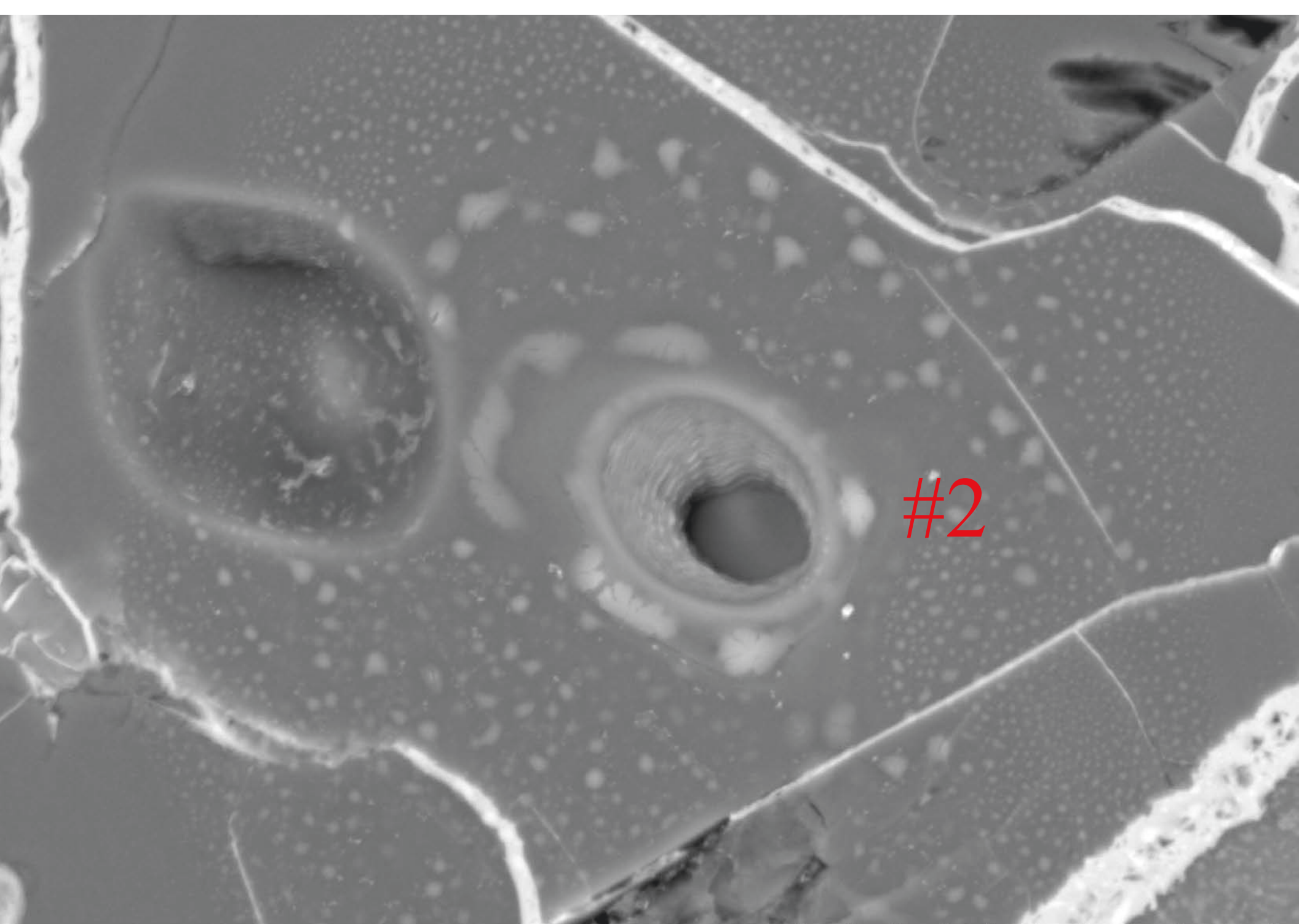
200um



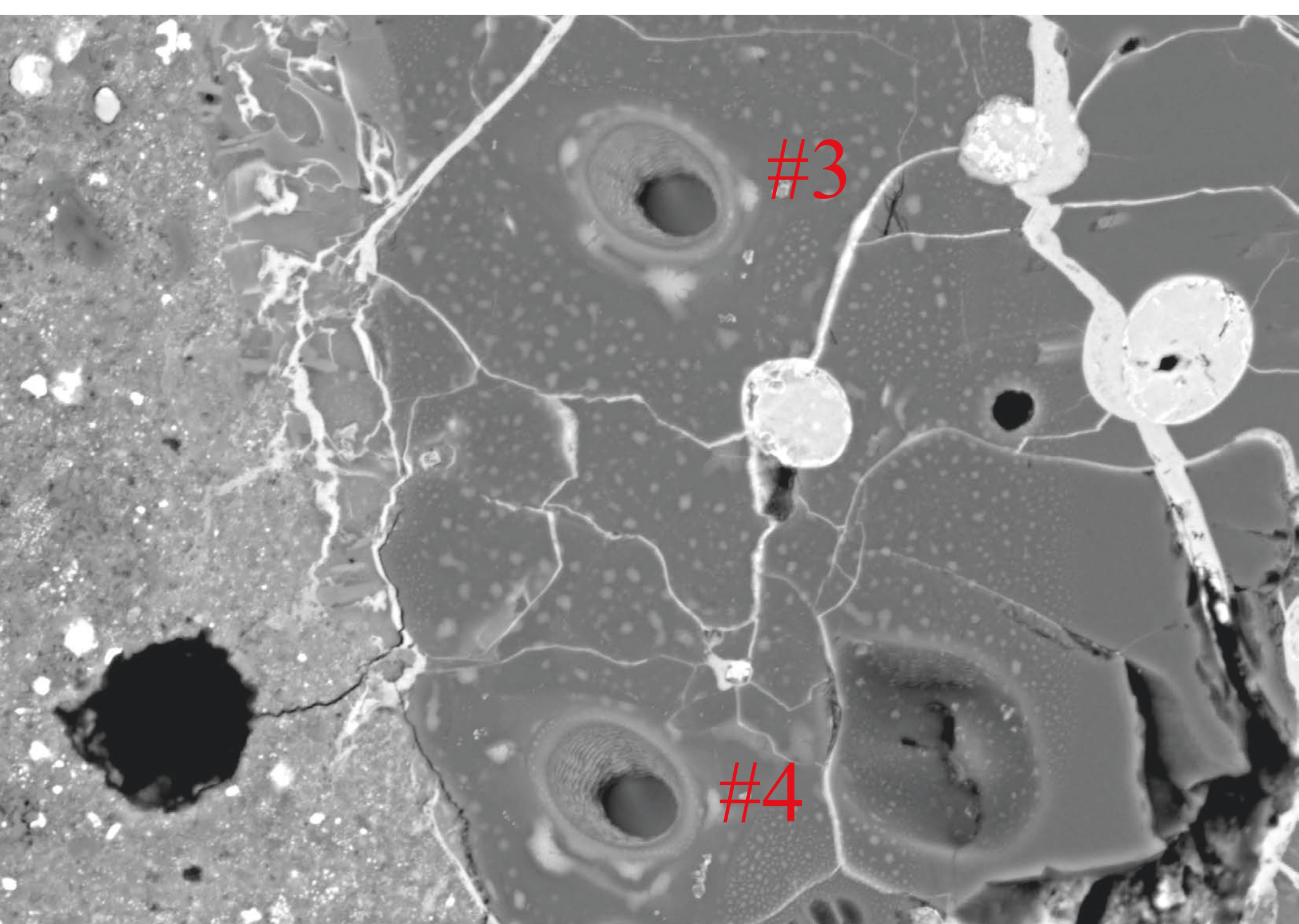
#1

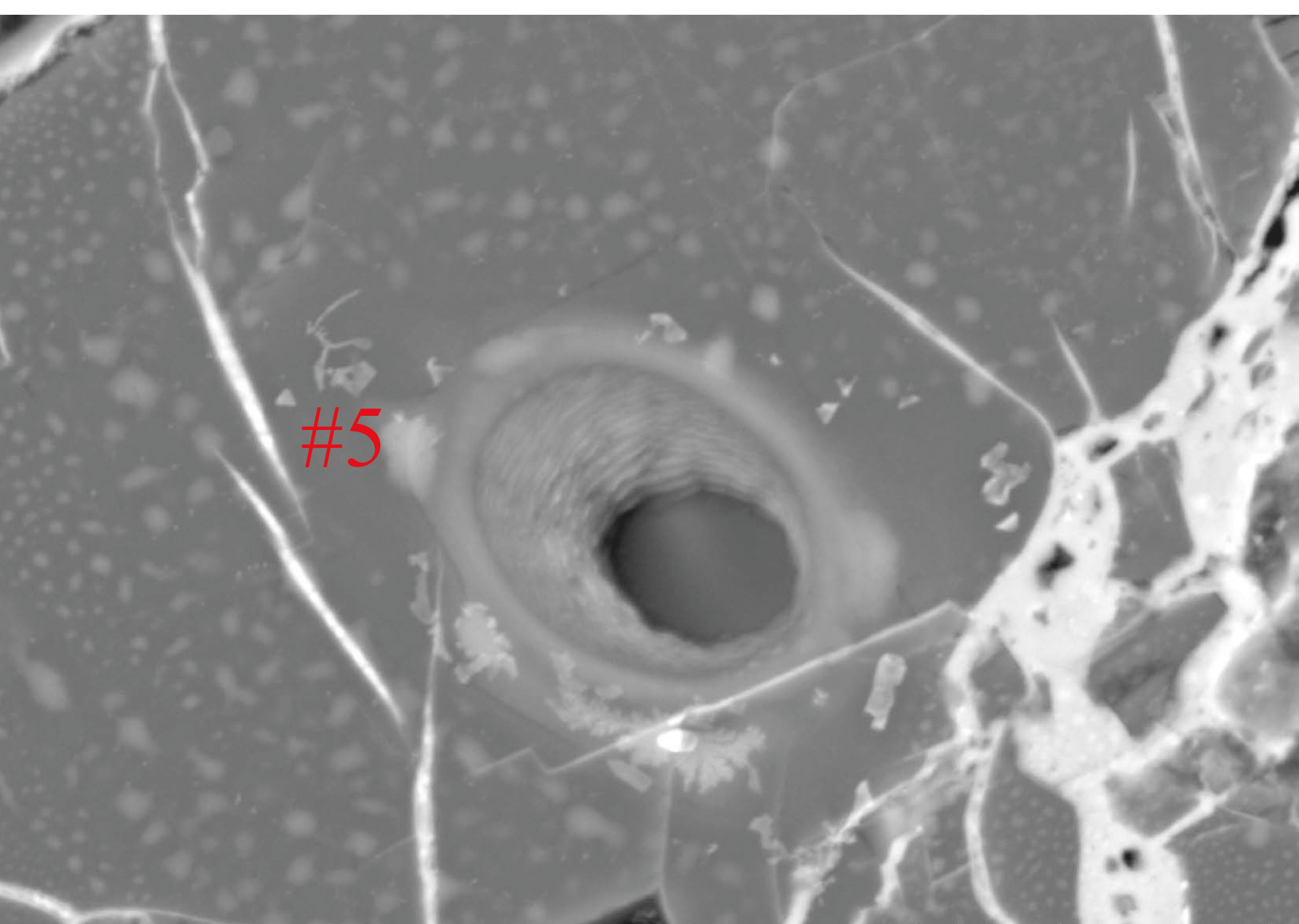
15.0kV x3.00k BSECOMP

10.0um

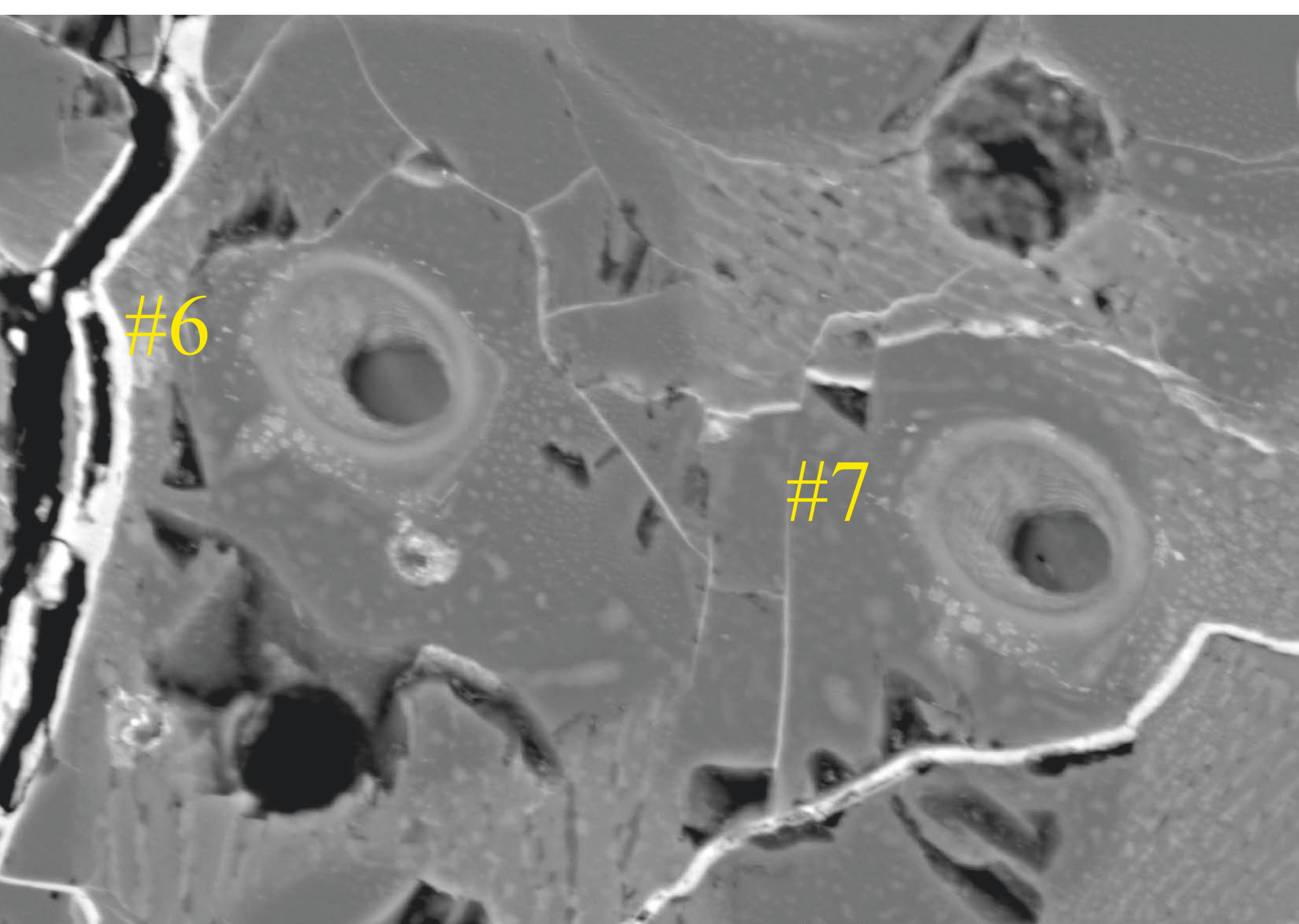


#2

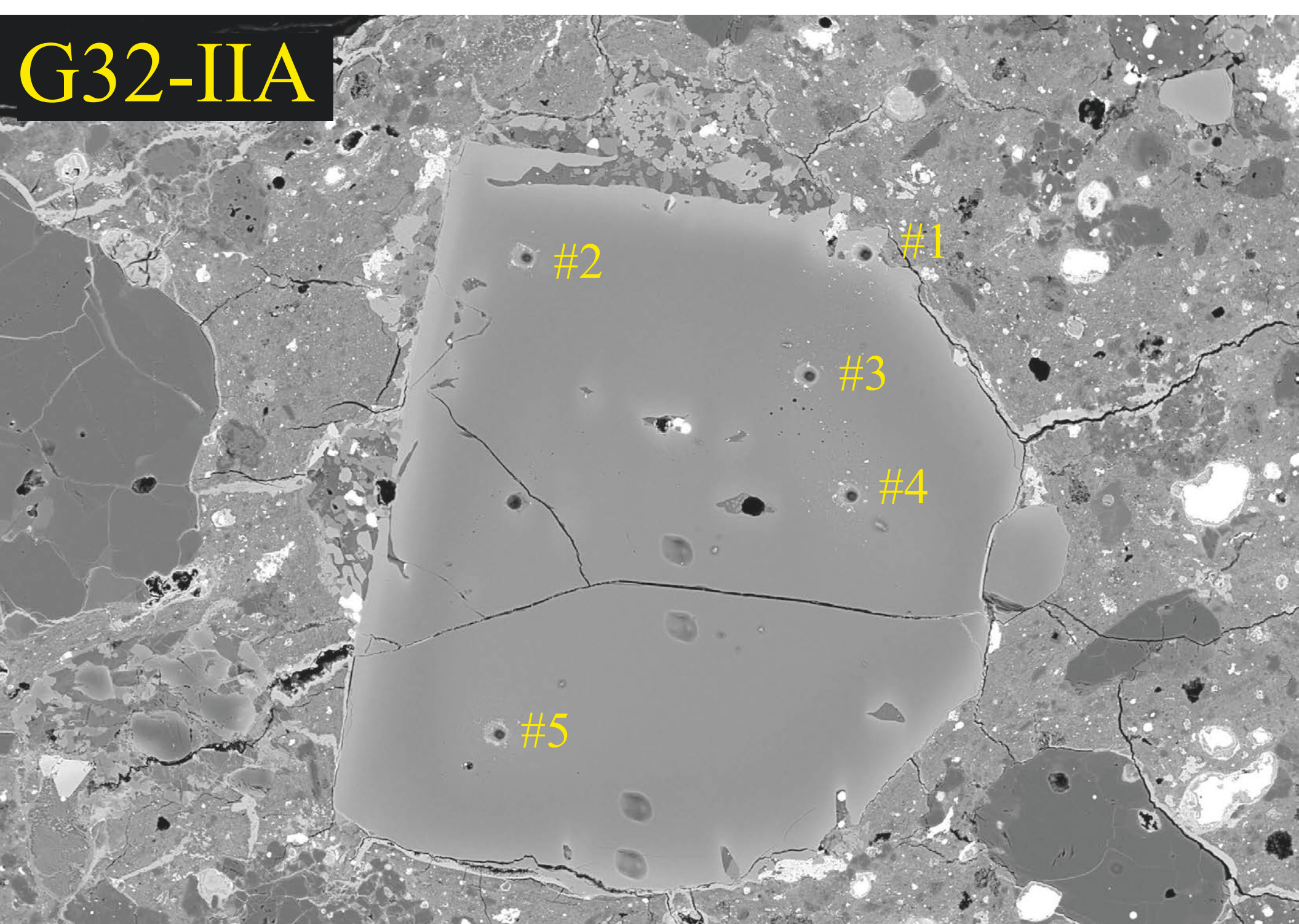




#5

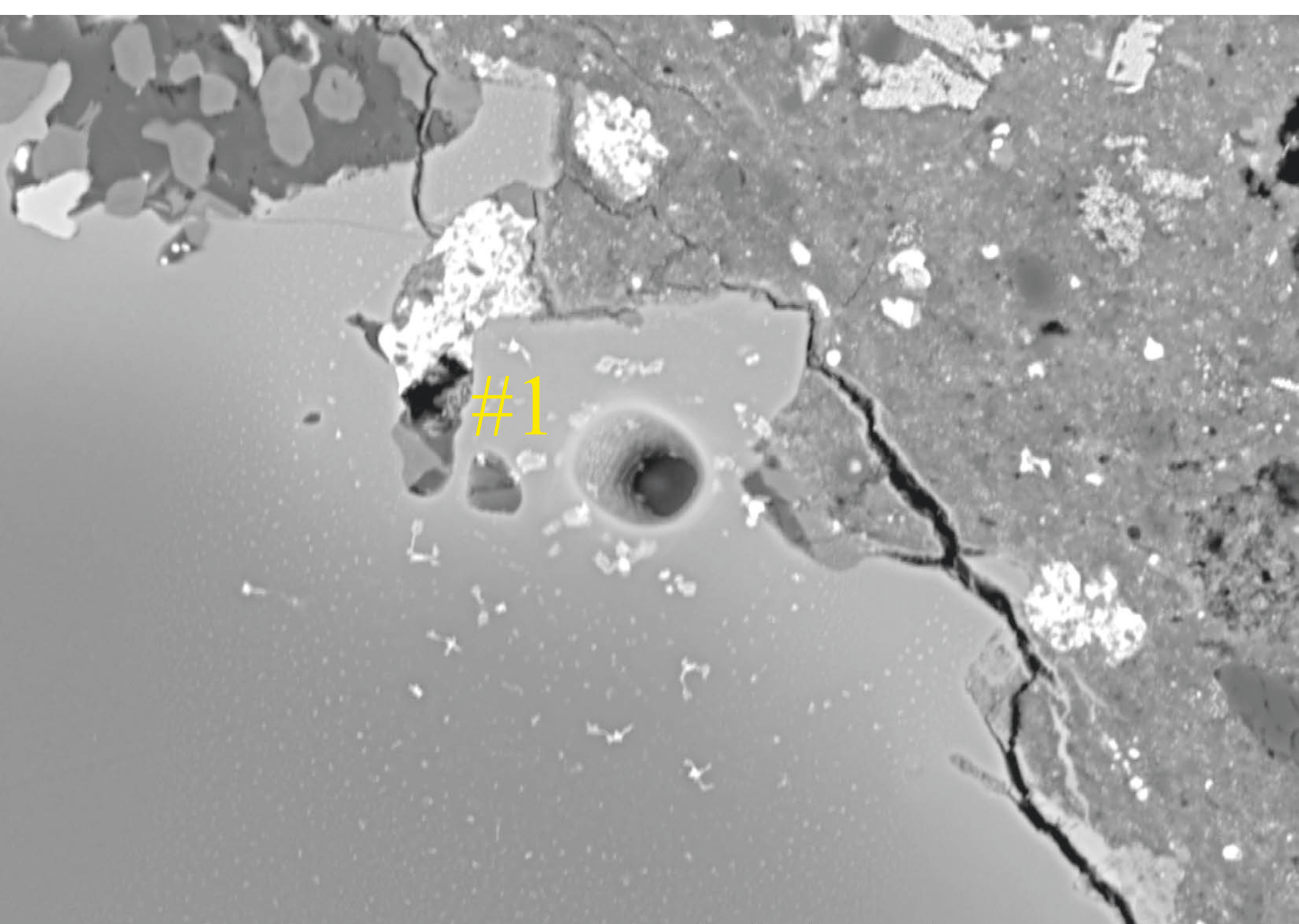


G32-IIA



15.0kV x210 BSECOMP

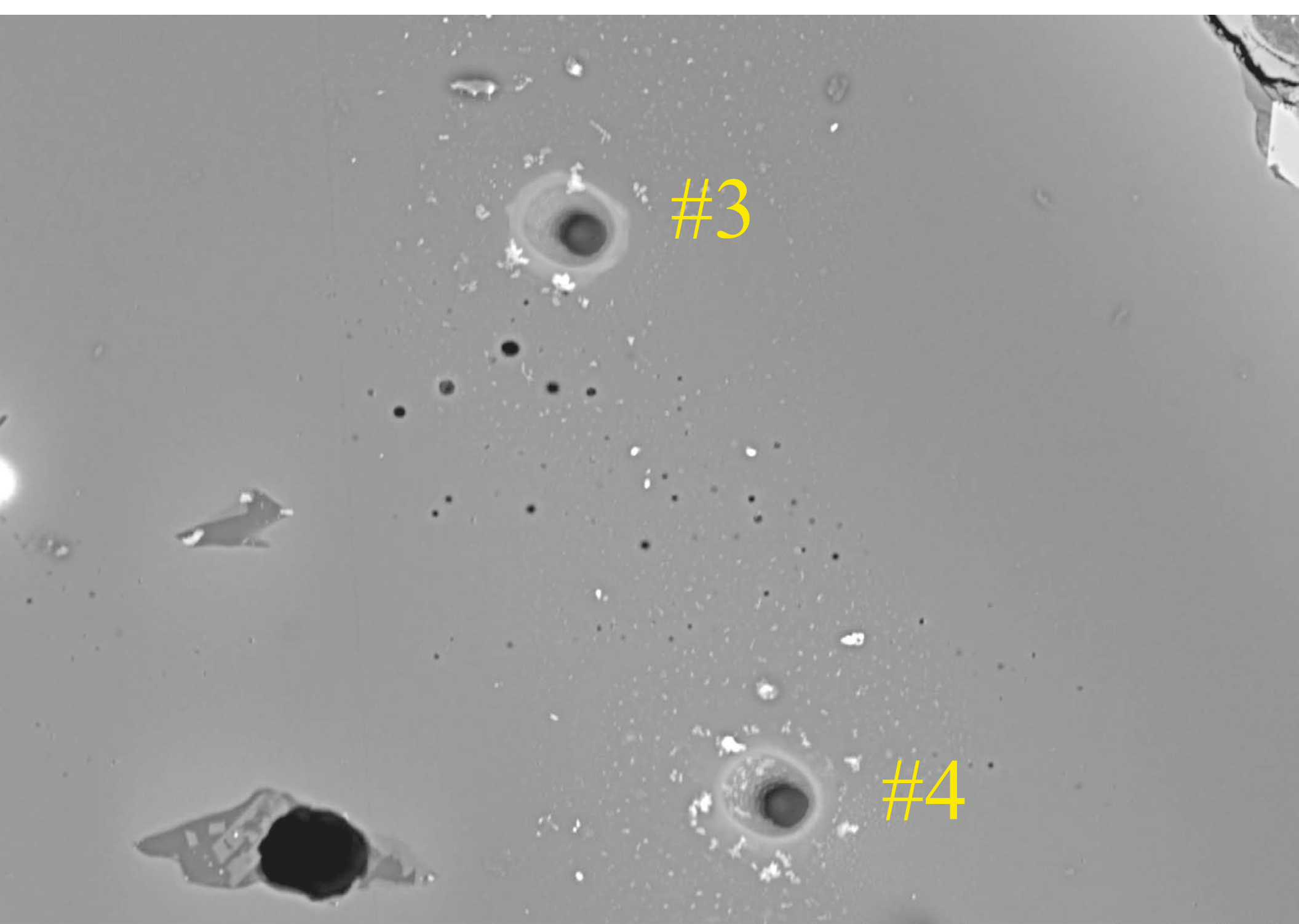
200um



15.0kV x1.40k BSECOMP

40.0um

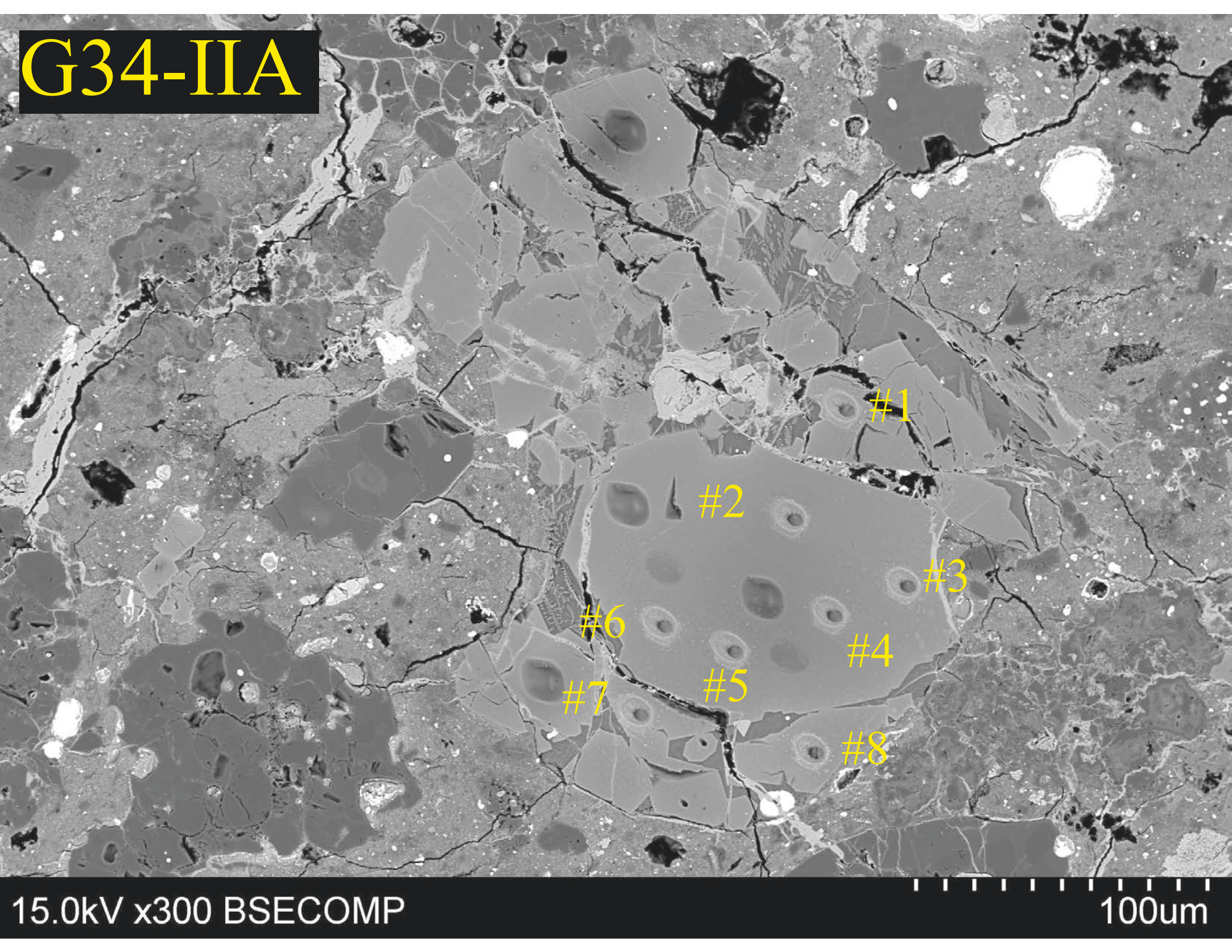
#2



#3

#4

#5



G34-IIA

#1

#2

#3

#4

#5

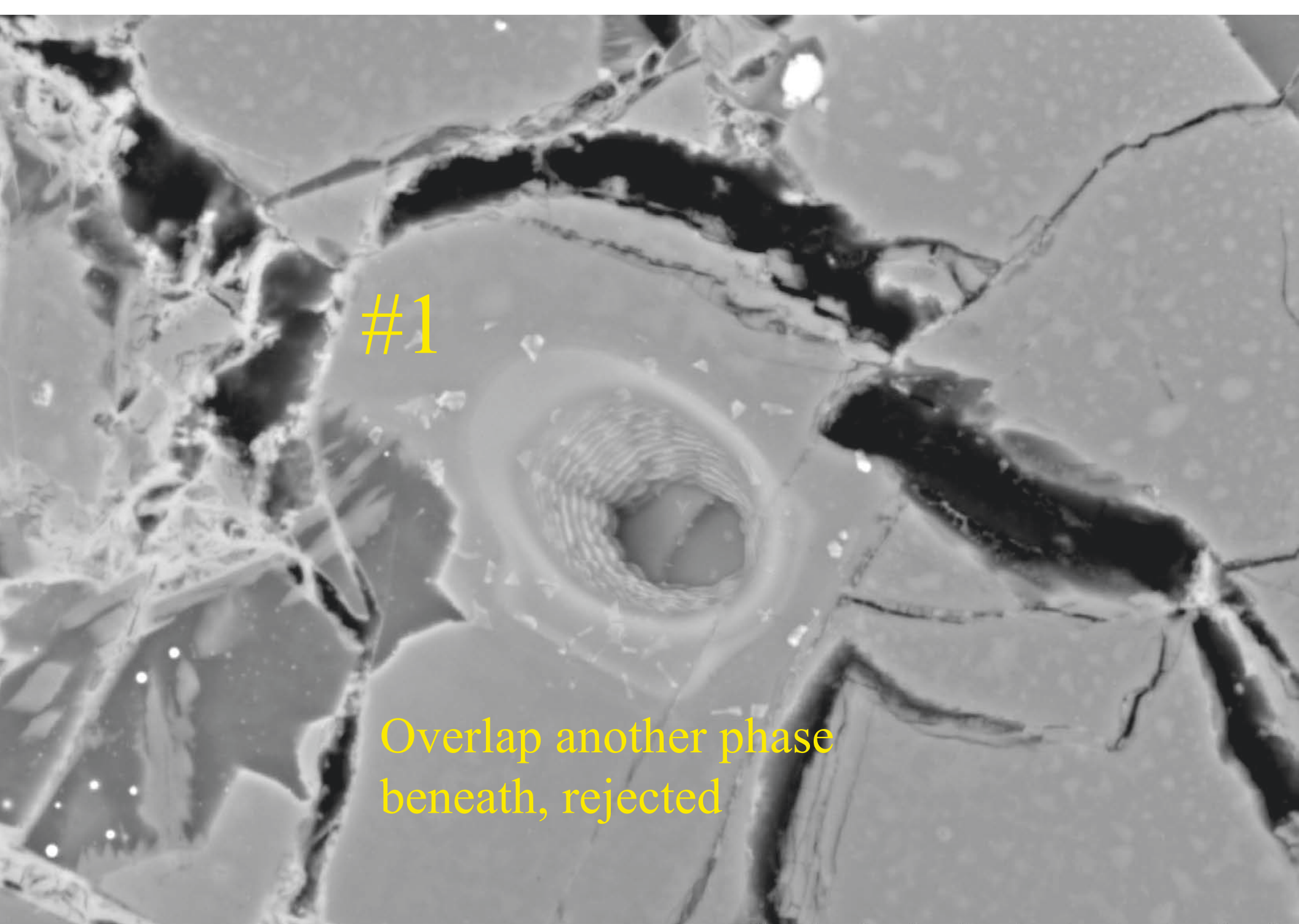
#7

#8

#6

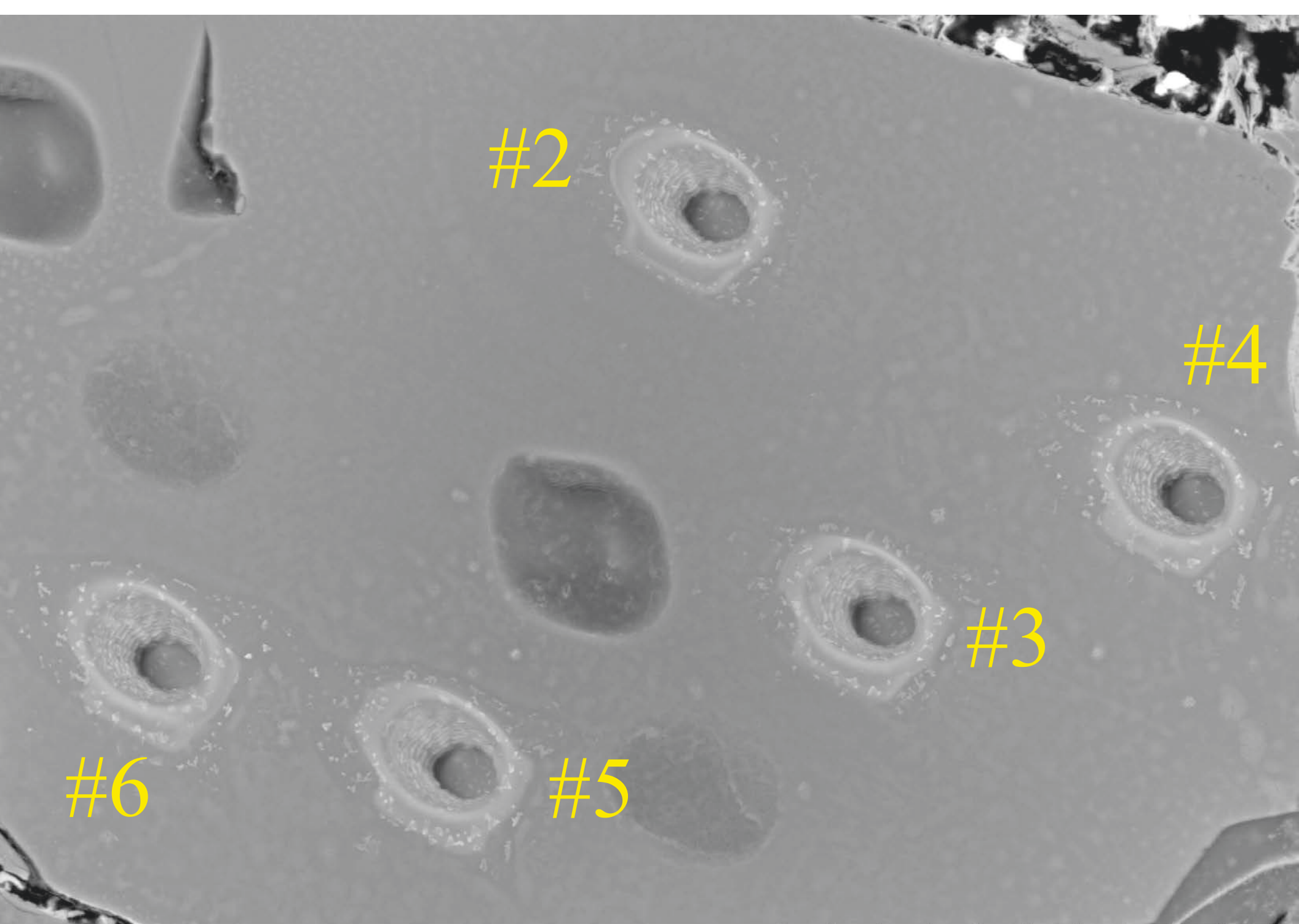
15.0kV x300 BSECOMP

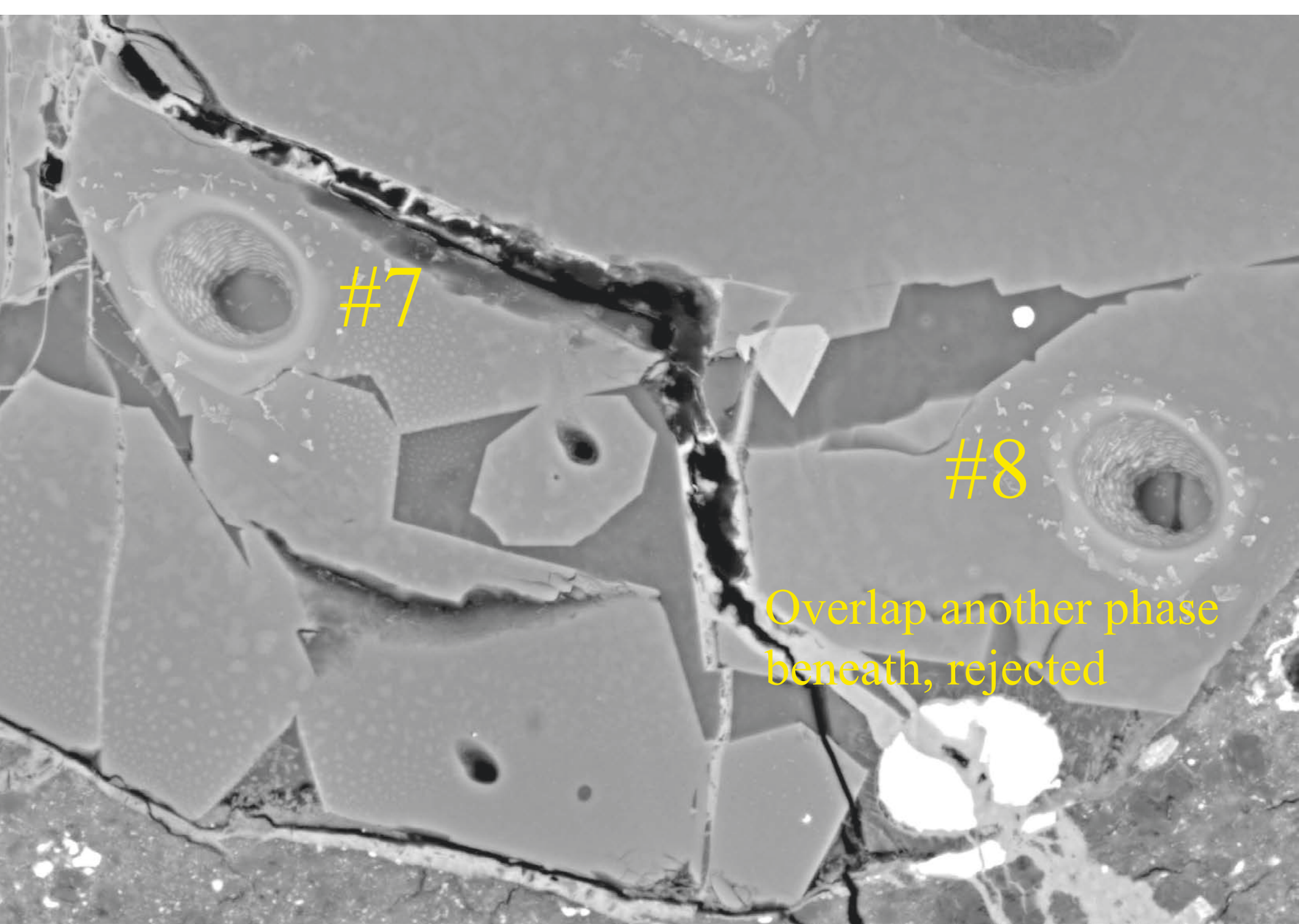
100um



#1

Overlap another phase
beneath, rejected



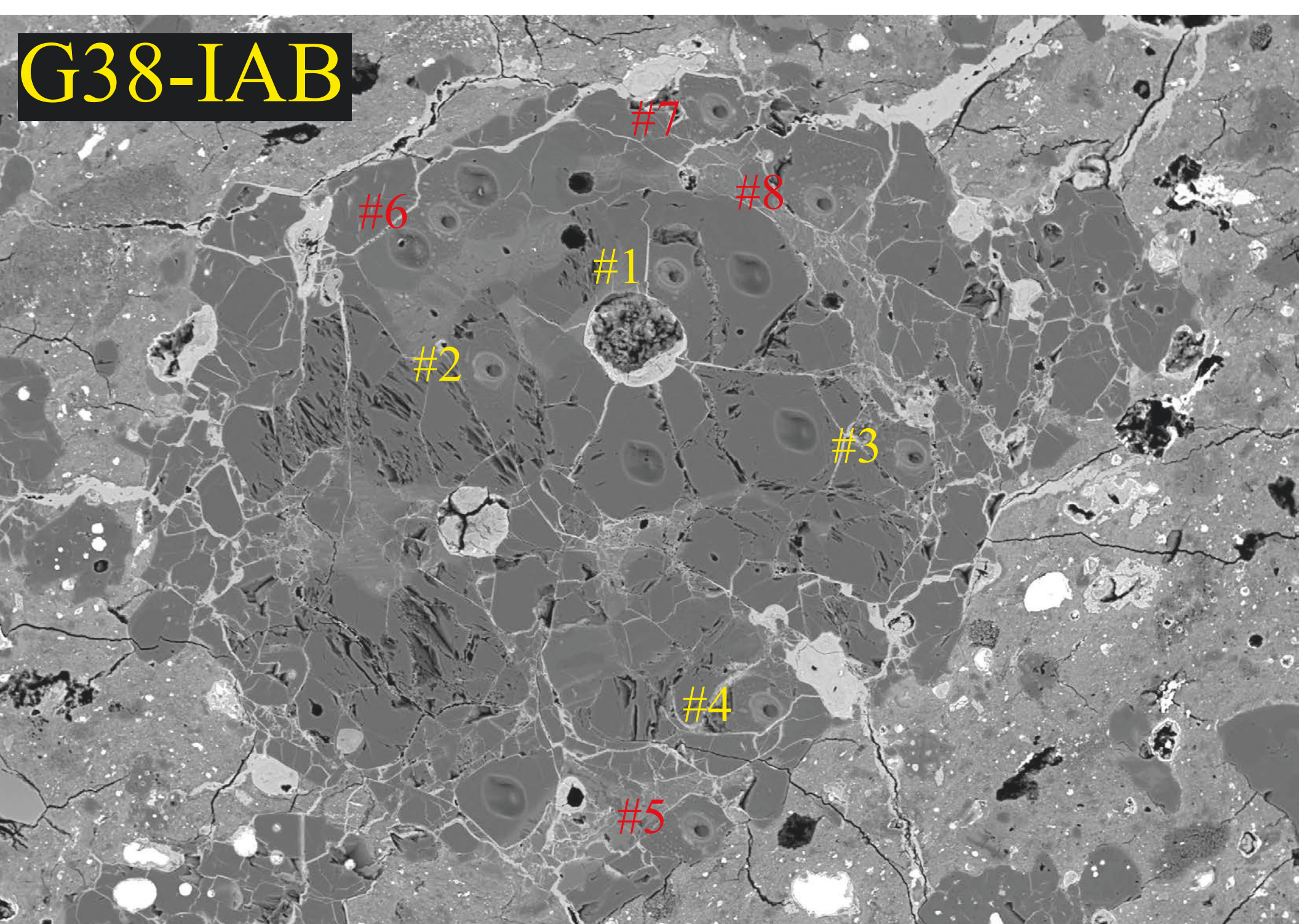


#7

#8

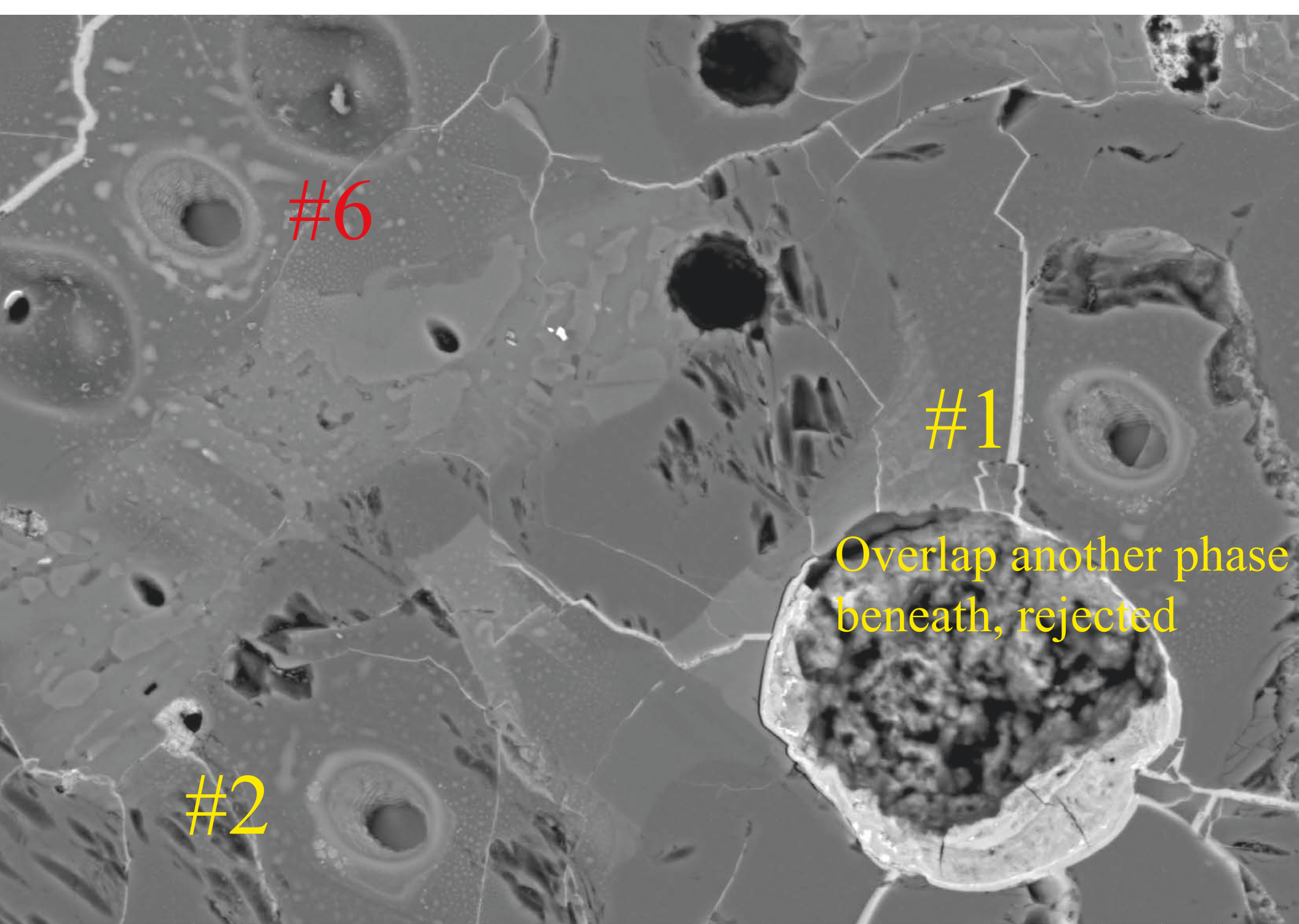
Overlap another phase
beneath, rejected

G38-IAB



15.0kV x270 BSECOMP

200um

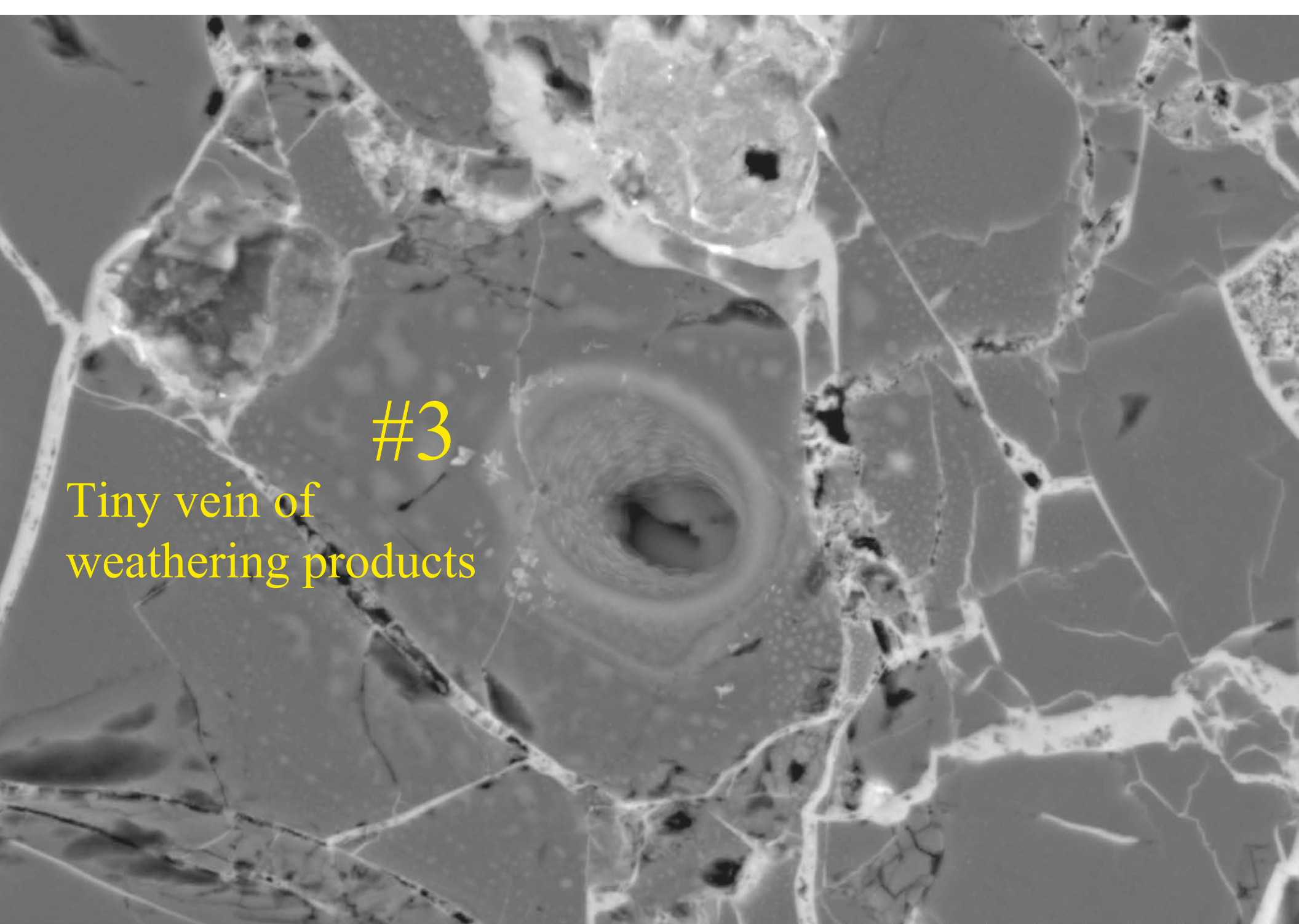


#6

#1

Overlap another phase
beneath, rejected

#2



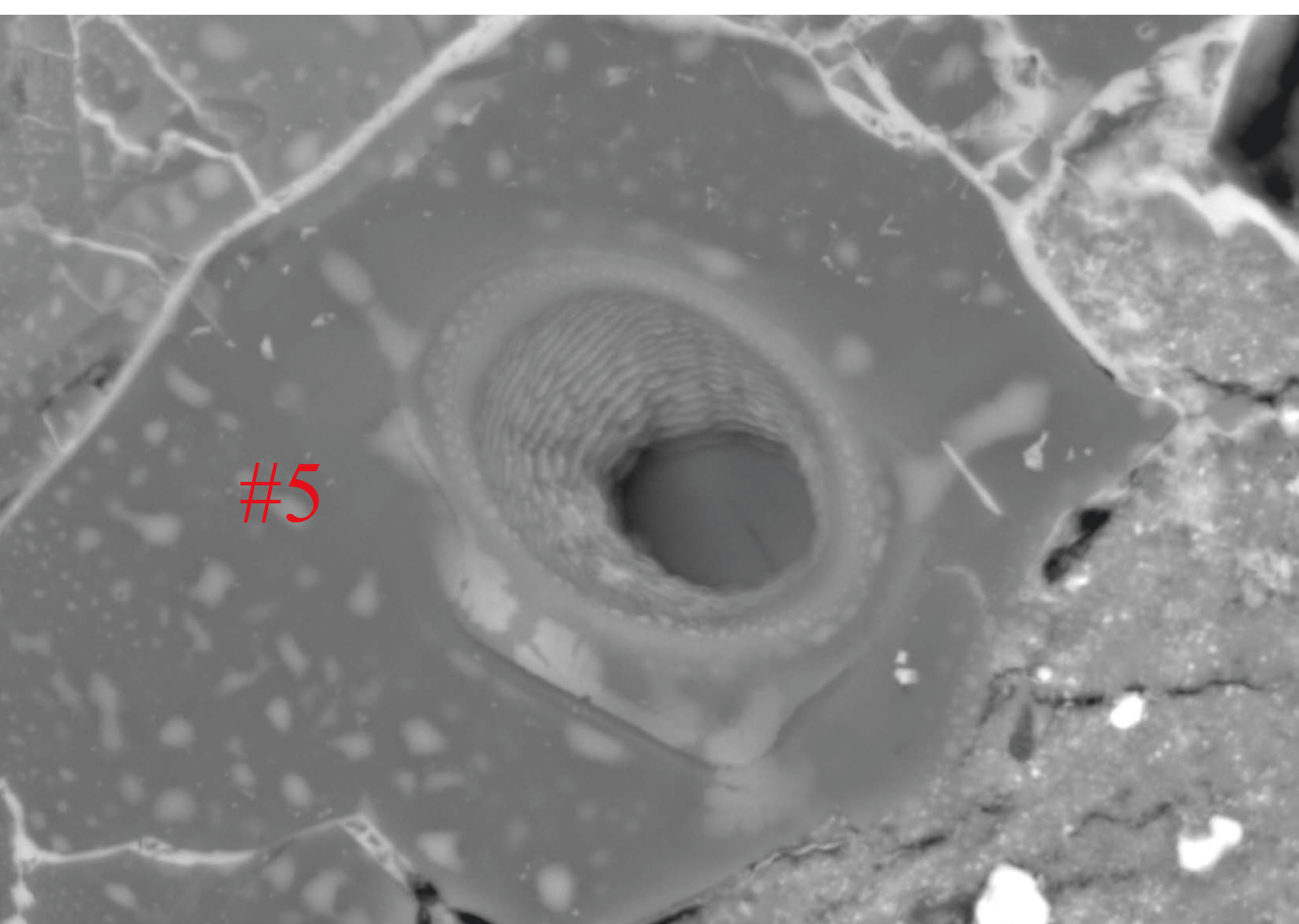
#3

Tiny vein of
weathering products

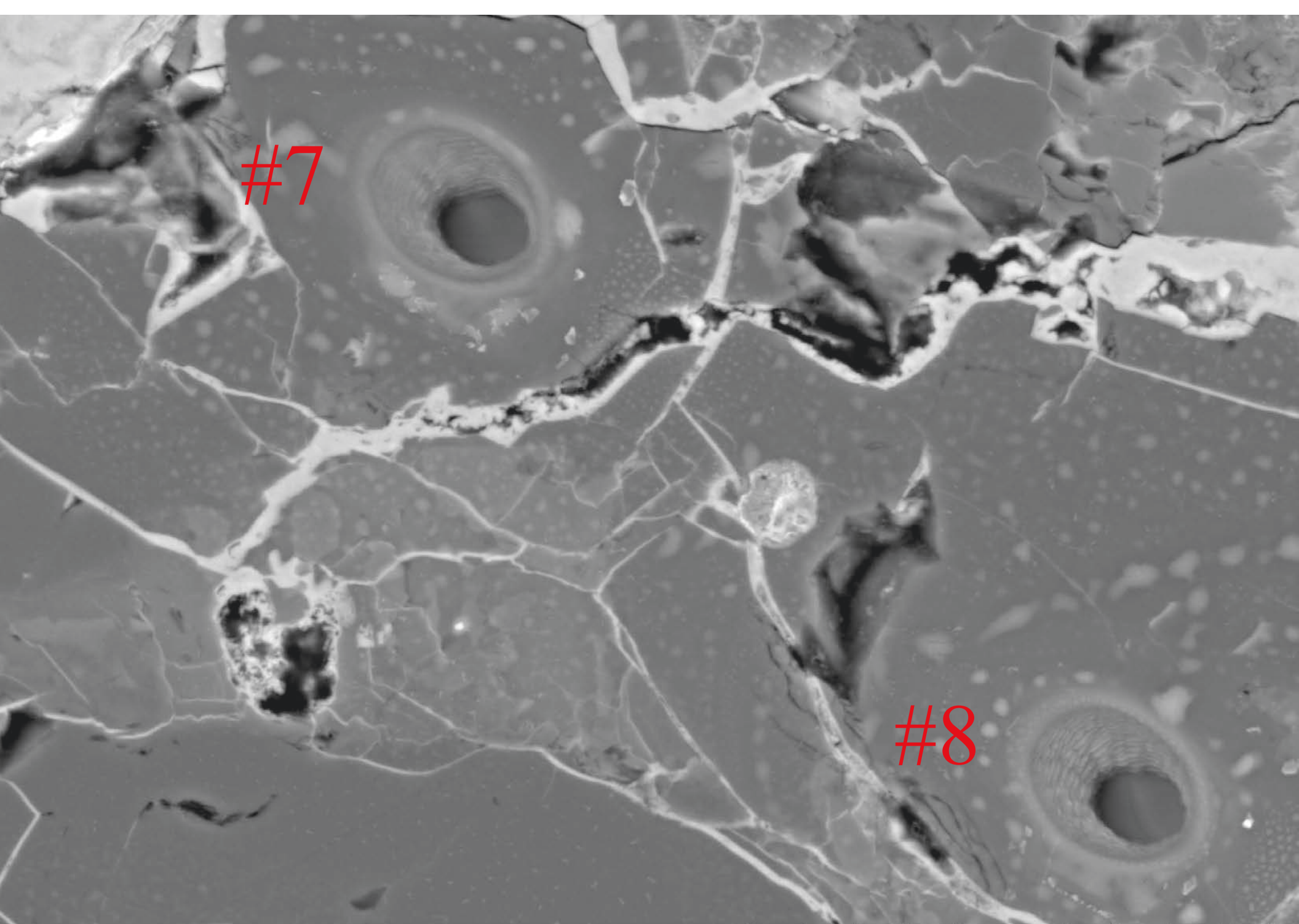
#4

15.0kV x3.70k BSECOMP

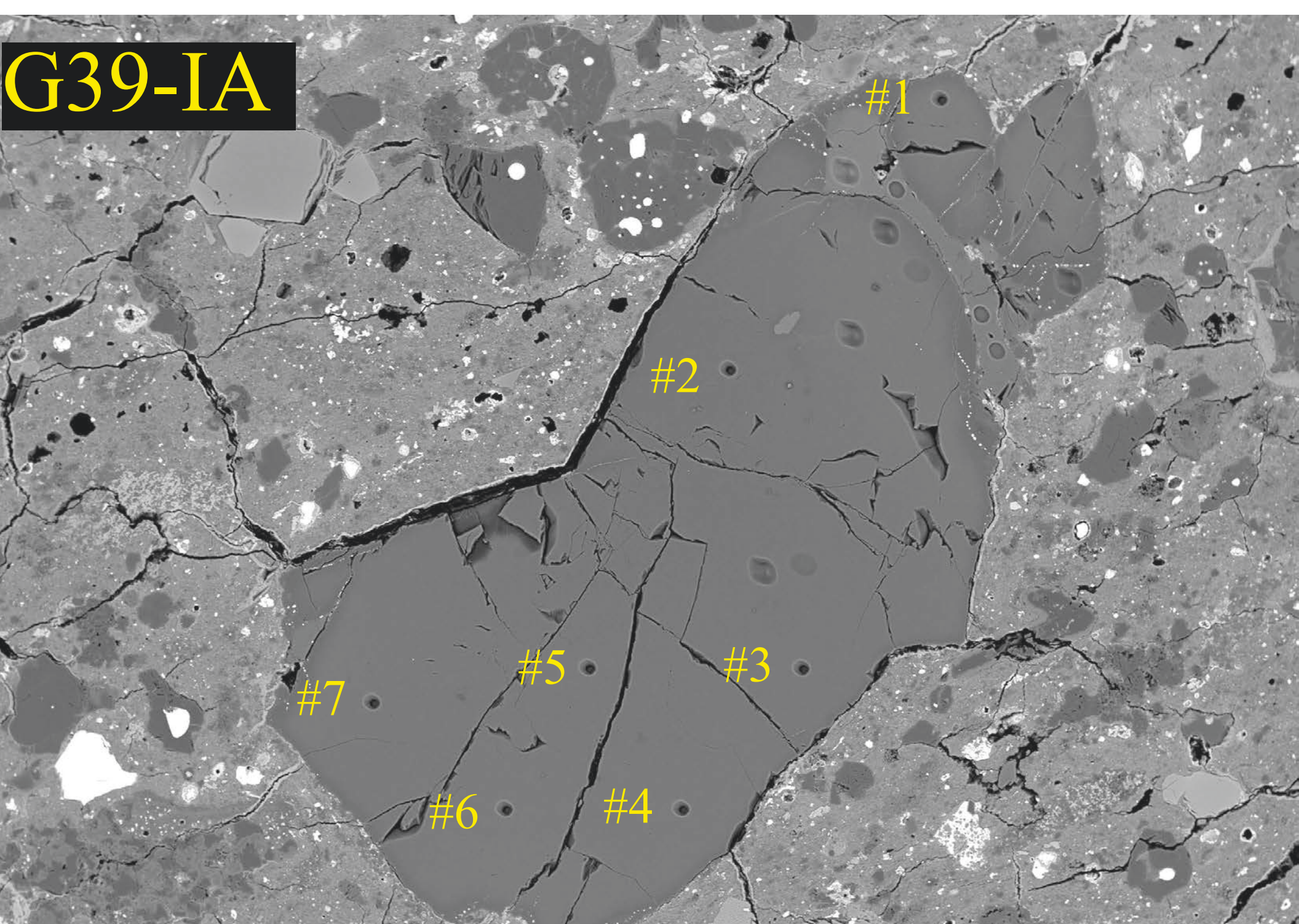
10.0um



#5

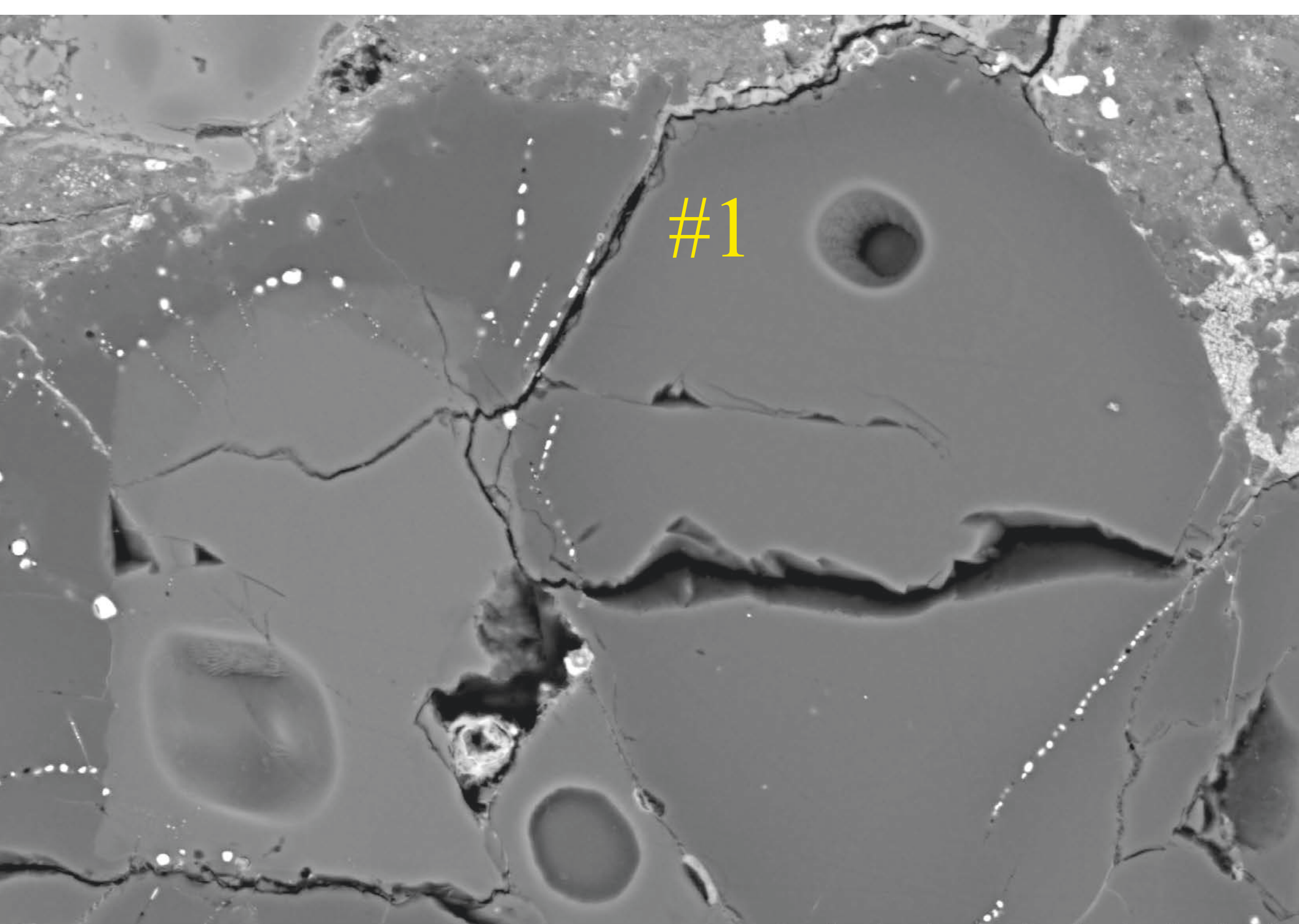


G39-1A



15.0kV x180 BSECOMP

300um

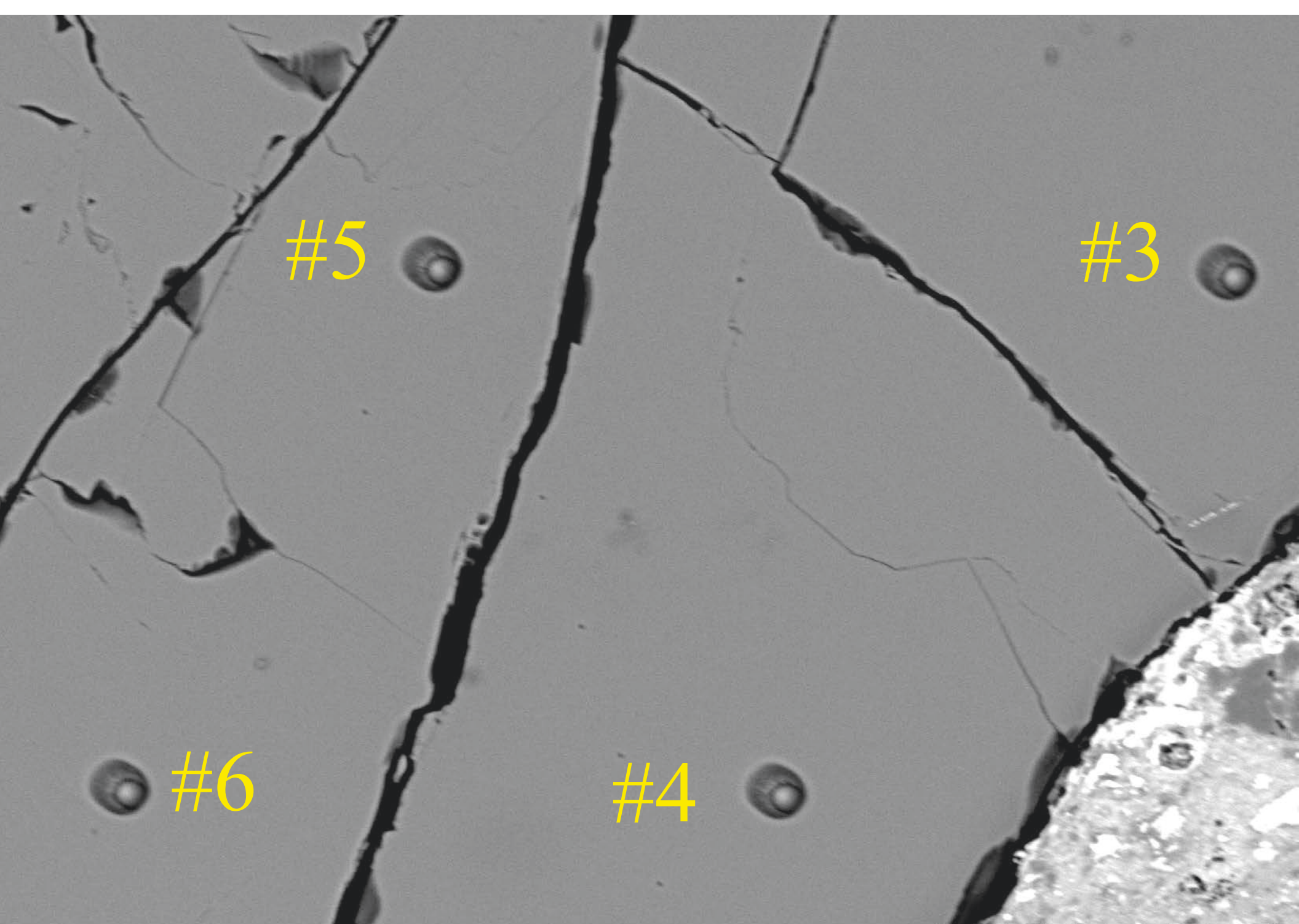


#1

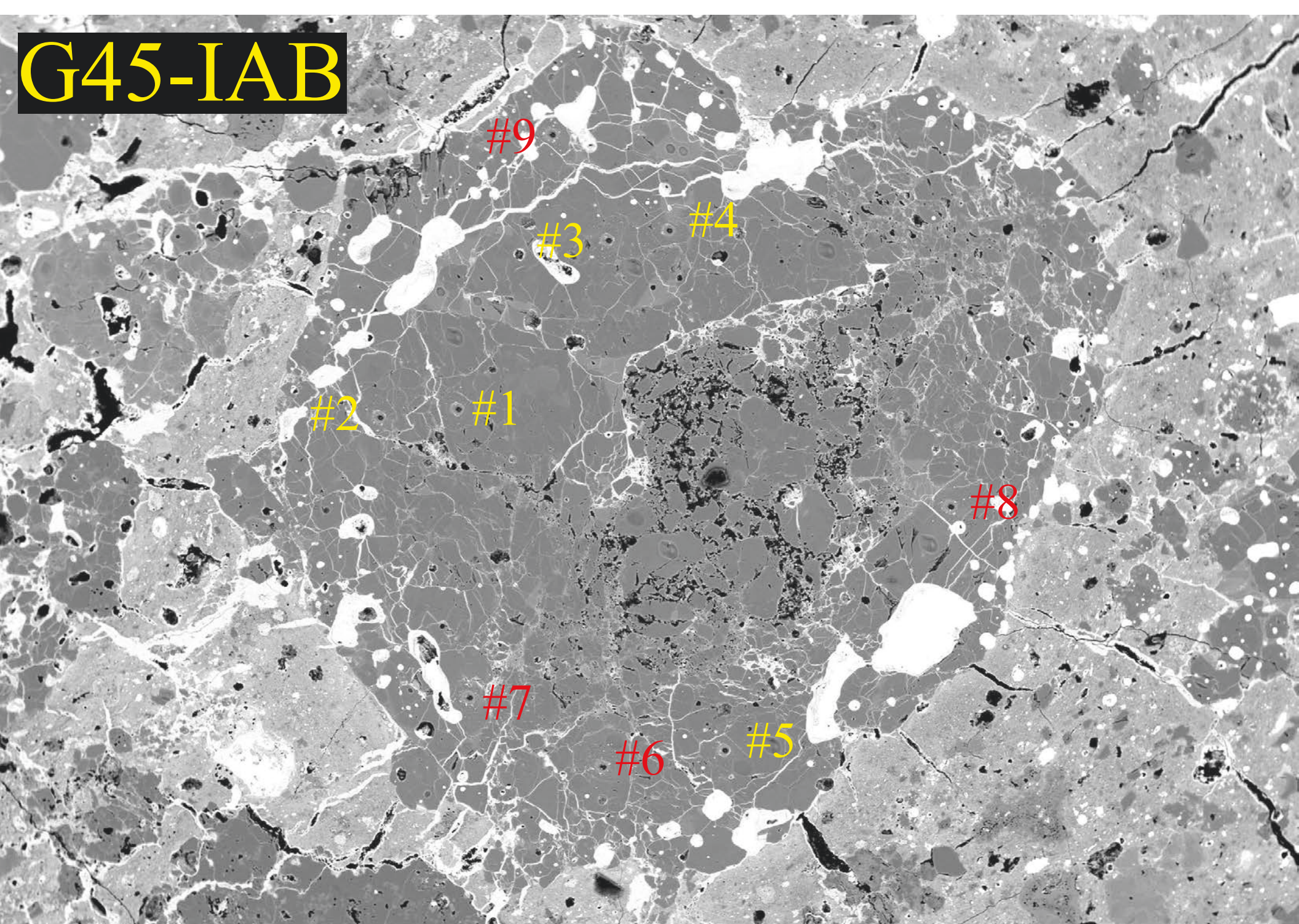
#2

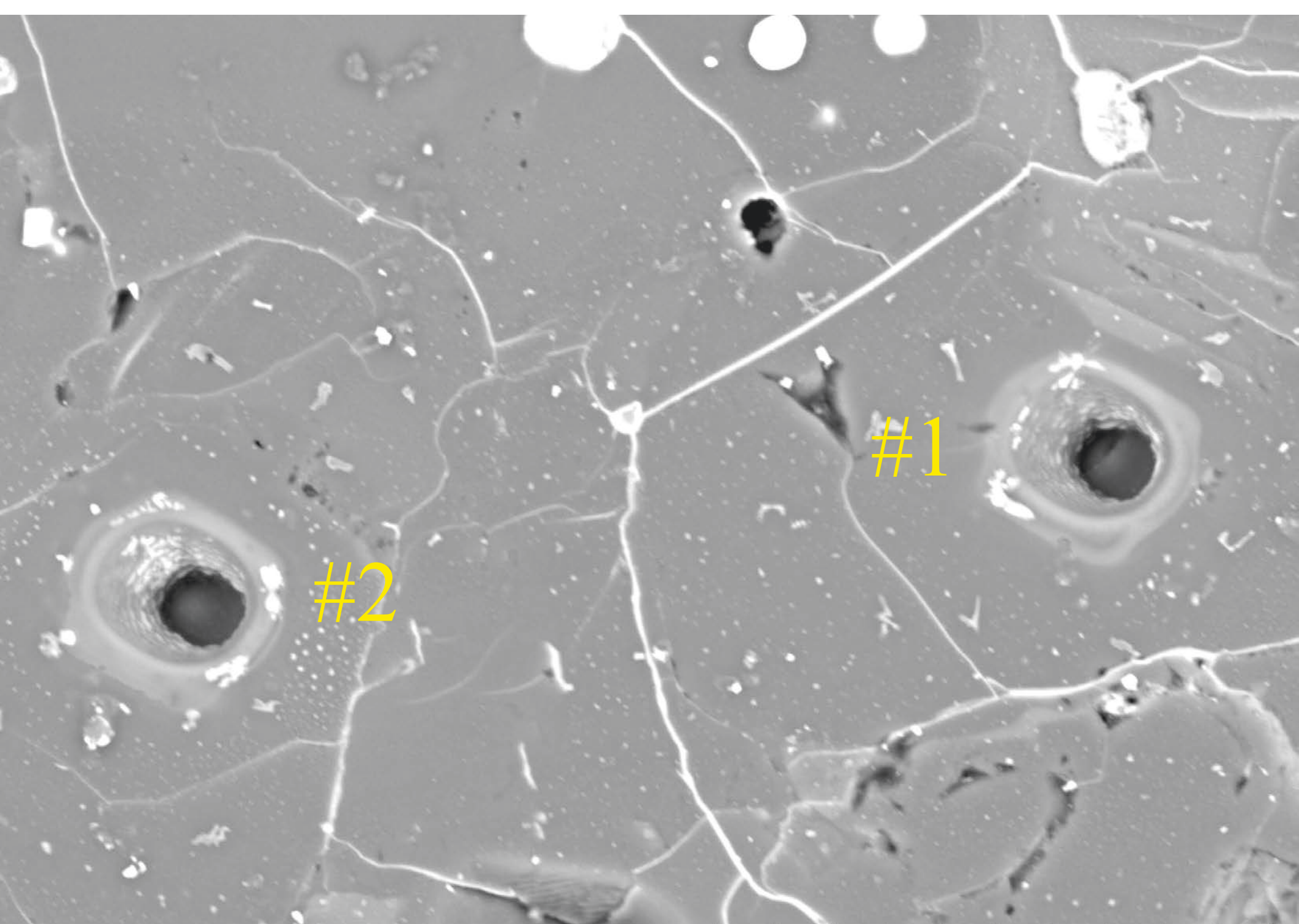
15.0kV x1.70k BSECOMP

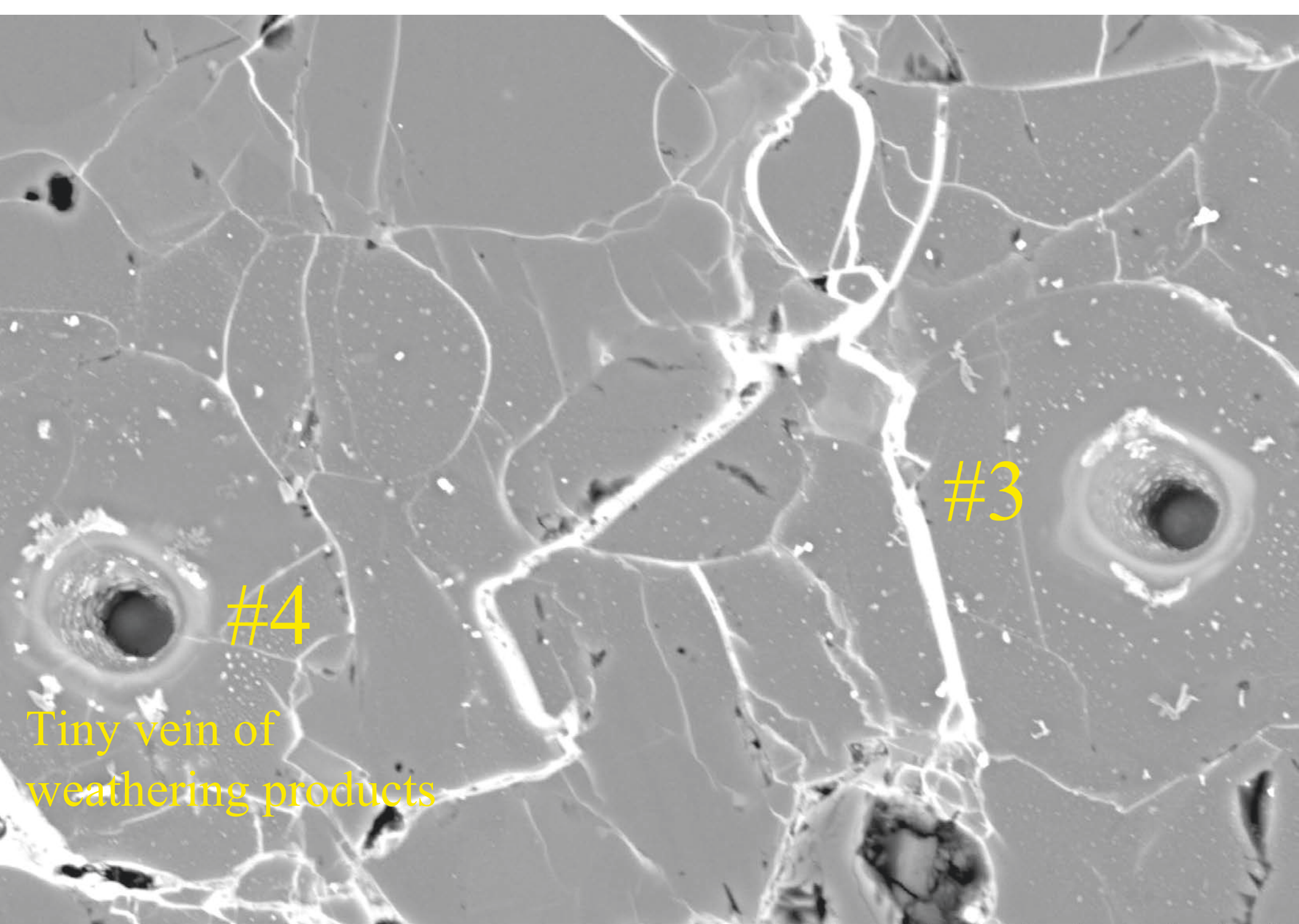
30.0um



G45-IAB



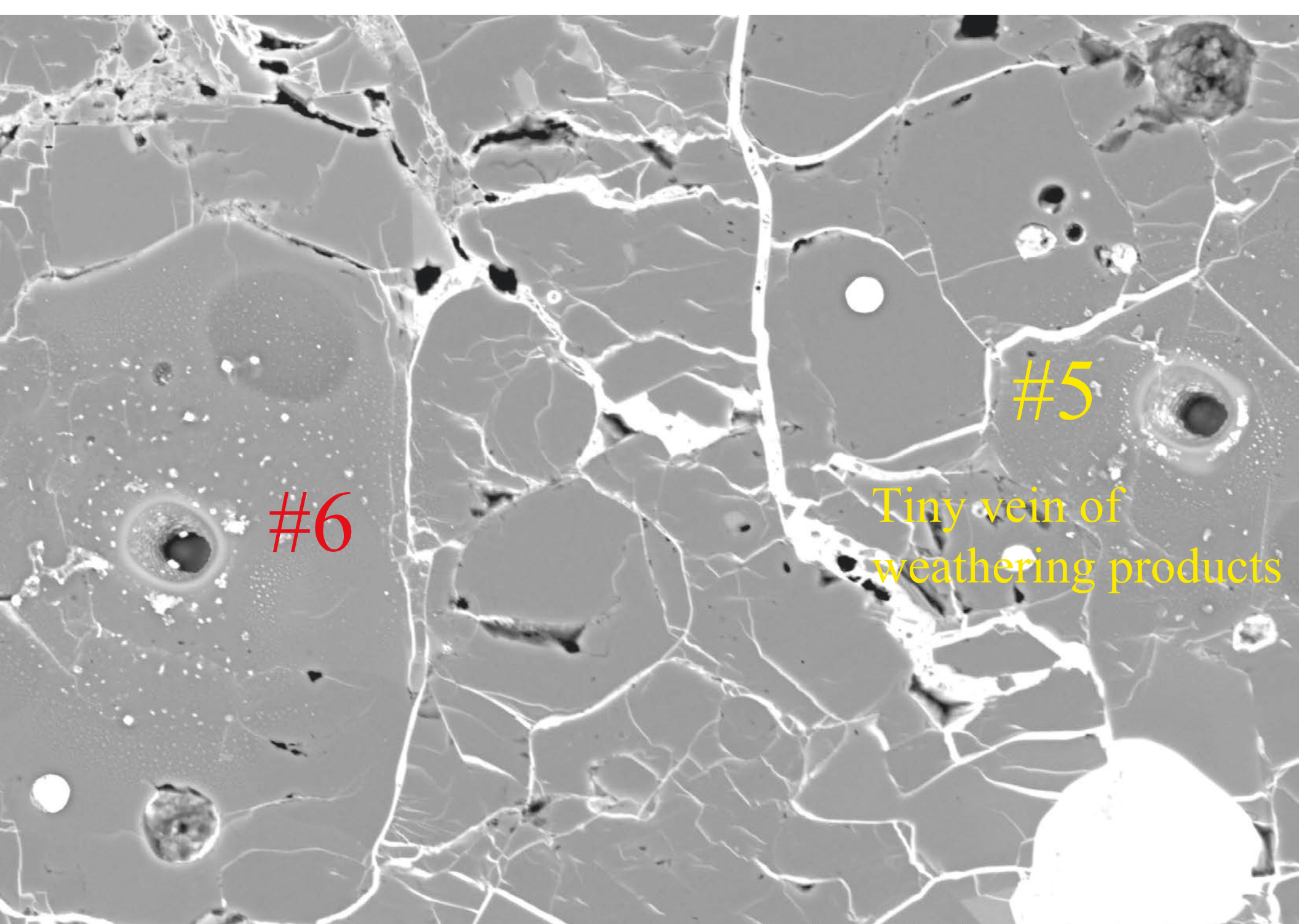




Tiny vein of
weathering products

#4

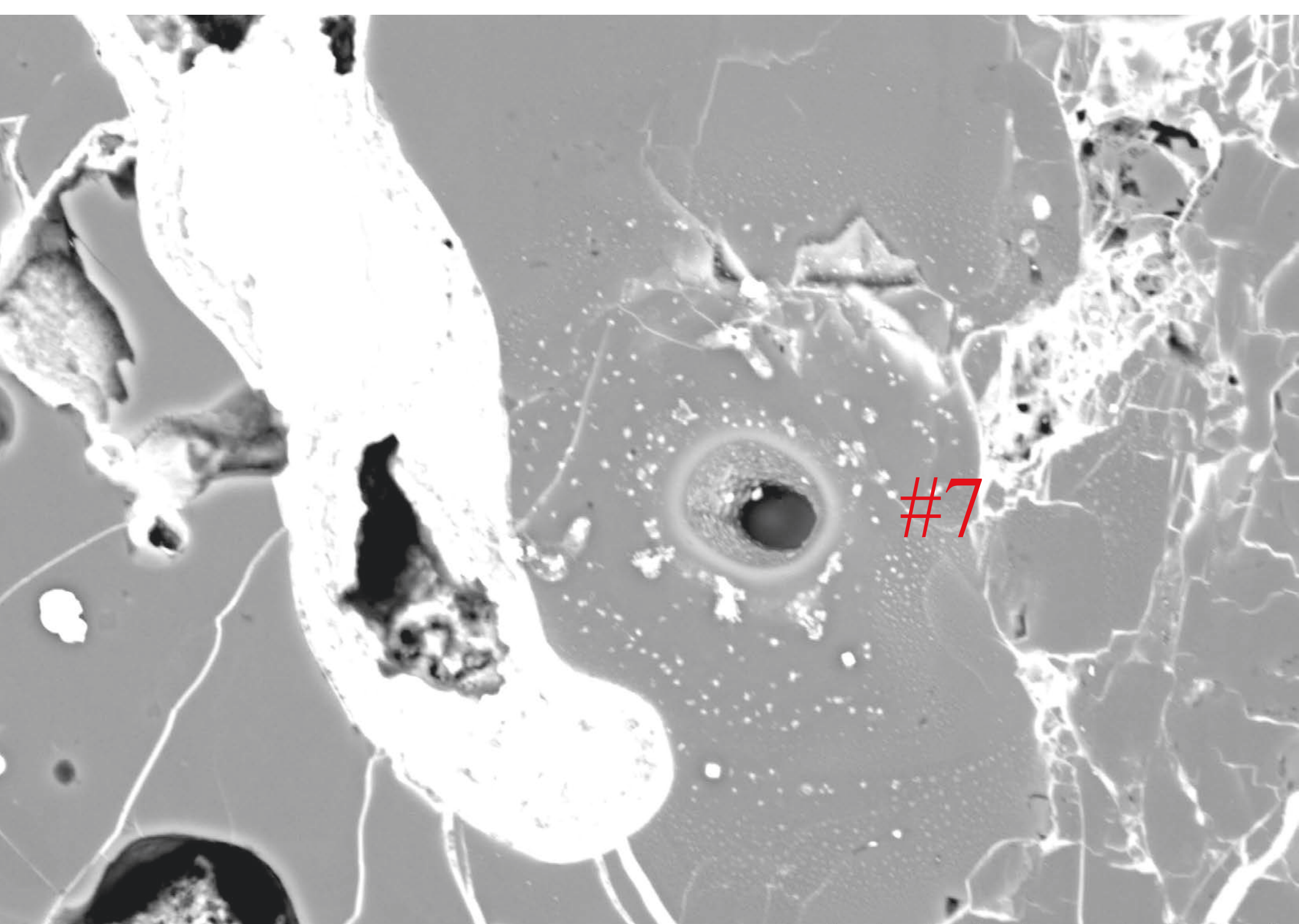
#3



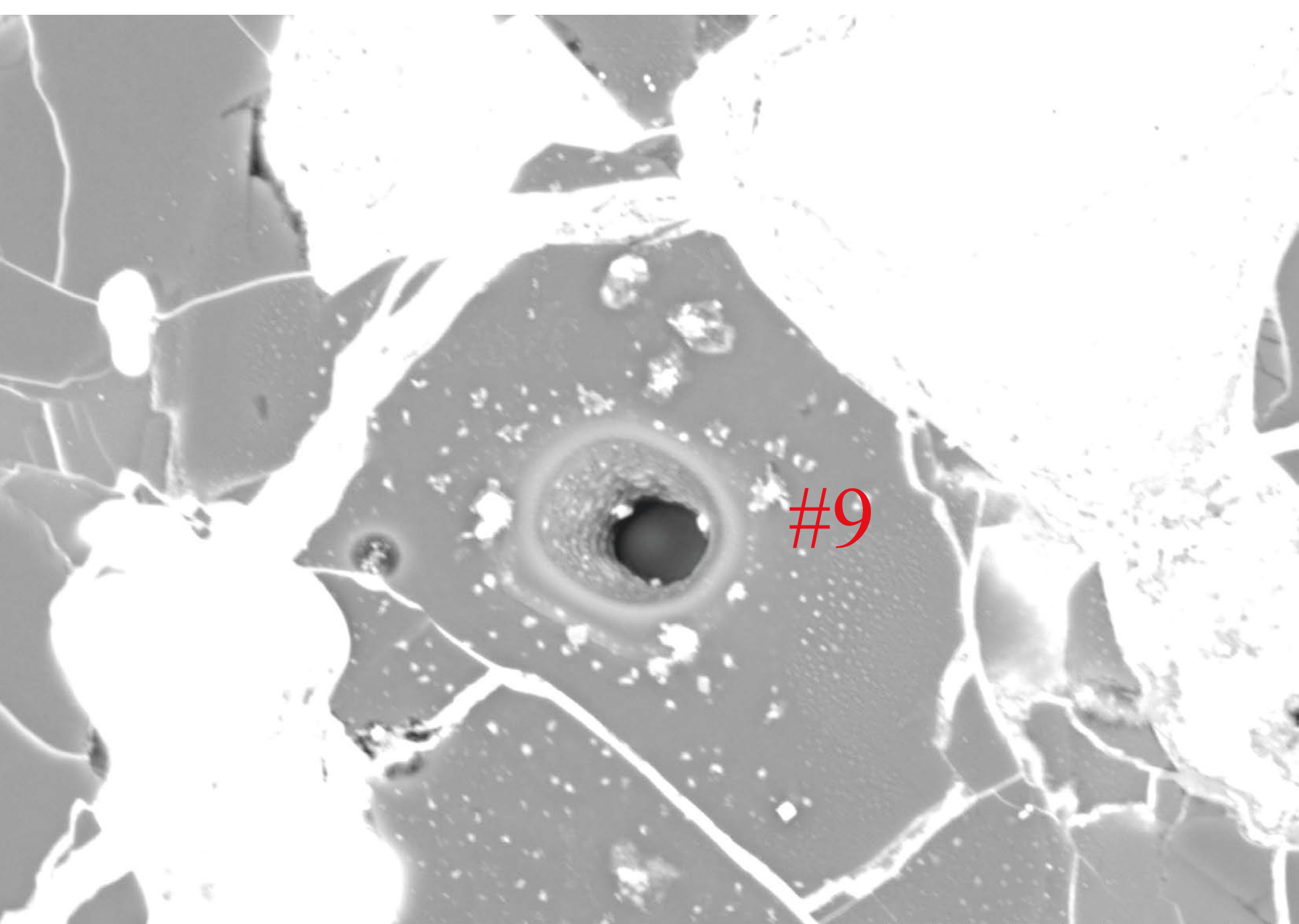
#6

#5

Tiny vein of
weathering products

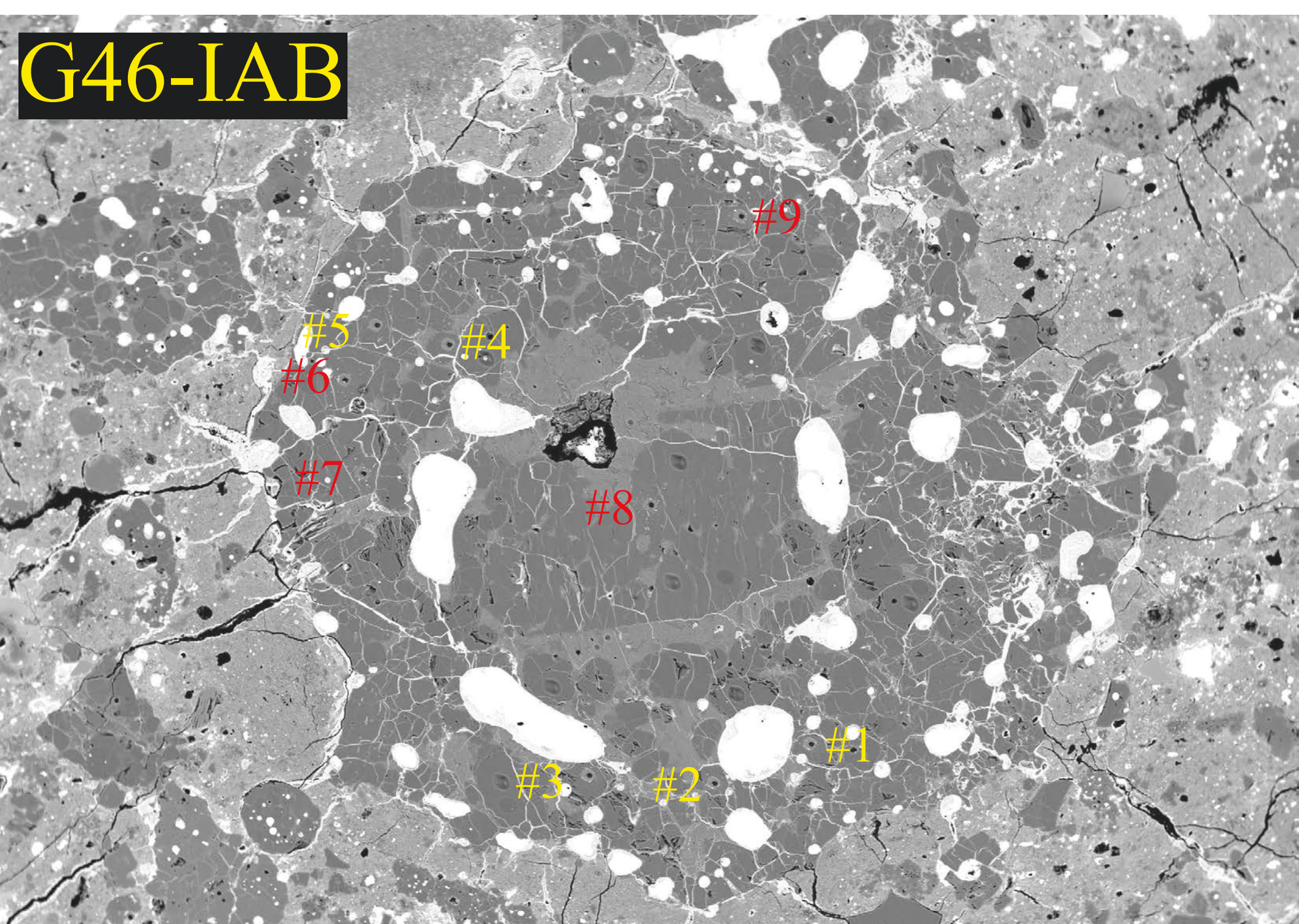


#7



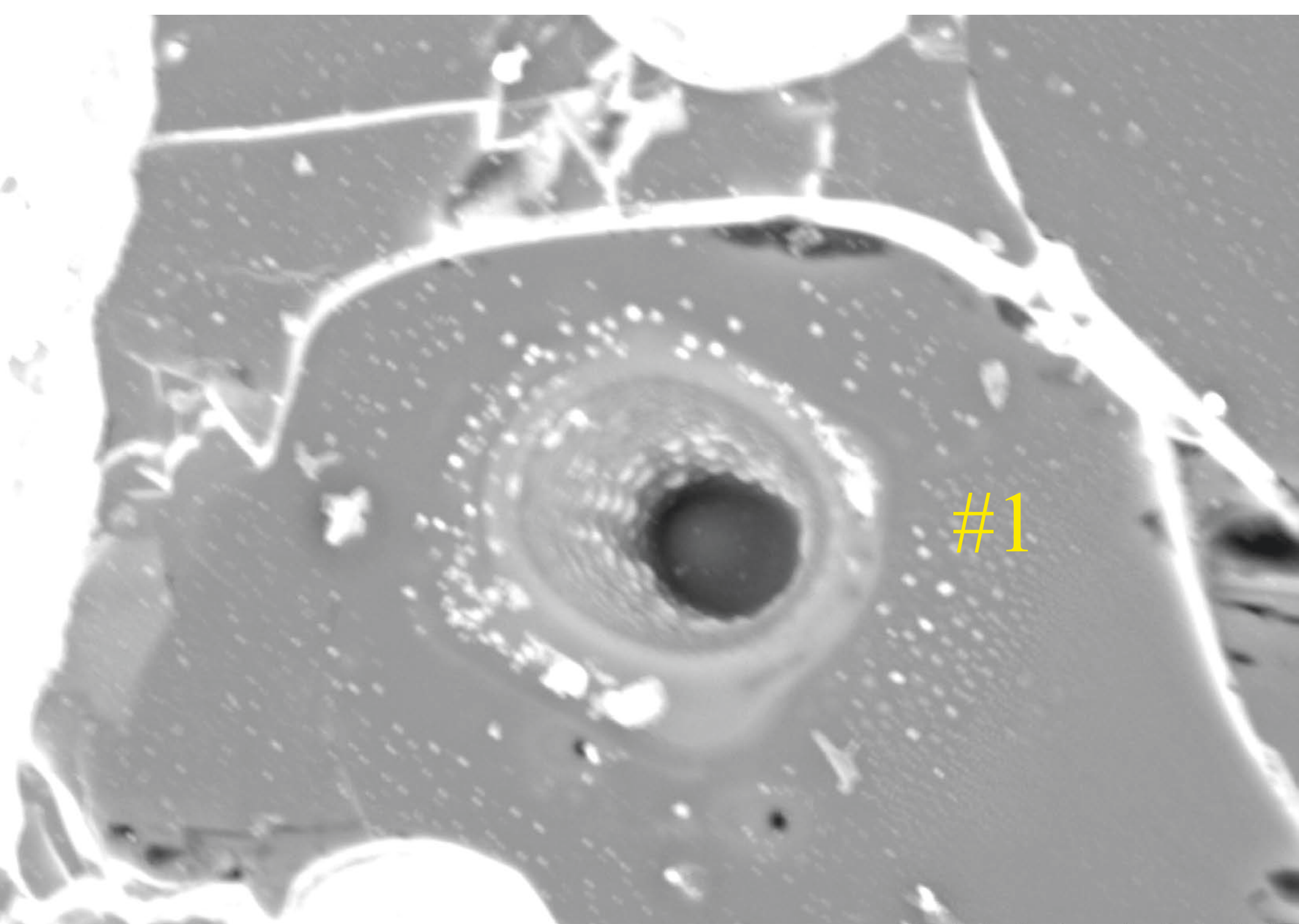
#9

G46-IAB

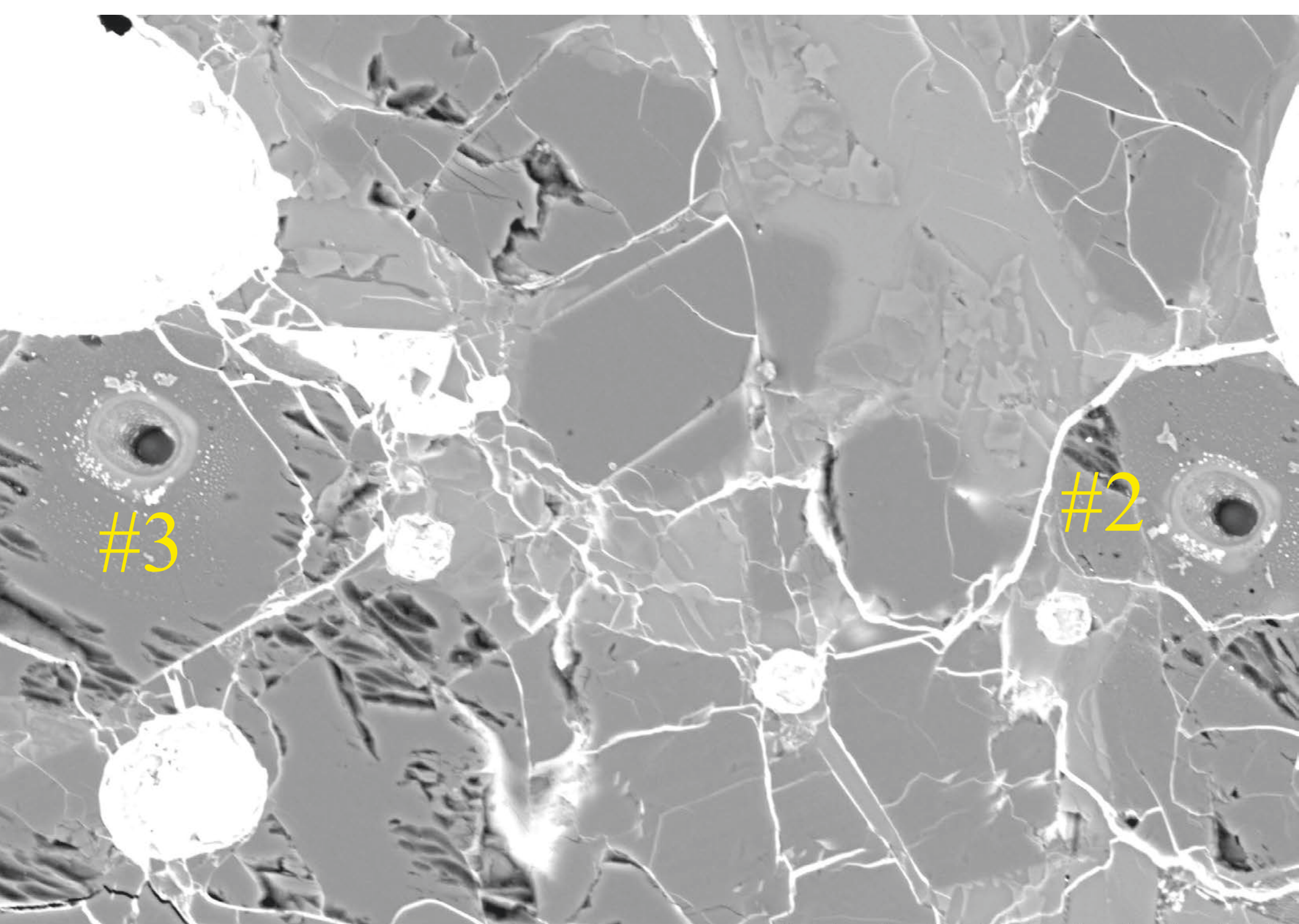


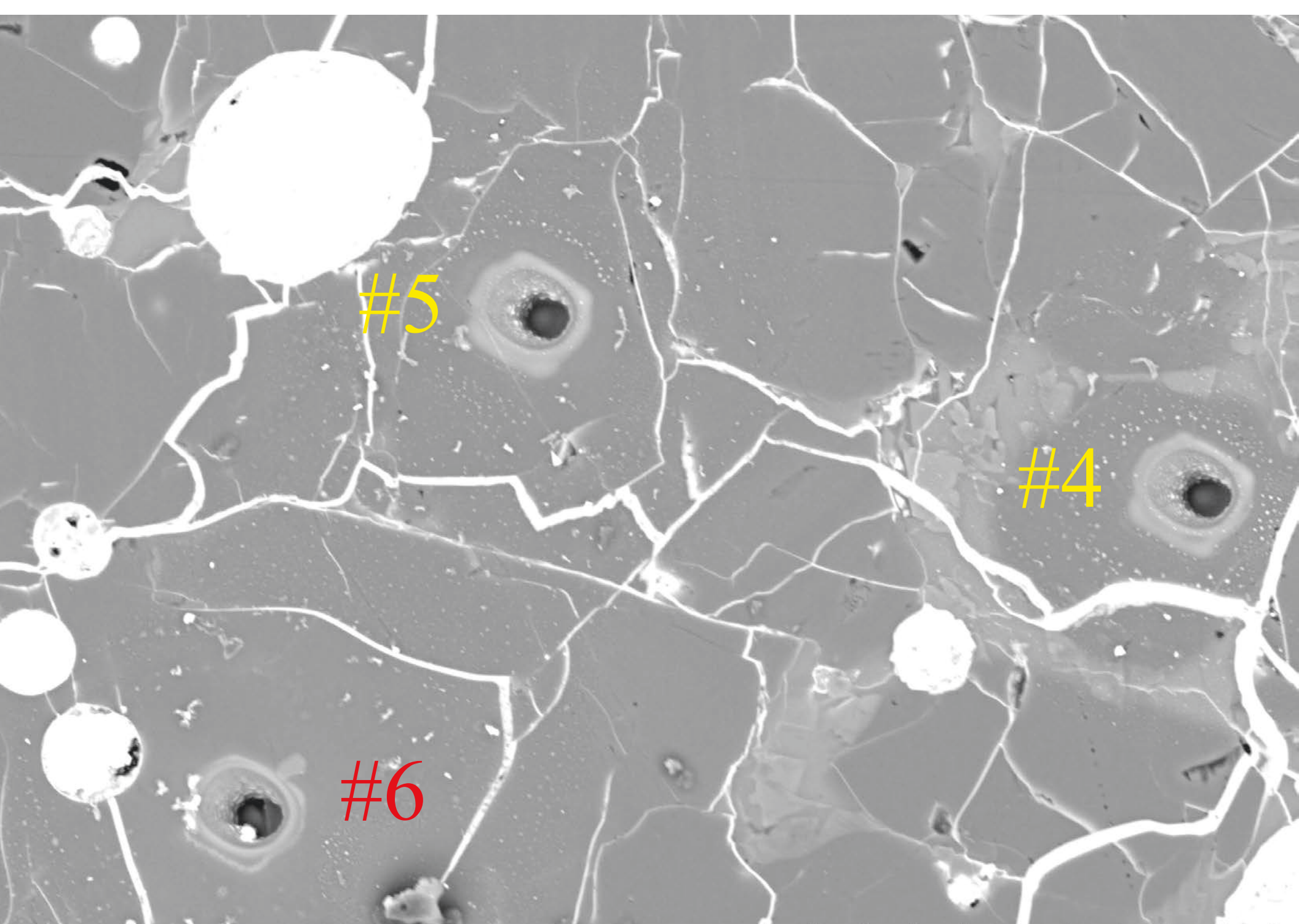
15.0kV x110 BSECOMP

500um



#1

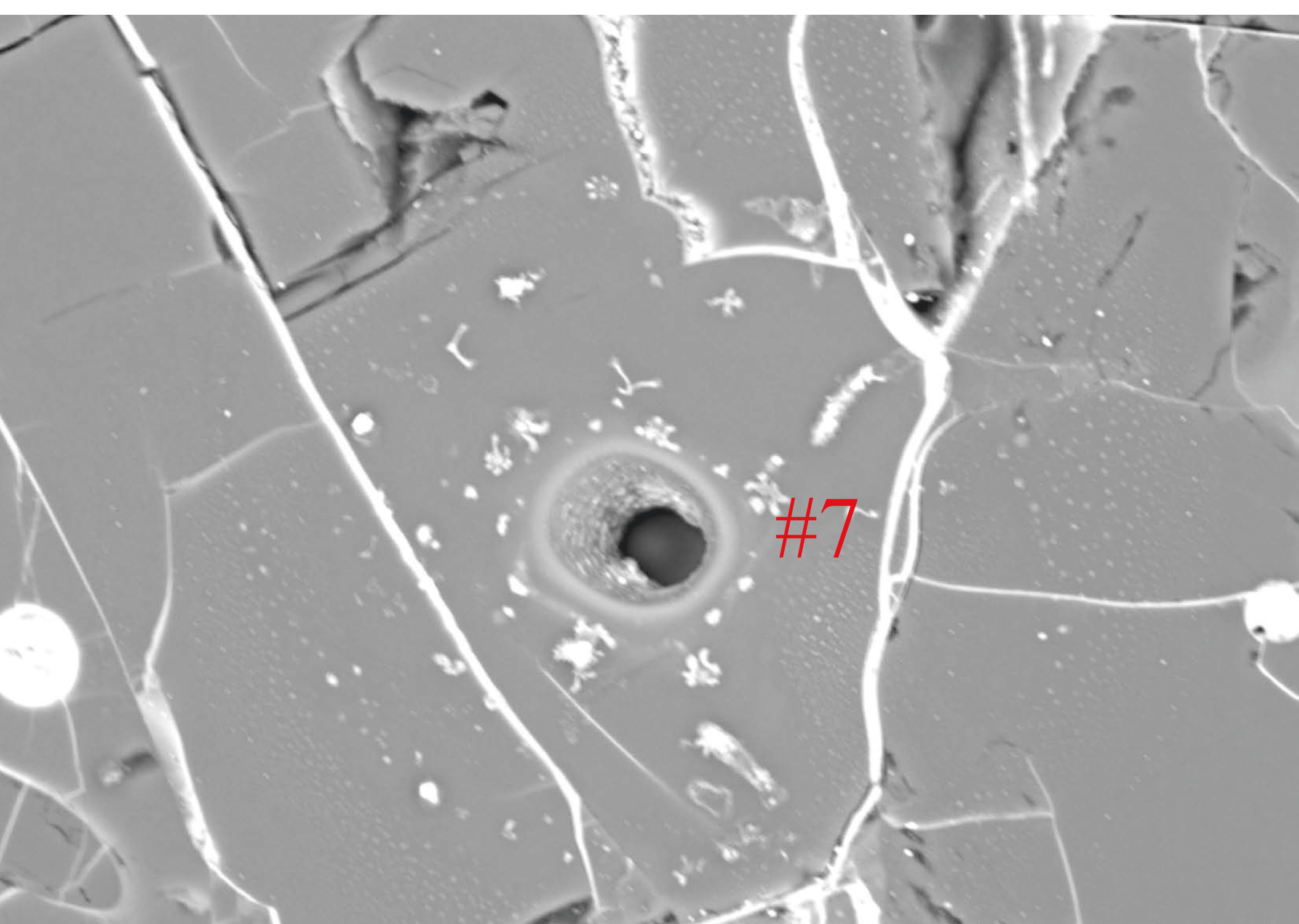




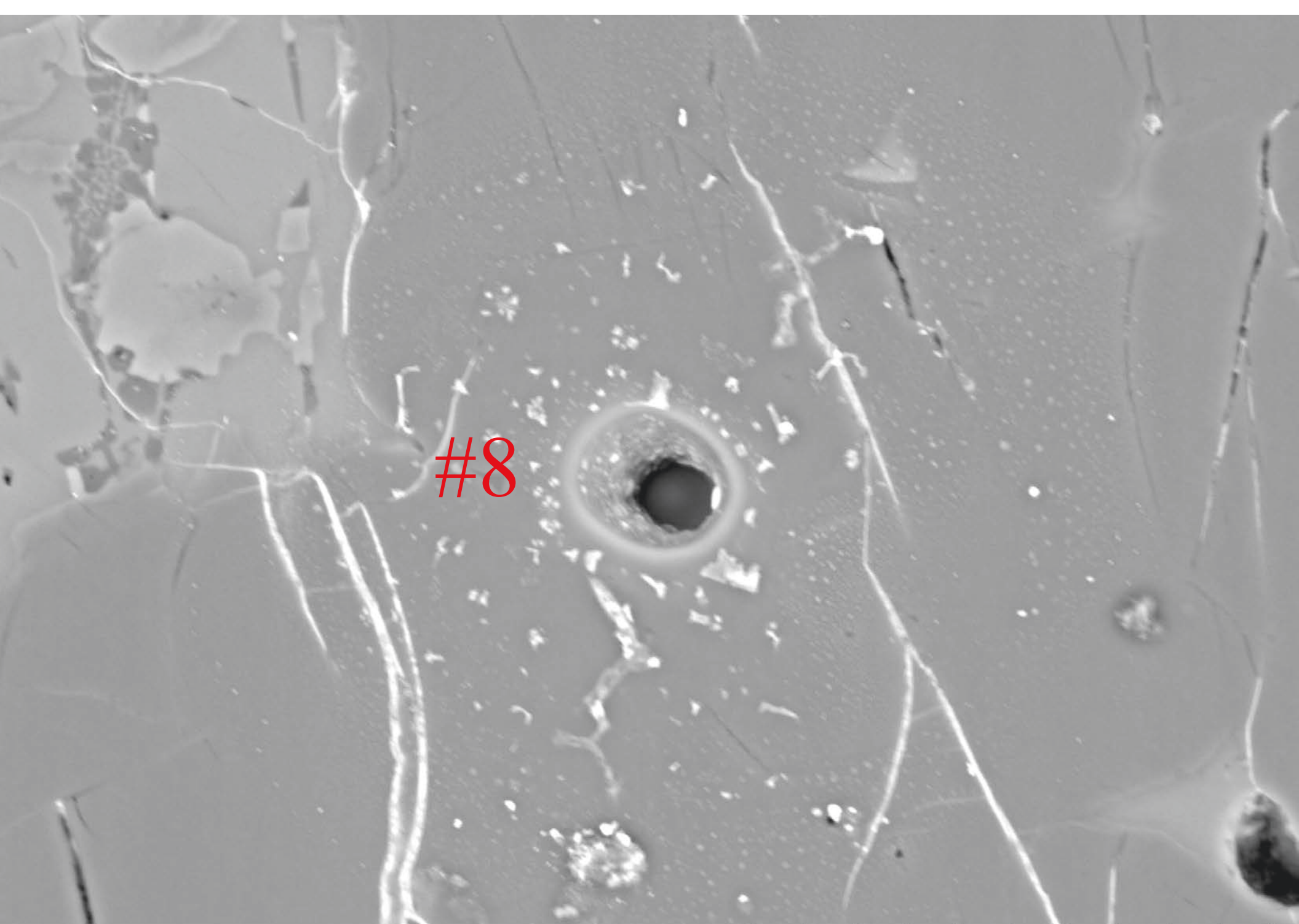
#5

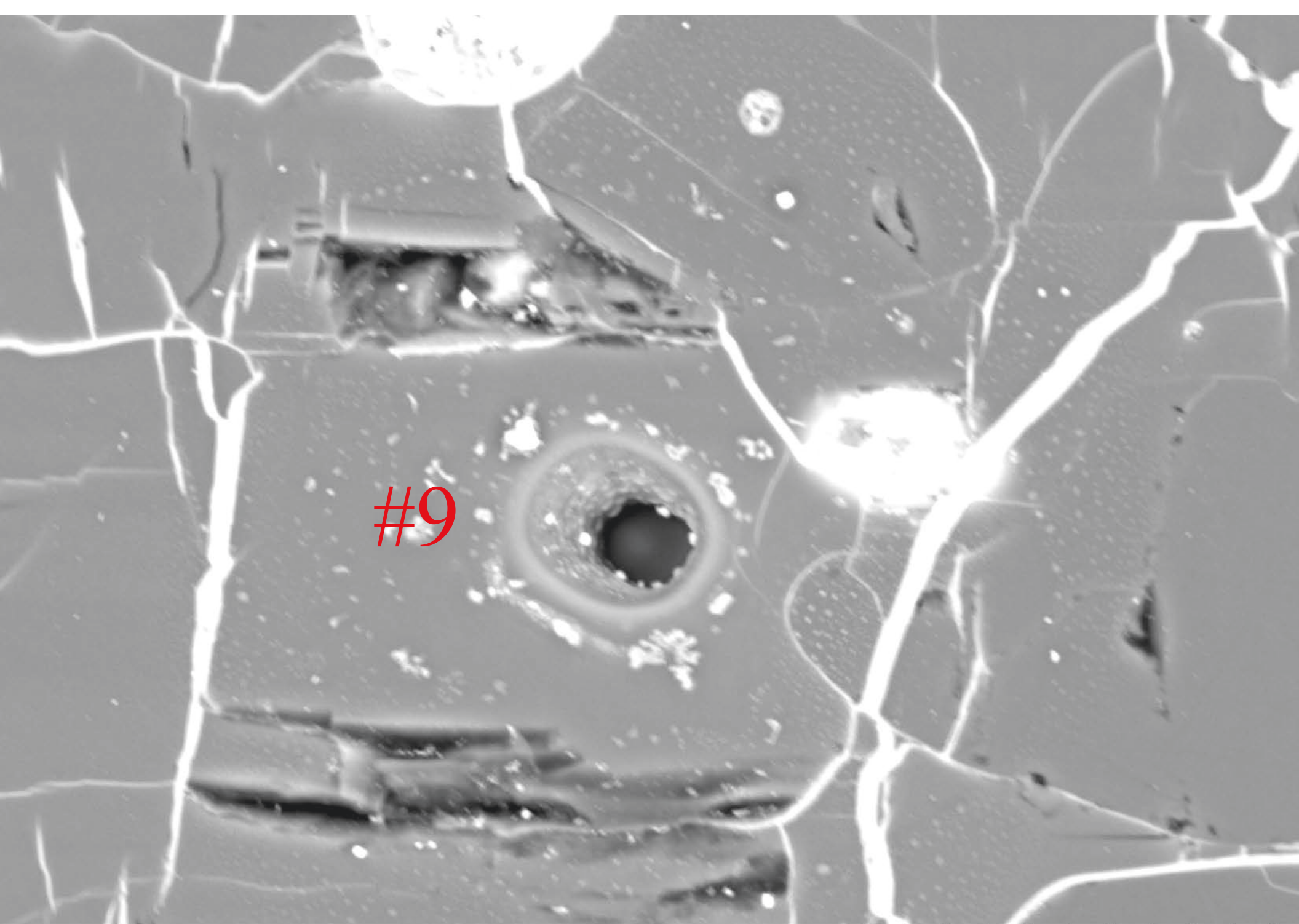
#4

#6



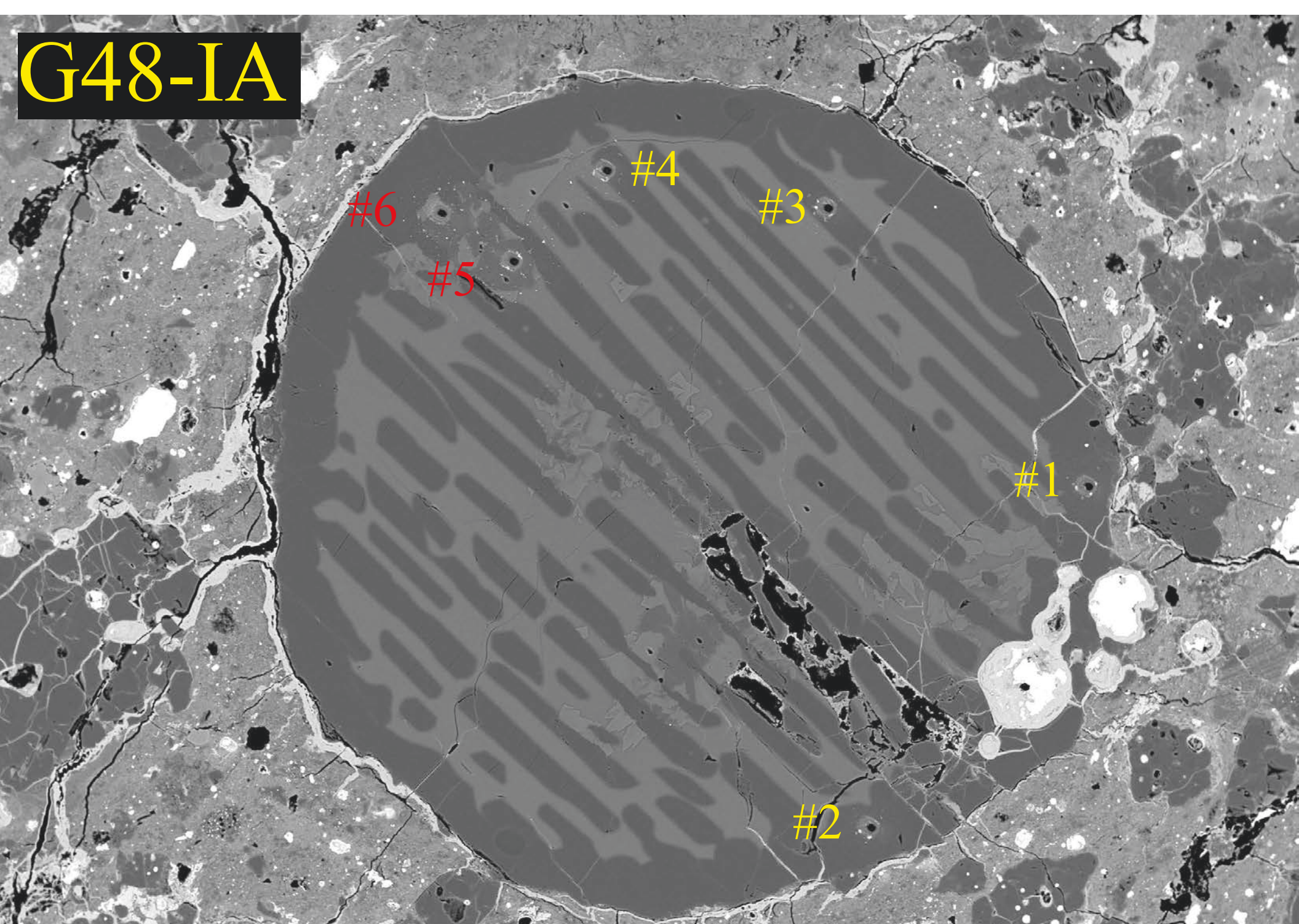
#7

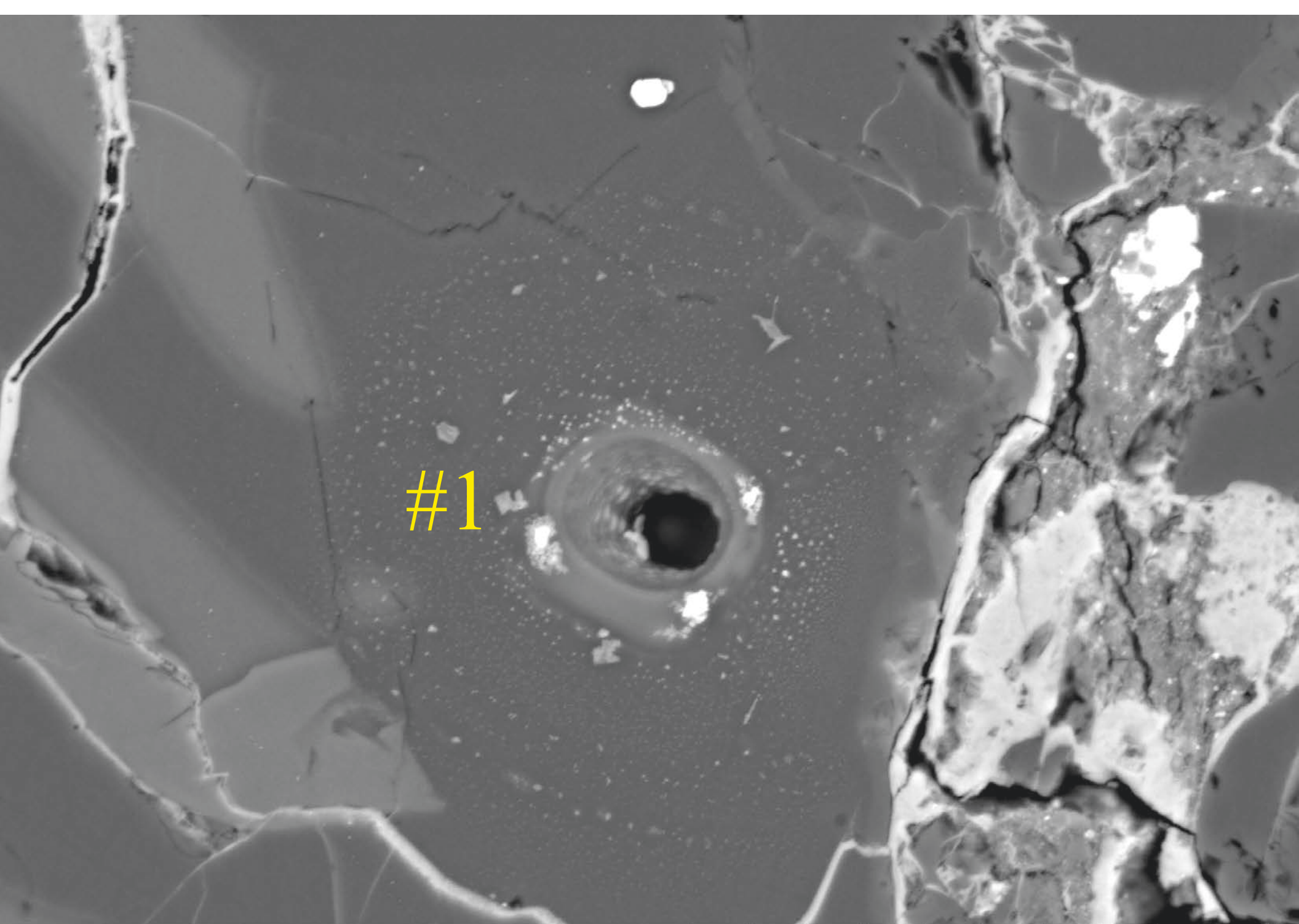




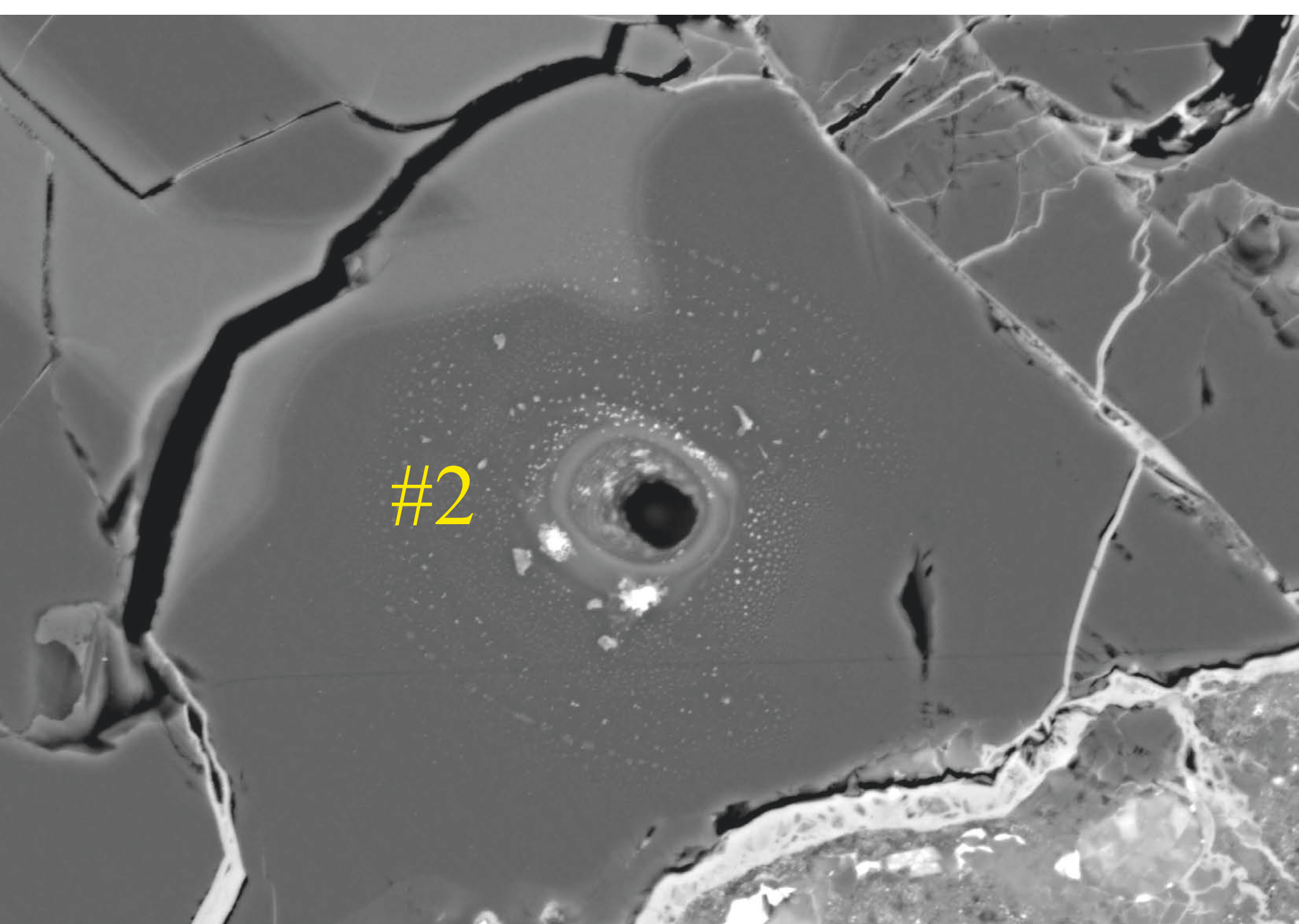
#9

G48-IA

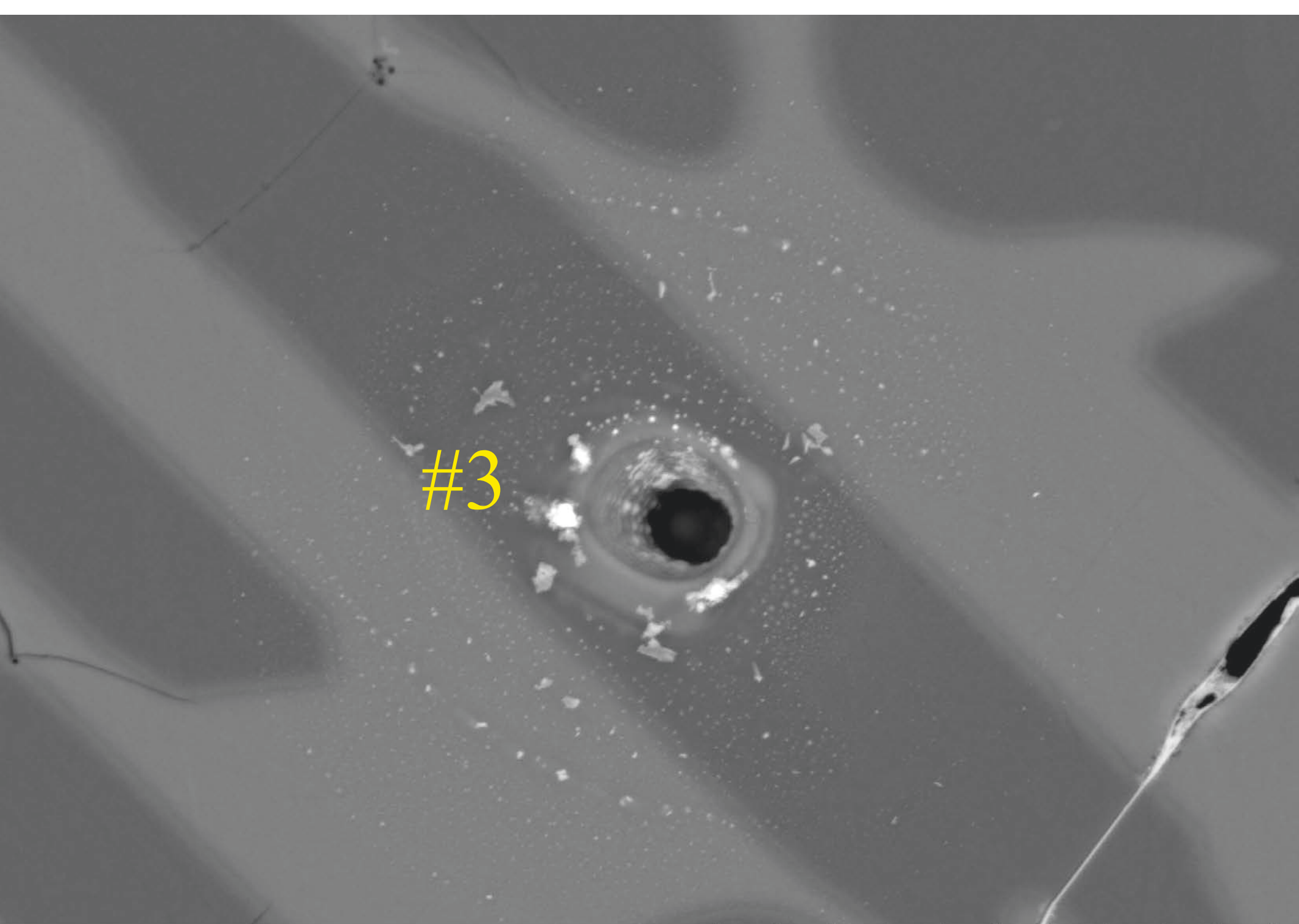




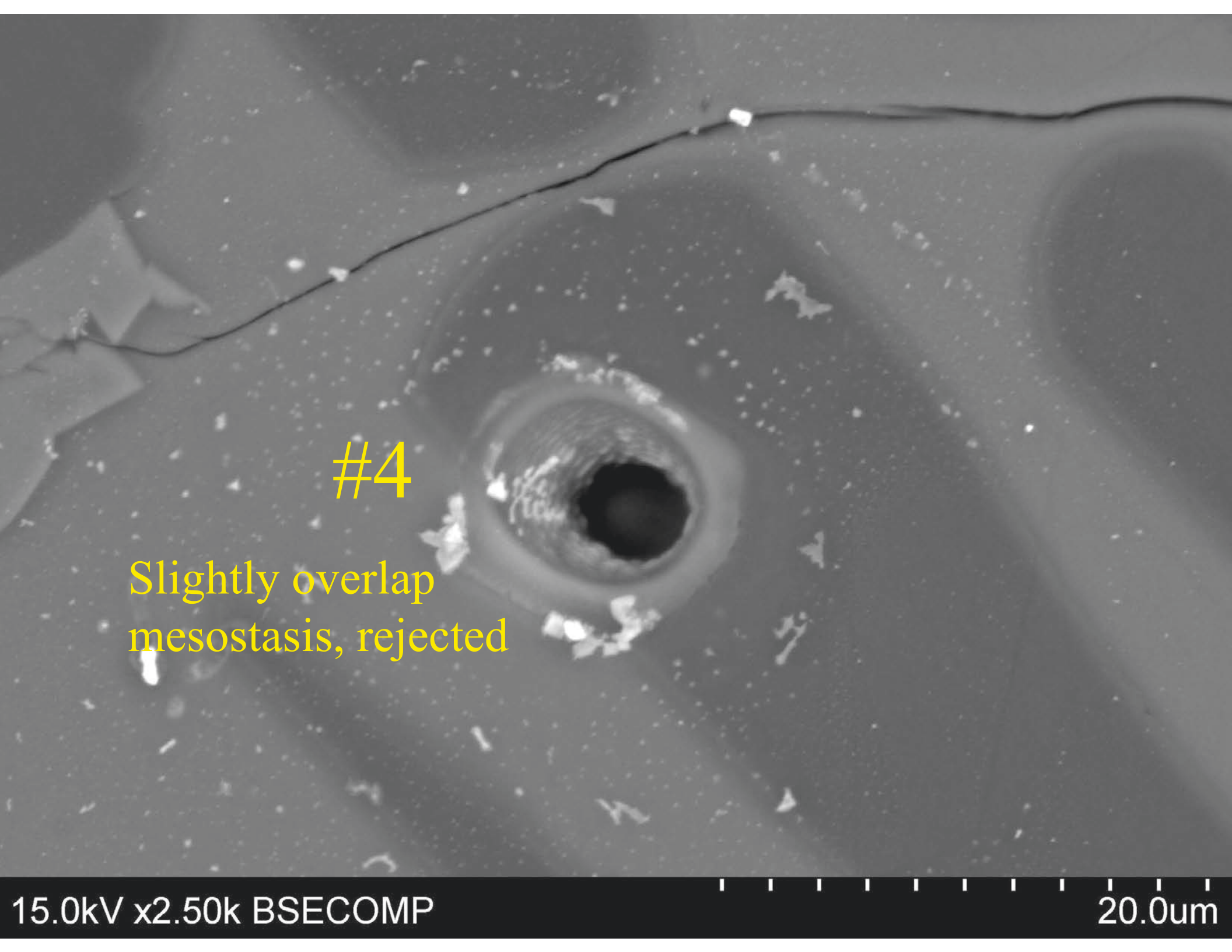
#1



#2



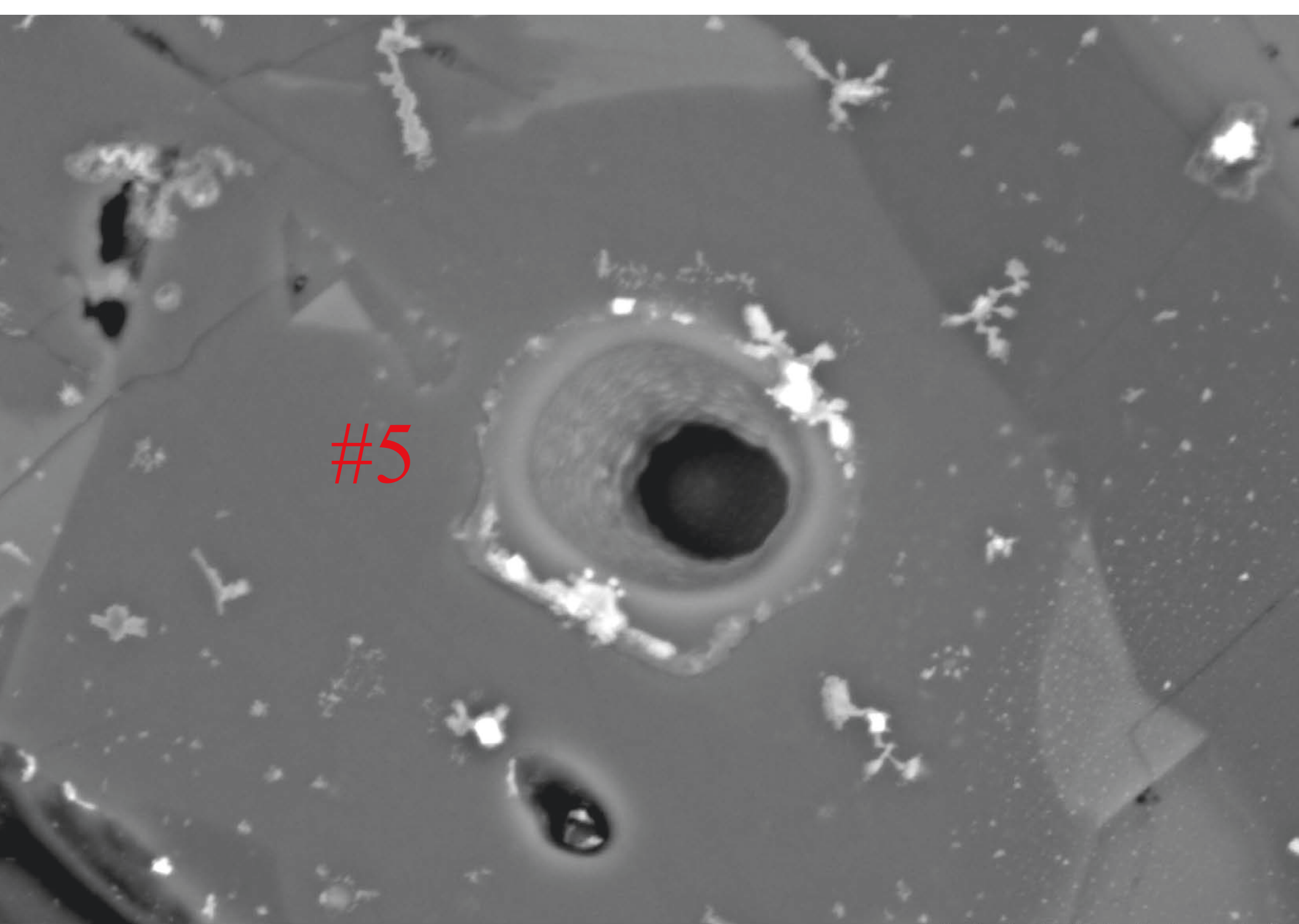
#3



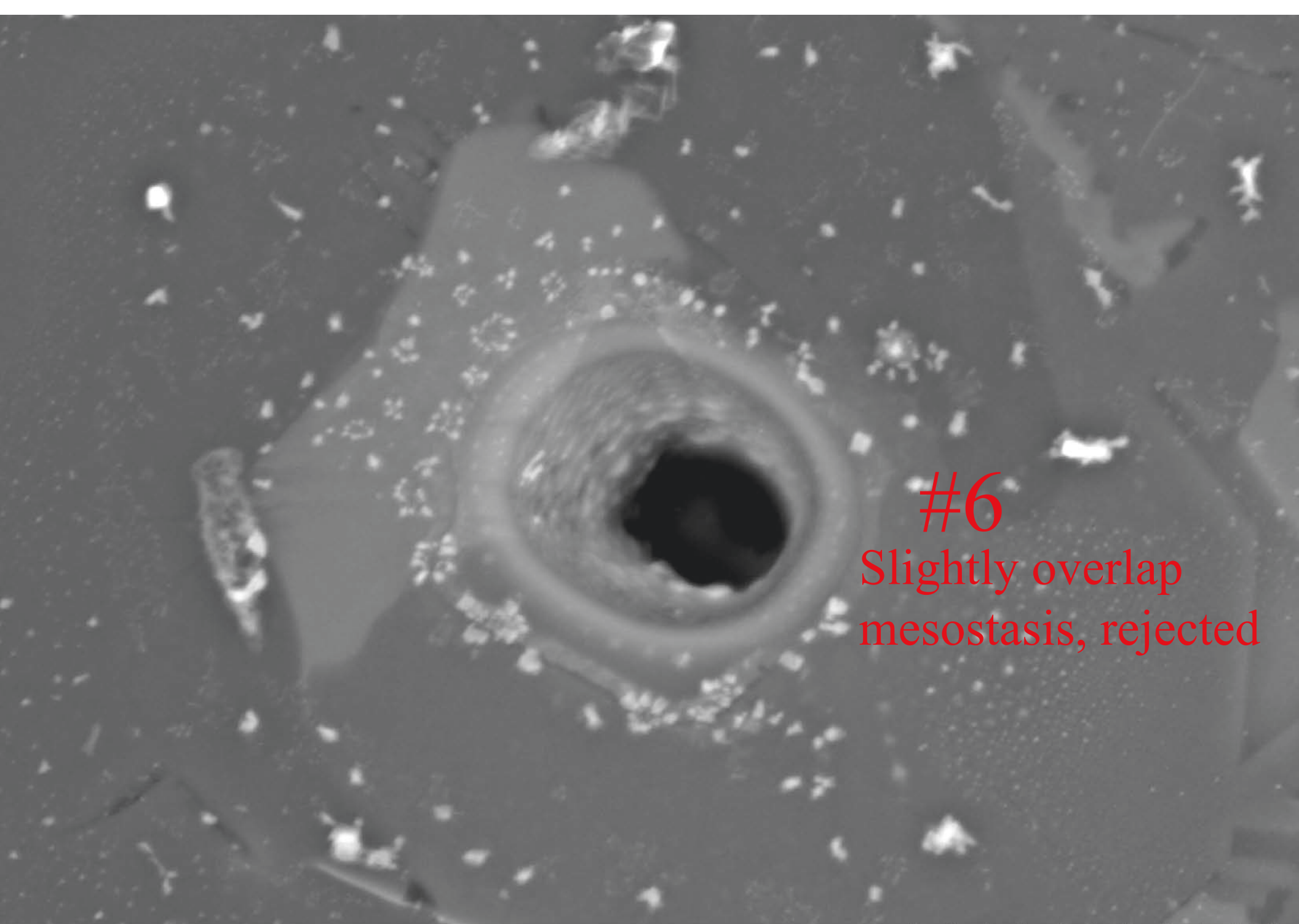
#4

This scanning electron micrograph (SEM) shows a circular hole in a material. A prominent crack runs diagonally across the upper portion of the image. The surface is covered with numerous small, bright, irregular particles or debris. The hole itself has a dark, circular center with some internal structure visible. The overall texture of the material appears granular.

Slightly overlap
mesostasis, rejected

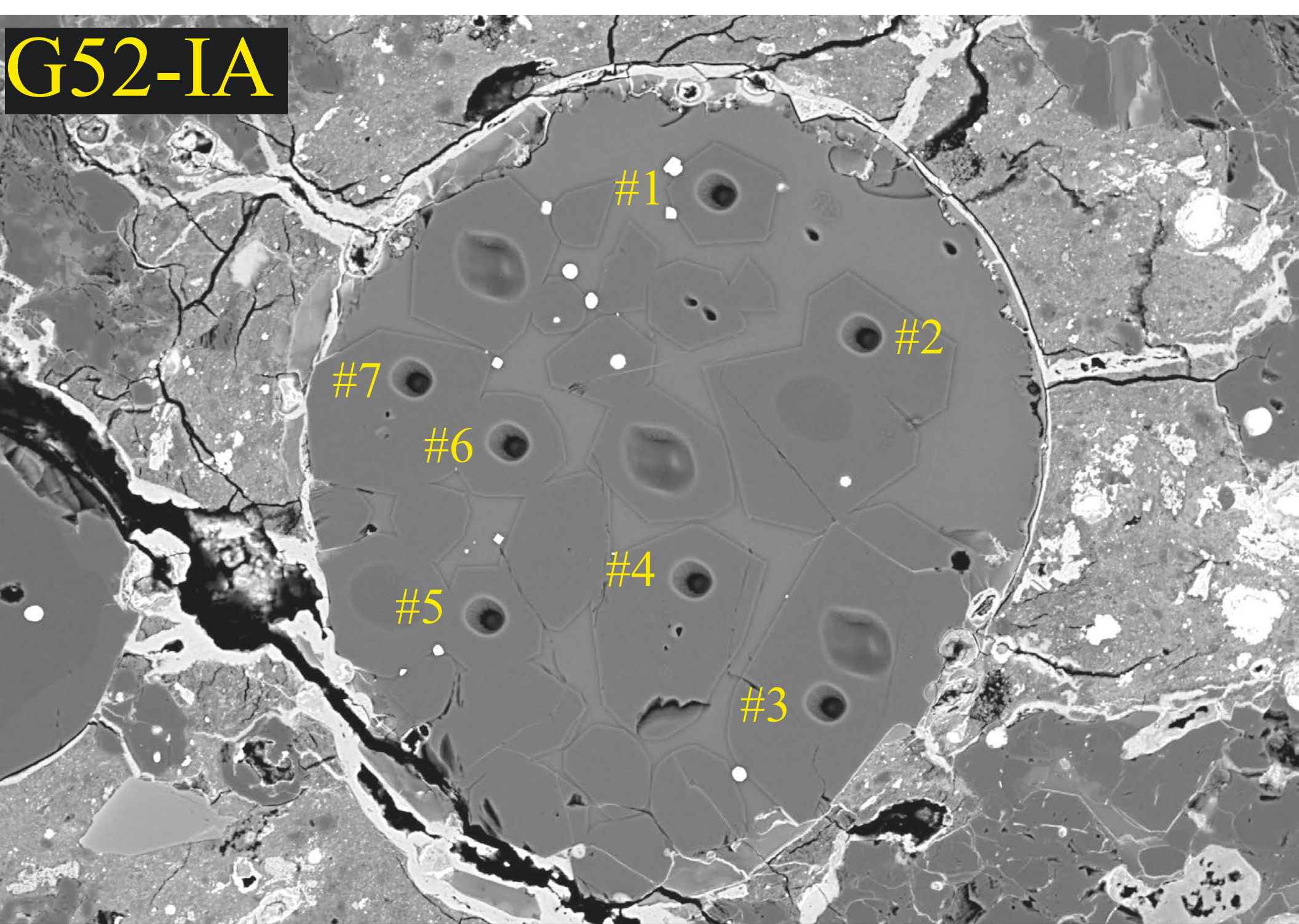


#5



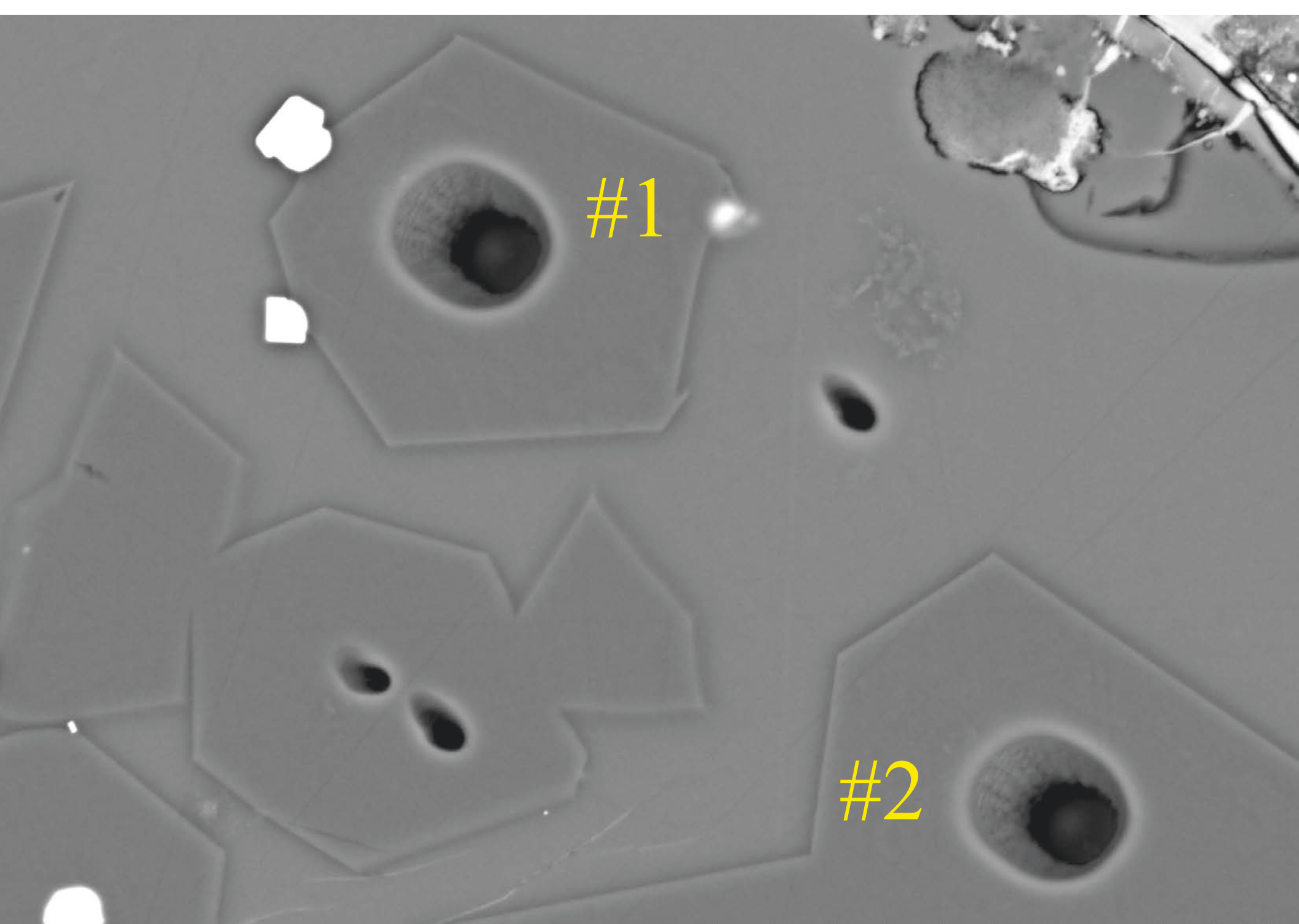
#6
Slightly overlap
mesostasis, rejected

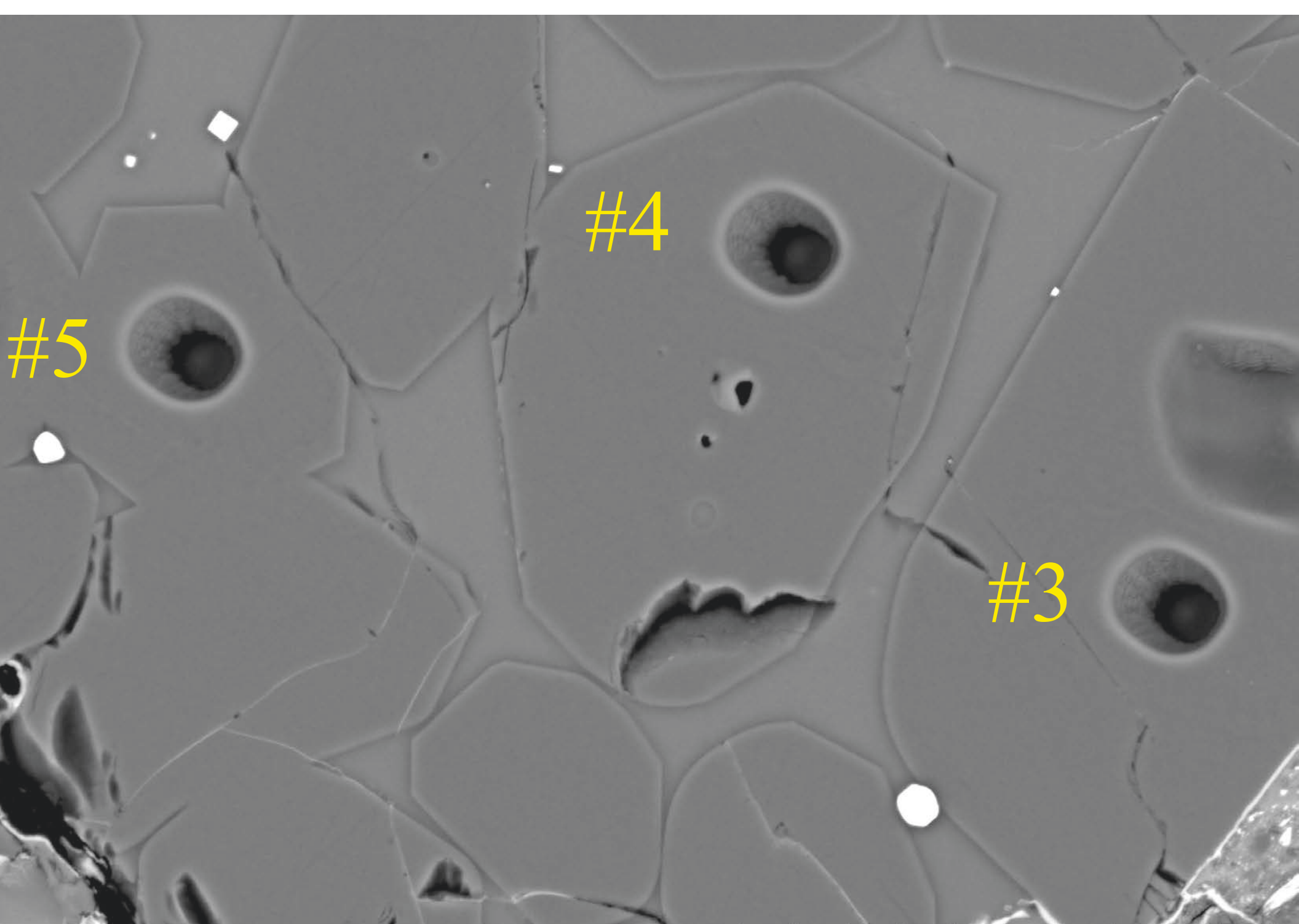
G52-1A



15.0kV x450 BSECOMP

100um





#4

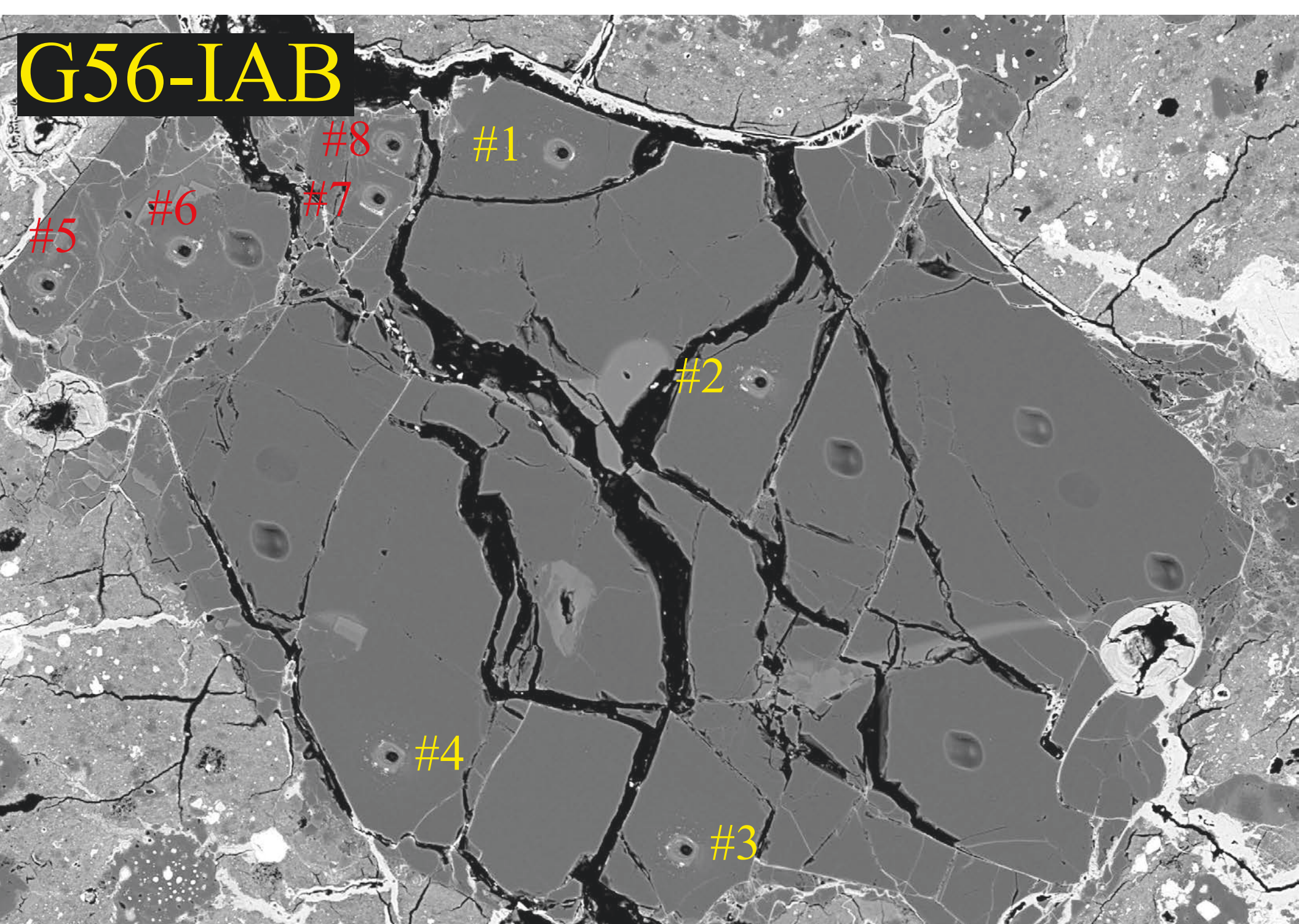
#5

#3

#7

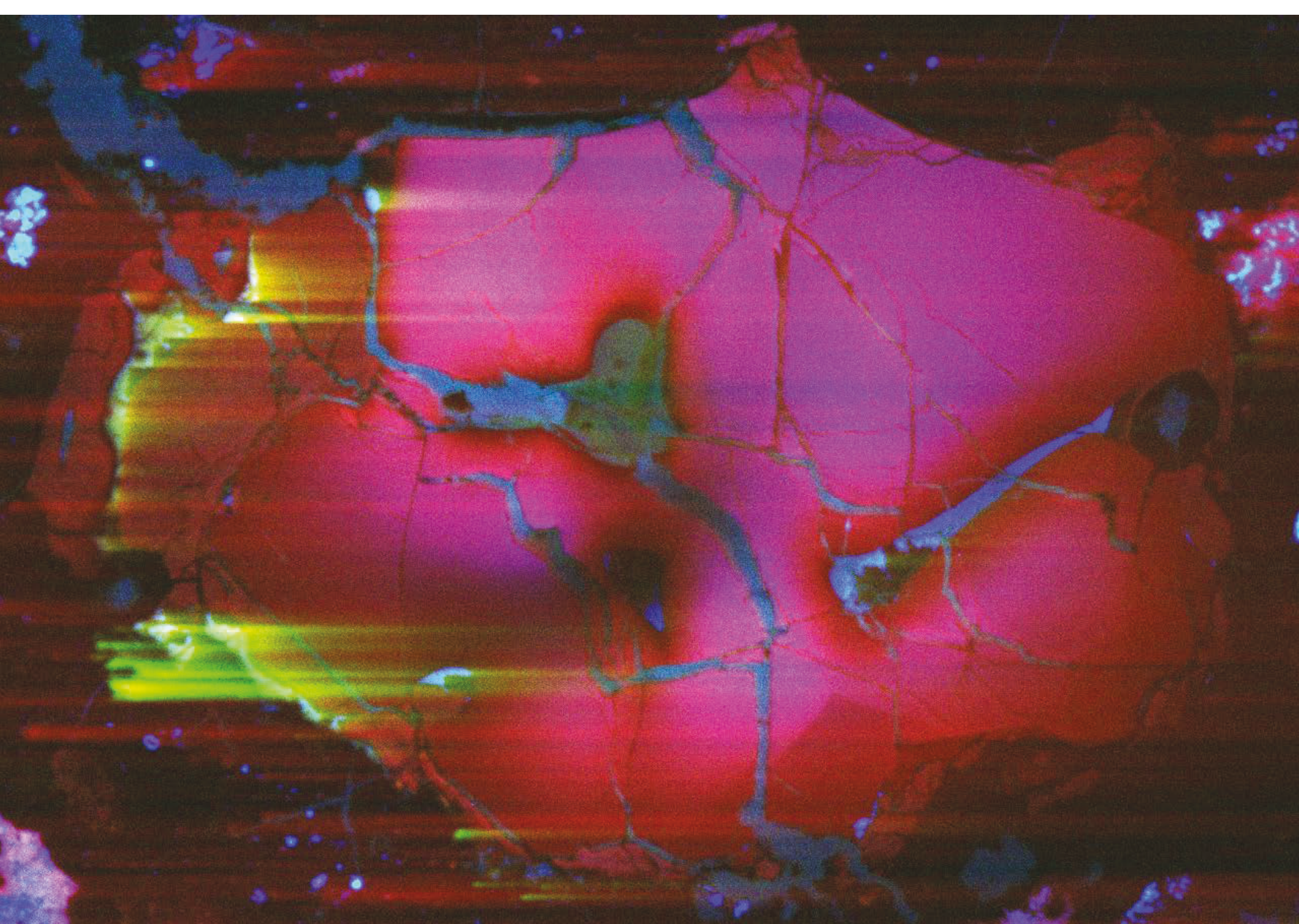
#6

G56-IAB



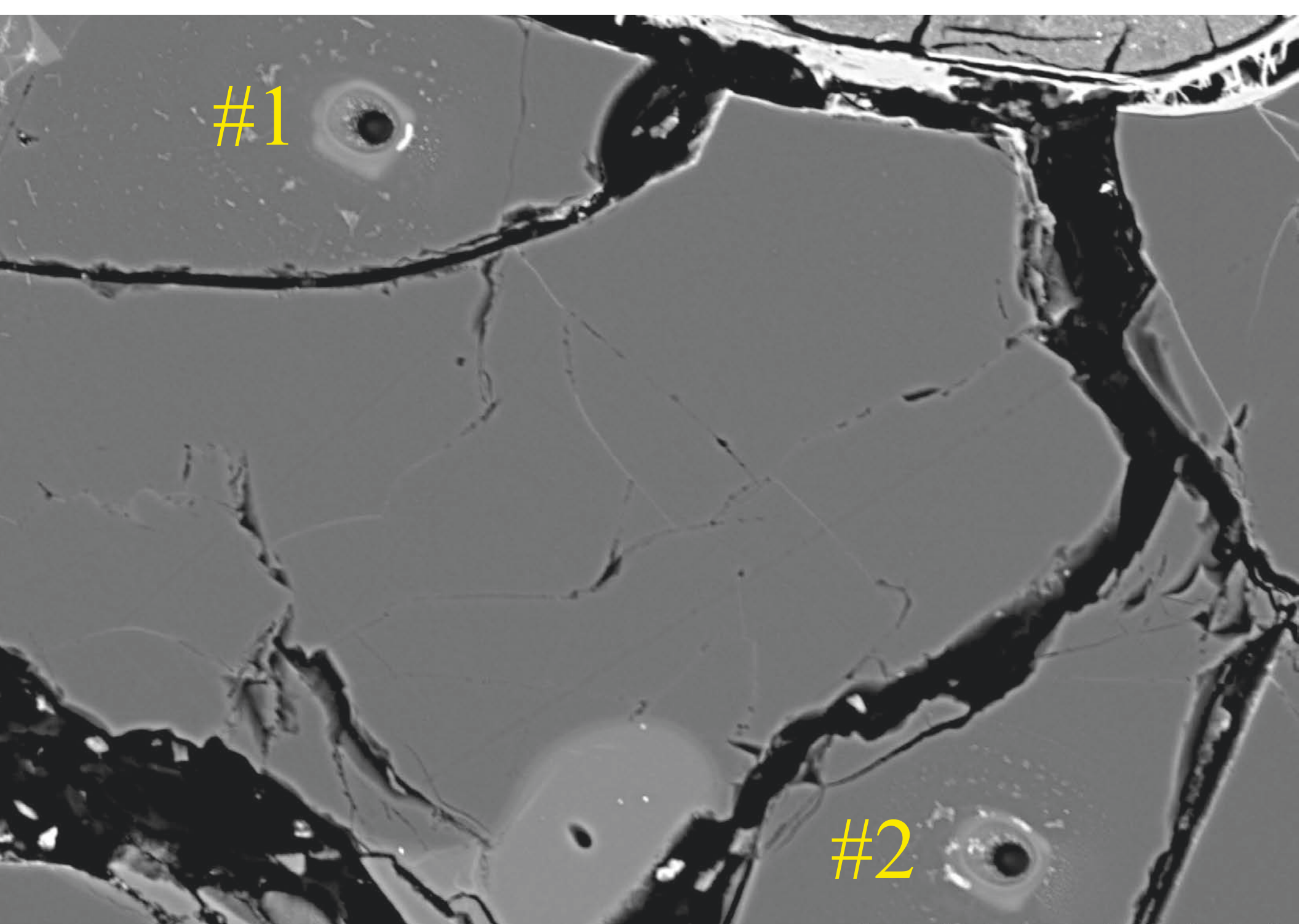
15.0kV x250 BSECOMP

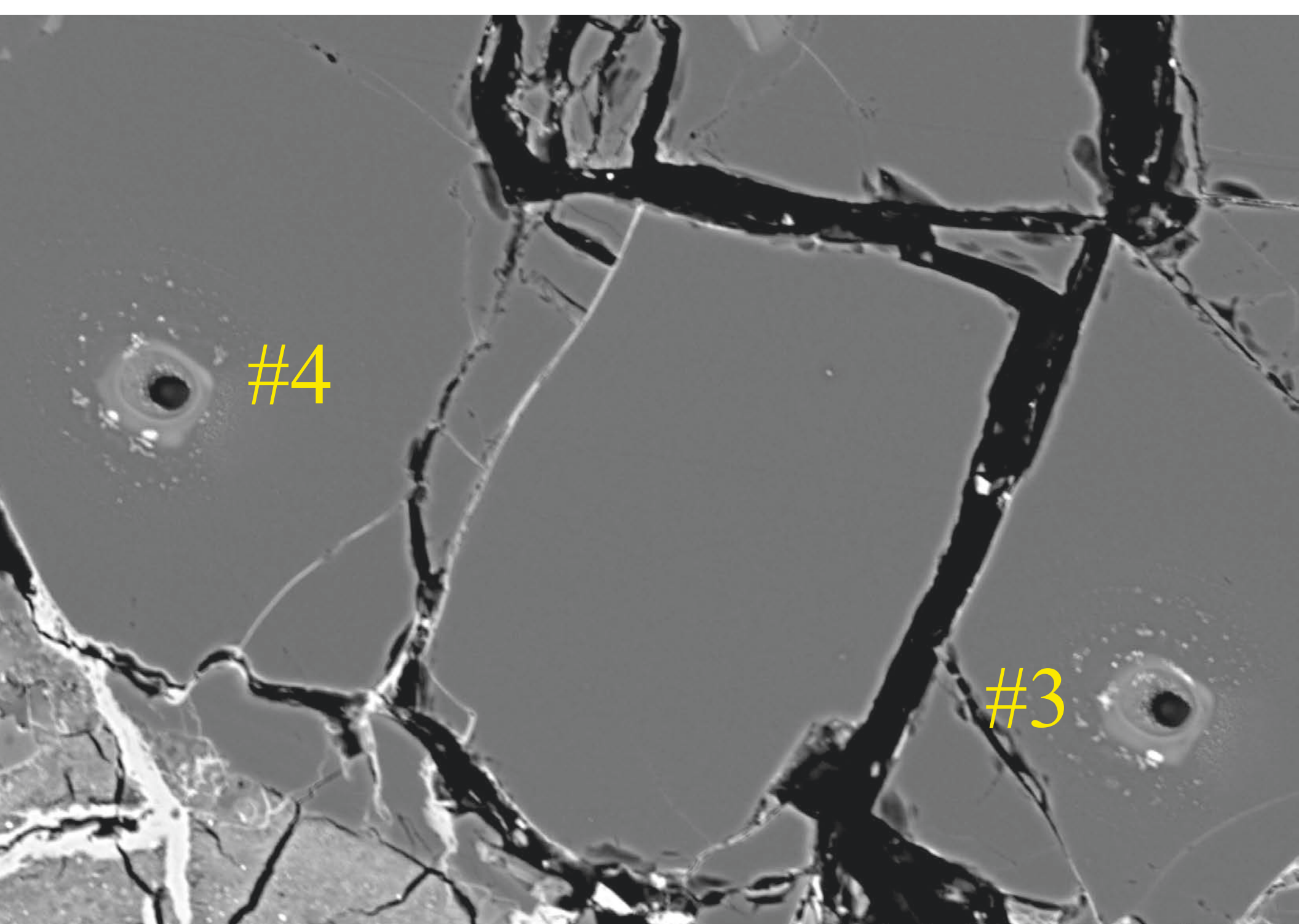
200um

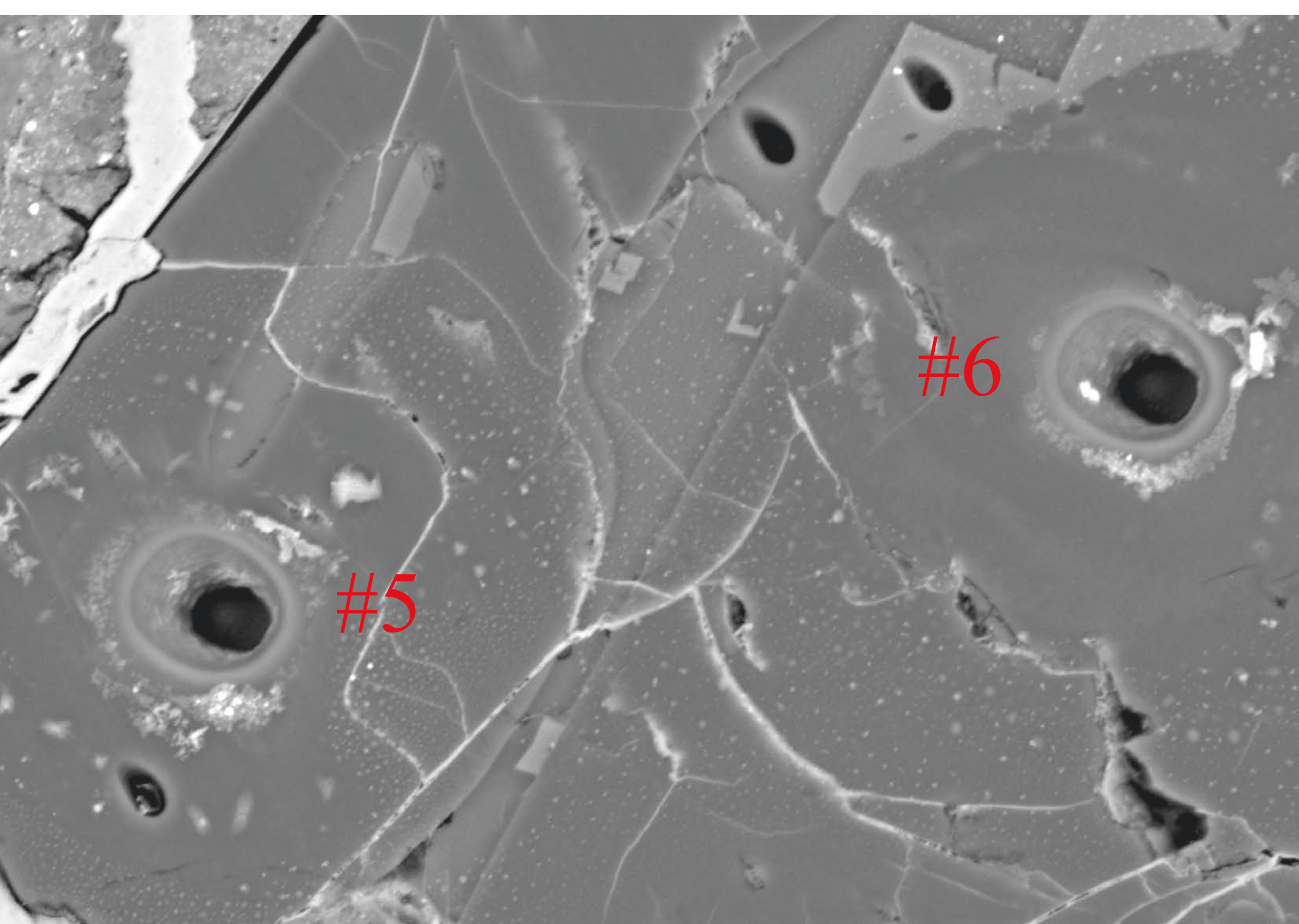


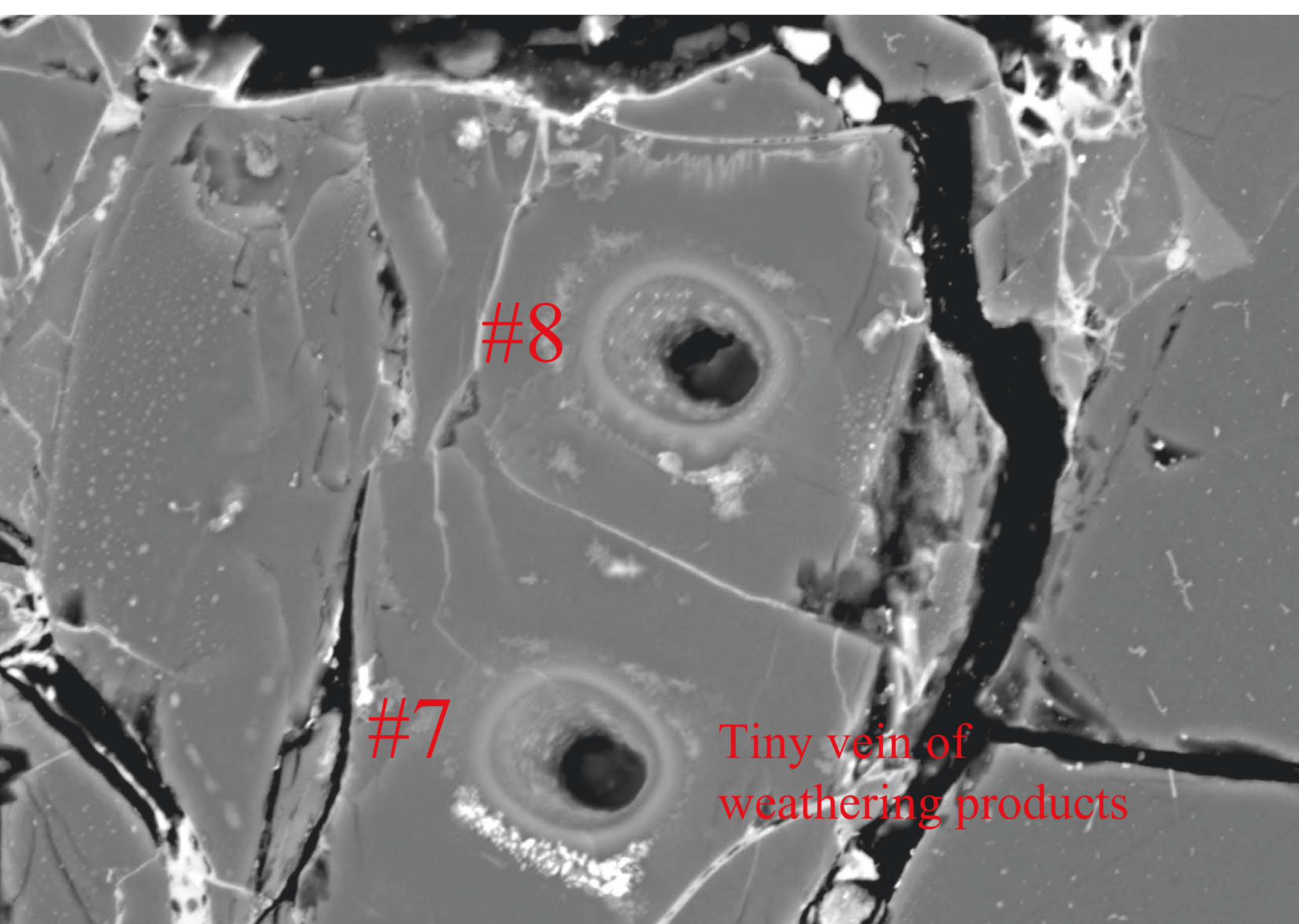
15.0kV x230 OTHER2 10/22/2008

200um

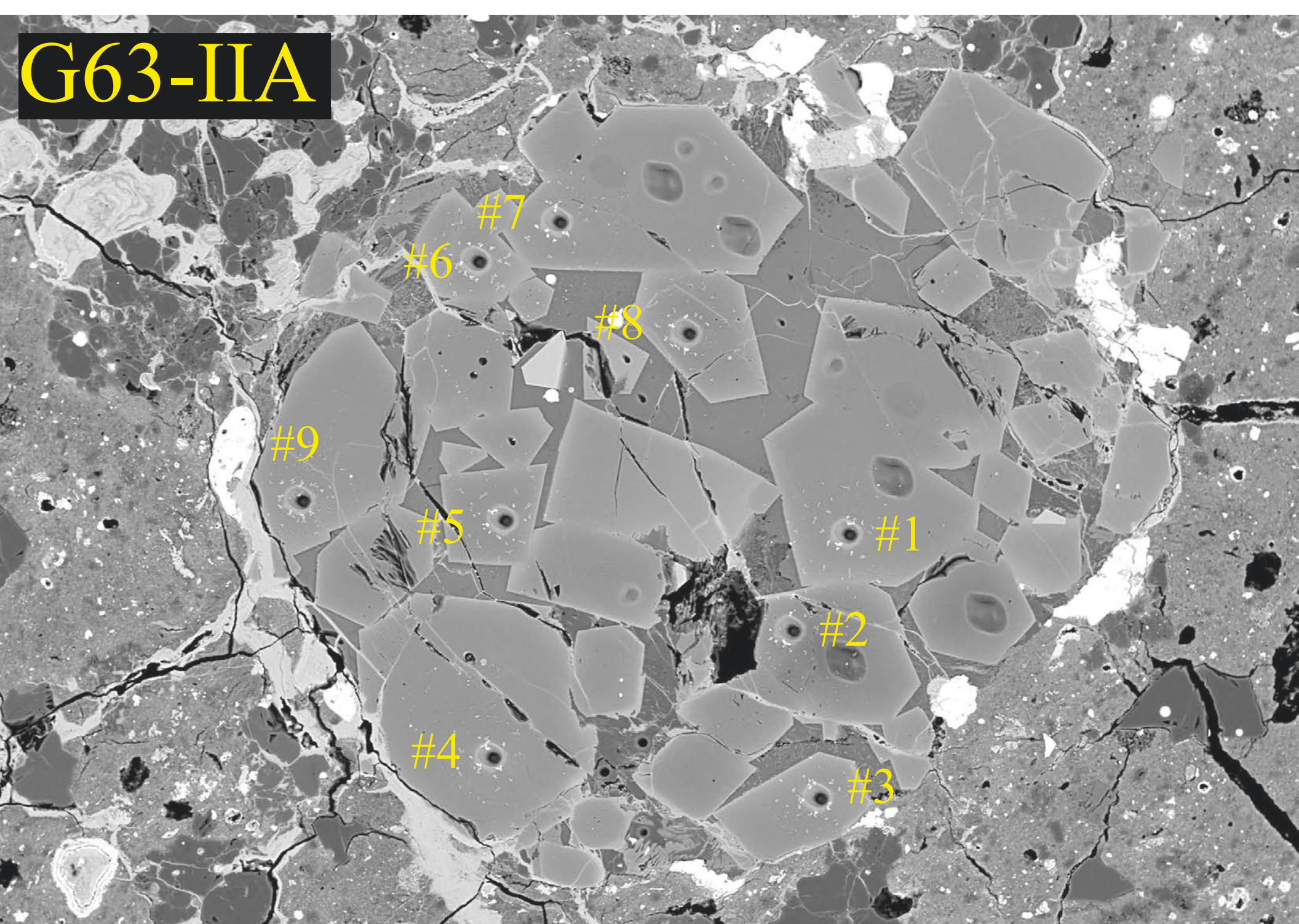






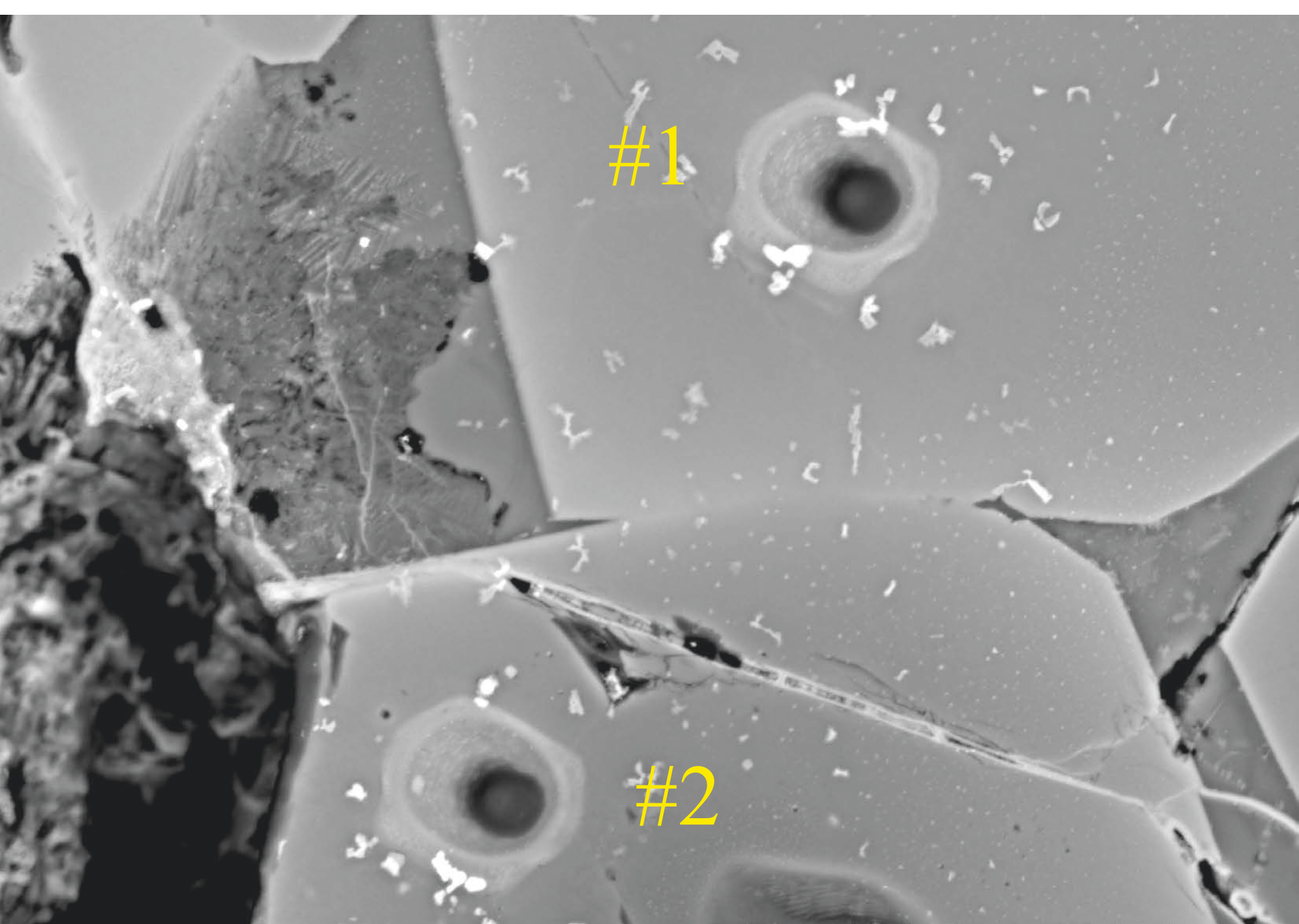


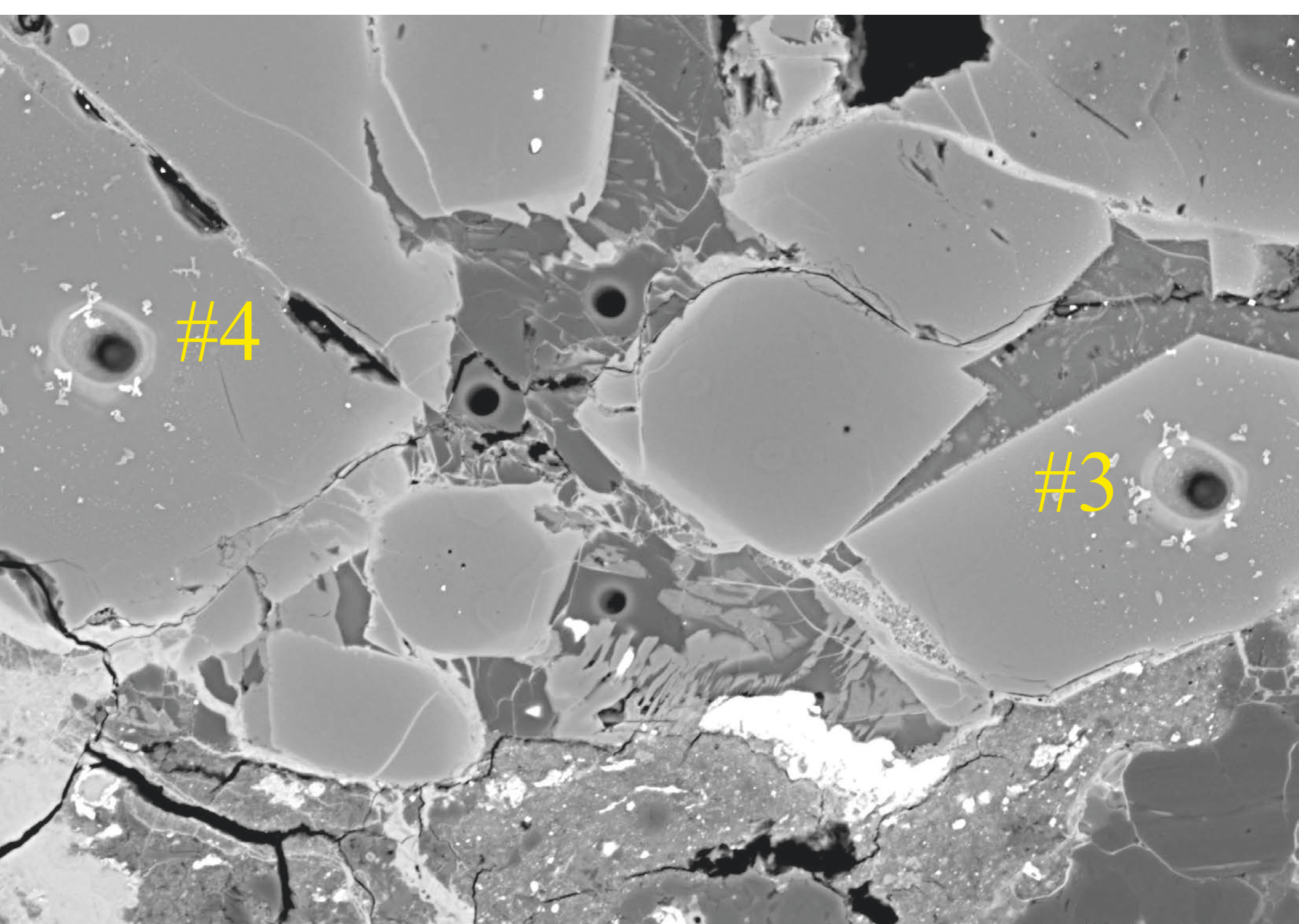
G63-IIA

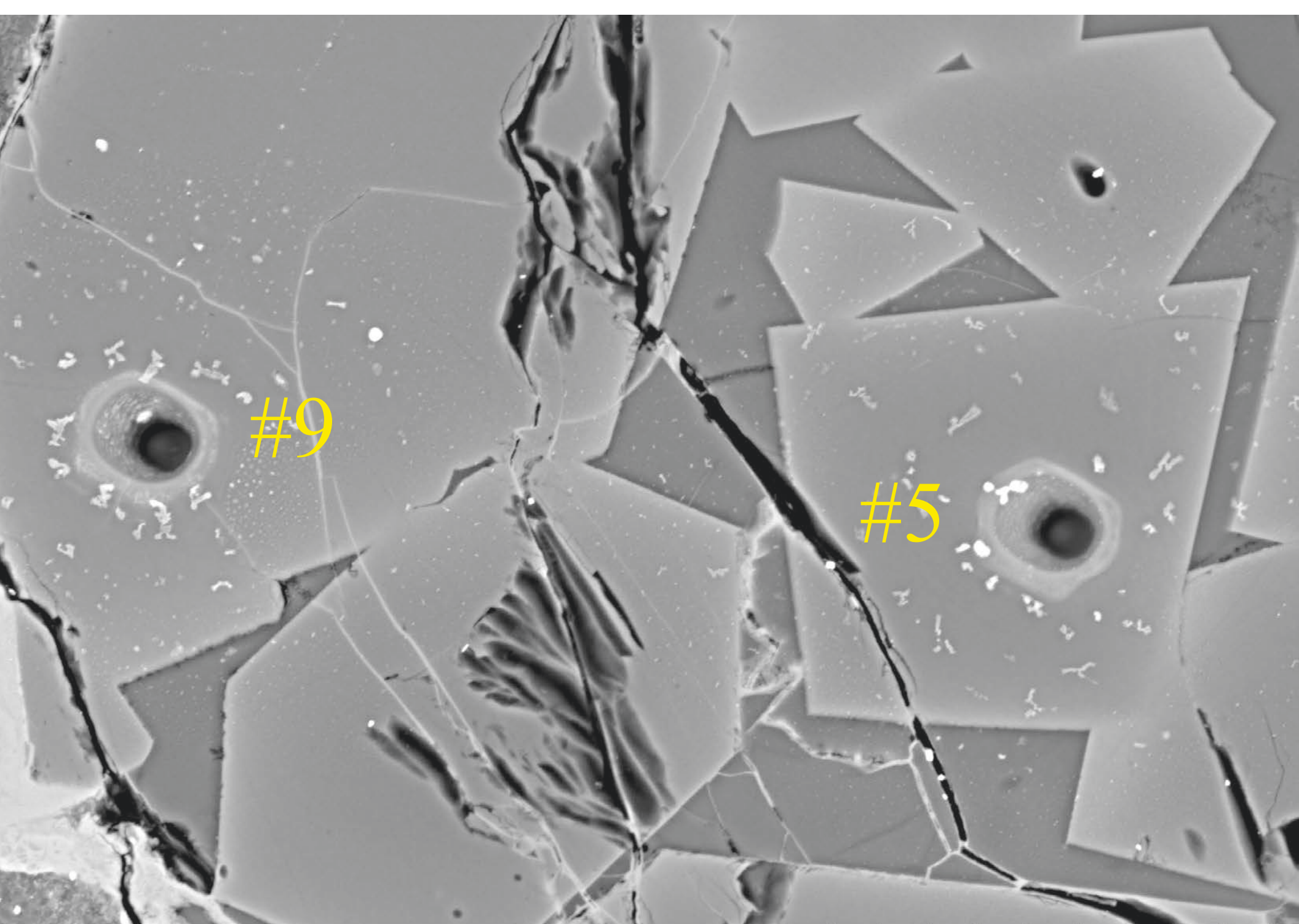


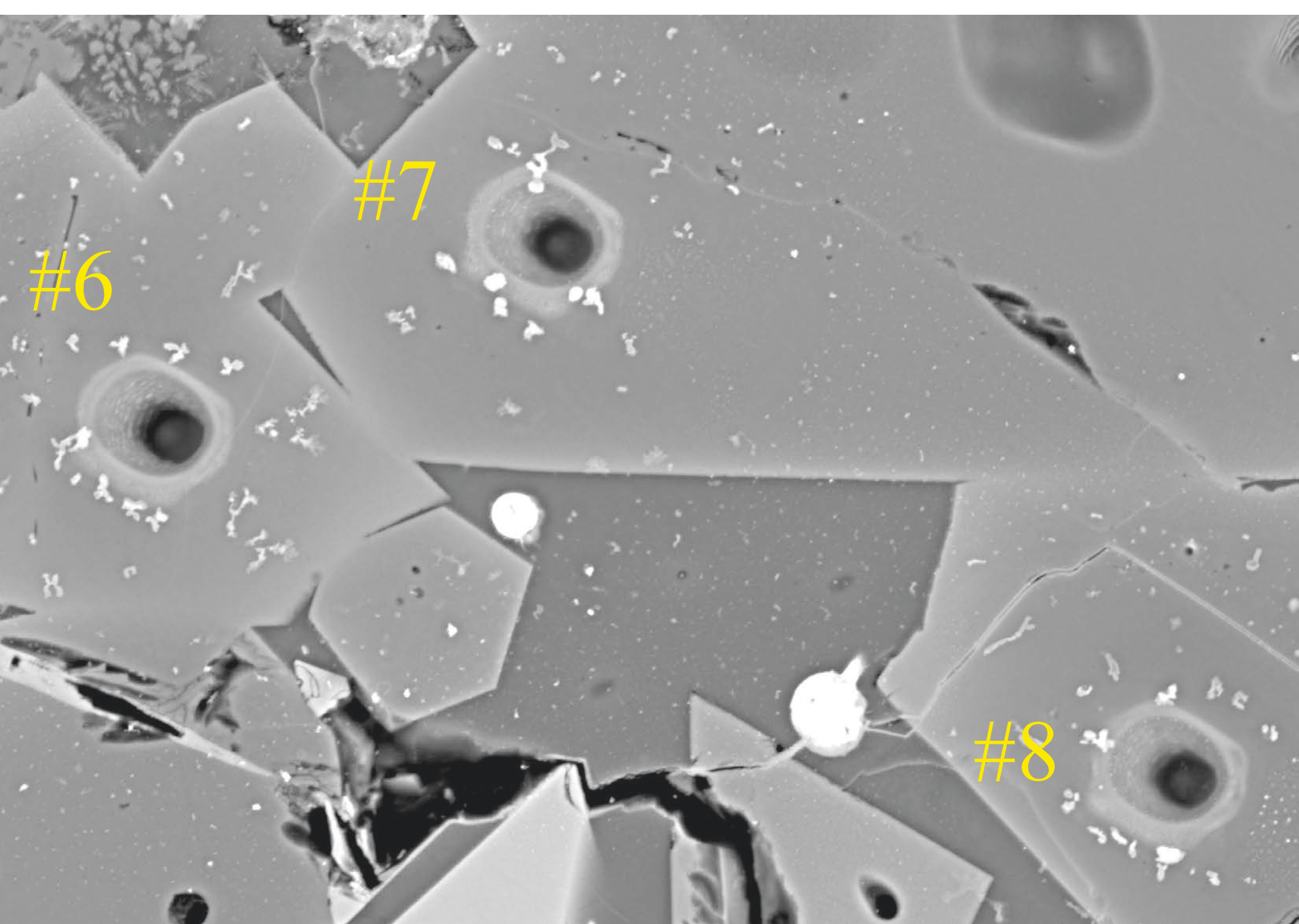
15.0kV x270 BSECOMP

200um

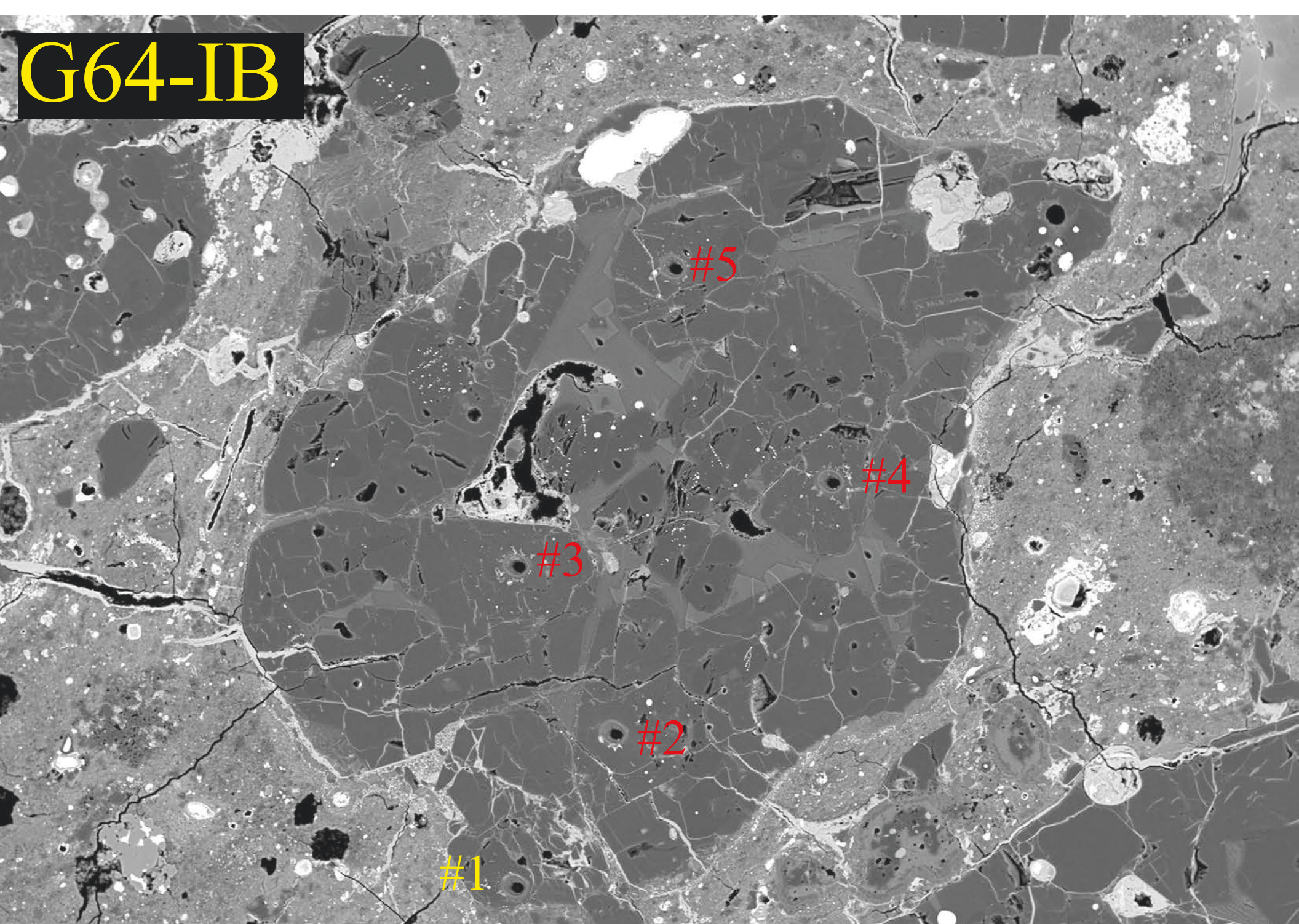






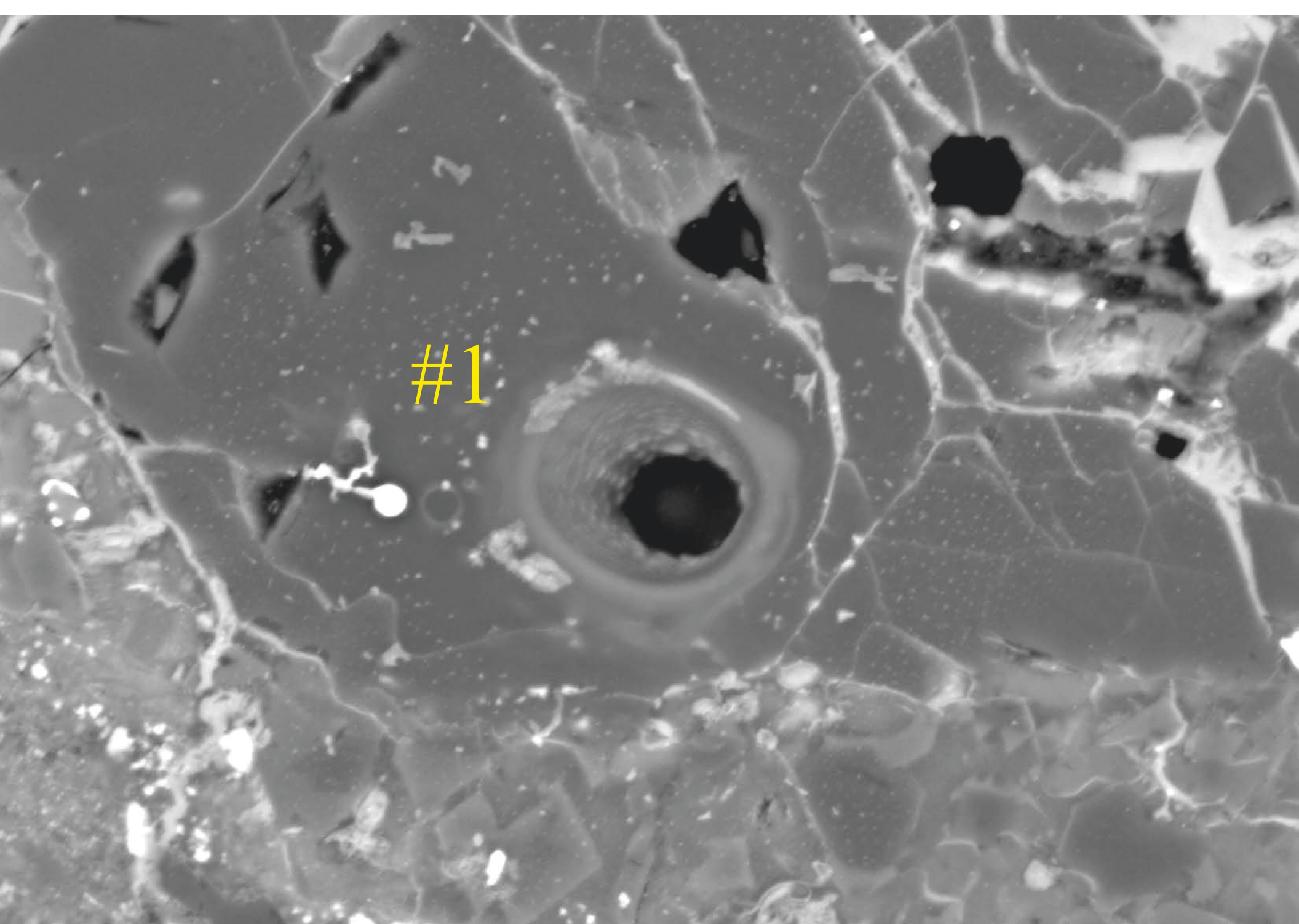


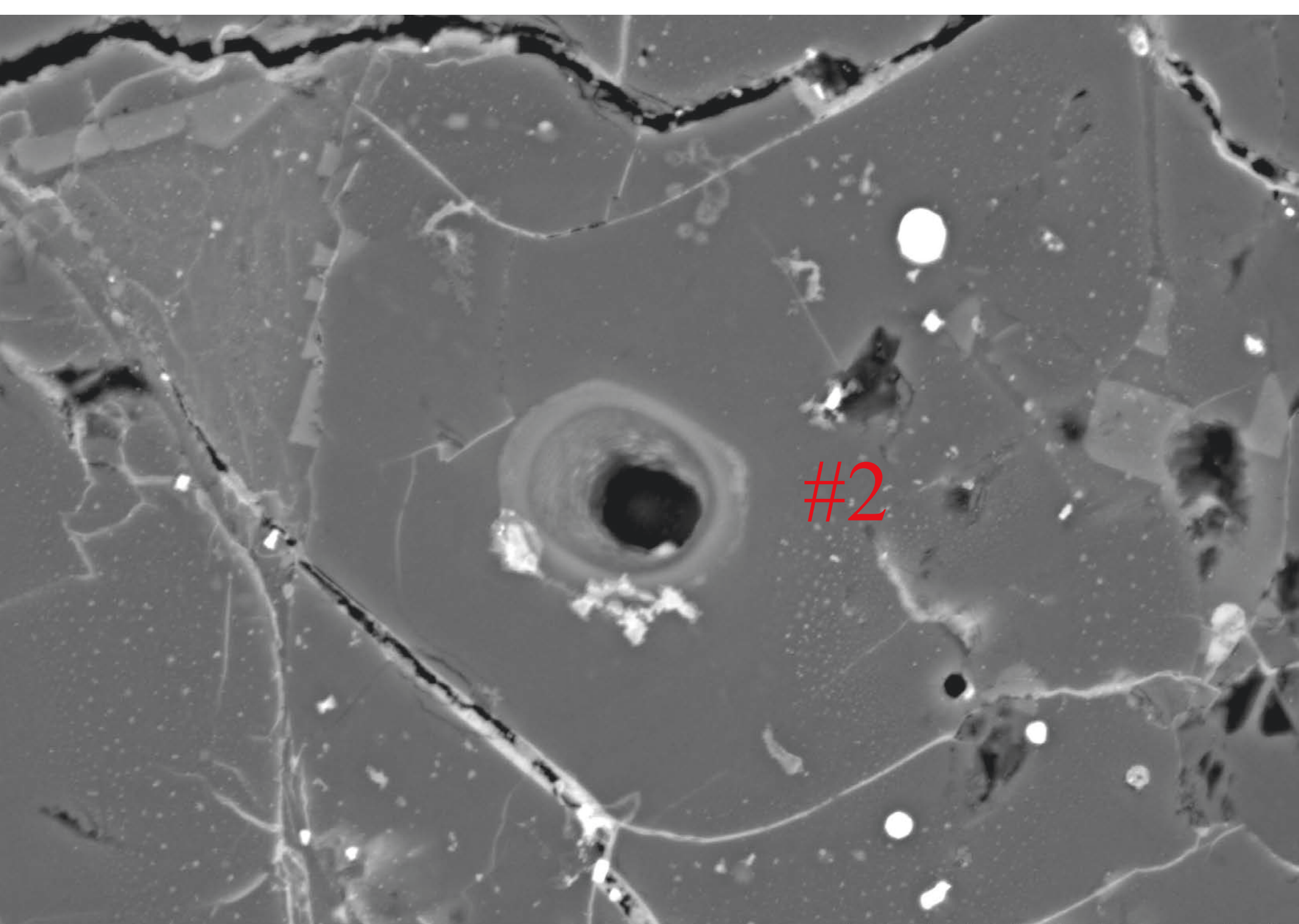
G64-IB



15.0kV x250 BSECOMP

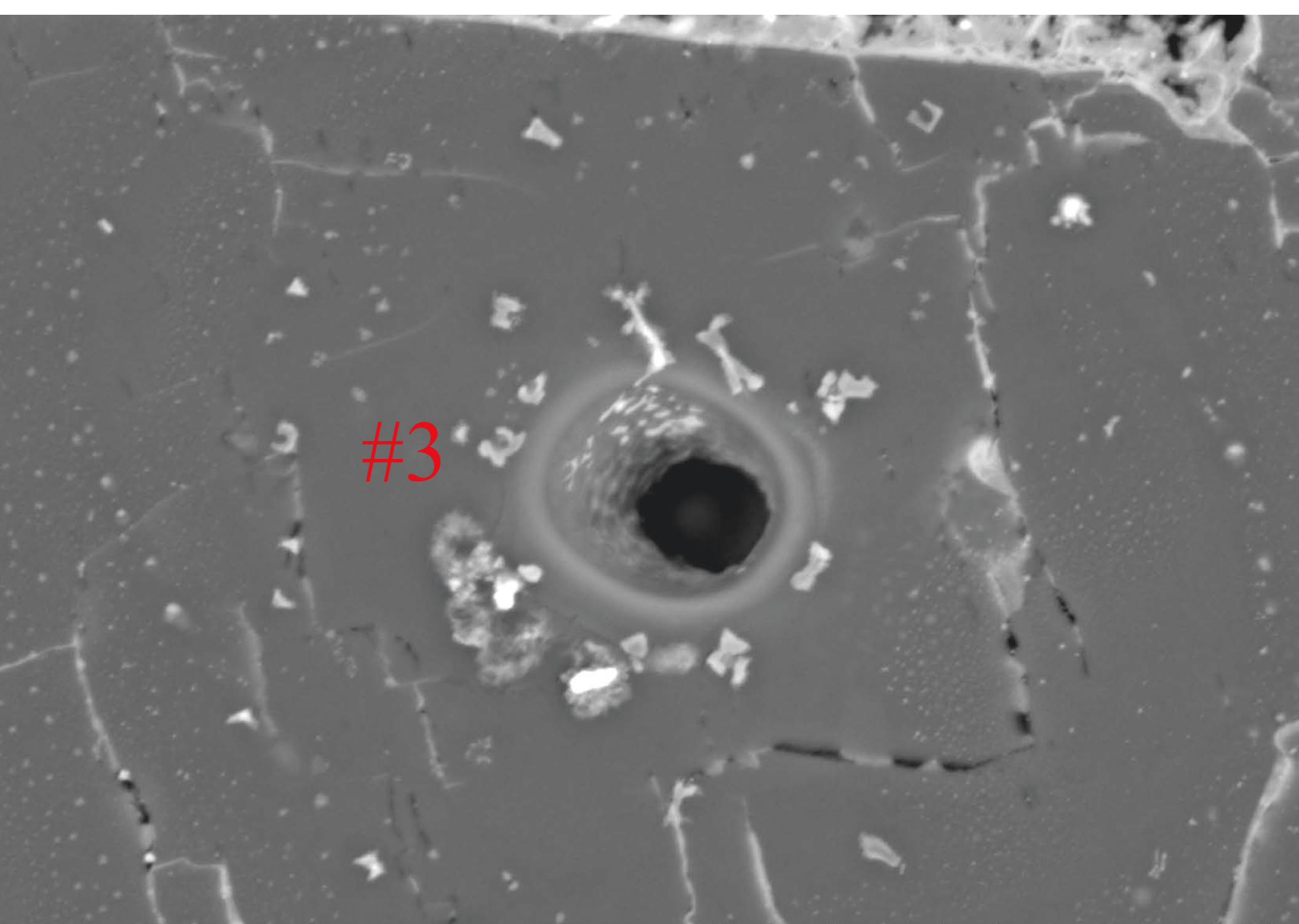
200um



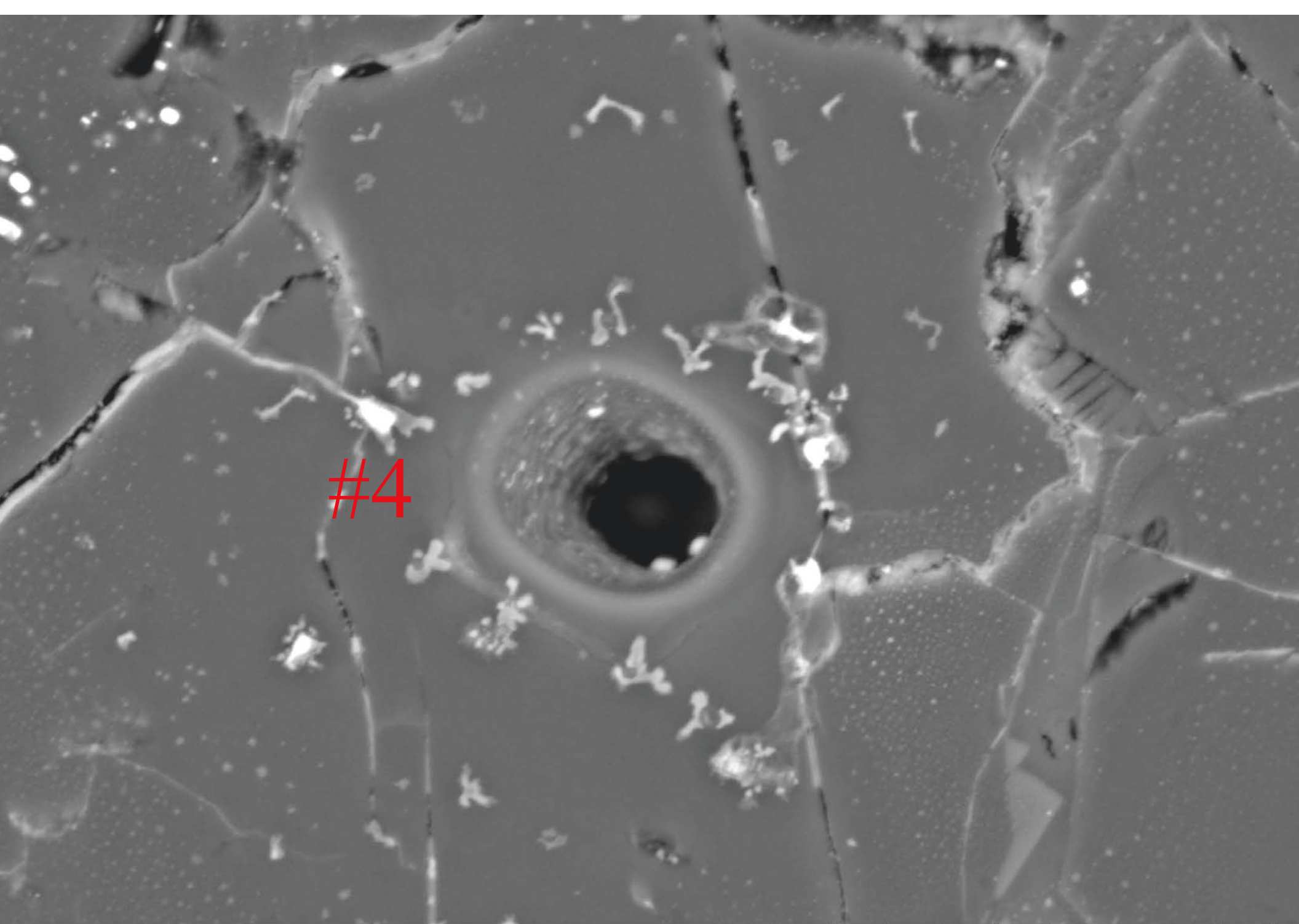


15.0kV x2.10k BSECOMP

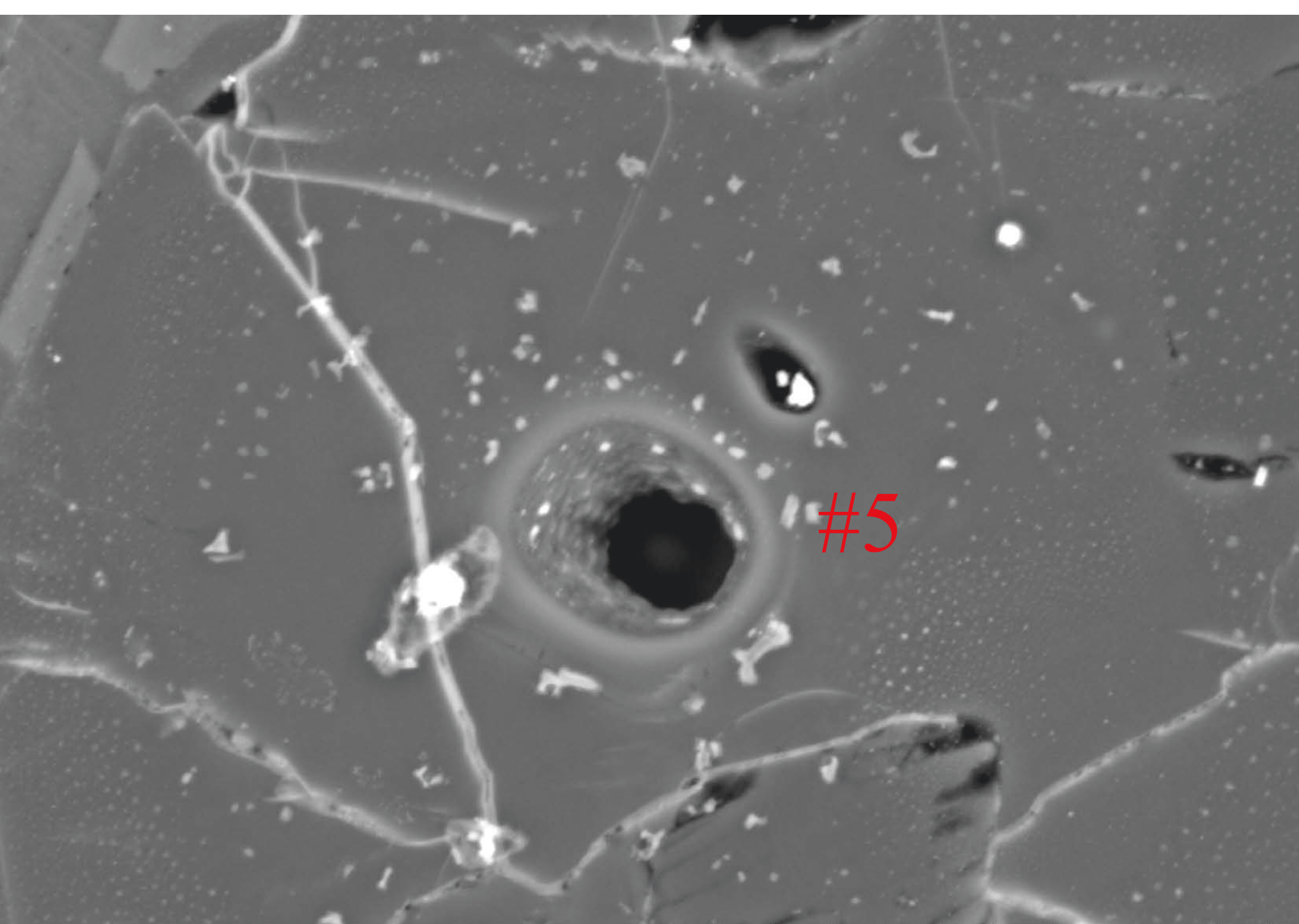
20.0um



#3



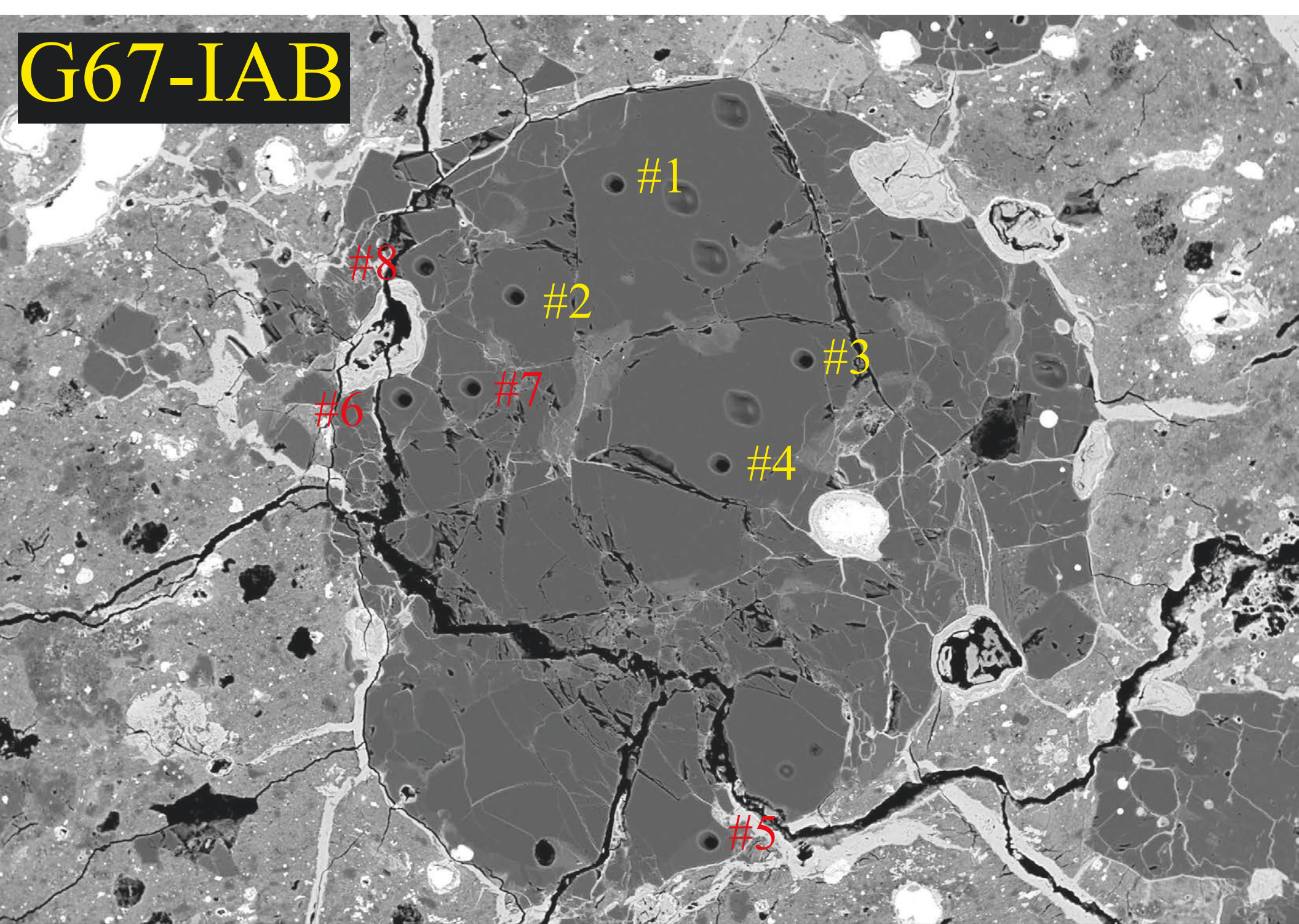
#4



15.0kV x2.70k BSECOMP

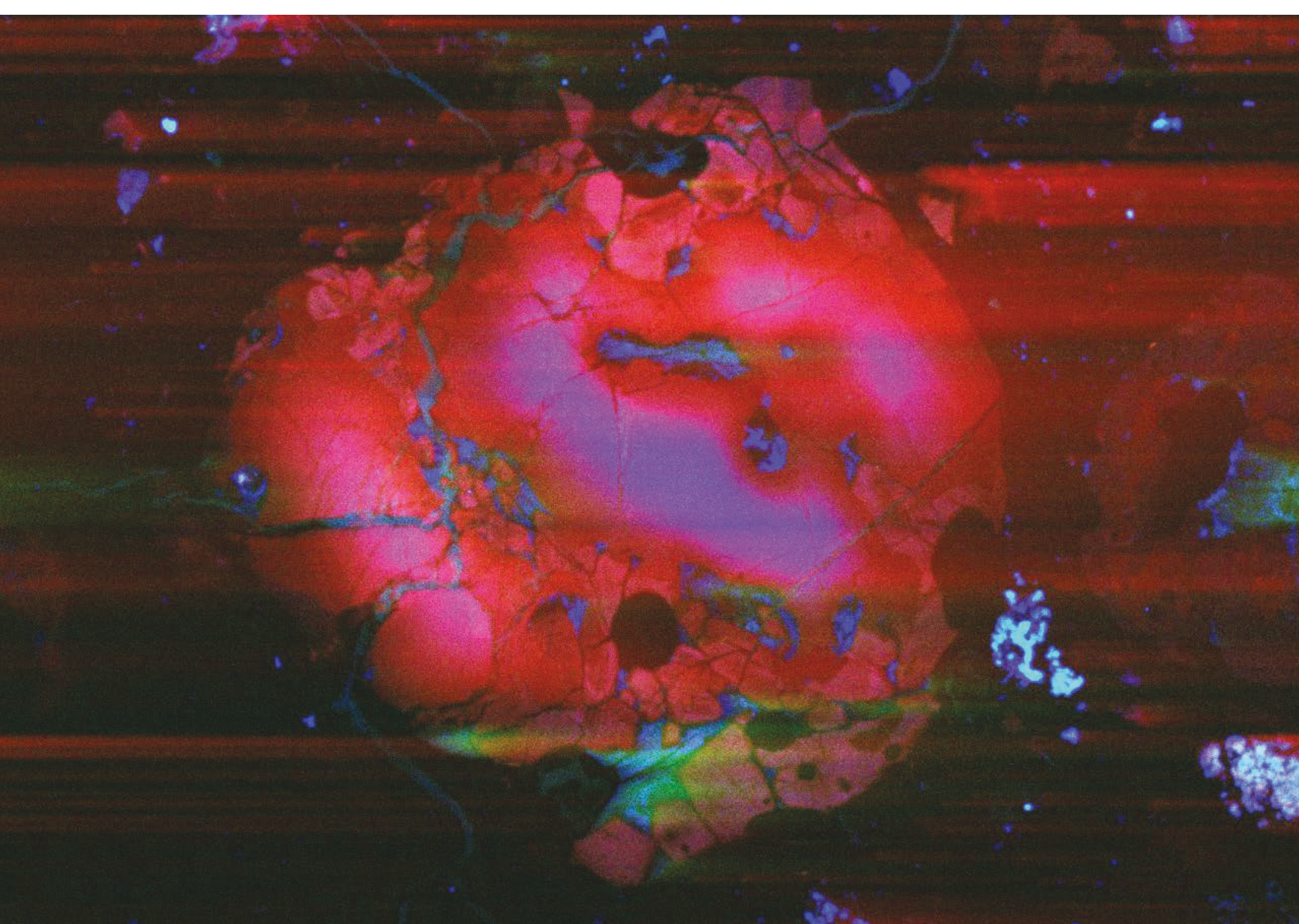
20.0um

G67-IAB



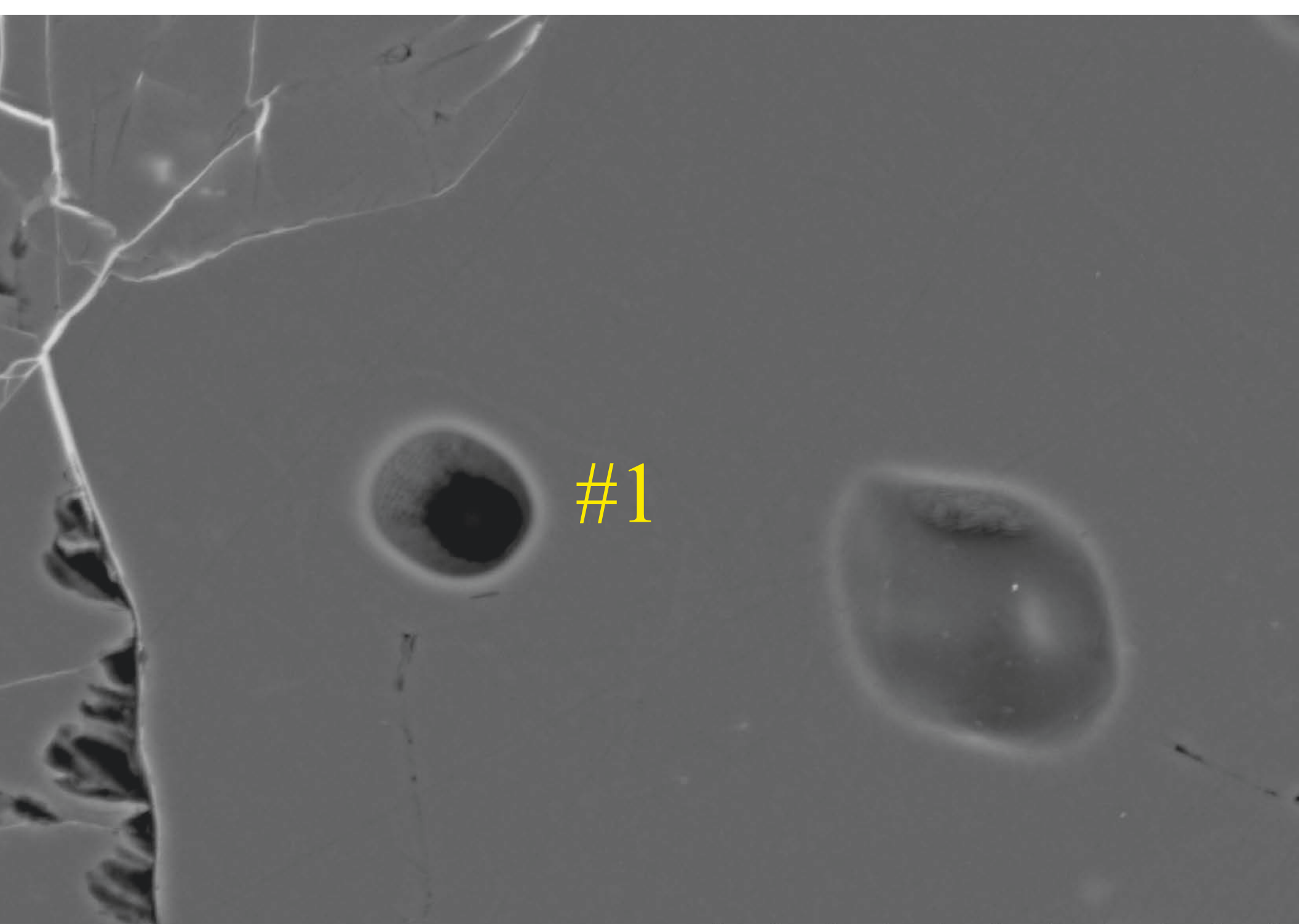
15.0kV x230 BSECOMP

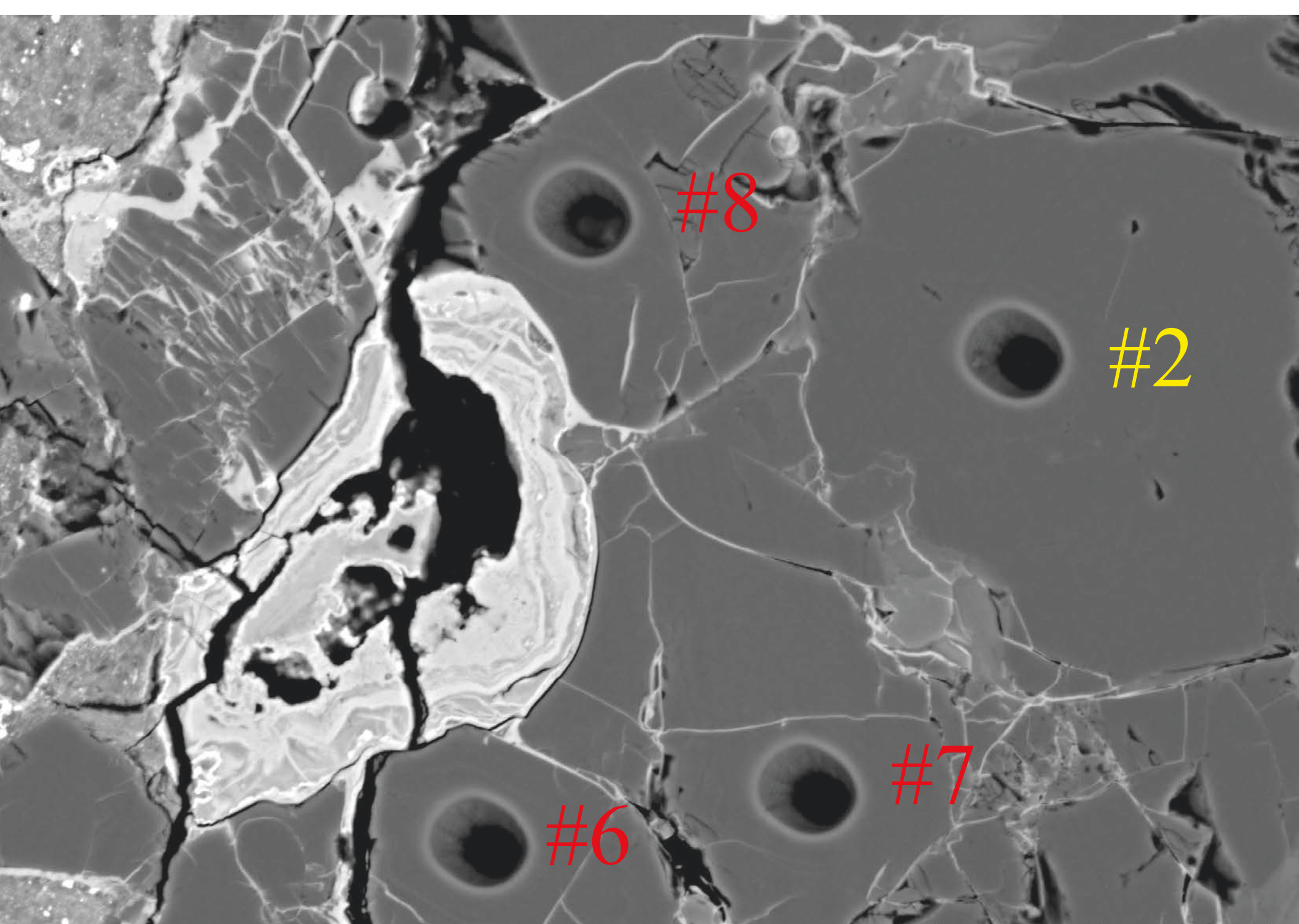
200um

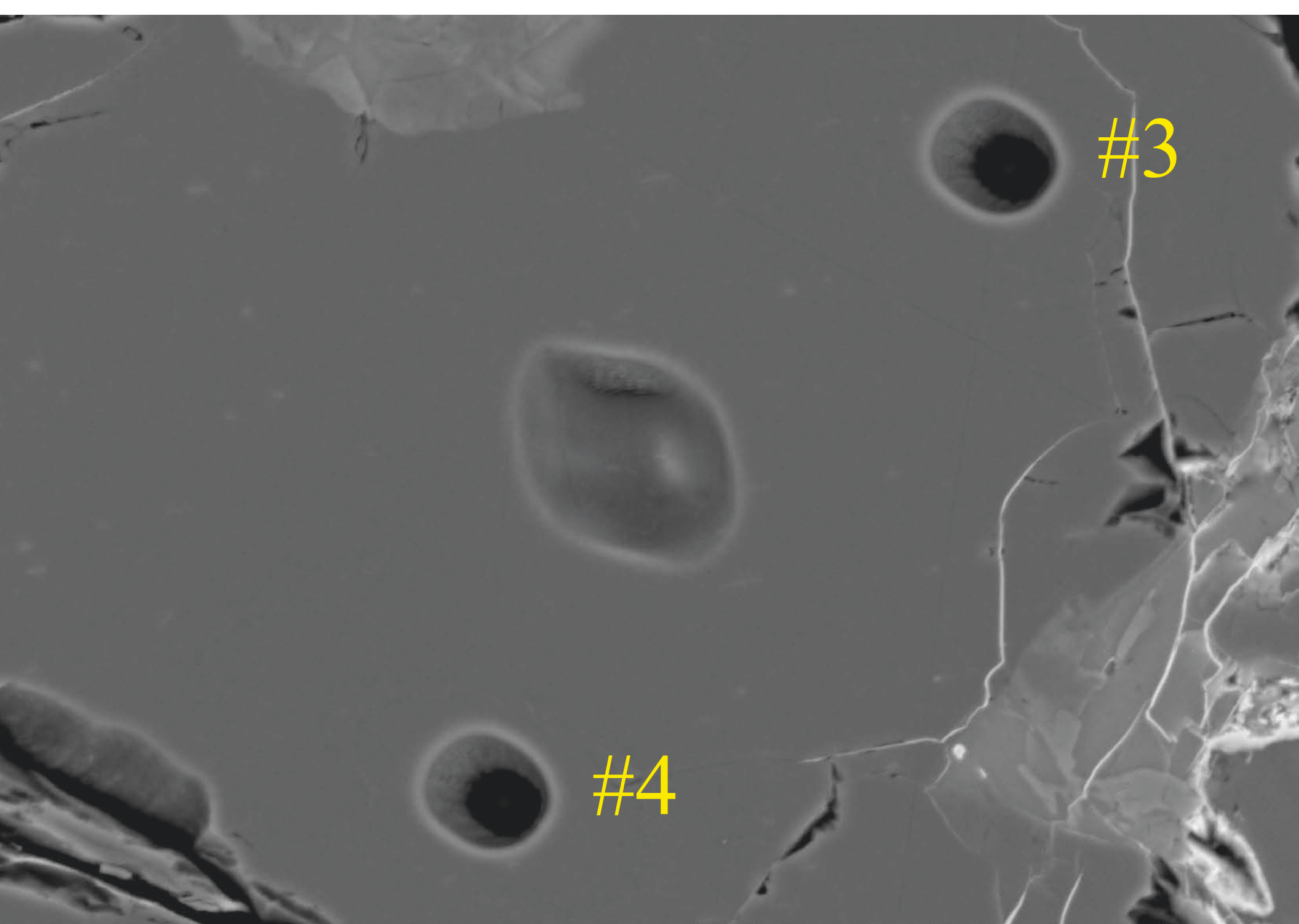


15.0kV x210 OTHER2 10/22/2008

200um

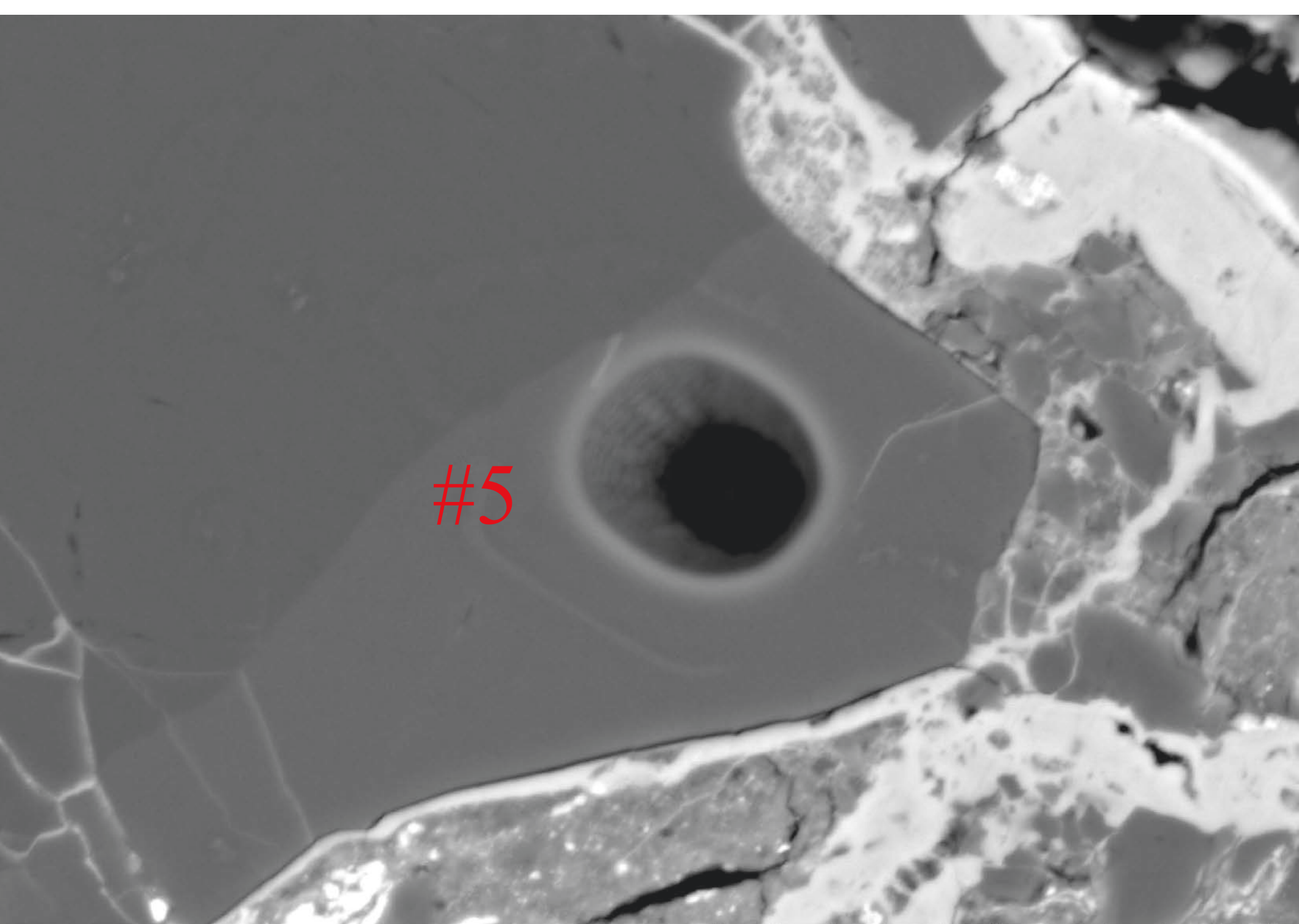




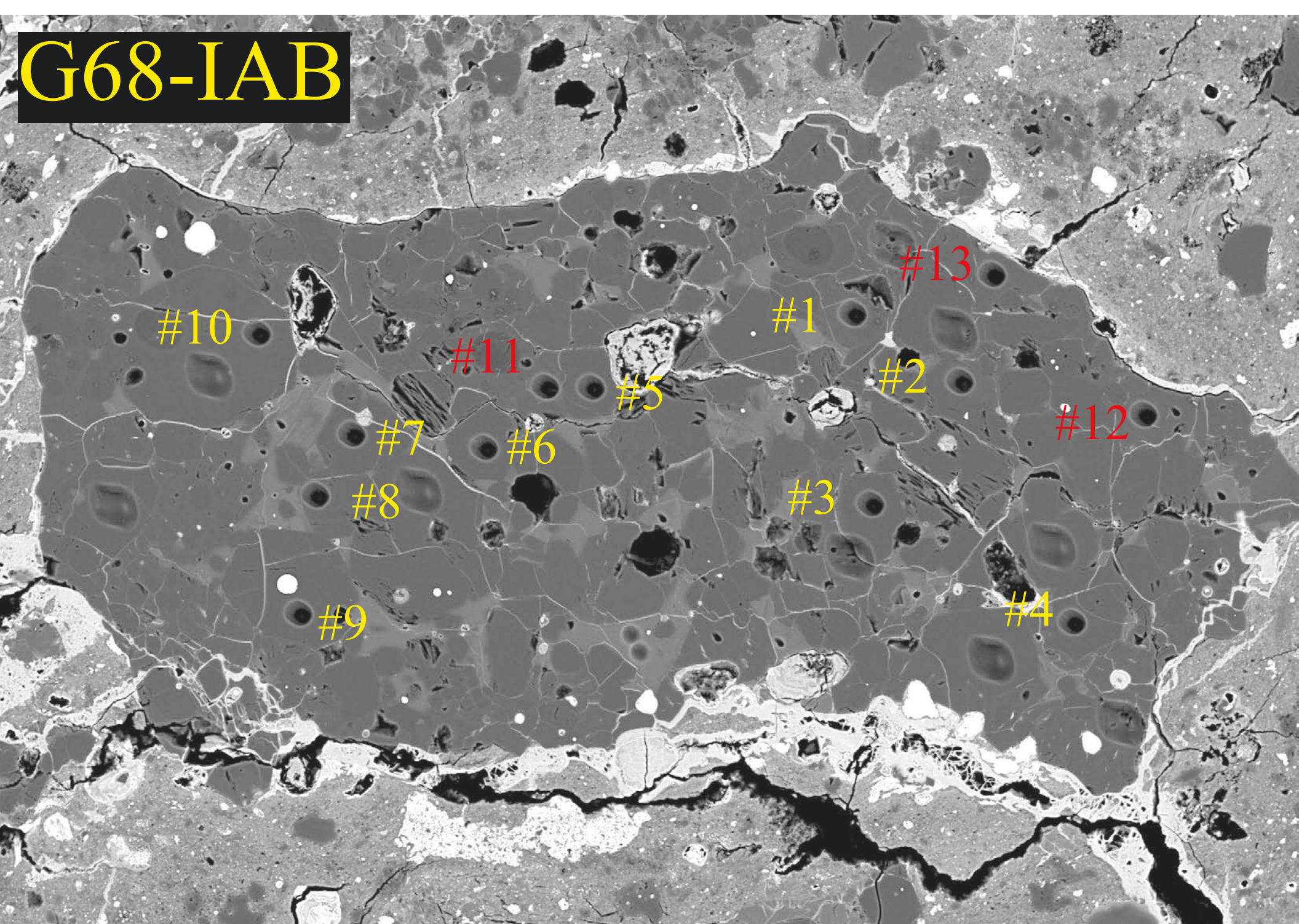


#3

#4

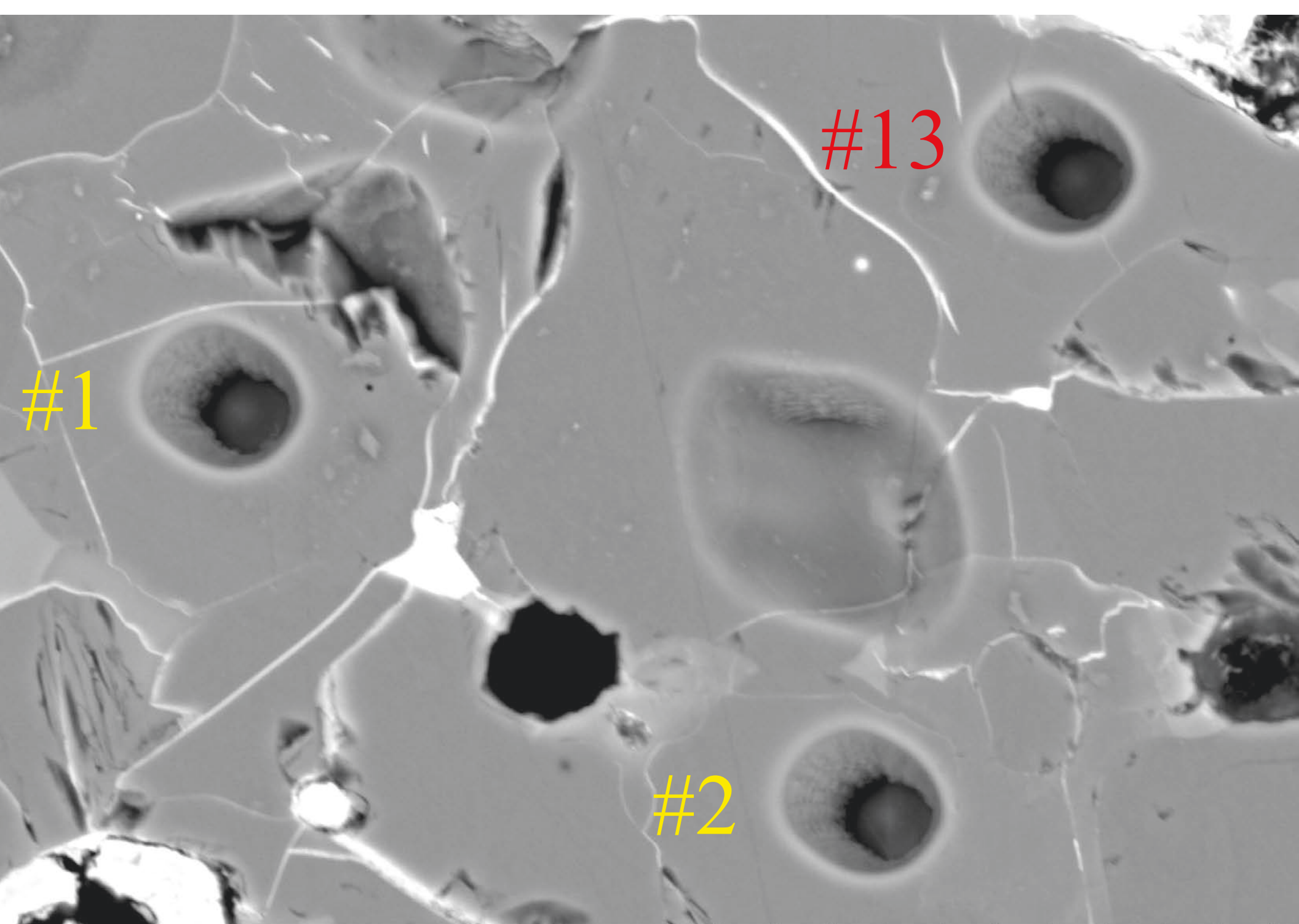


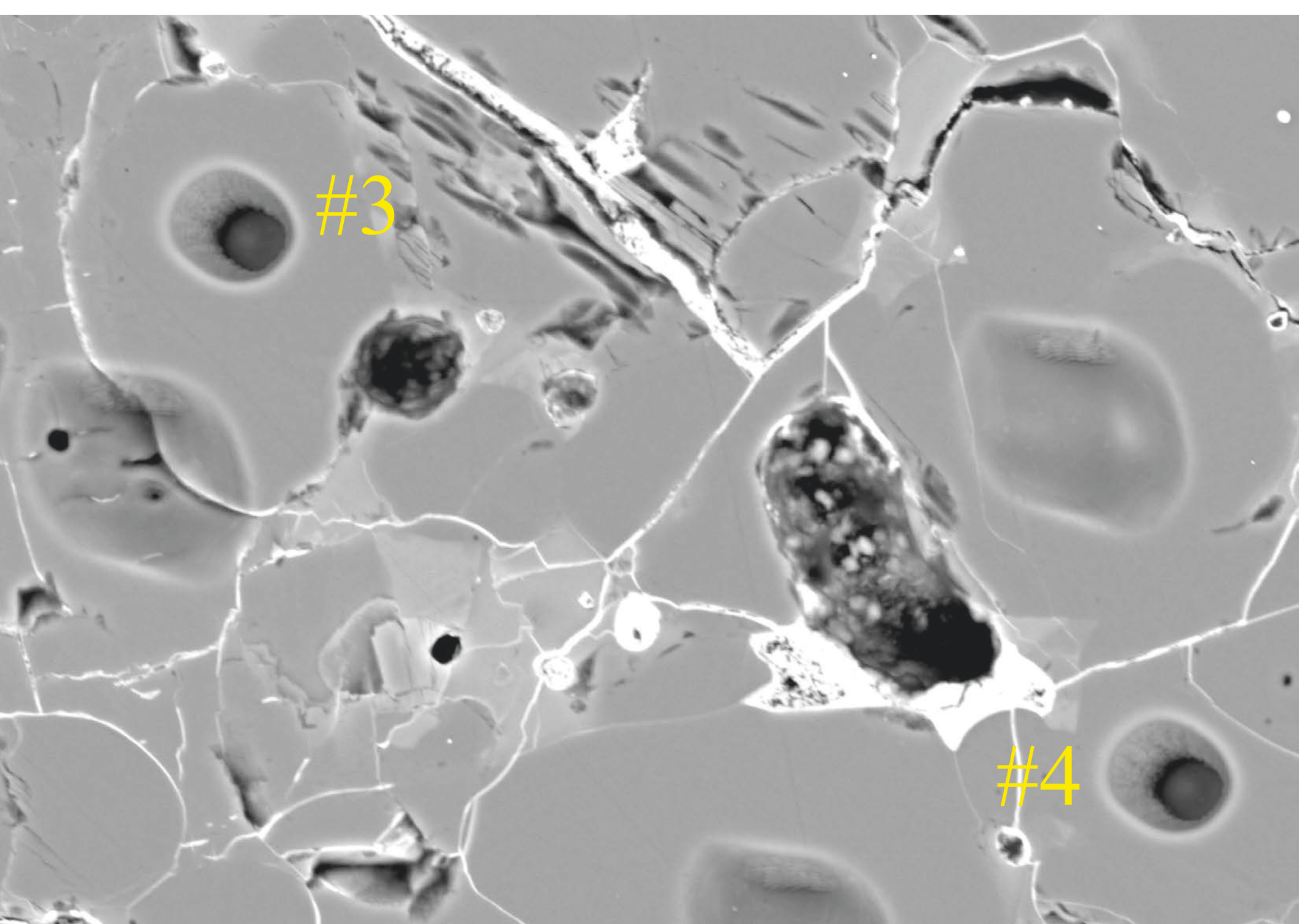
G68-IAB

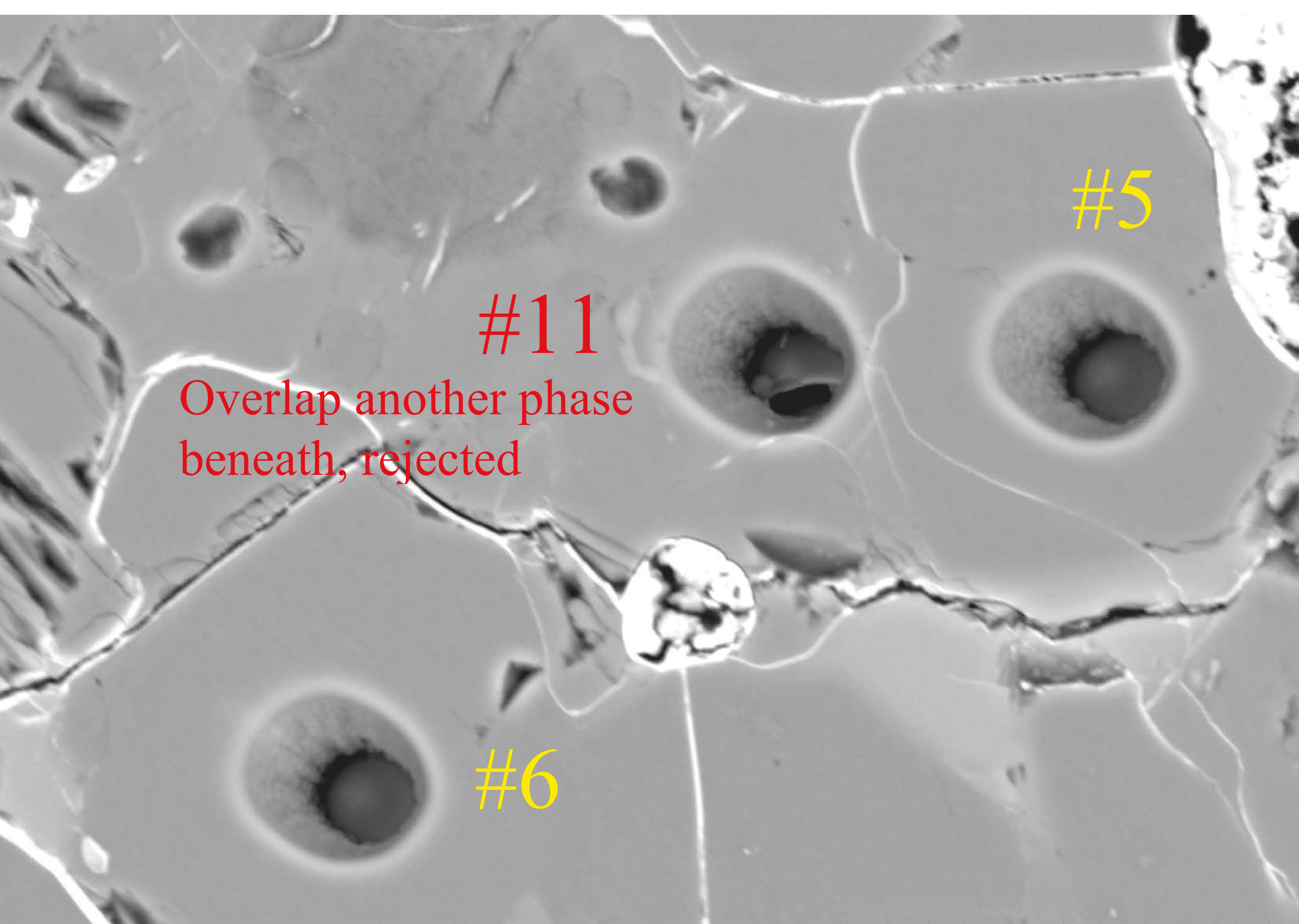


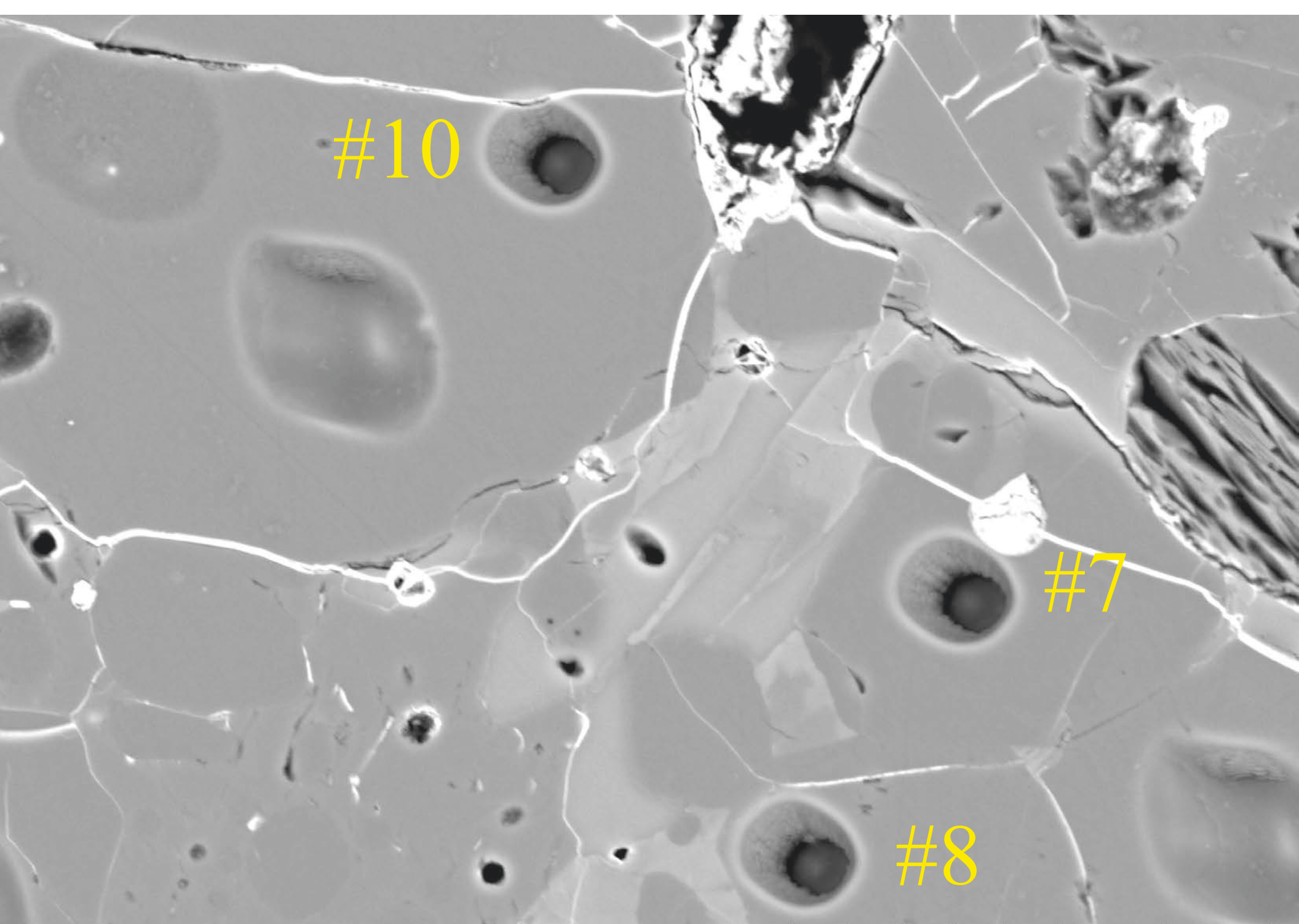
15.0kV x300 BSECOMP

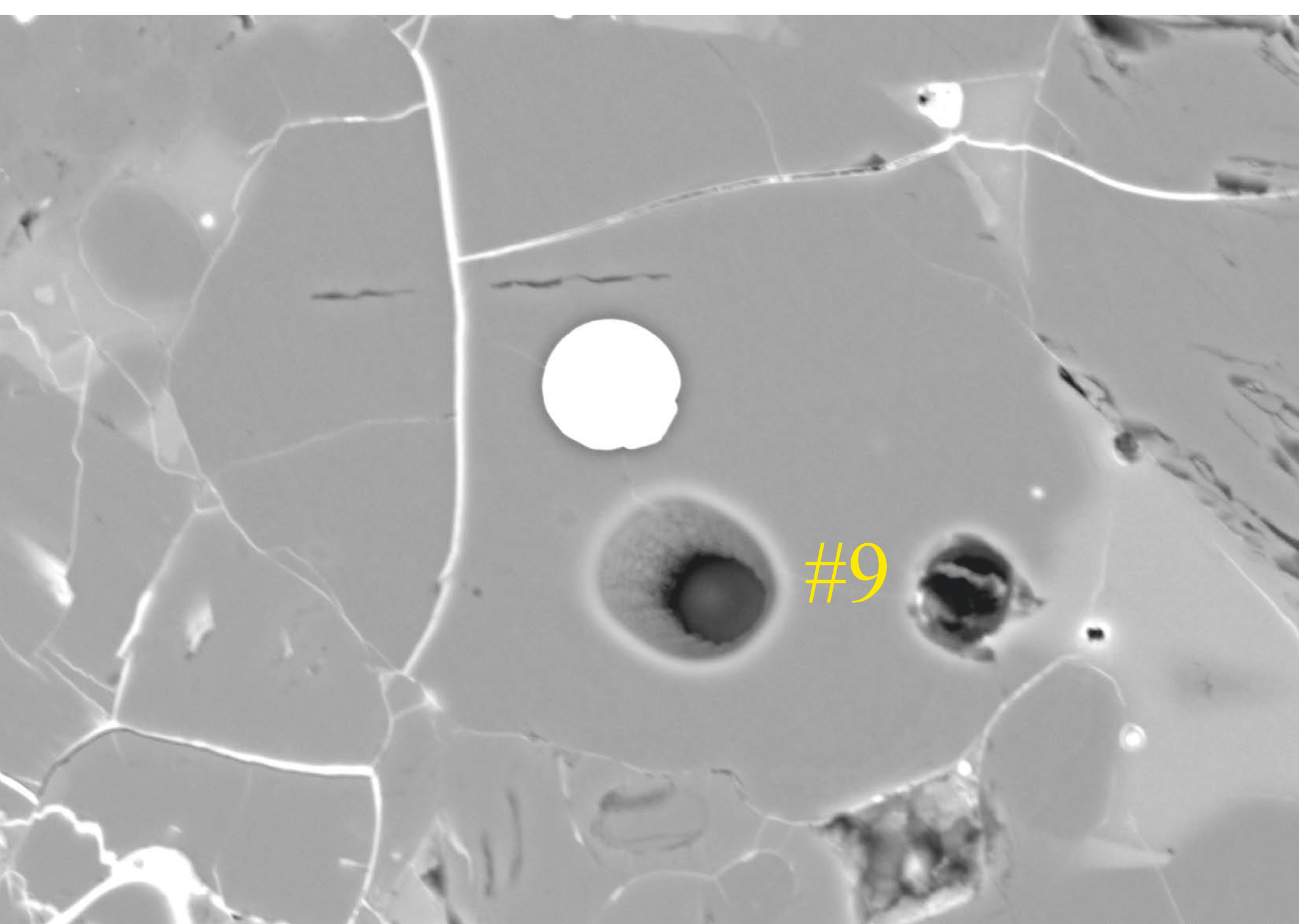
100um











15.0kV x2.00k BSECOMP

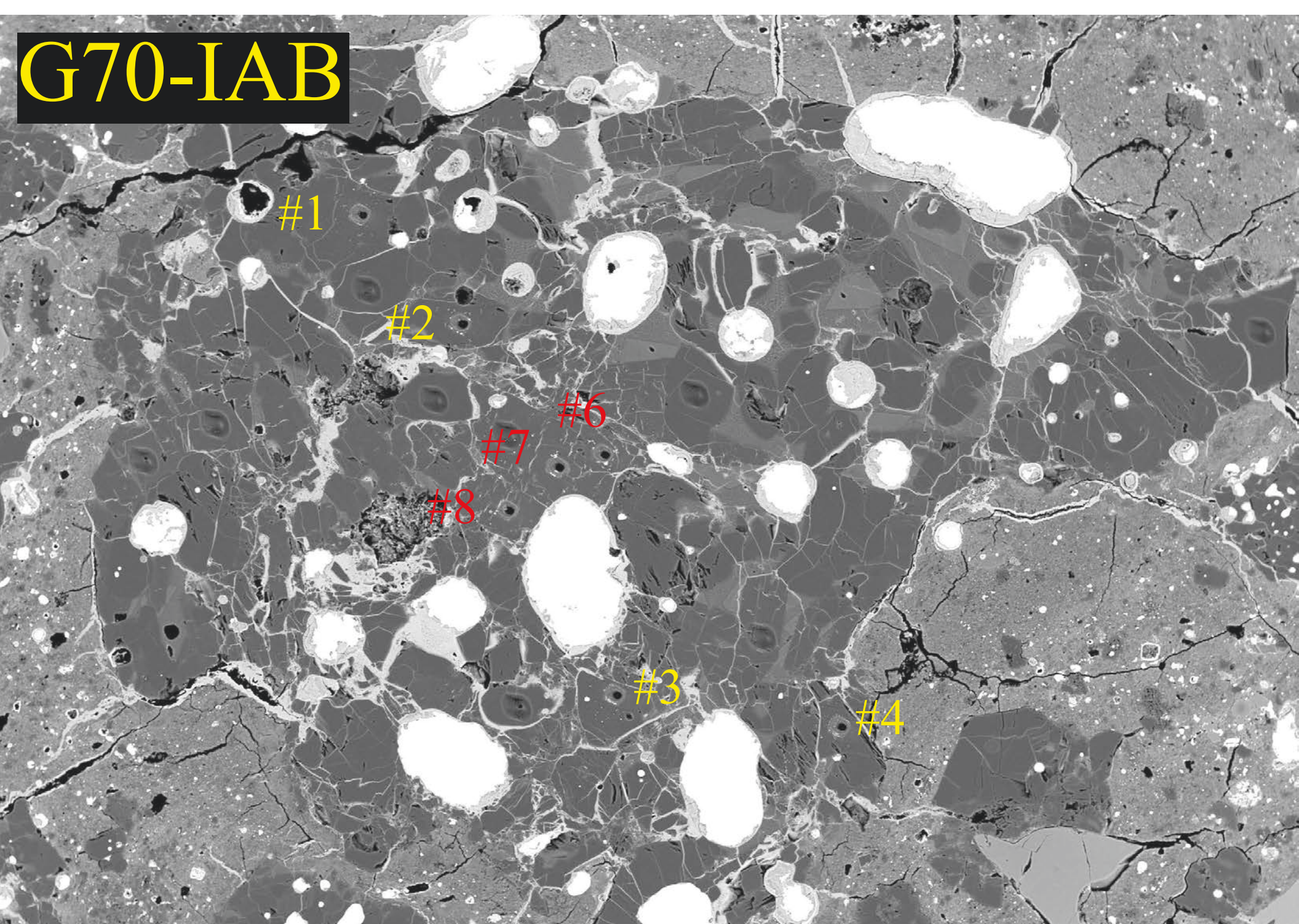
20.0um

#12

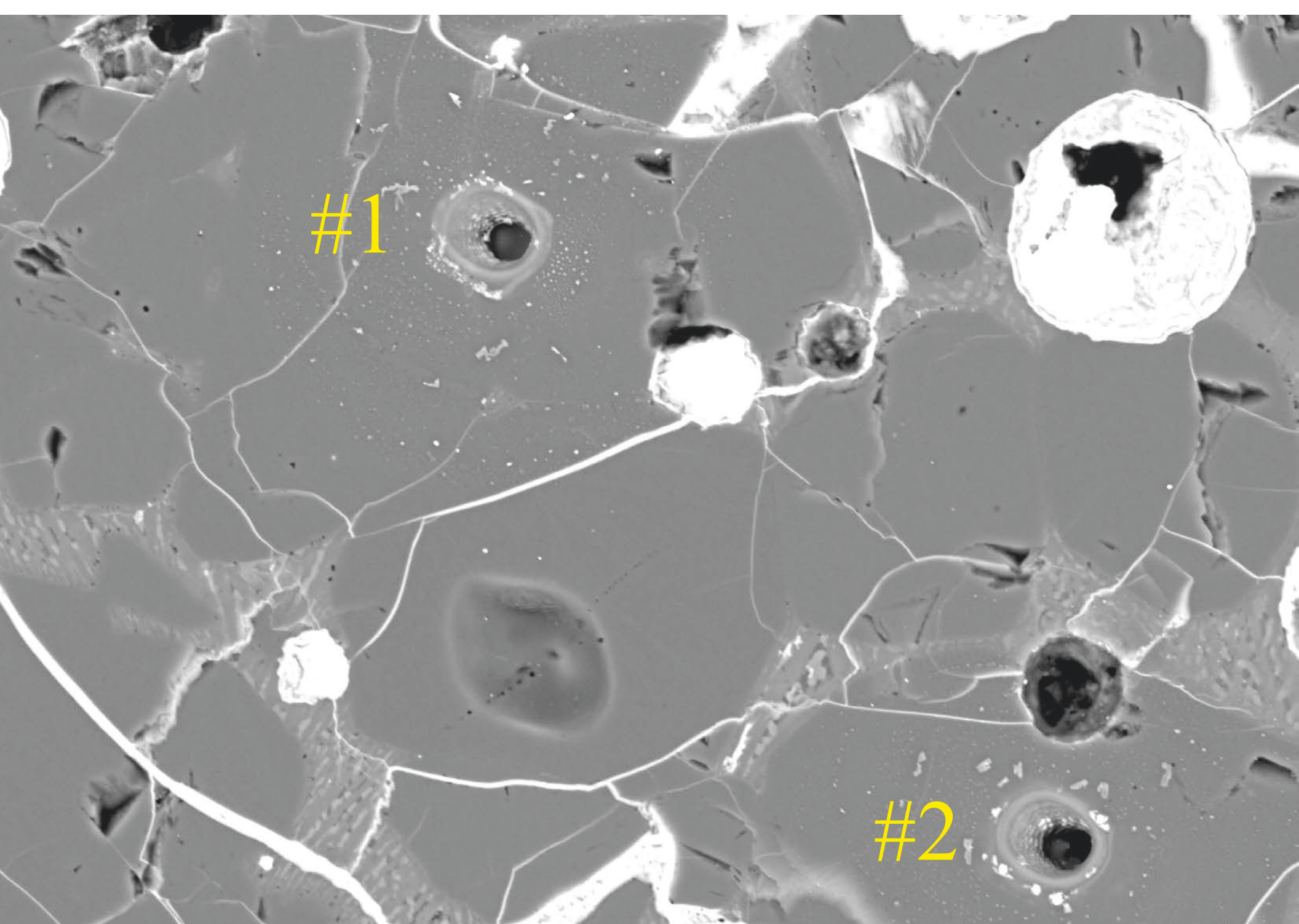
15.0kV x3.20k BSECOMP

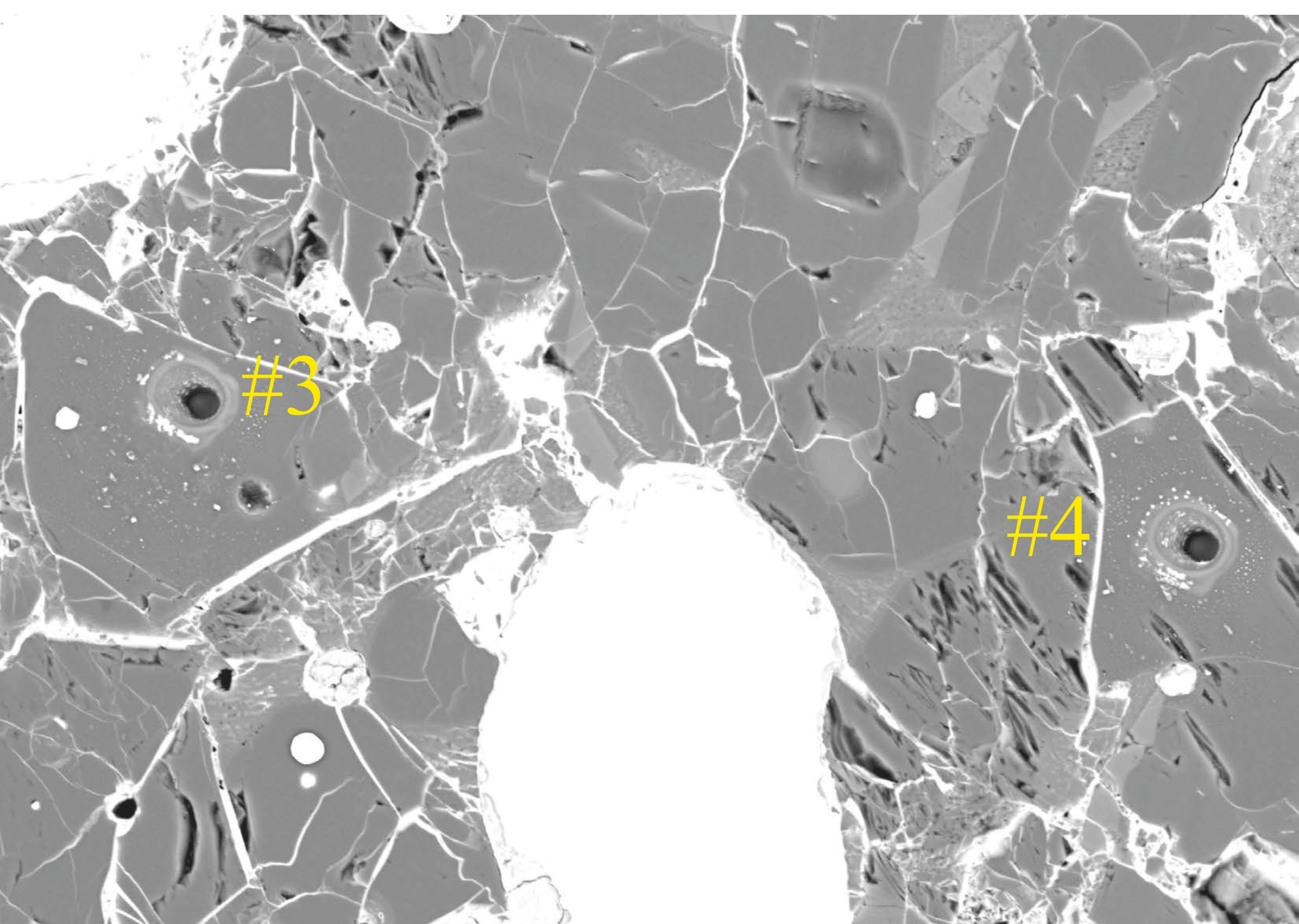
10.0um

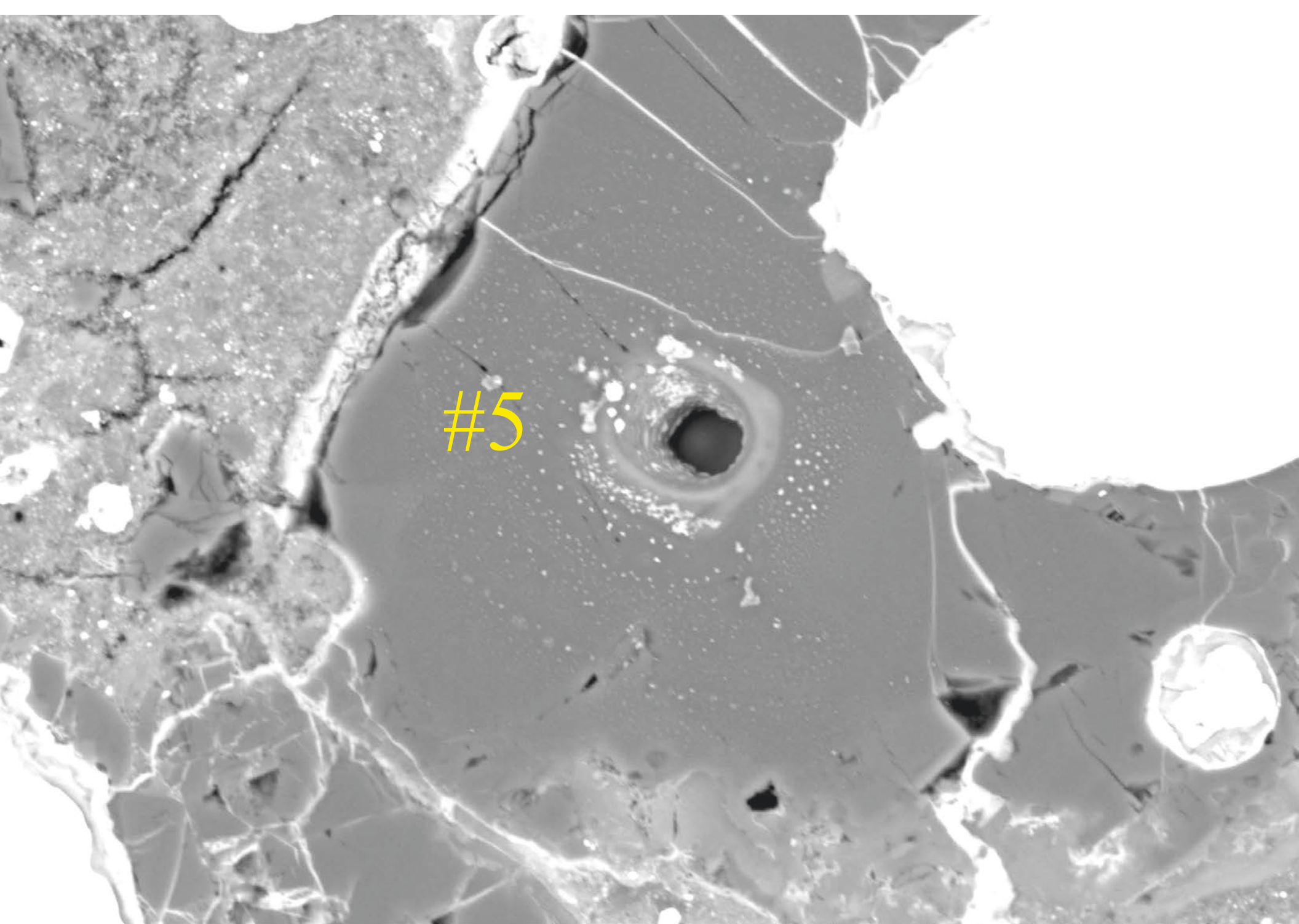
G70-IAB



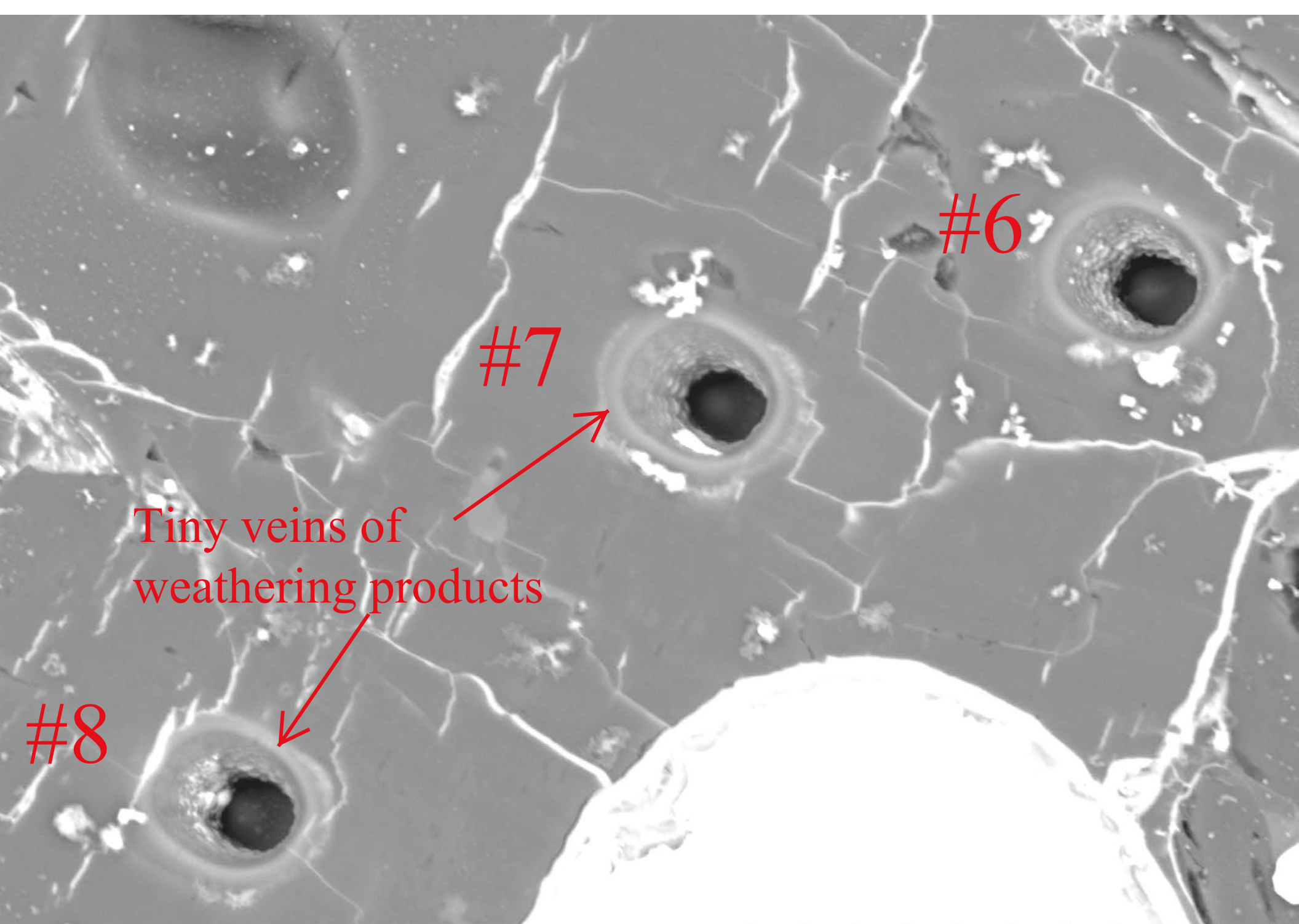
15.0kV x180 BSECOMP 300um

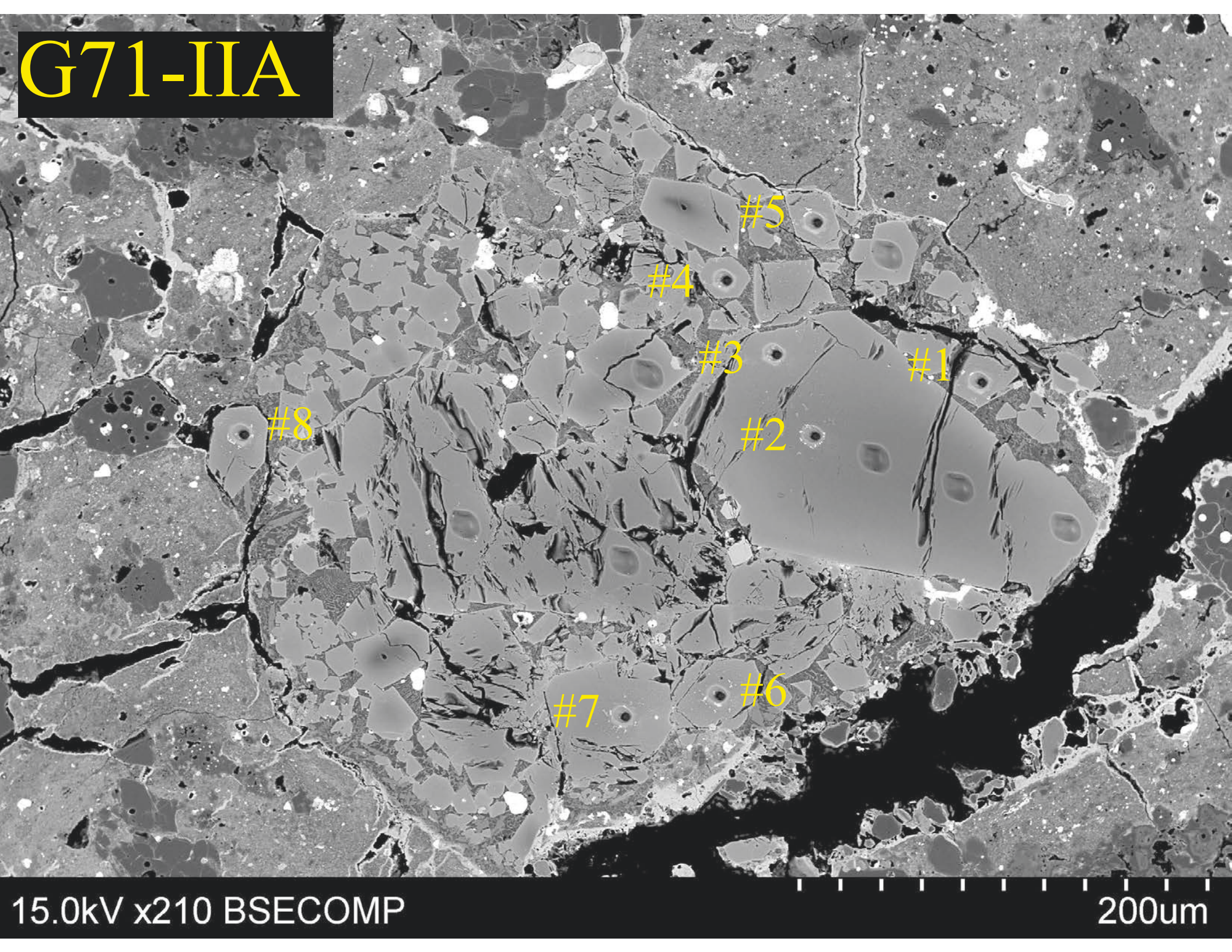






#5





G71-IIA

#8

#4

#5

#3

#1

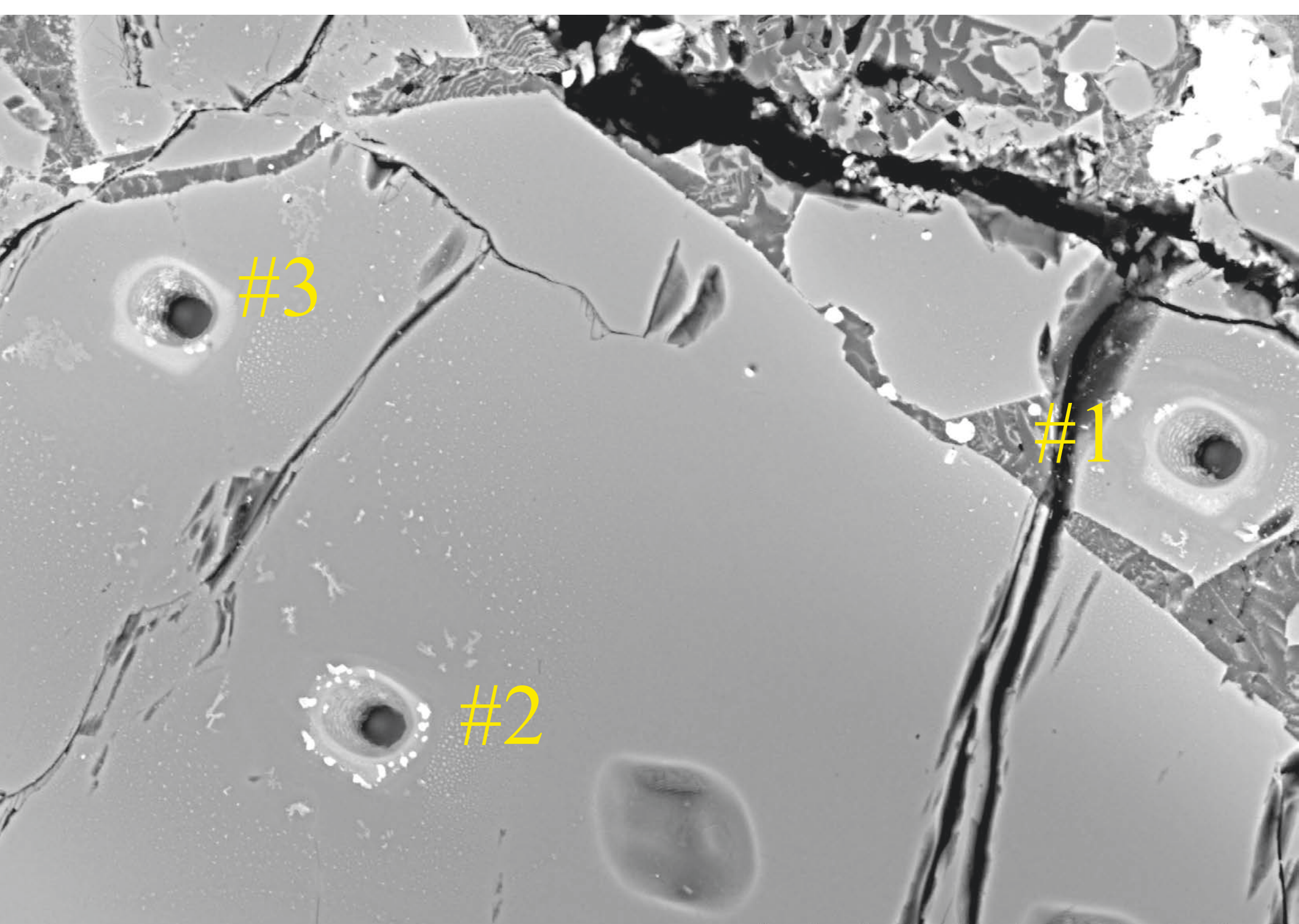
#2

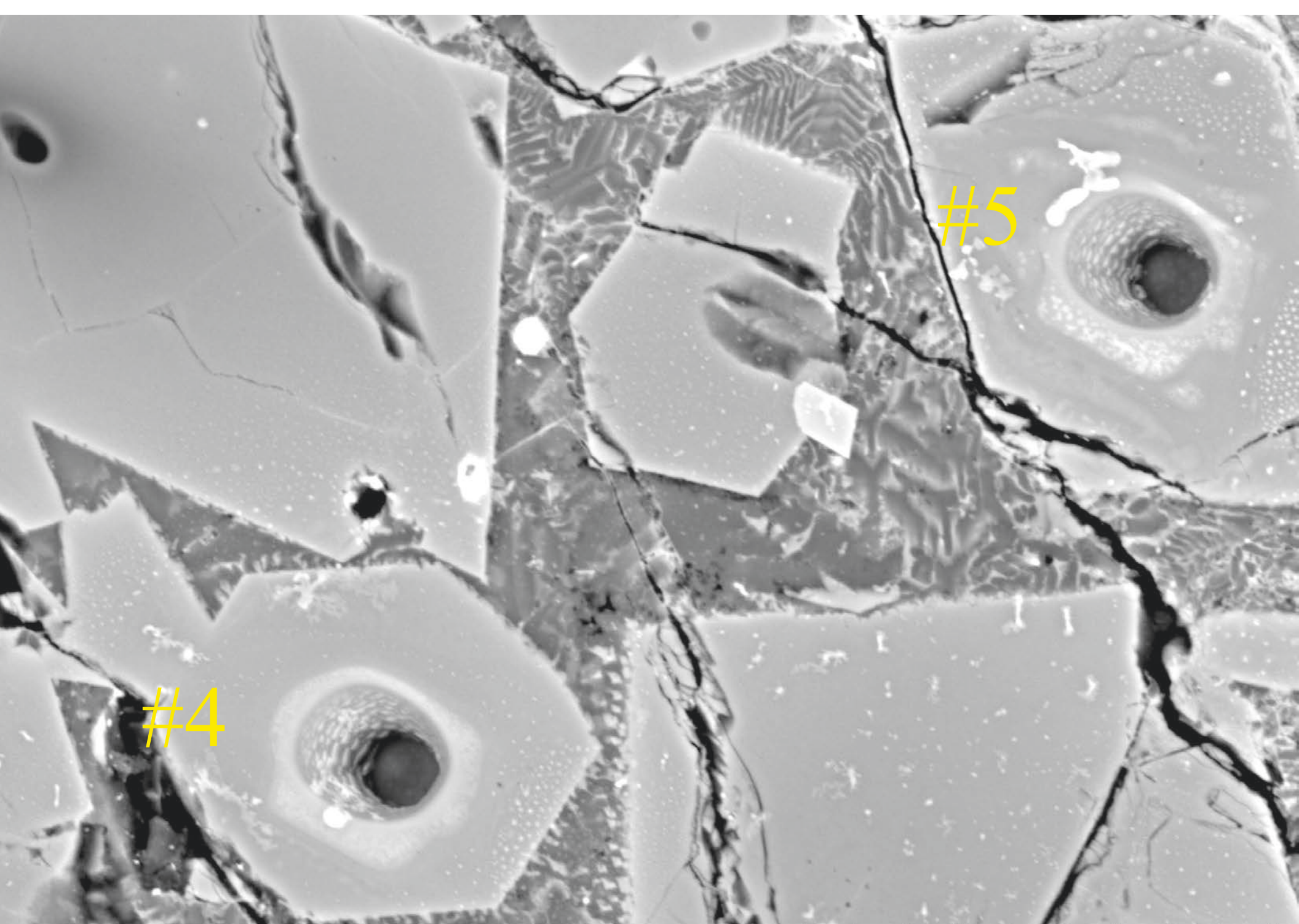
#7

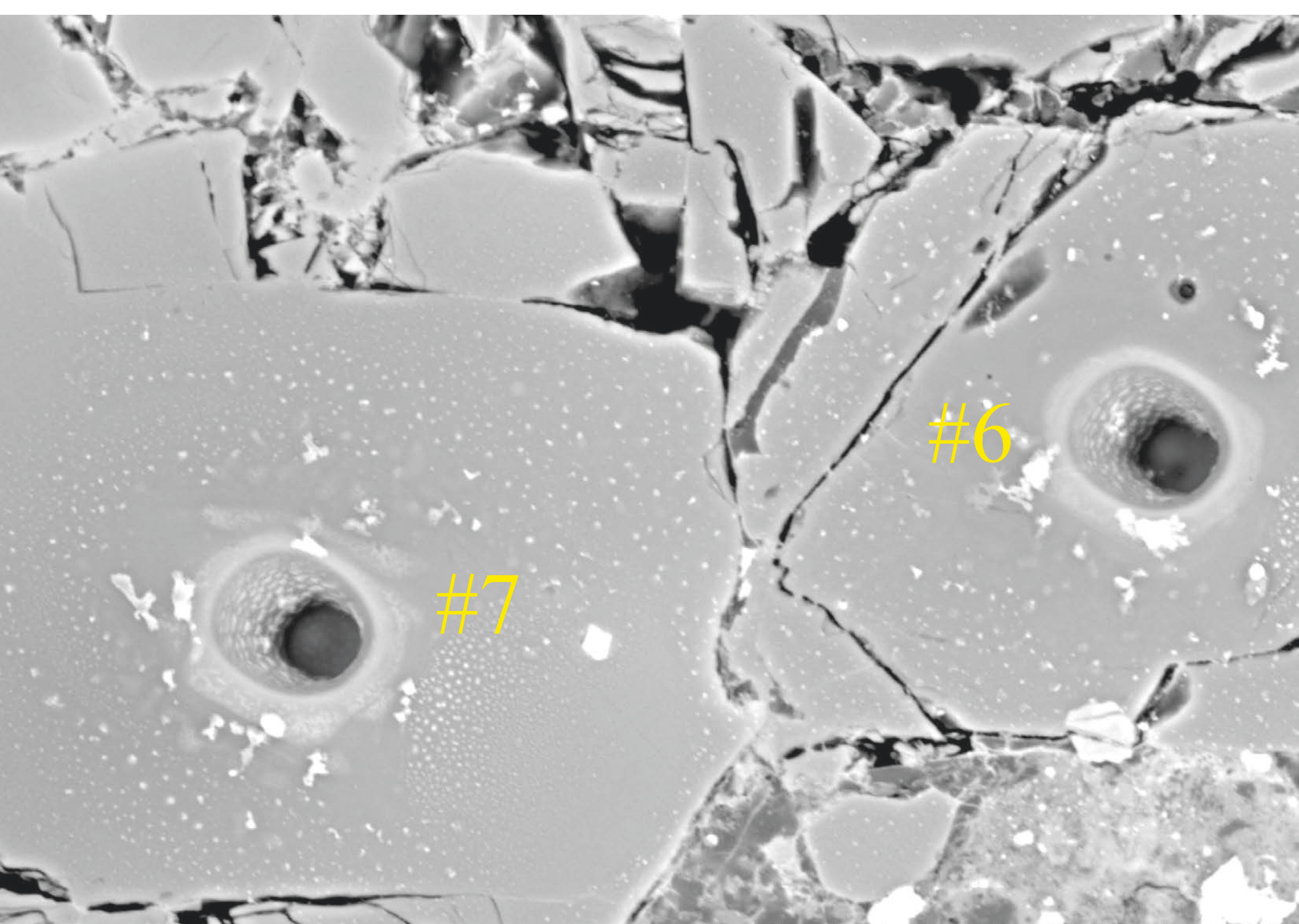
#6

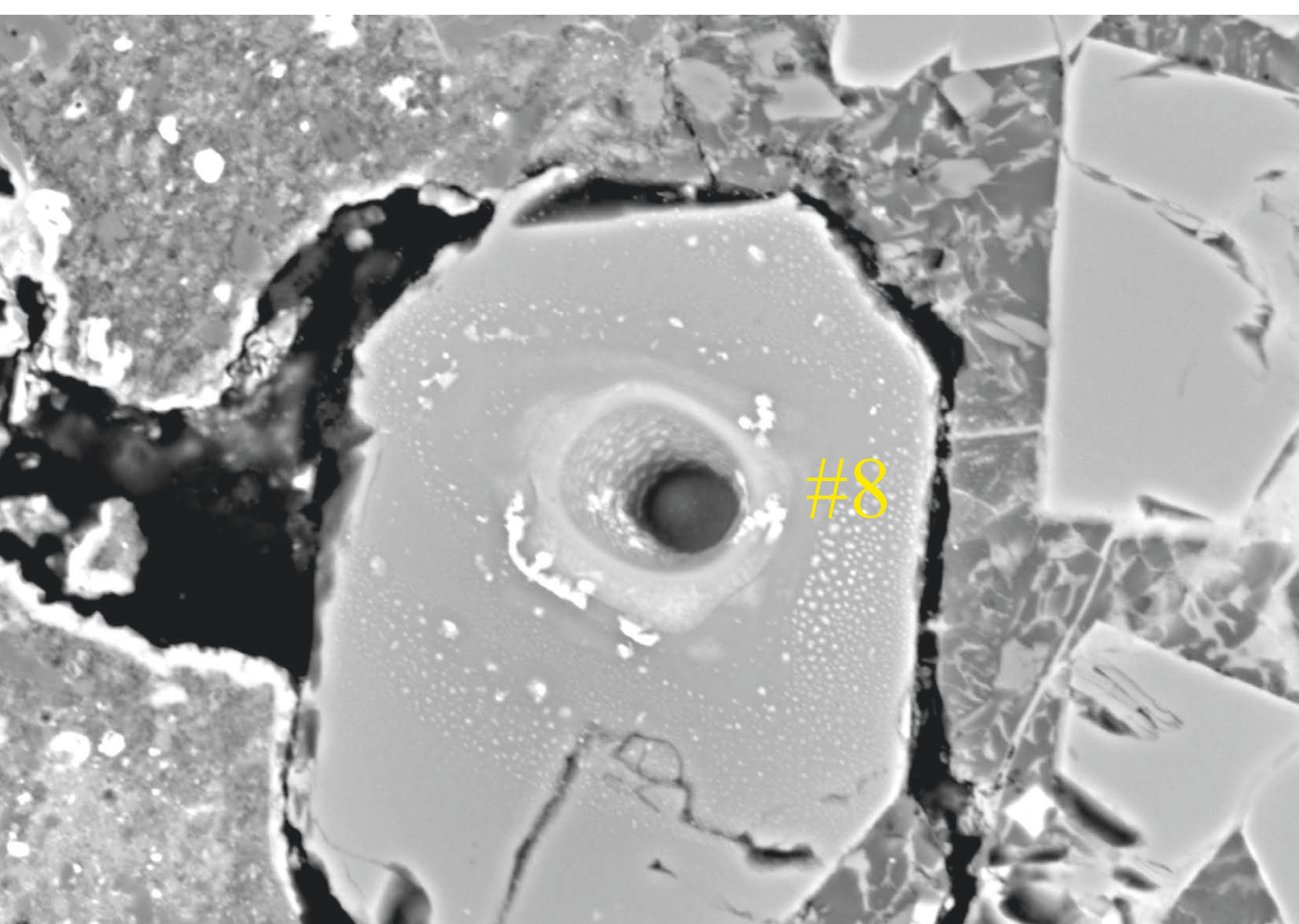
15.0kV x210 BSECOMP

200um





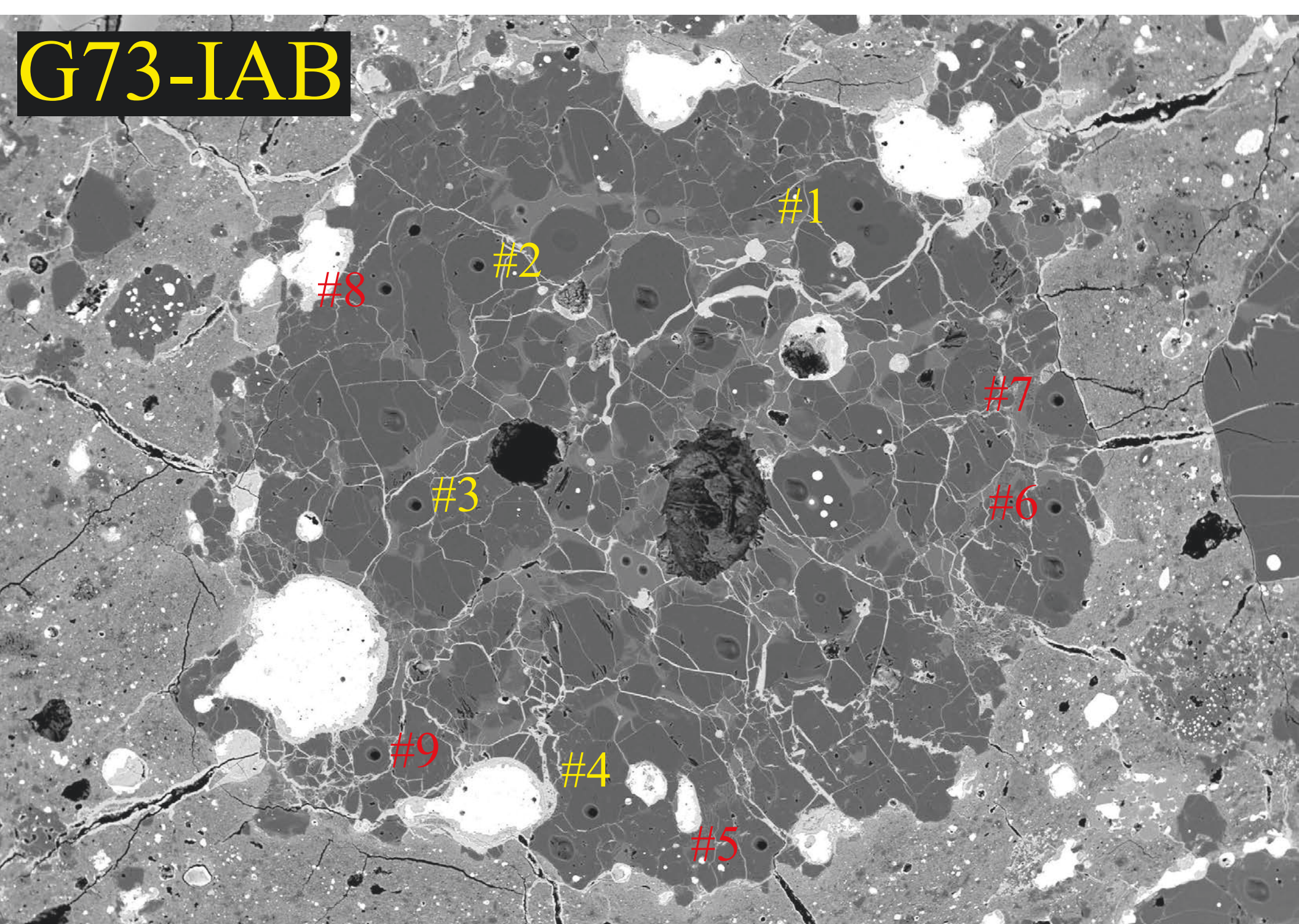


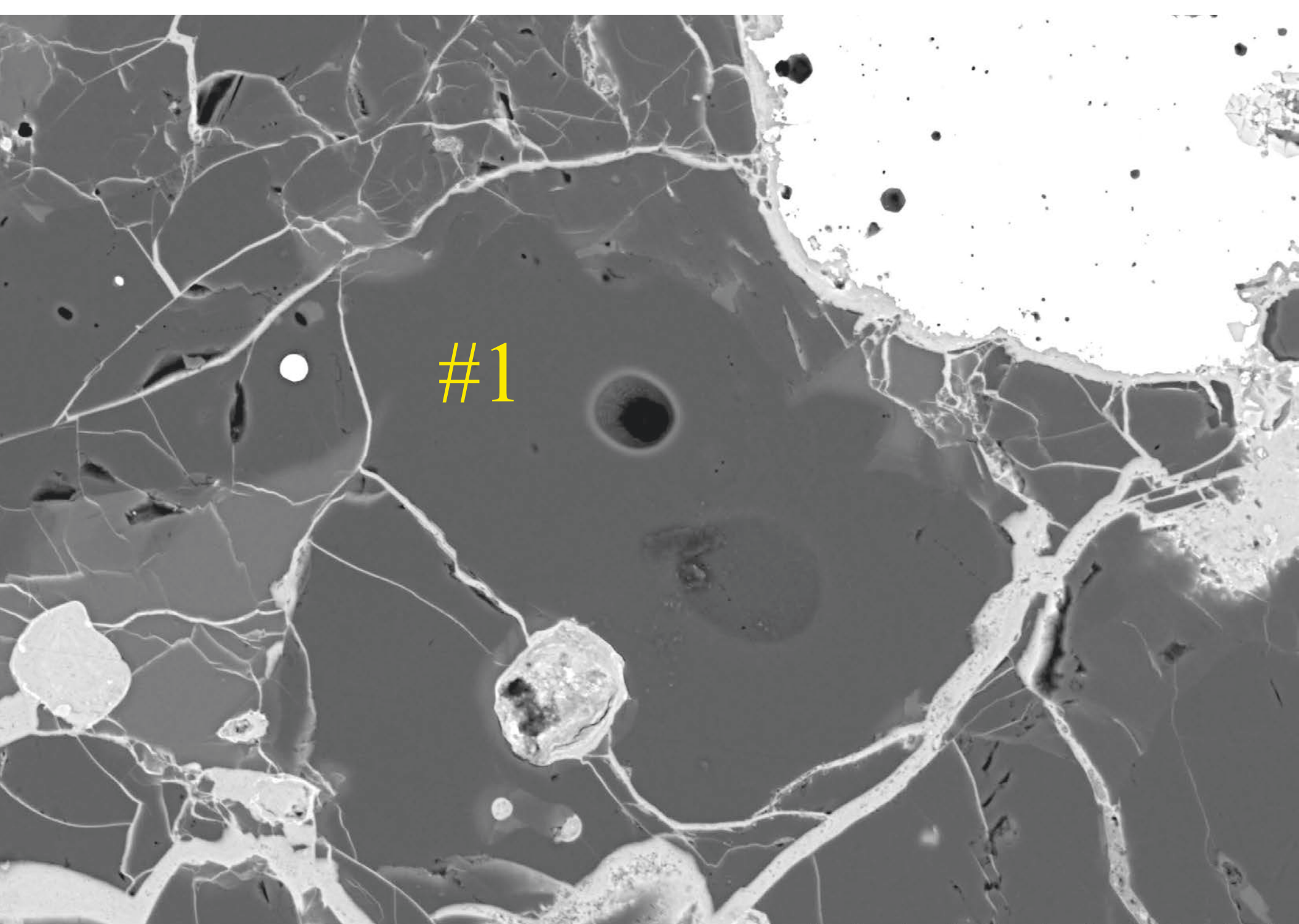


15.0kV x2.10k BSECOMP

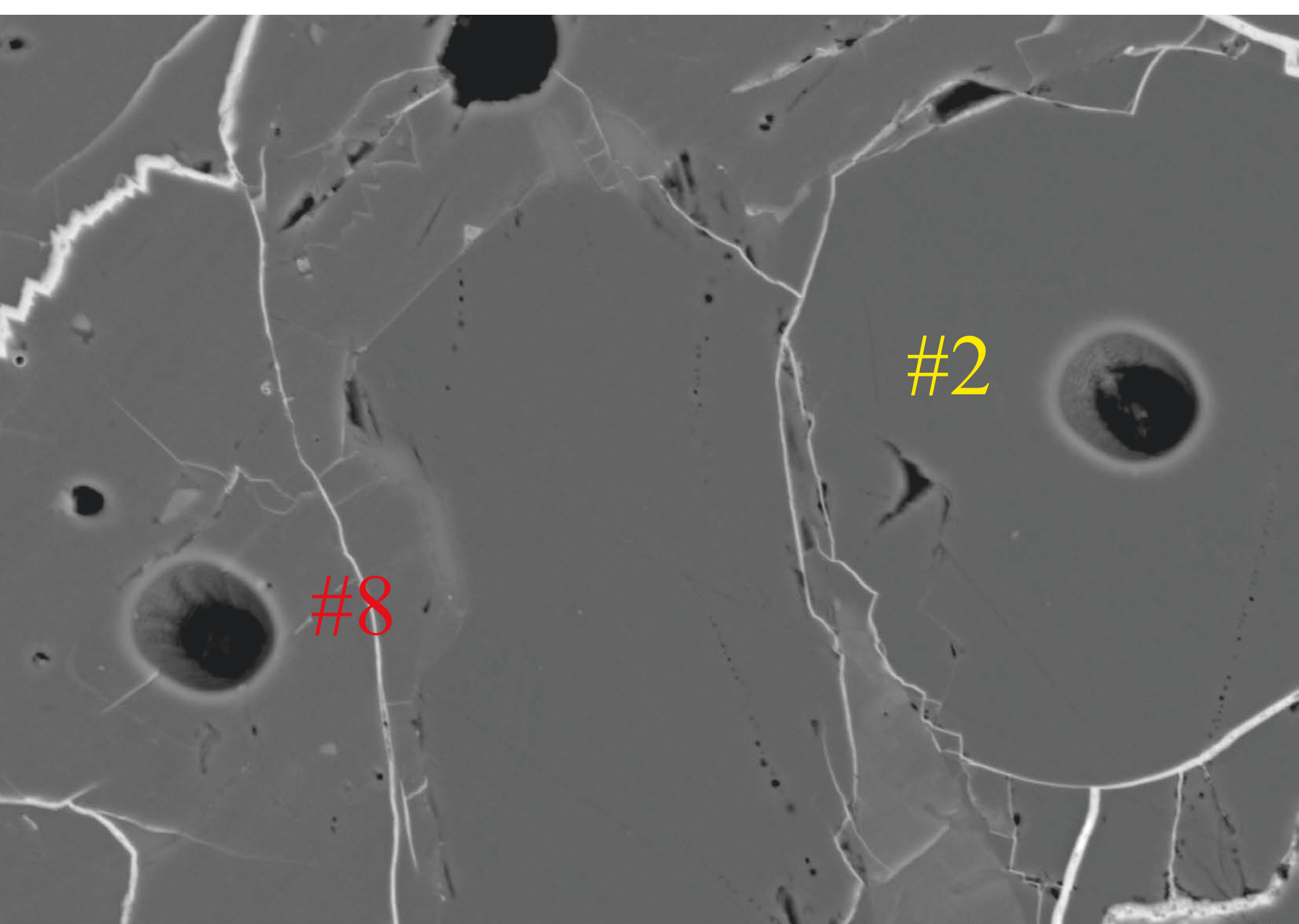
20.0um

G73-IAB



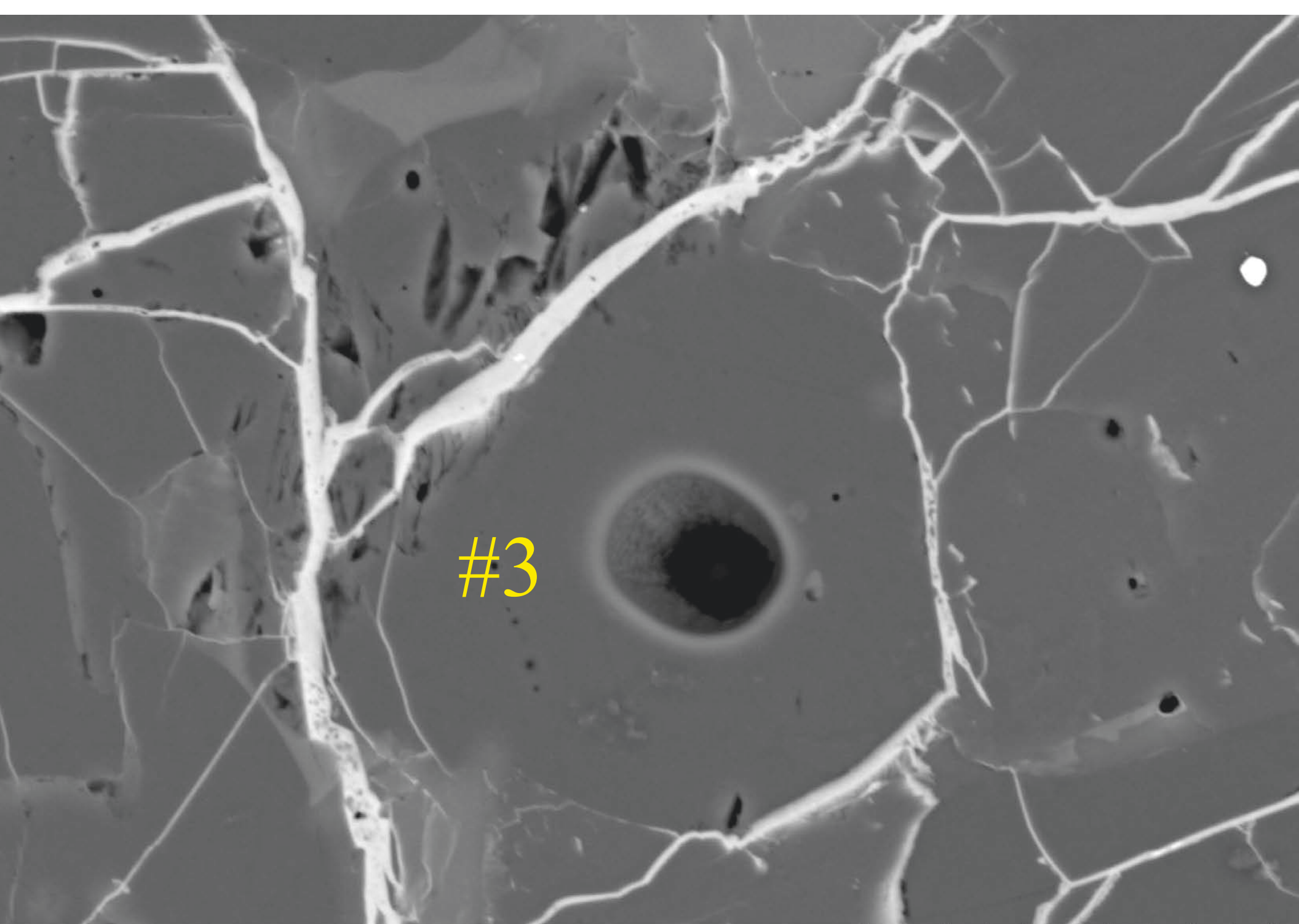


#1

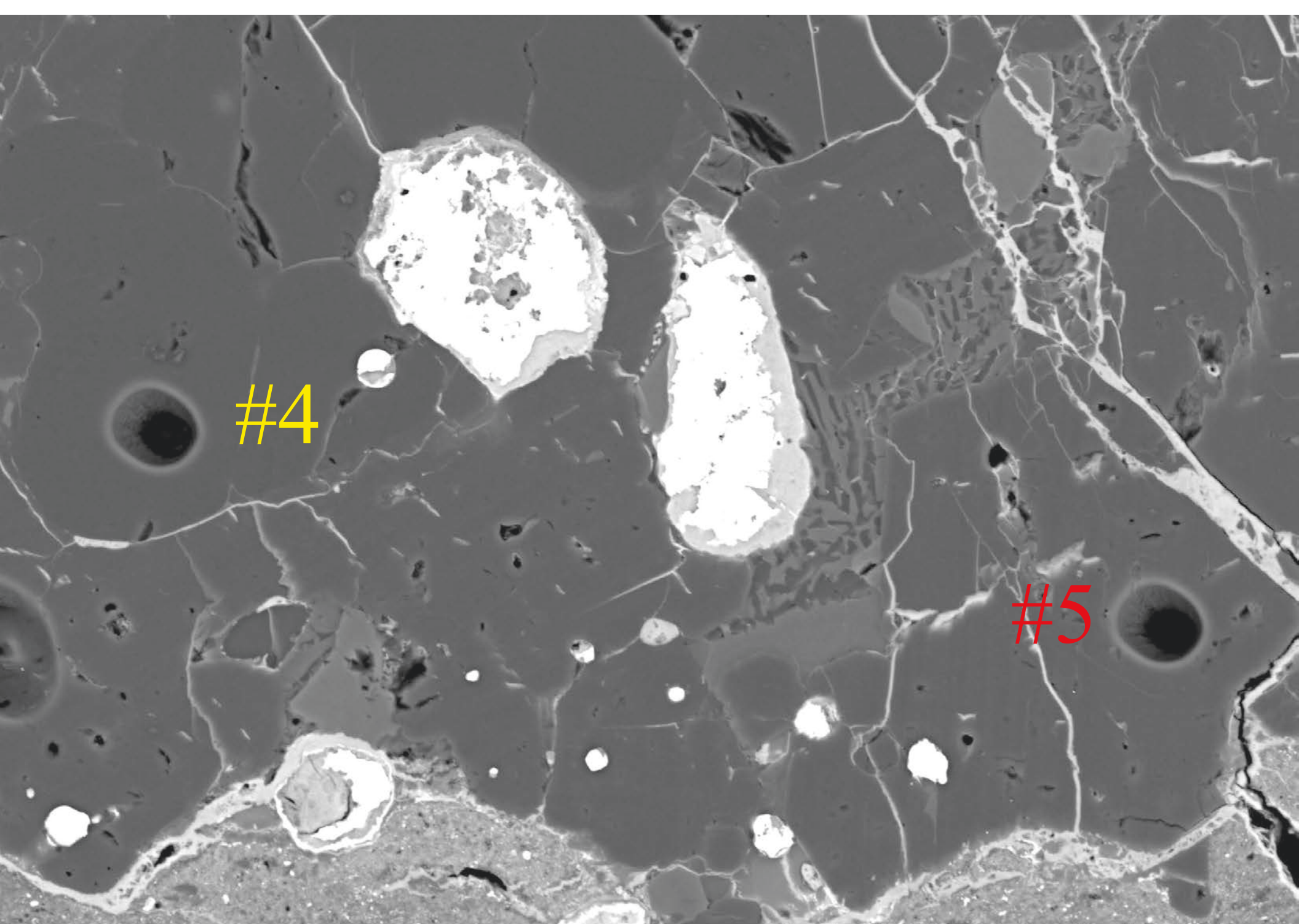


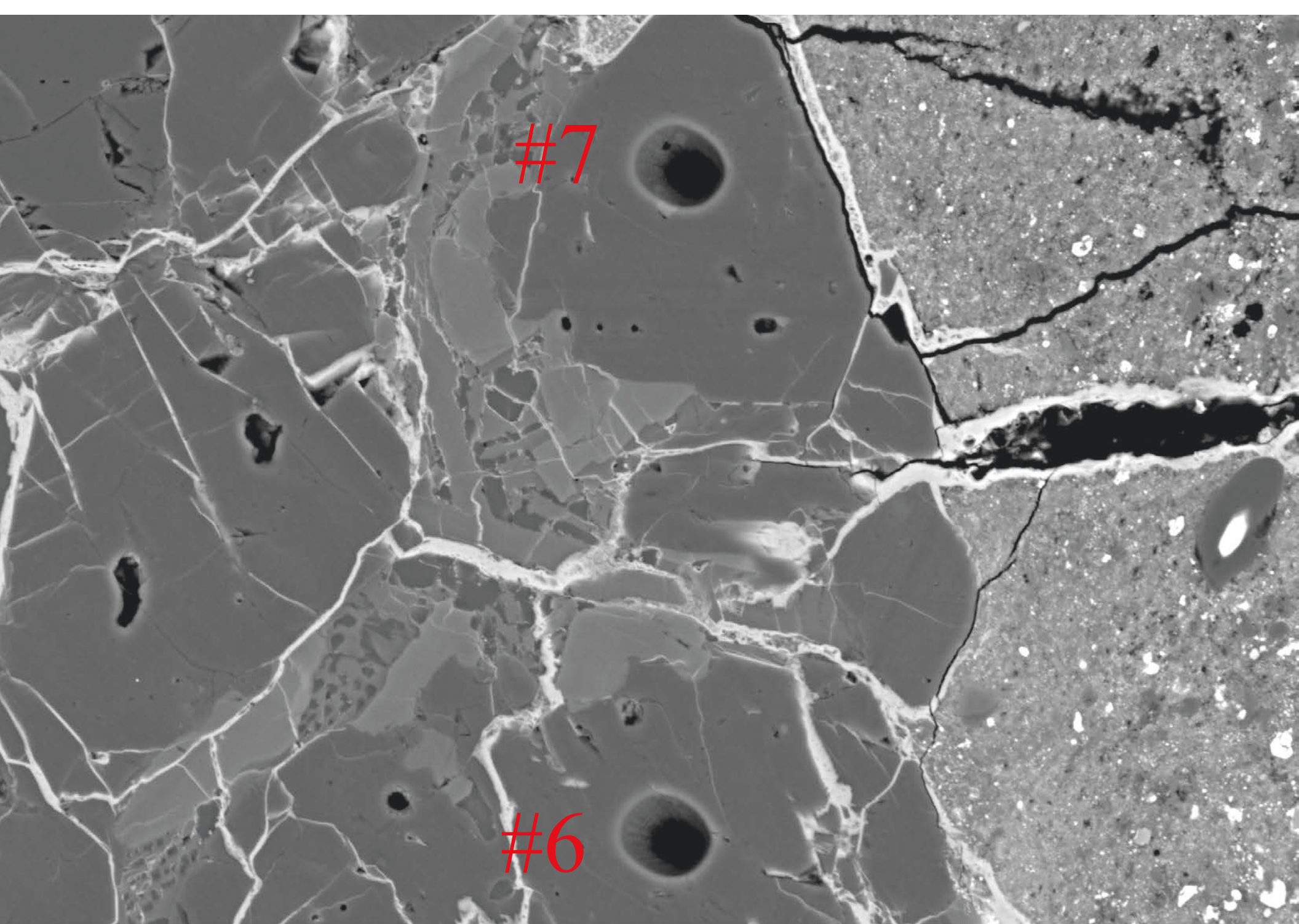
#2

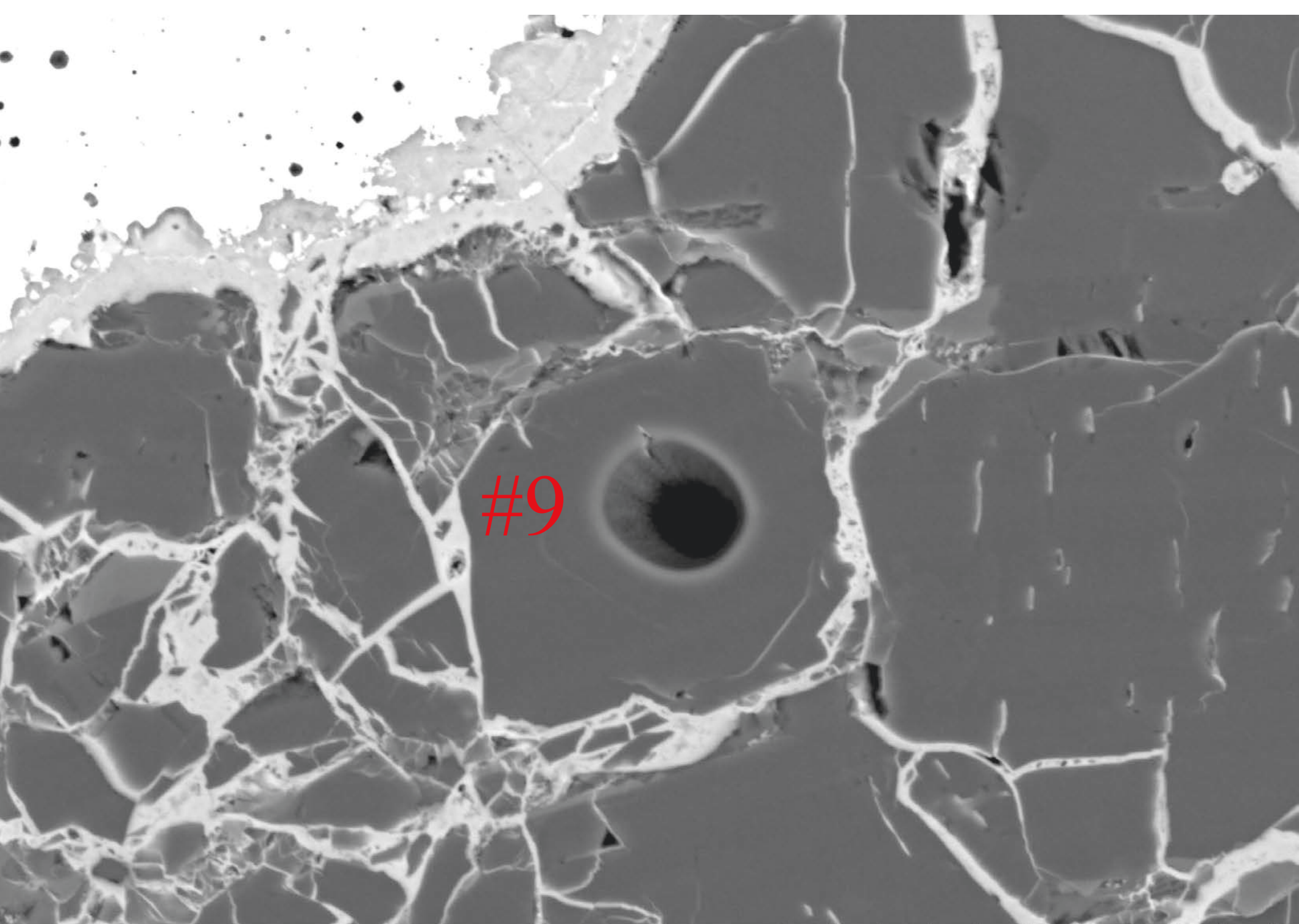
#8



#3



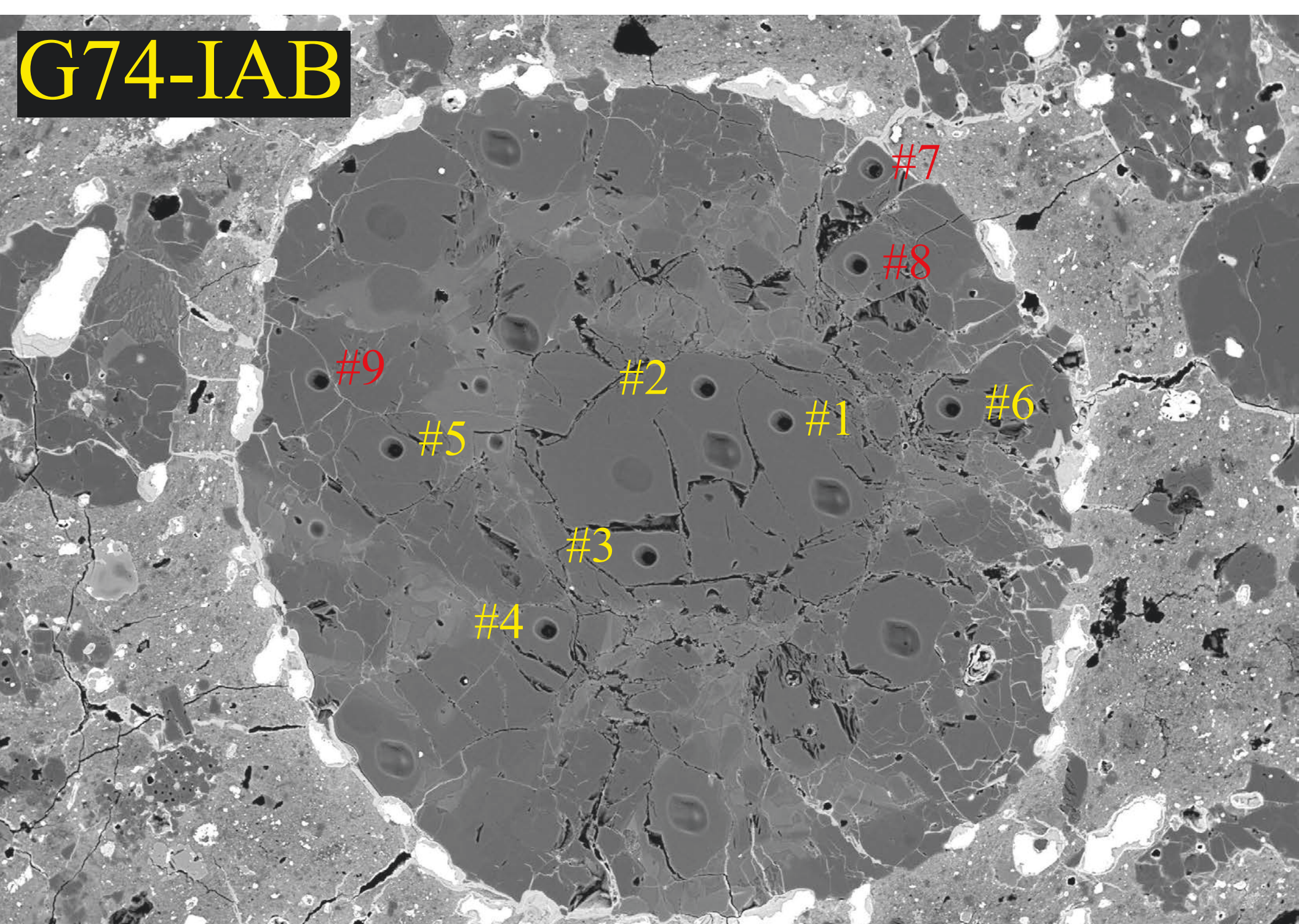




15.0kV x1.60k BSECOMP

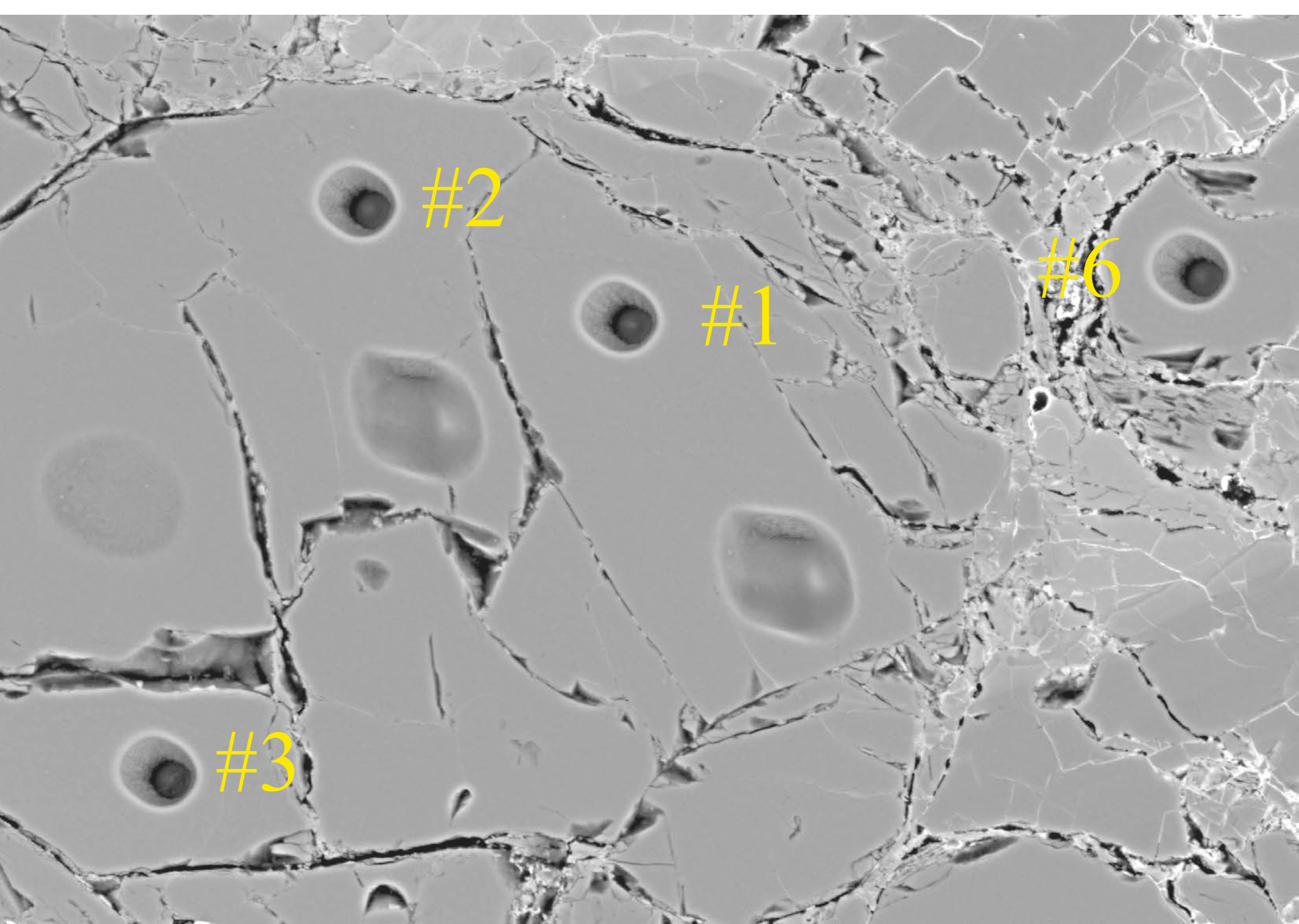
30.0um

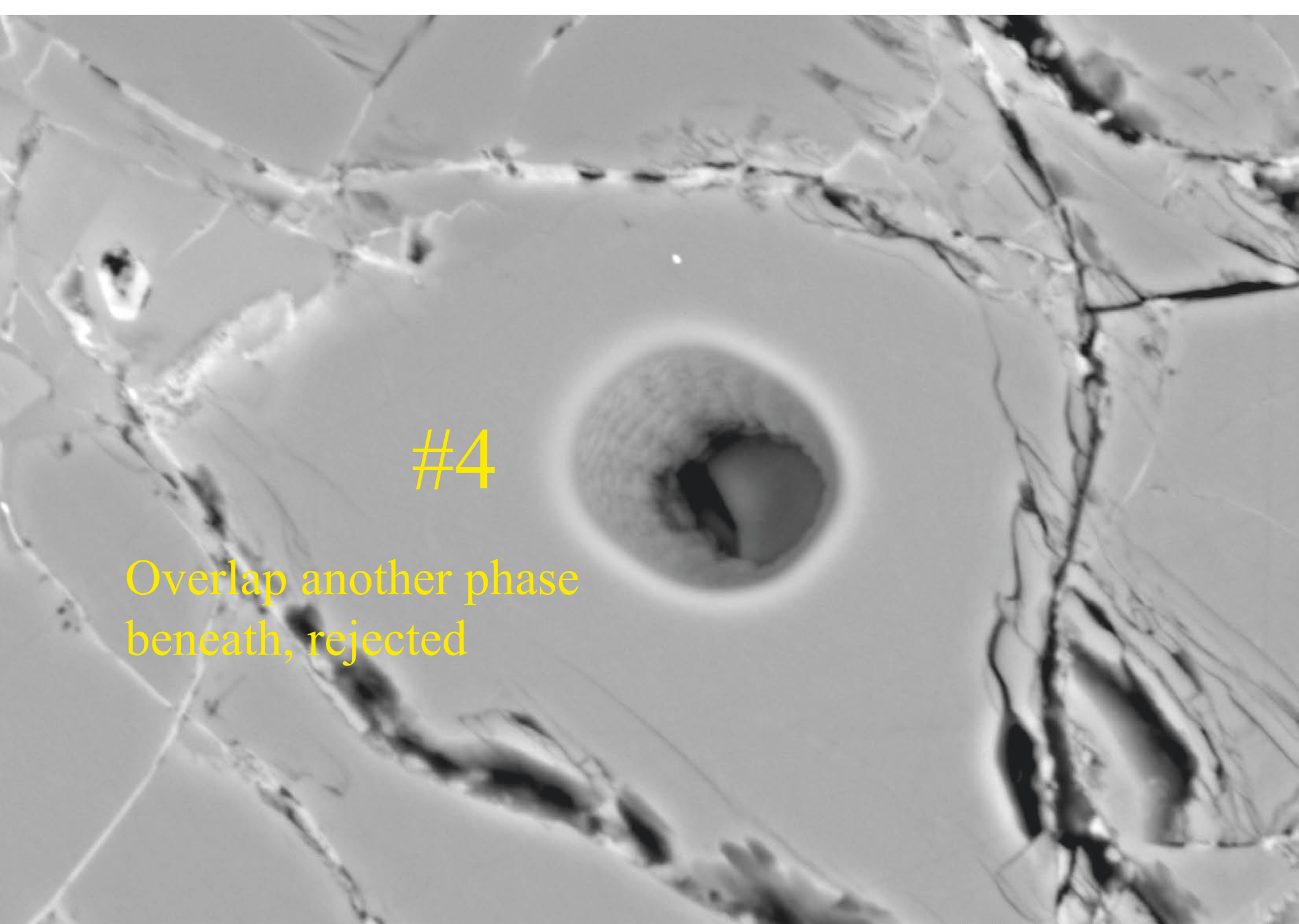
G74-IAB



15.0kV x250 BSECOMP

200um

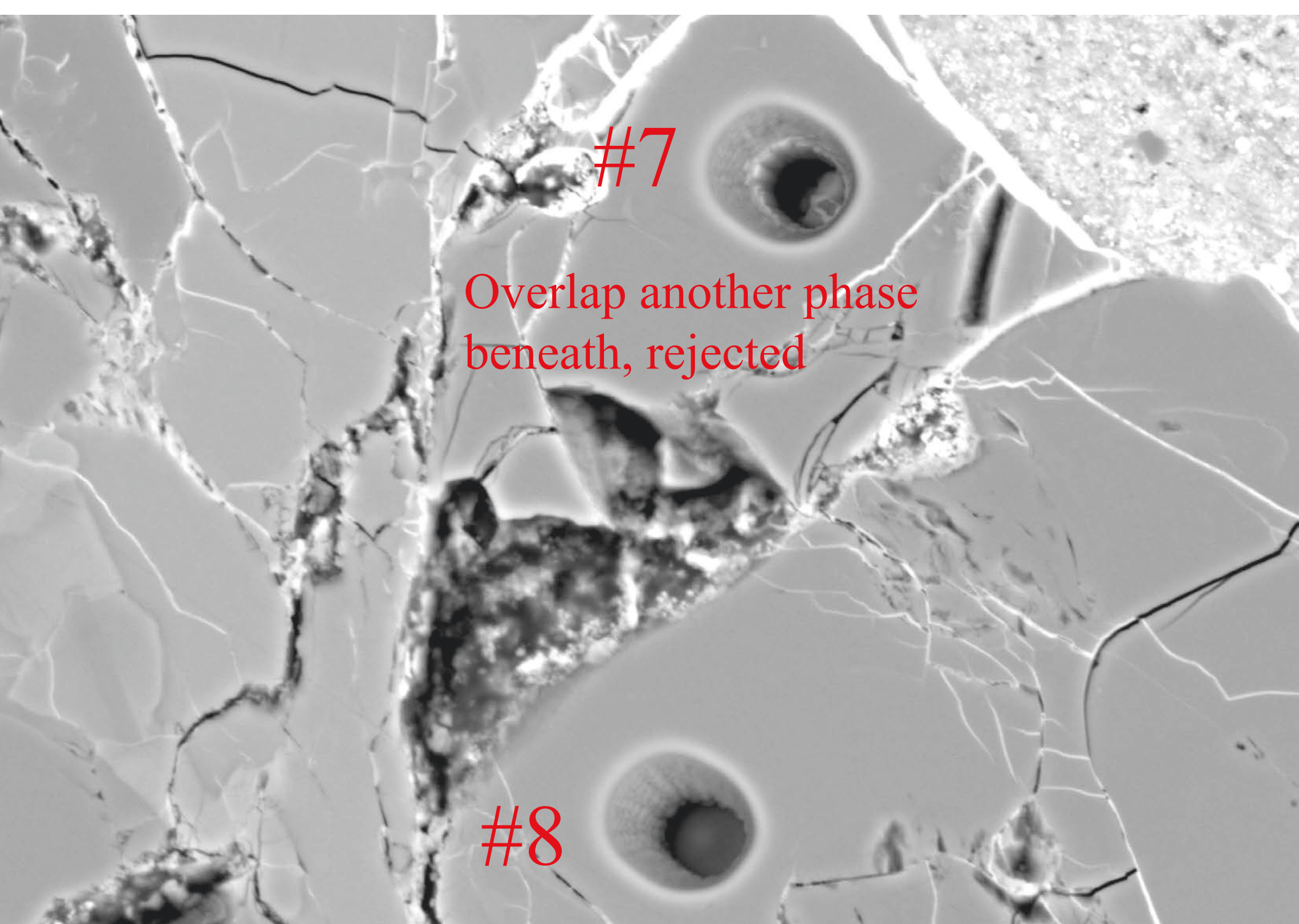




#4

This scanning electron micrograph (SEM) shows a large, roughly circular feature in the center of the frame. The feature has a dark, irregularly shaped core surrounded by a lighter, concentric ring. The surrounding material is textured with various grain boundaries and smaller, dark, elongated features. The image is labeled with a yellow '#4' and a descriptive text block.

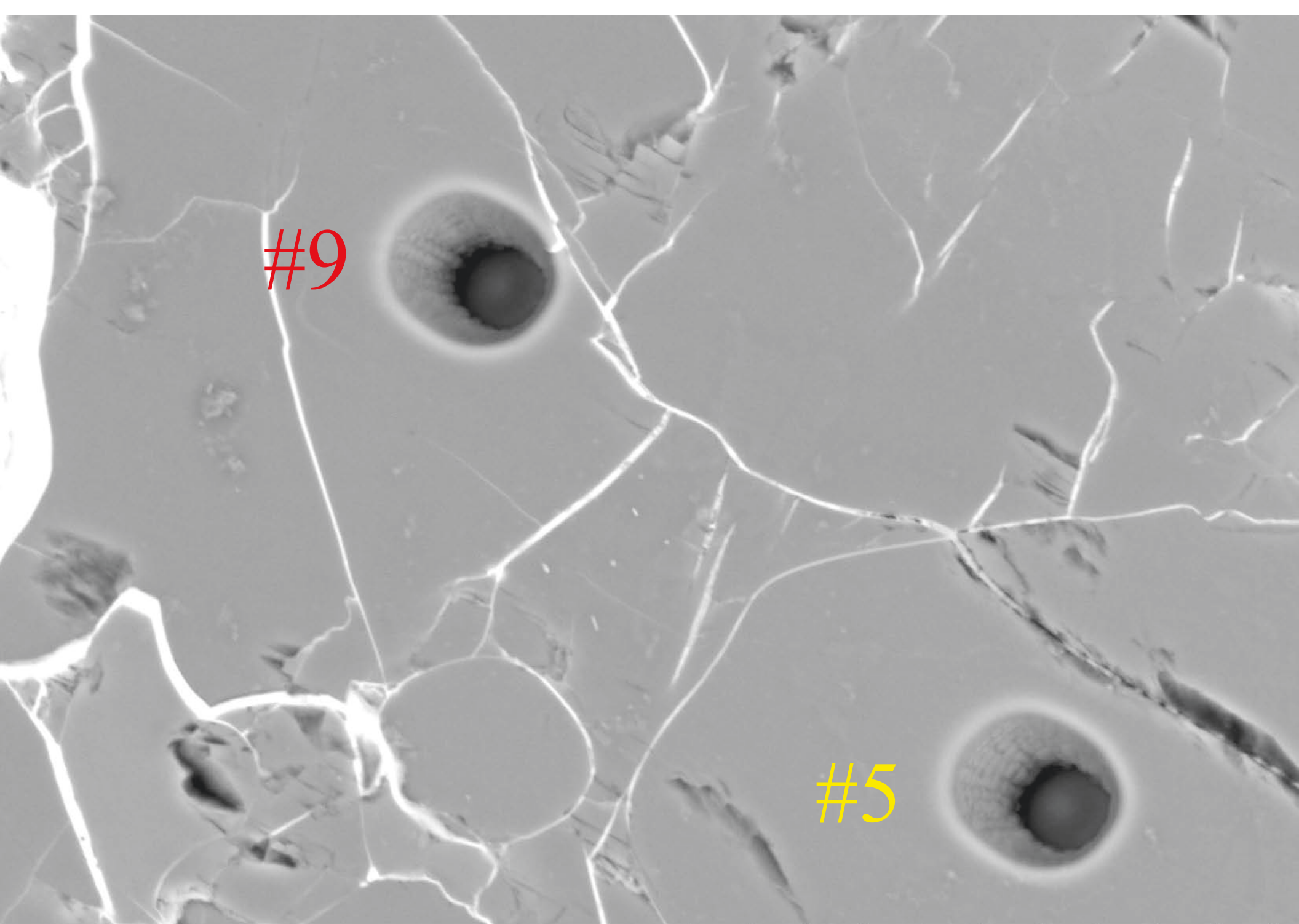
Overlap another phase
beneath, rejected



#7

Overlap another phase
beneath, rejected

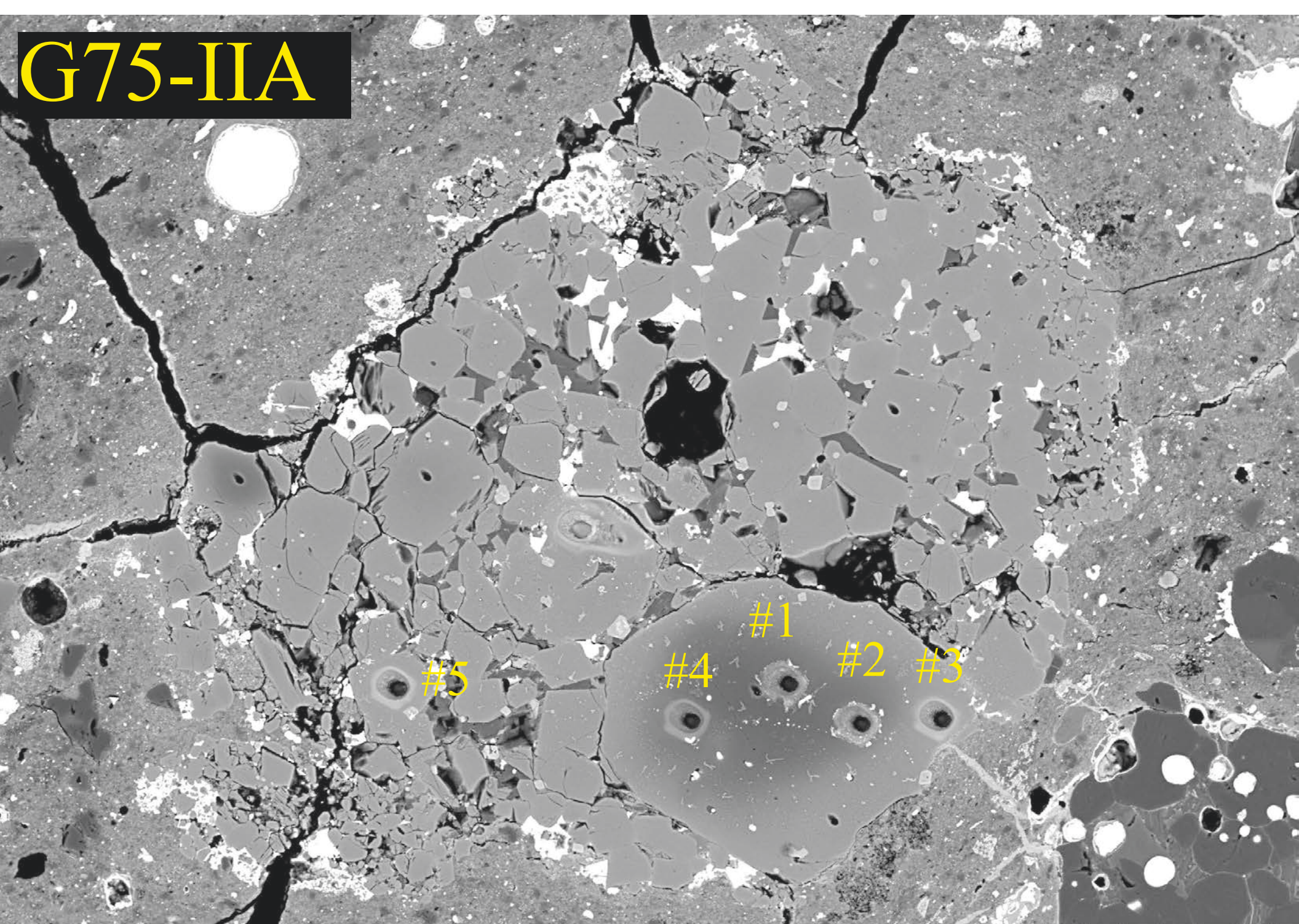
#8



#9

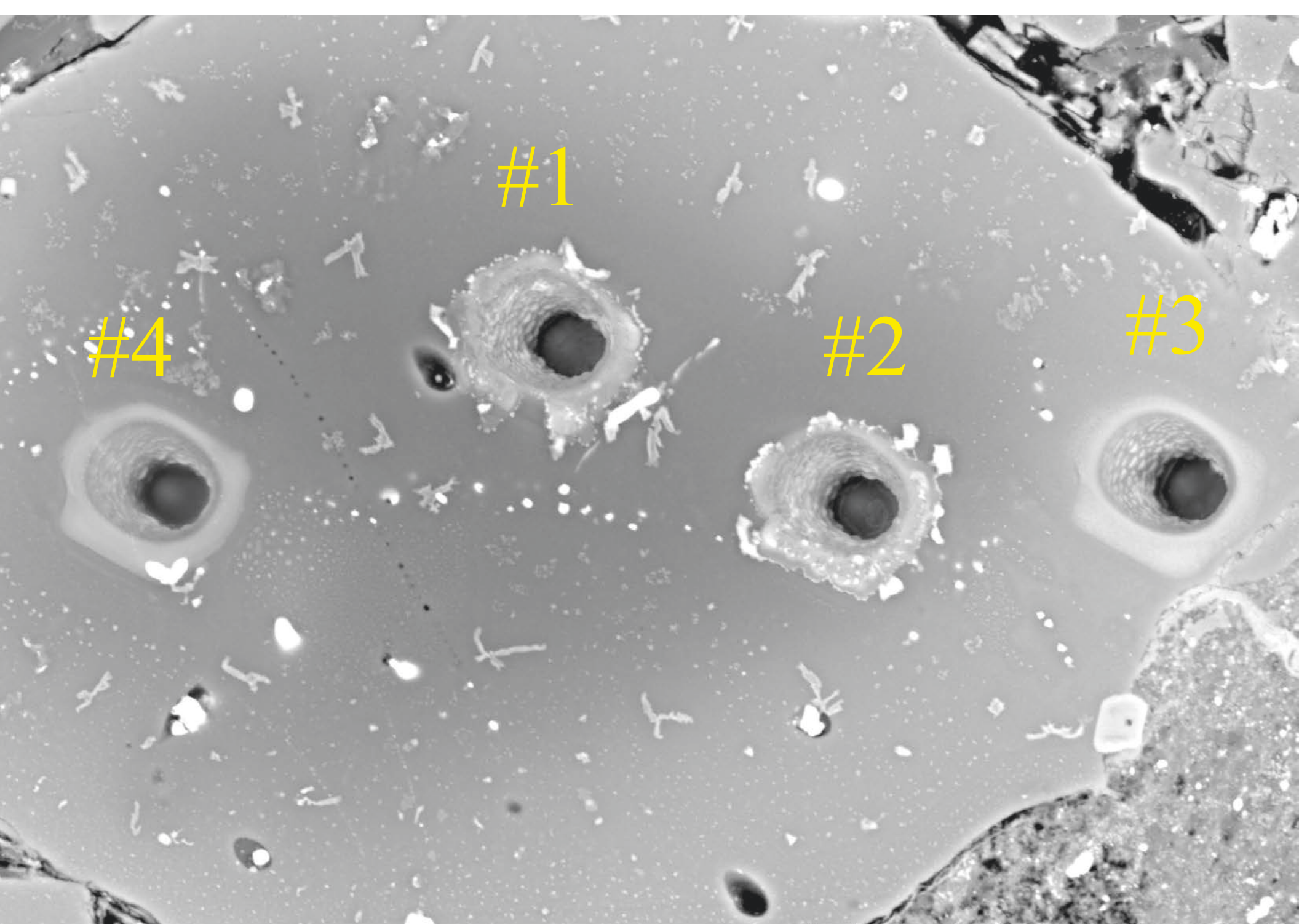
#5

G75-IIA



15.0kV x370 BSECOMP

100um

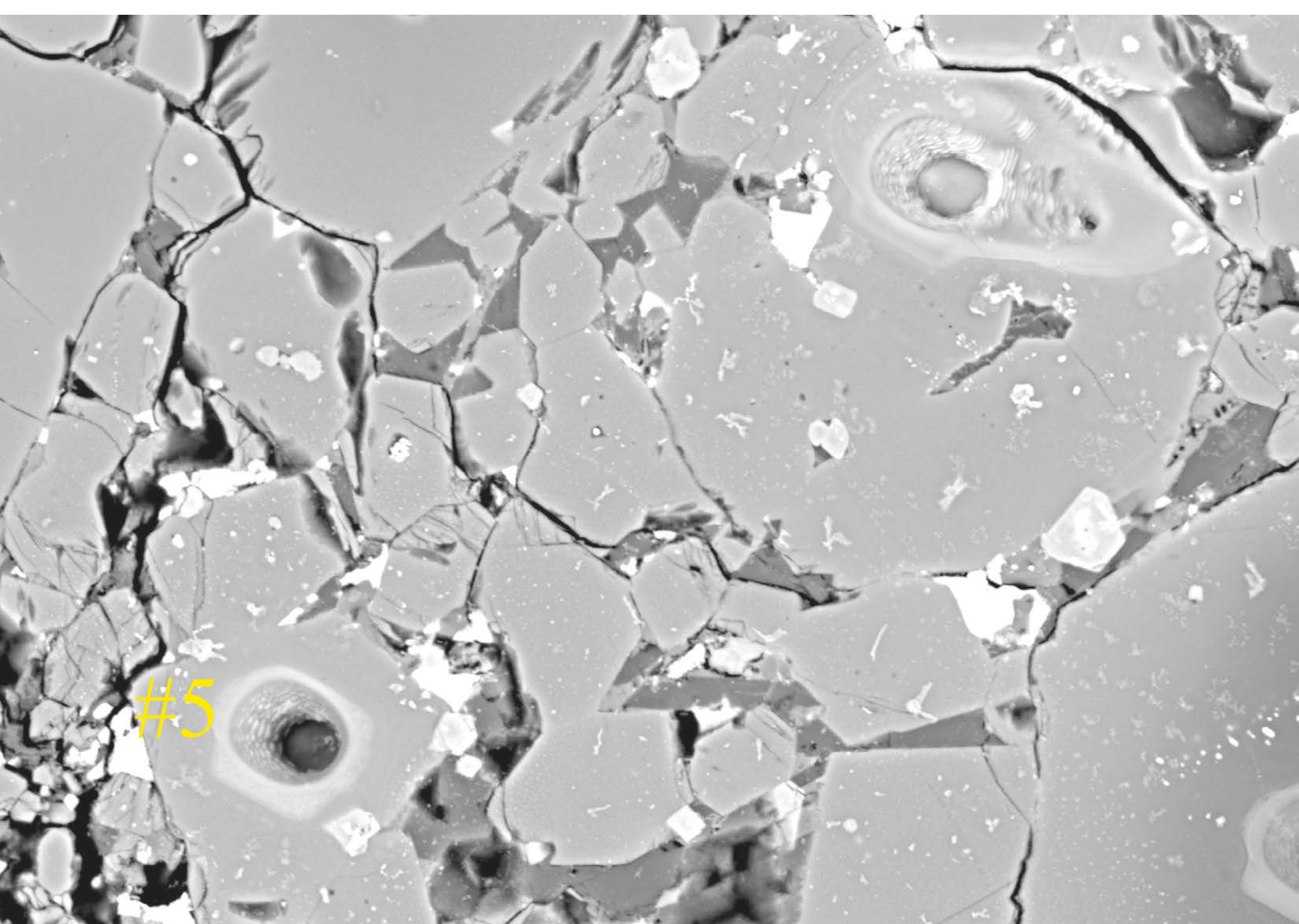


#1

#2

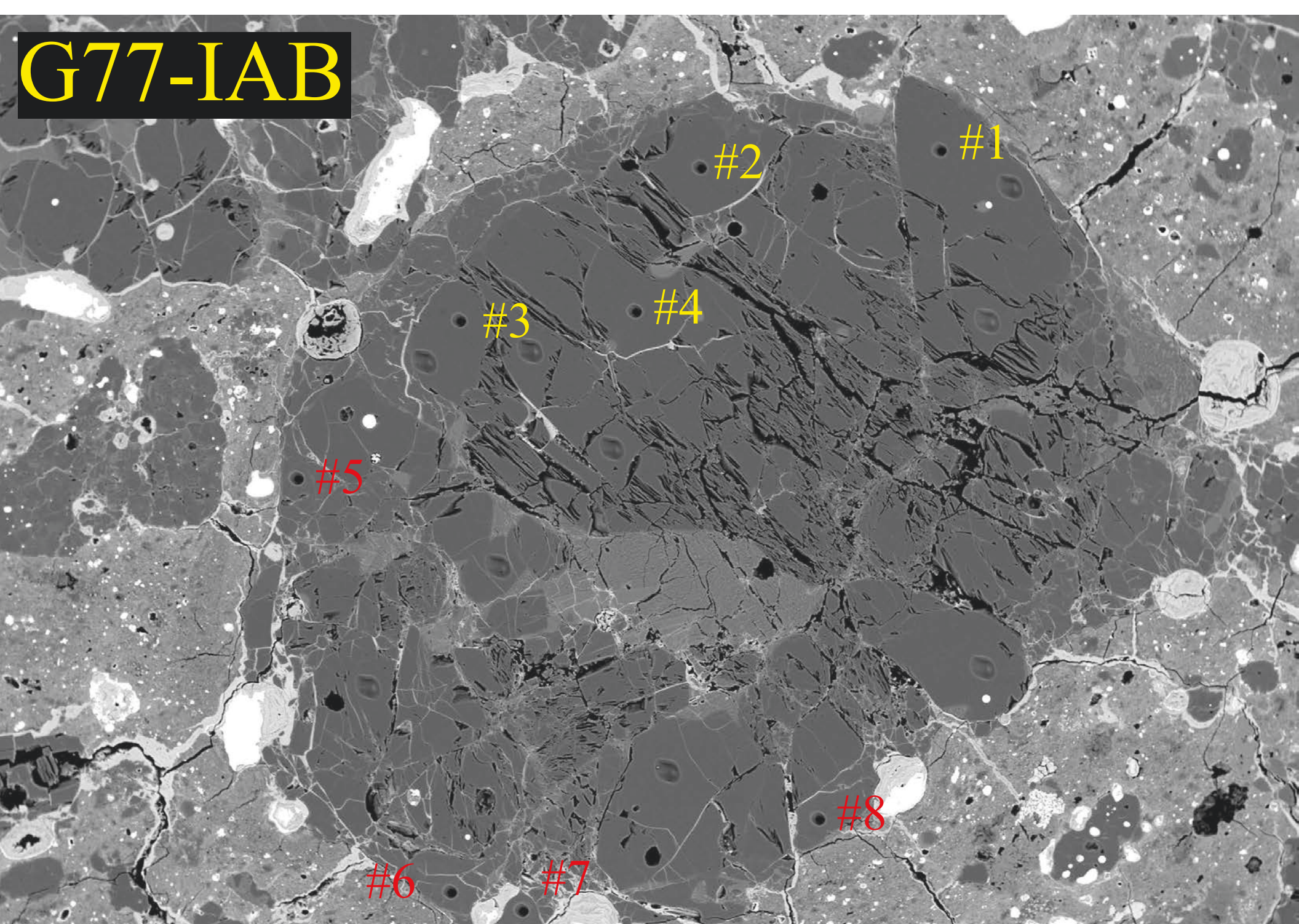
#3

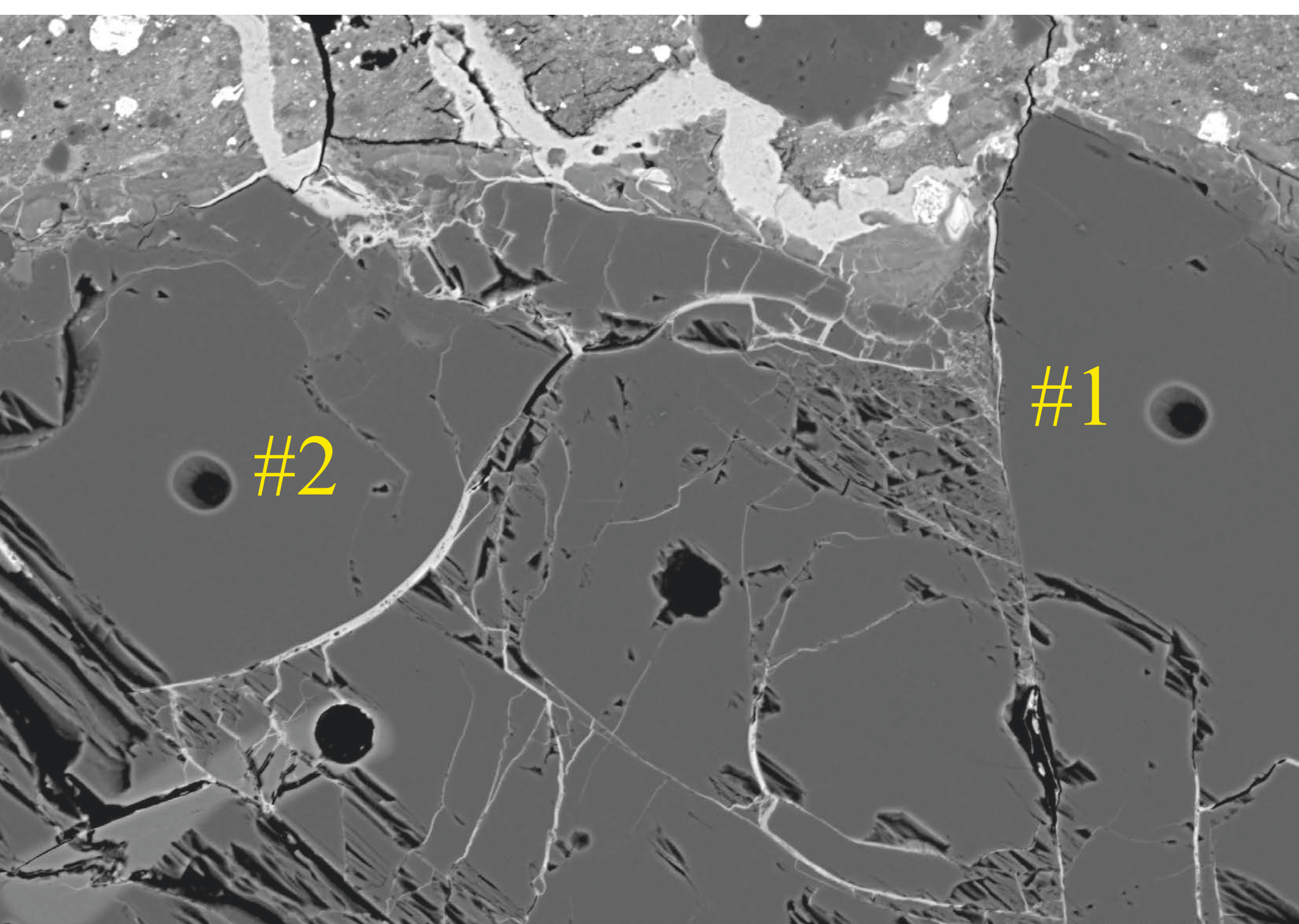
#4

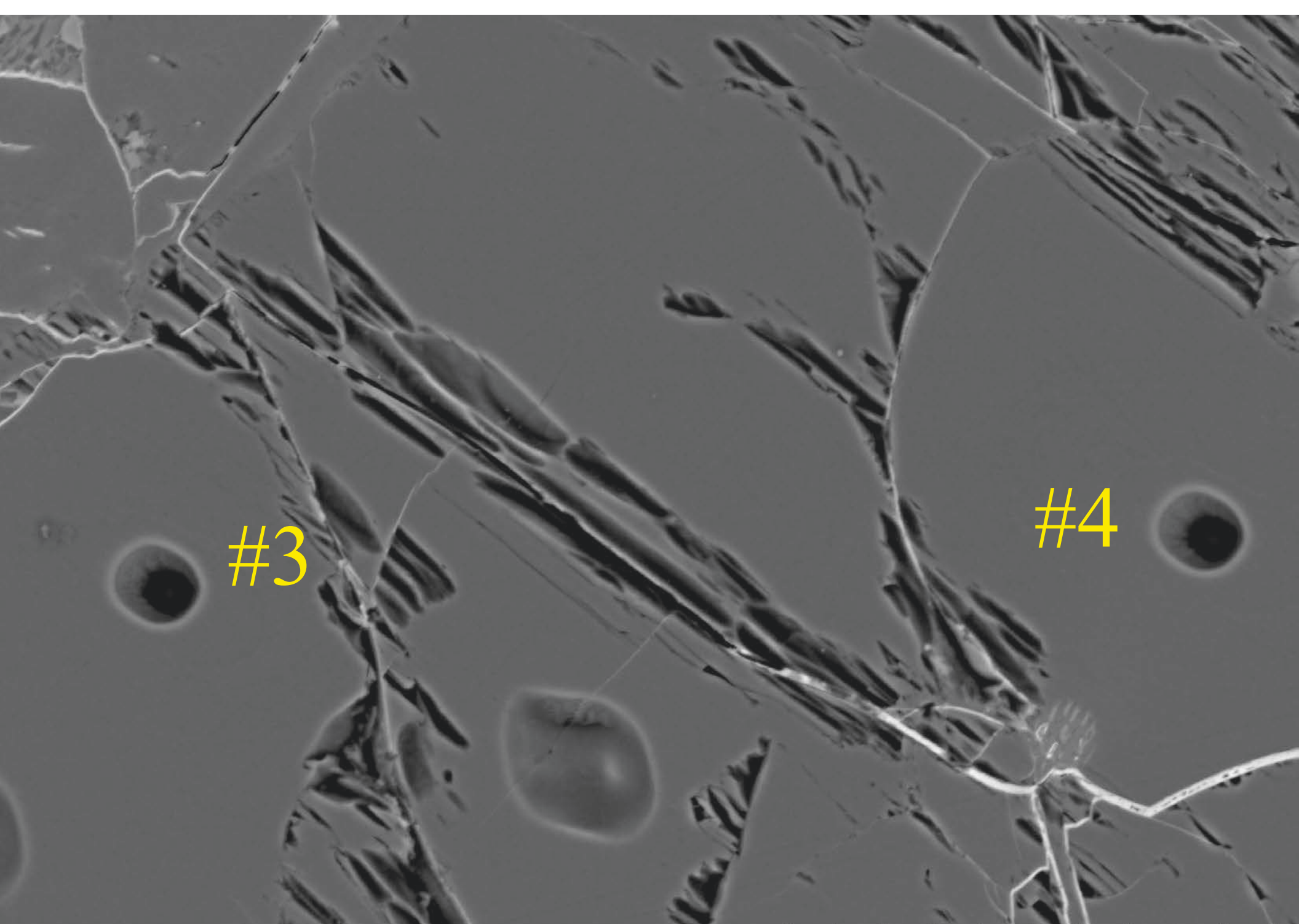


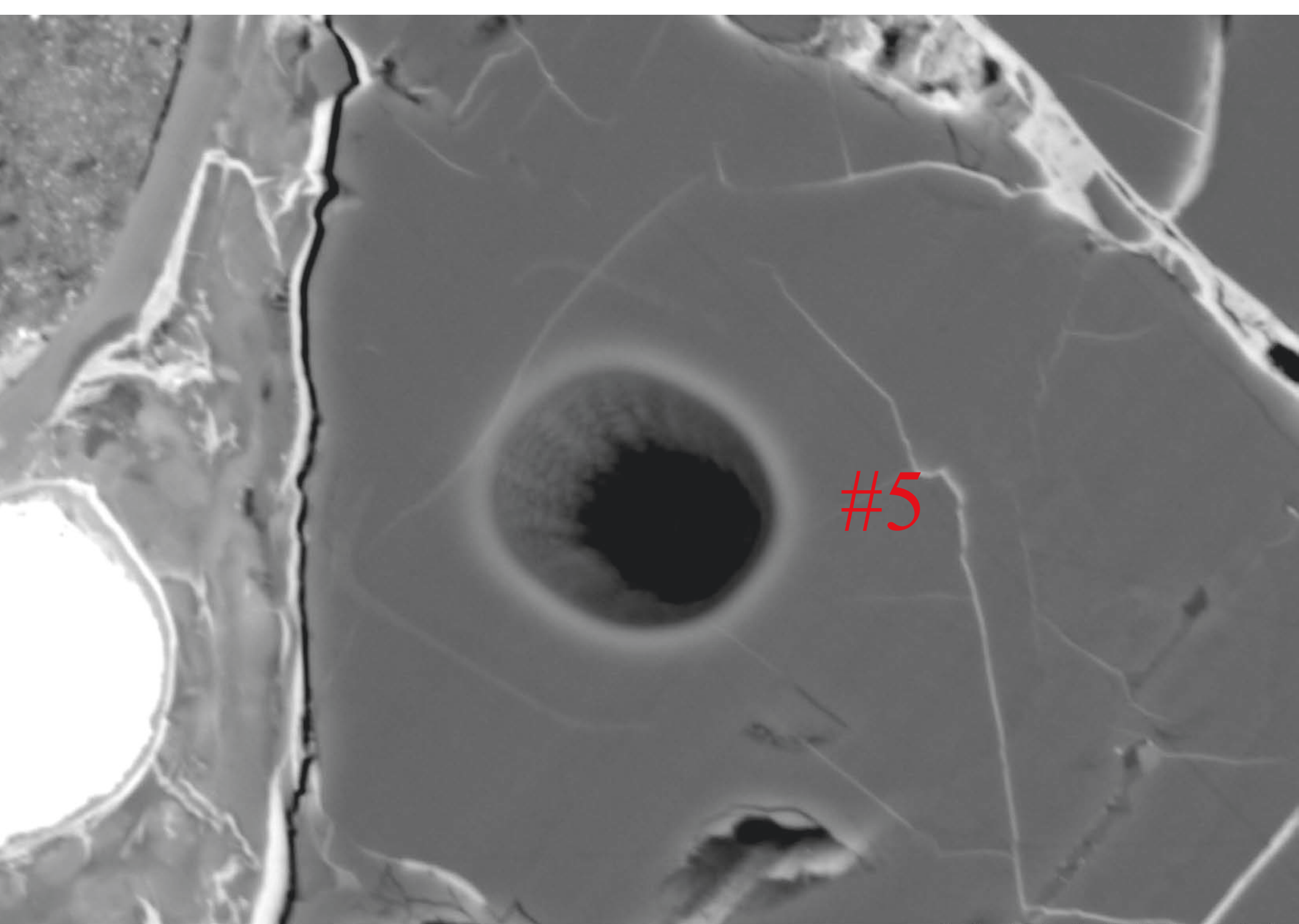
#5

G77-IAB





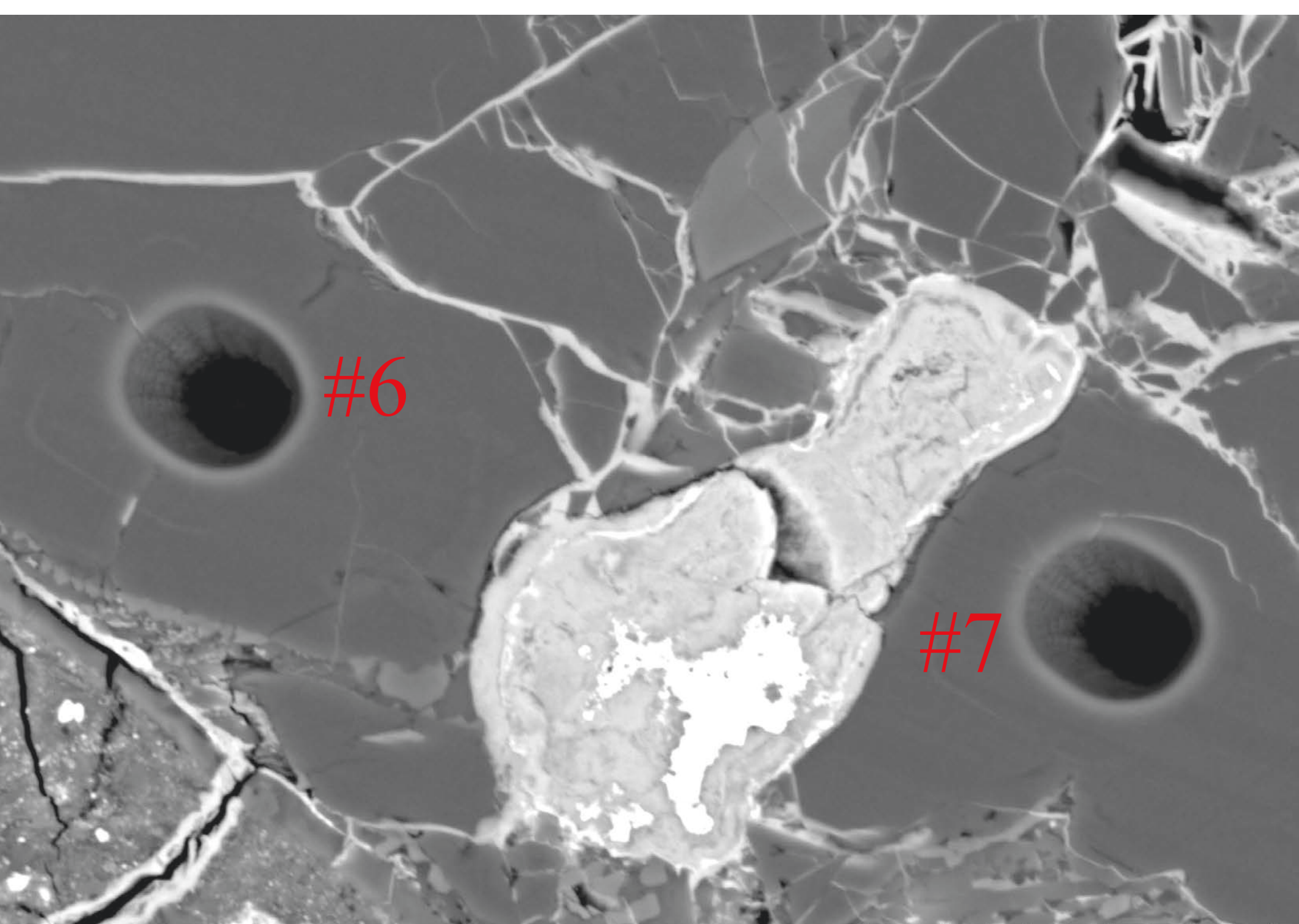




#5

15.0kV x3.20k BSECOMP

10.0um

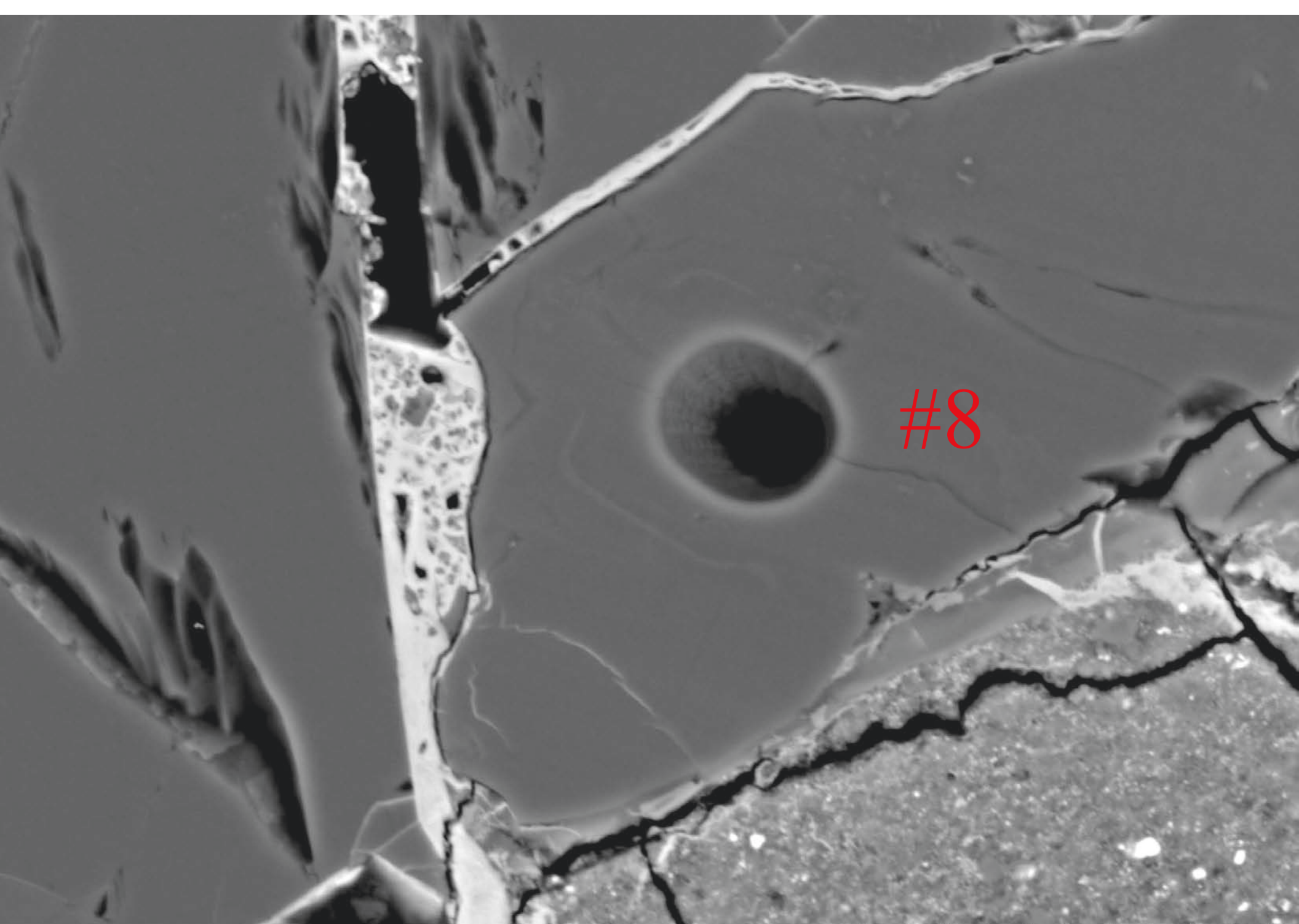


#6

#7

15.0kV x2.00k BSECOMP

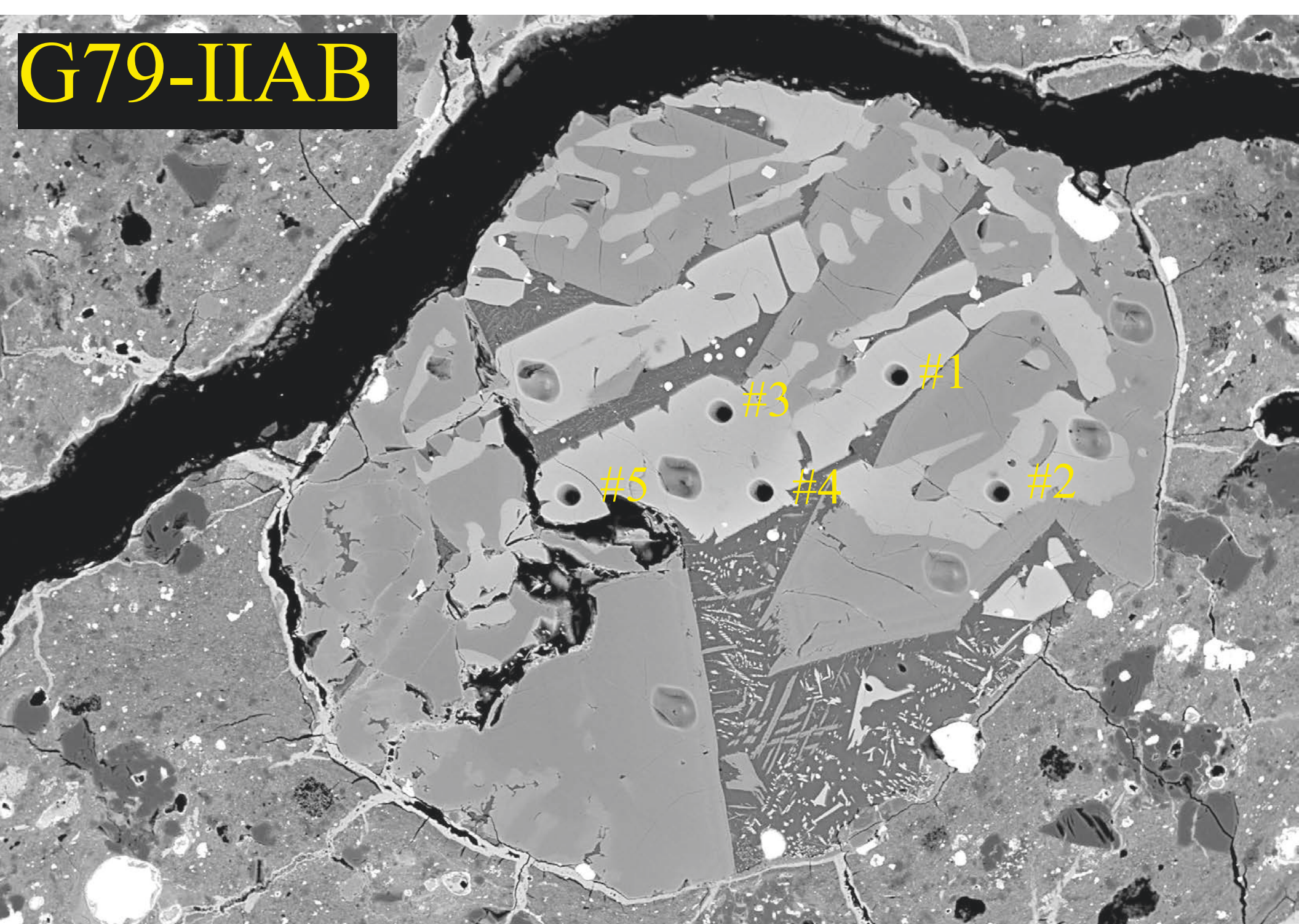
20.0um



15.0kV x2.00k BSECOMP

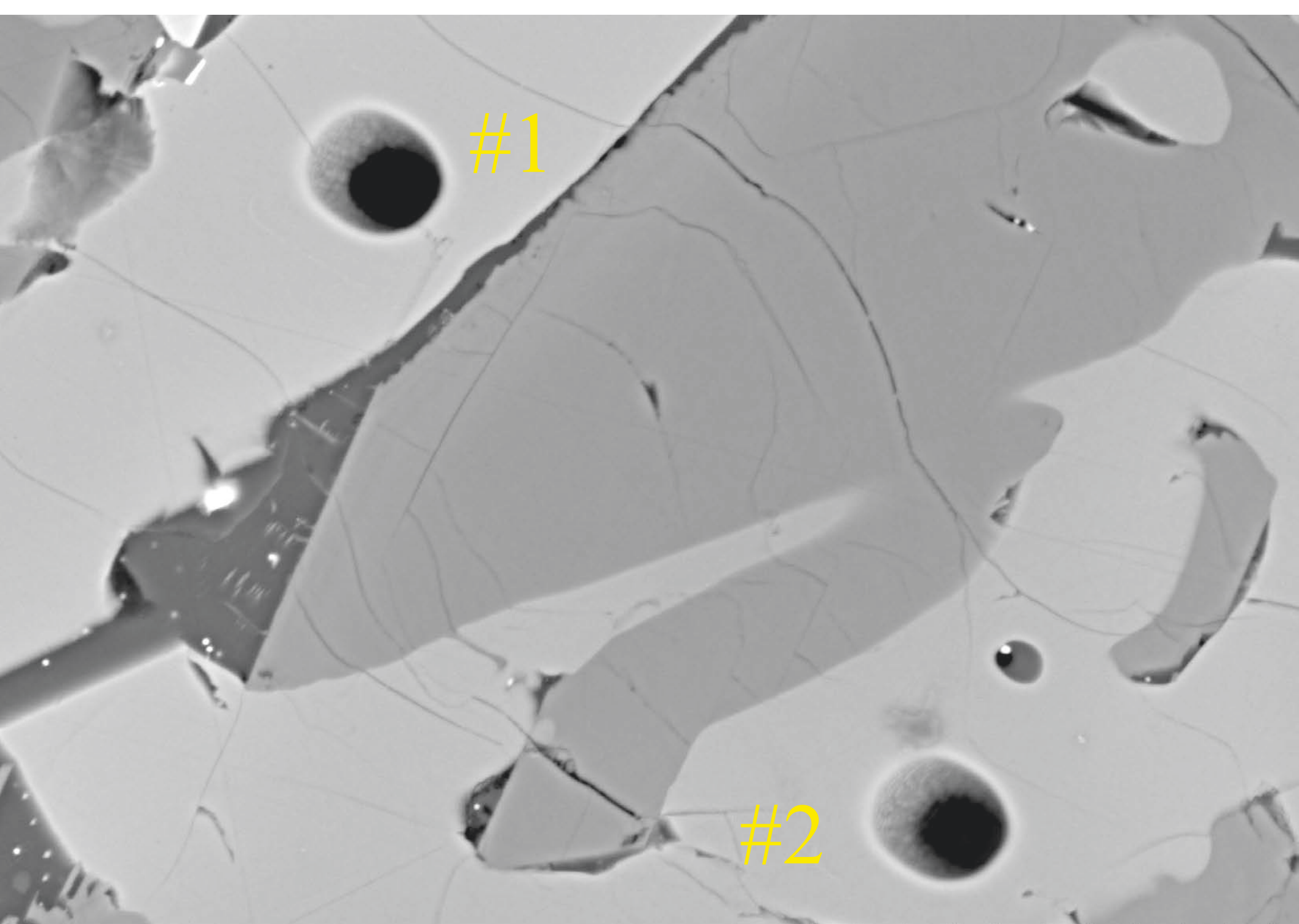
20.0um

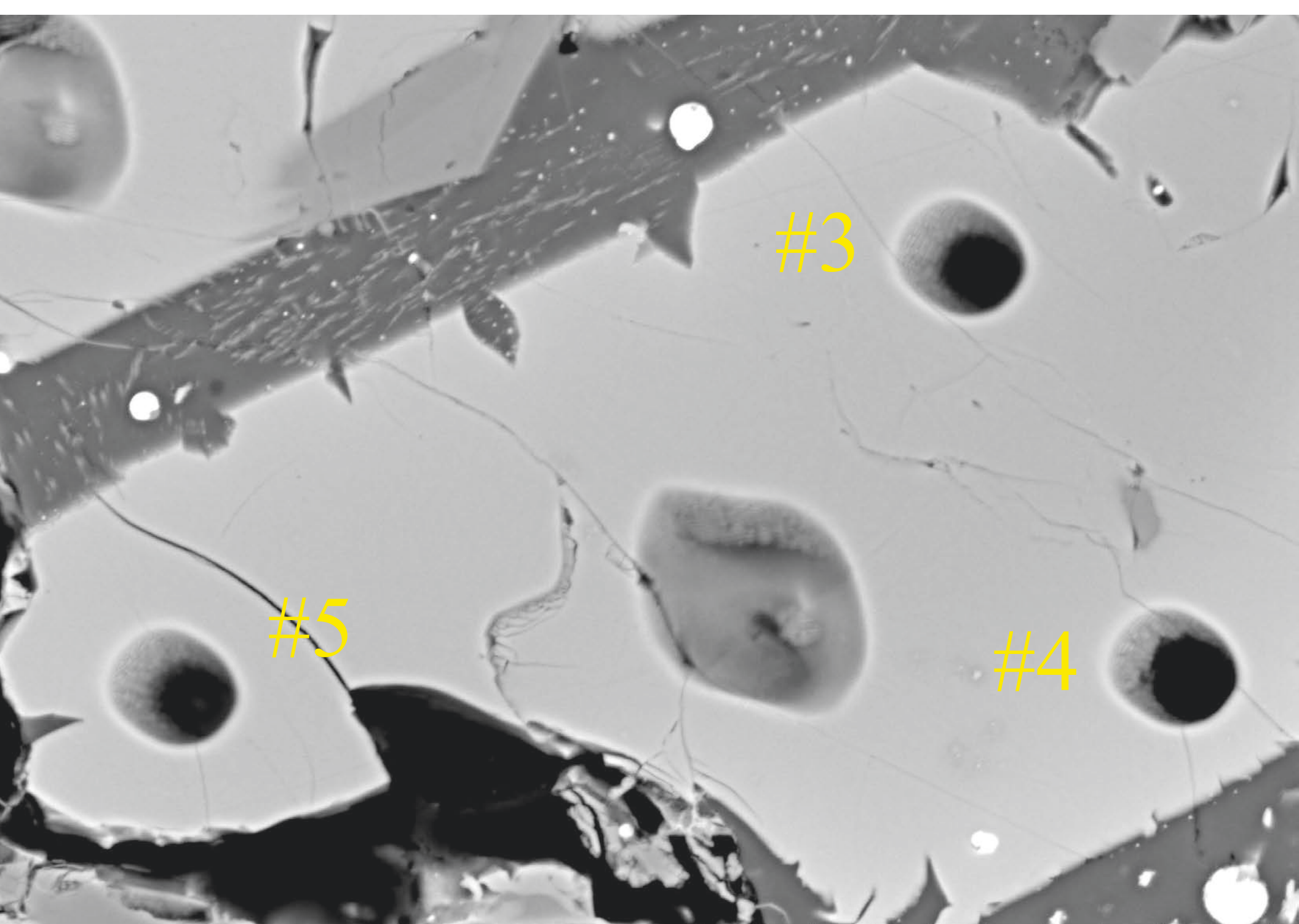
G79-IIAB



15.0kV x270 BSECOMP

200um



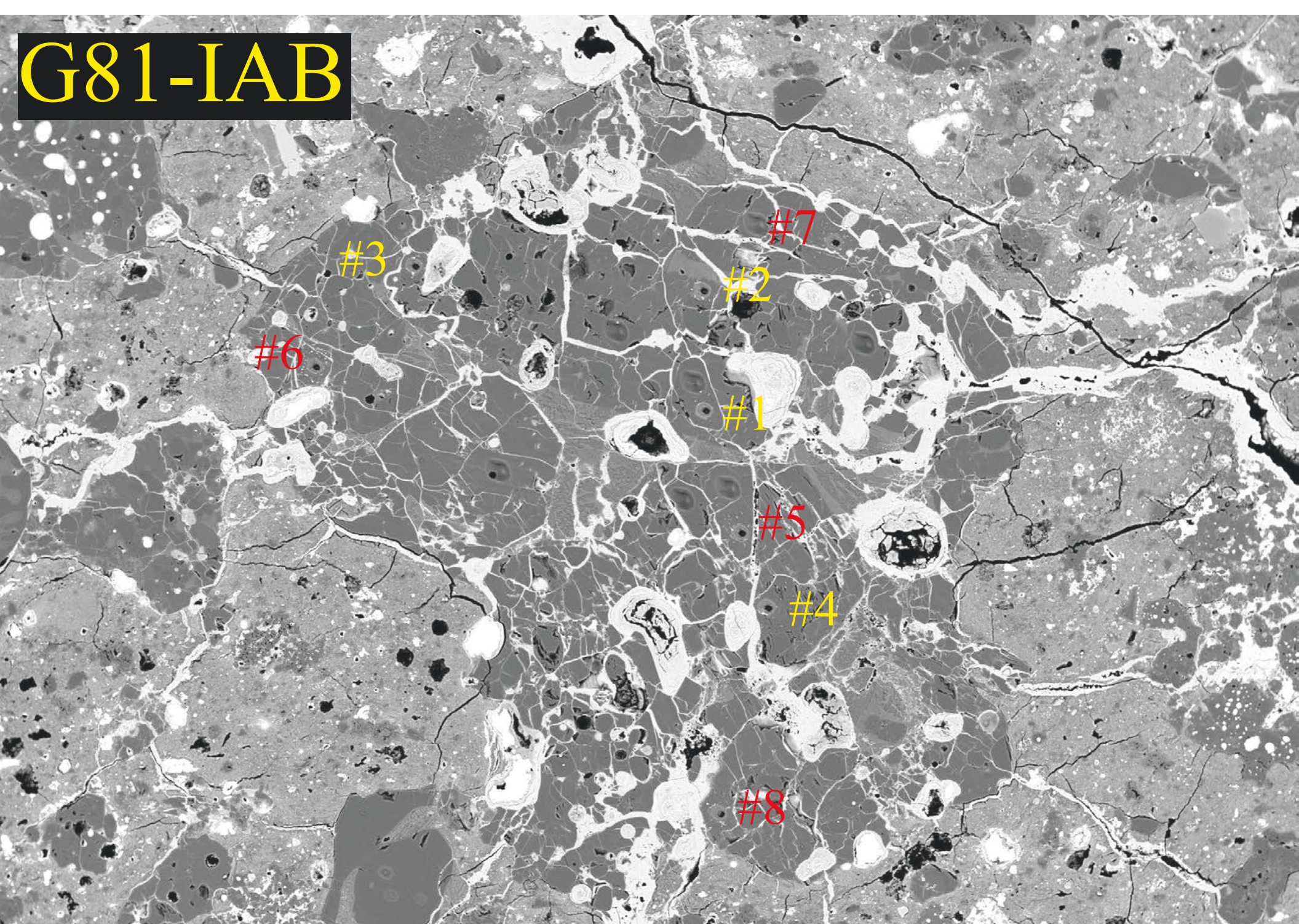


#3

#5

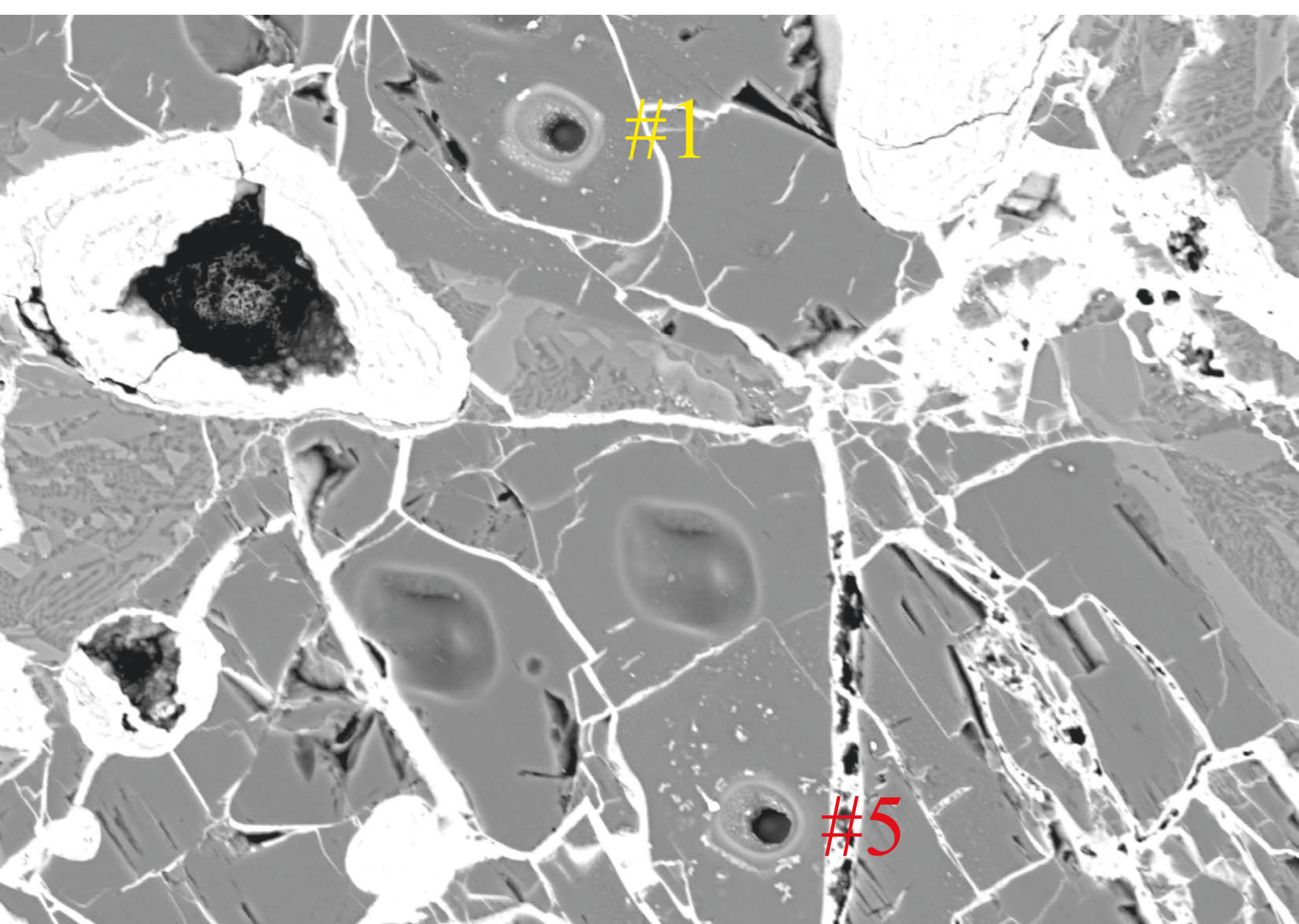
#4

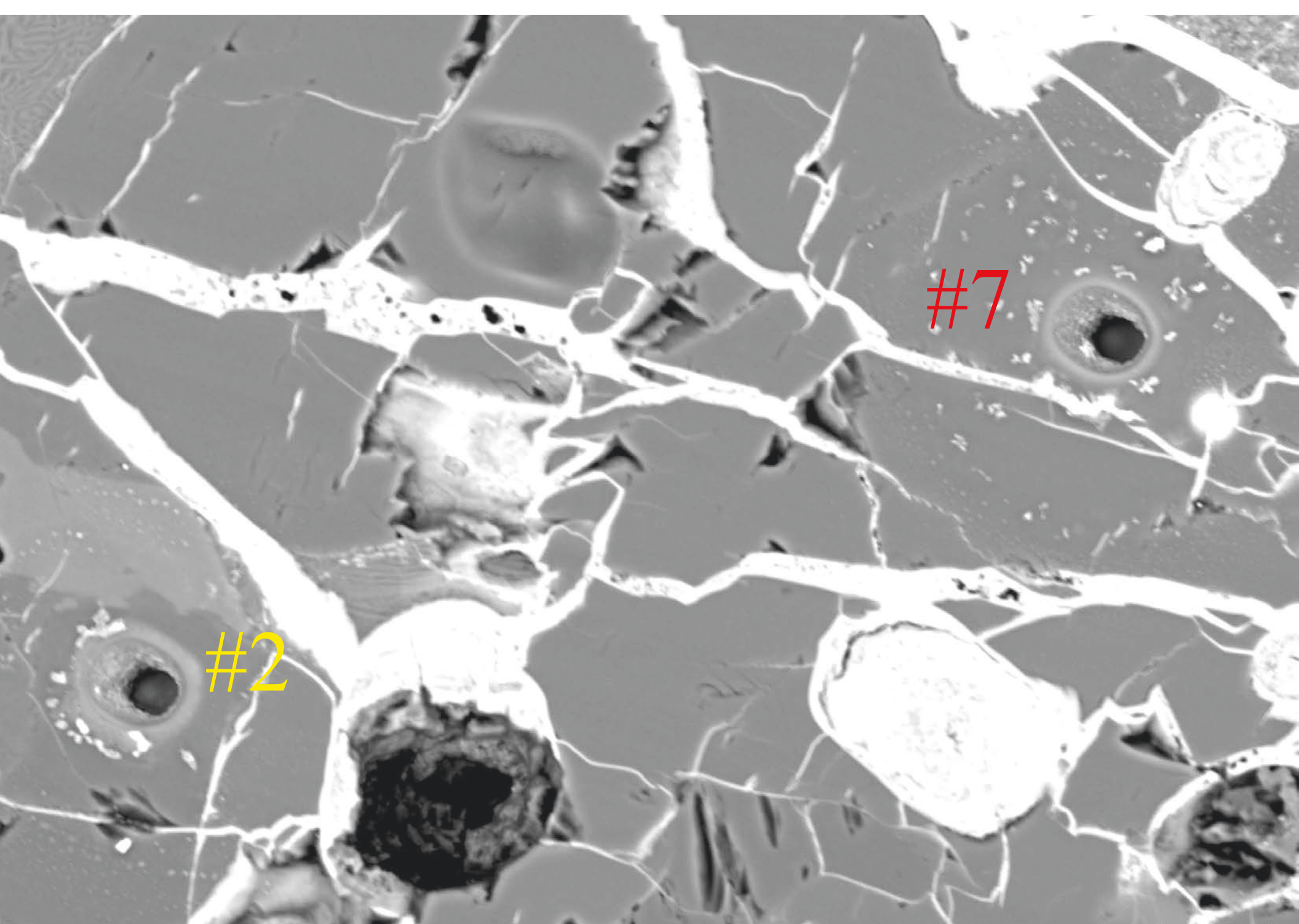
G81-IAB

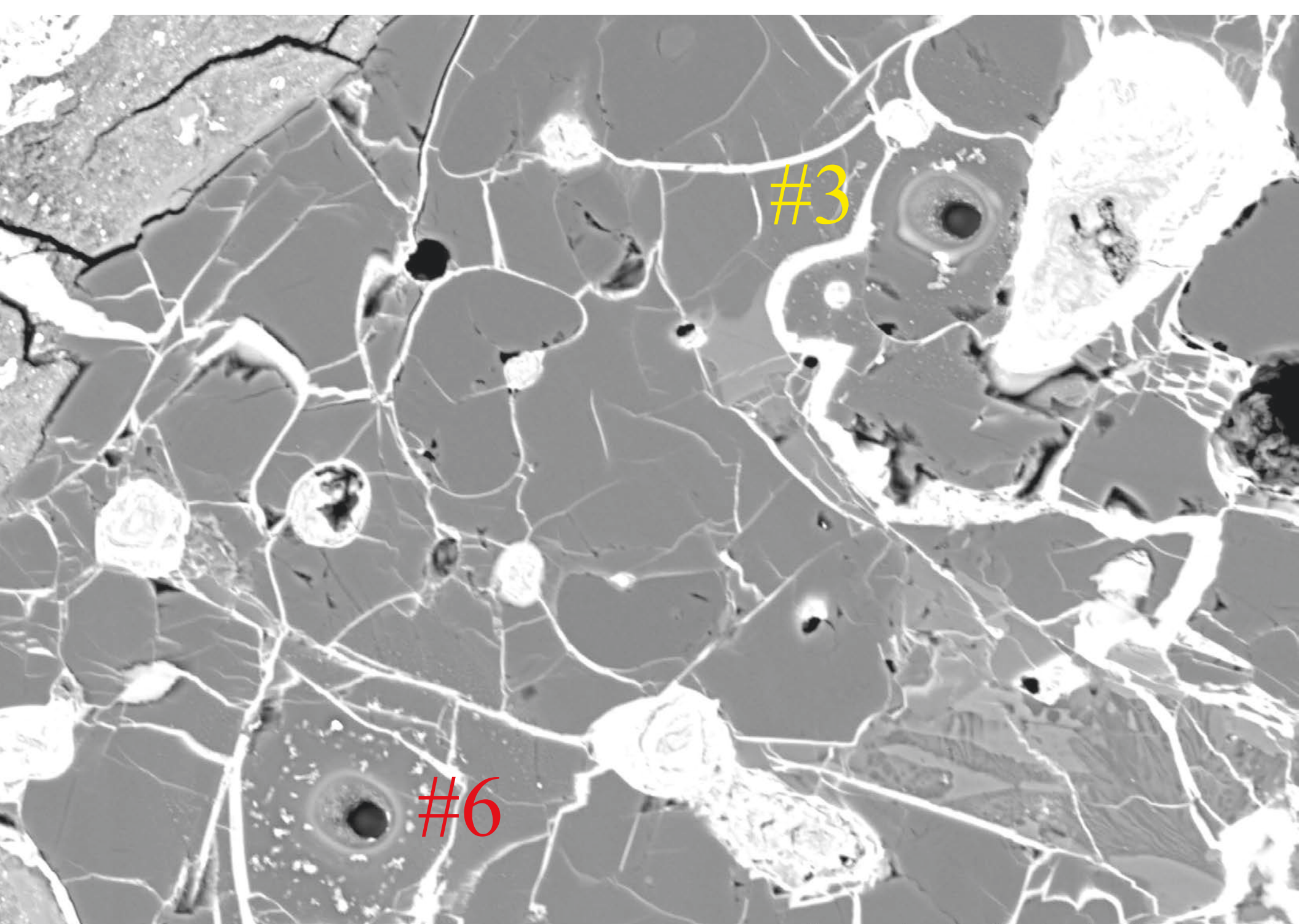


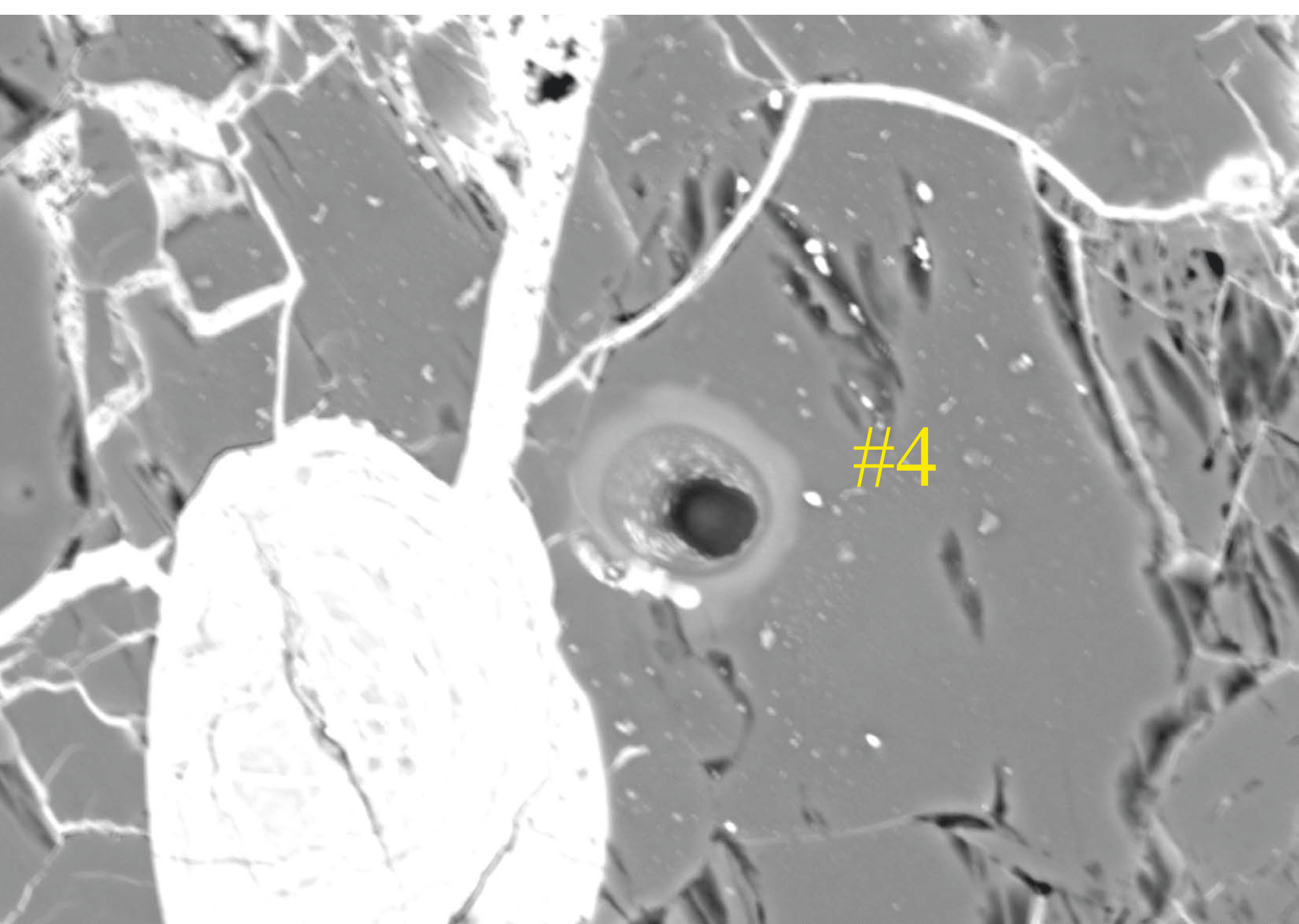
15.0kV x150 BSECOMP

300um

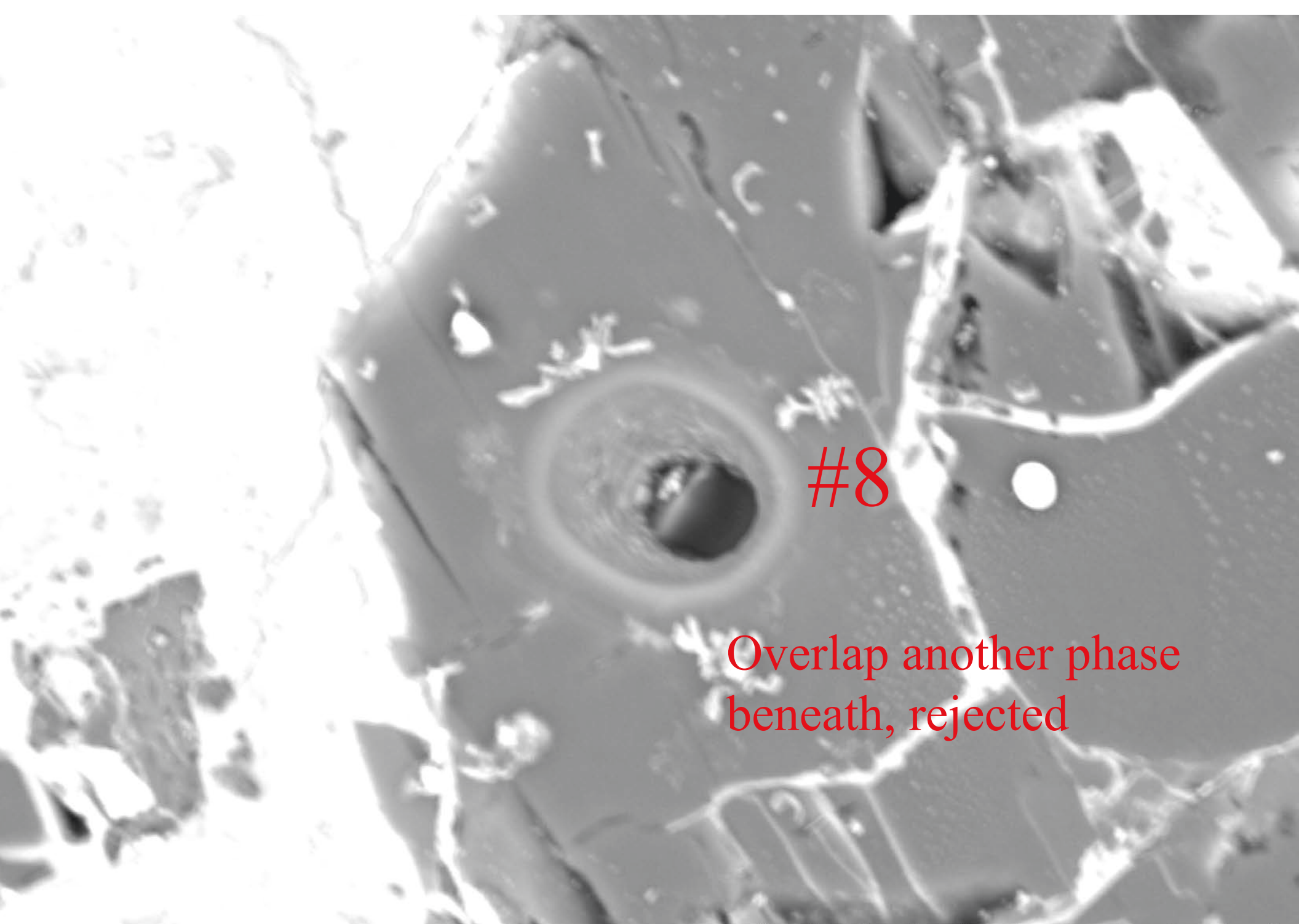








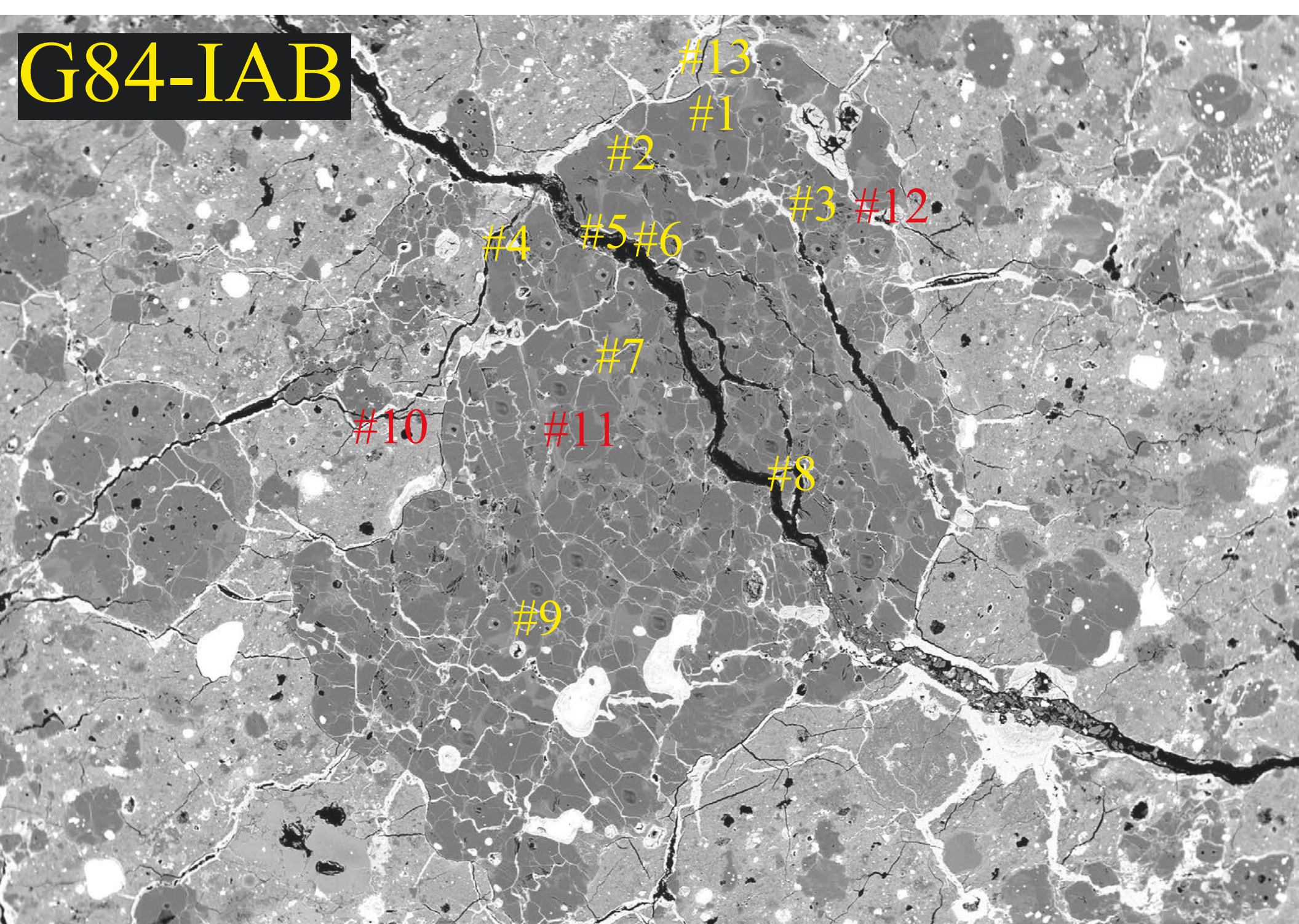
#4

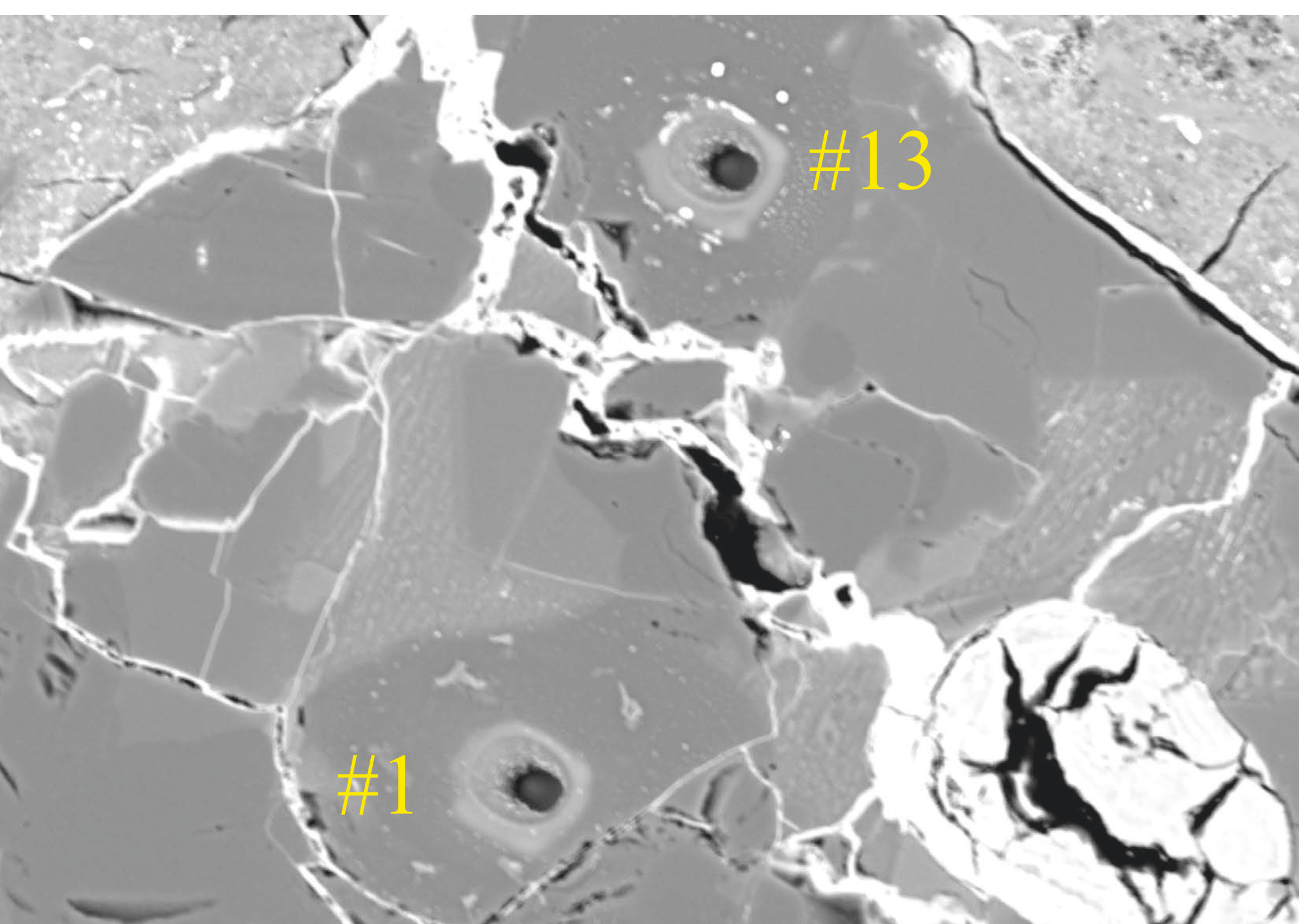


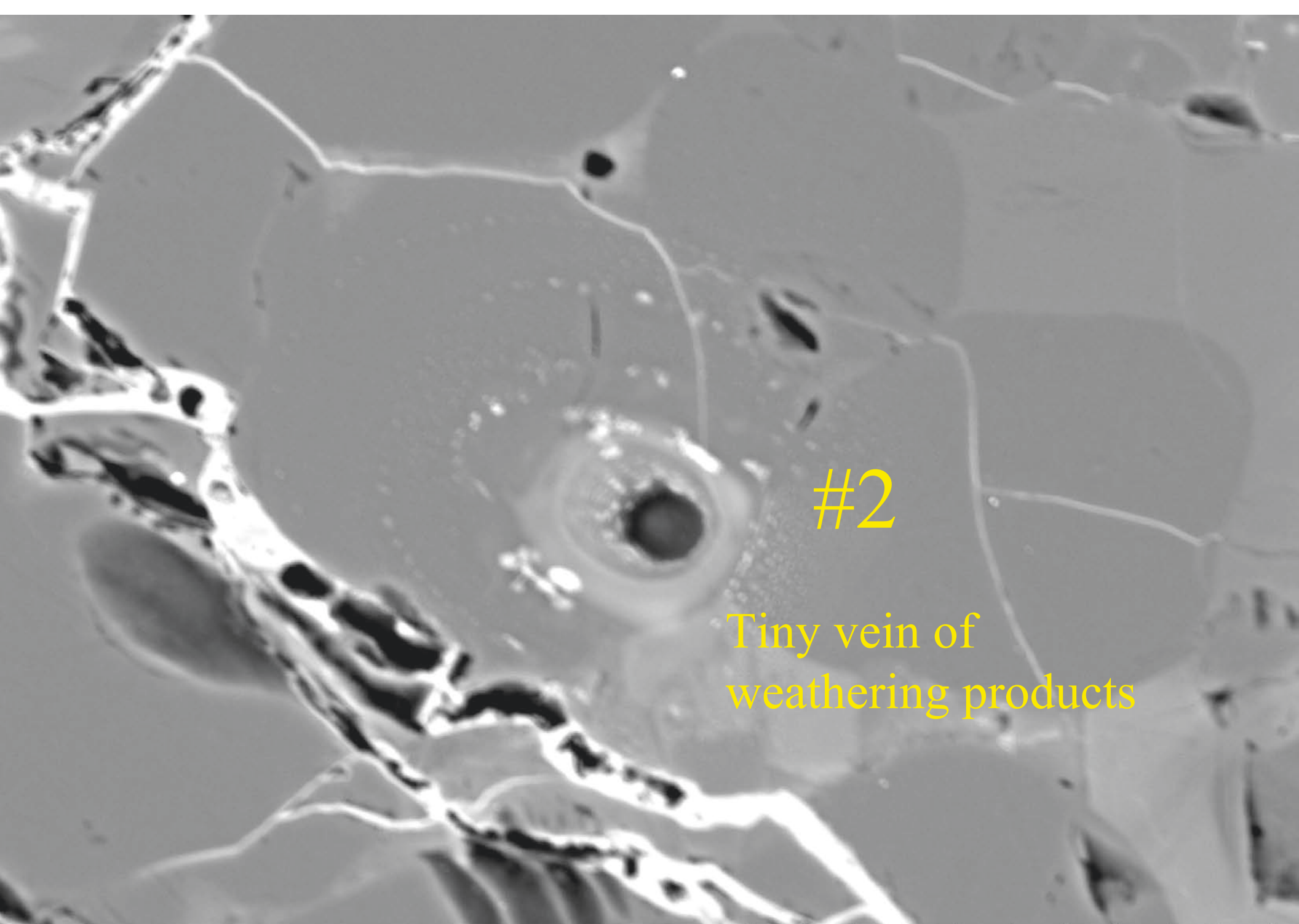
#8

Overlap another phase
beneath, rejected

G84-IAB

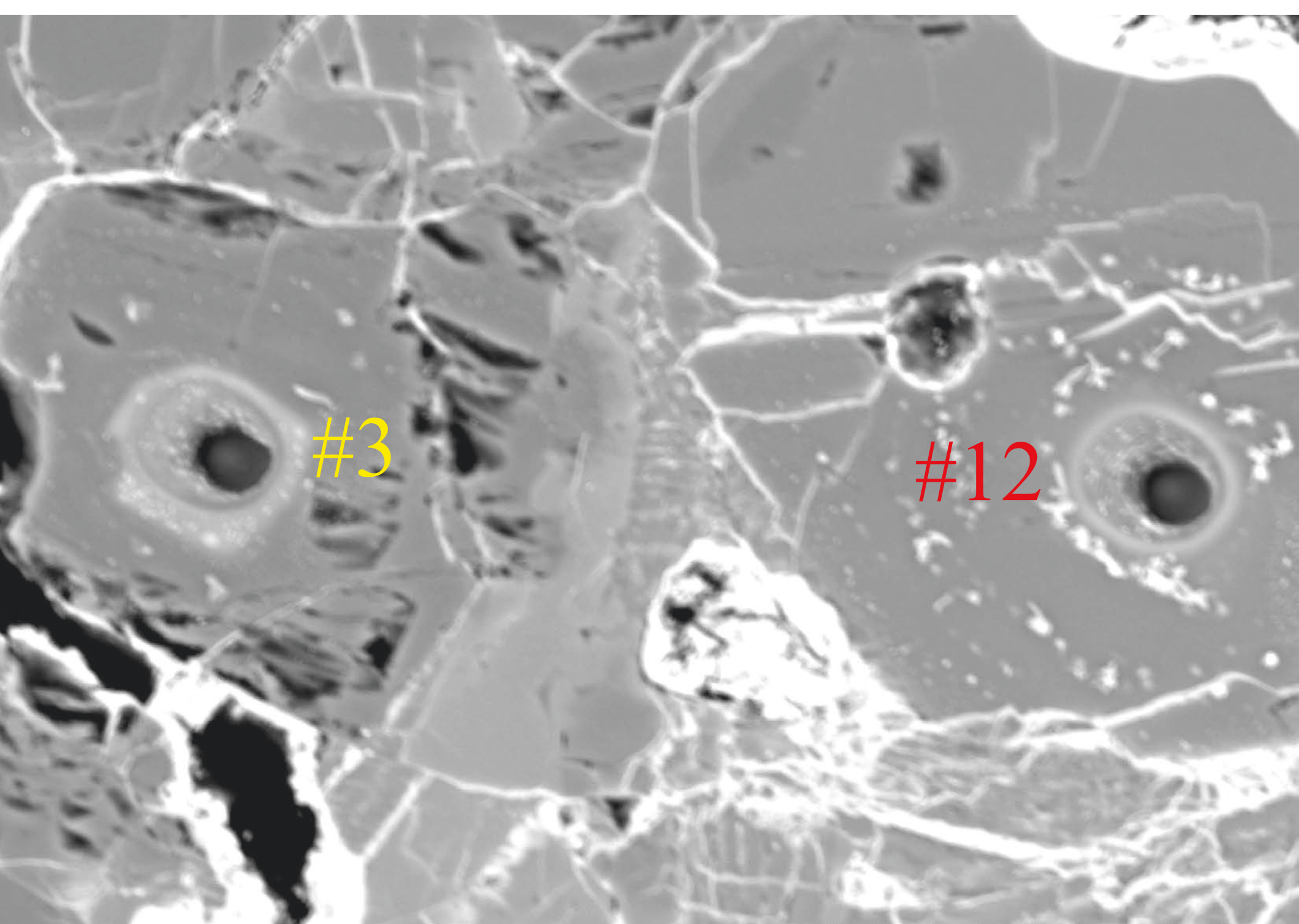


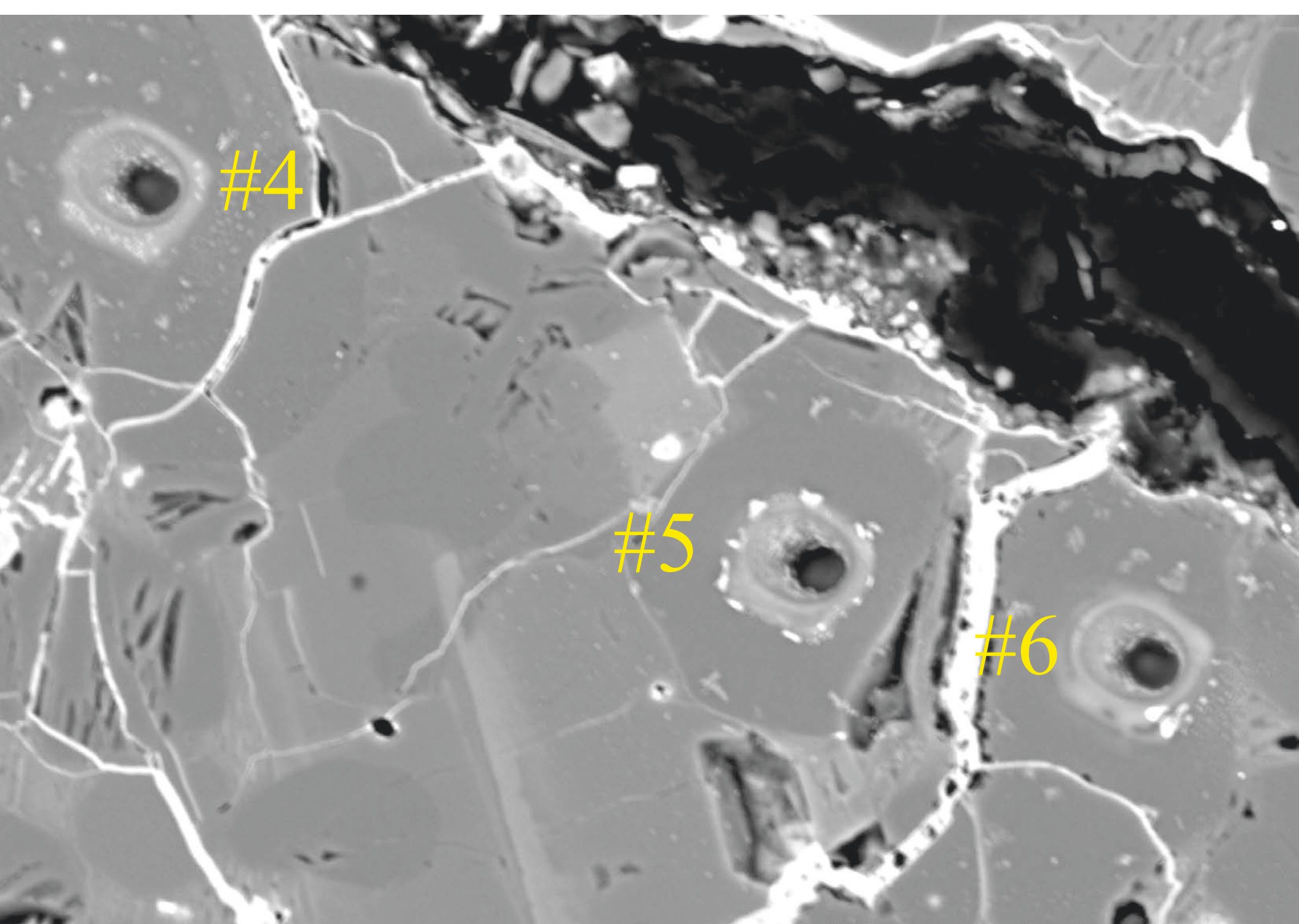


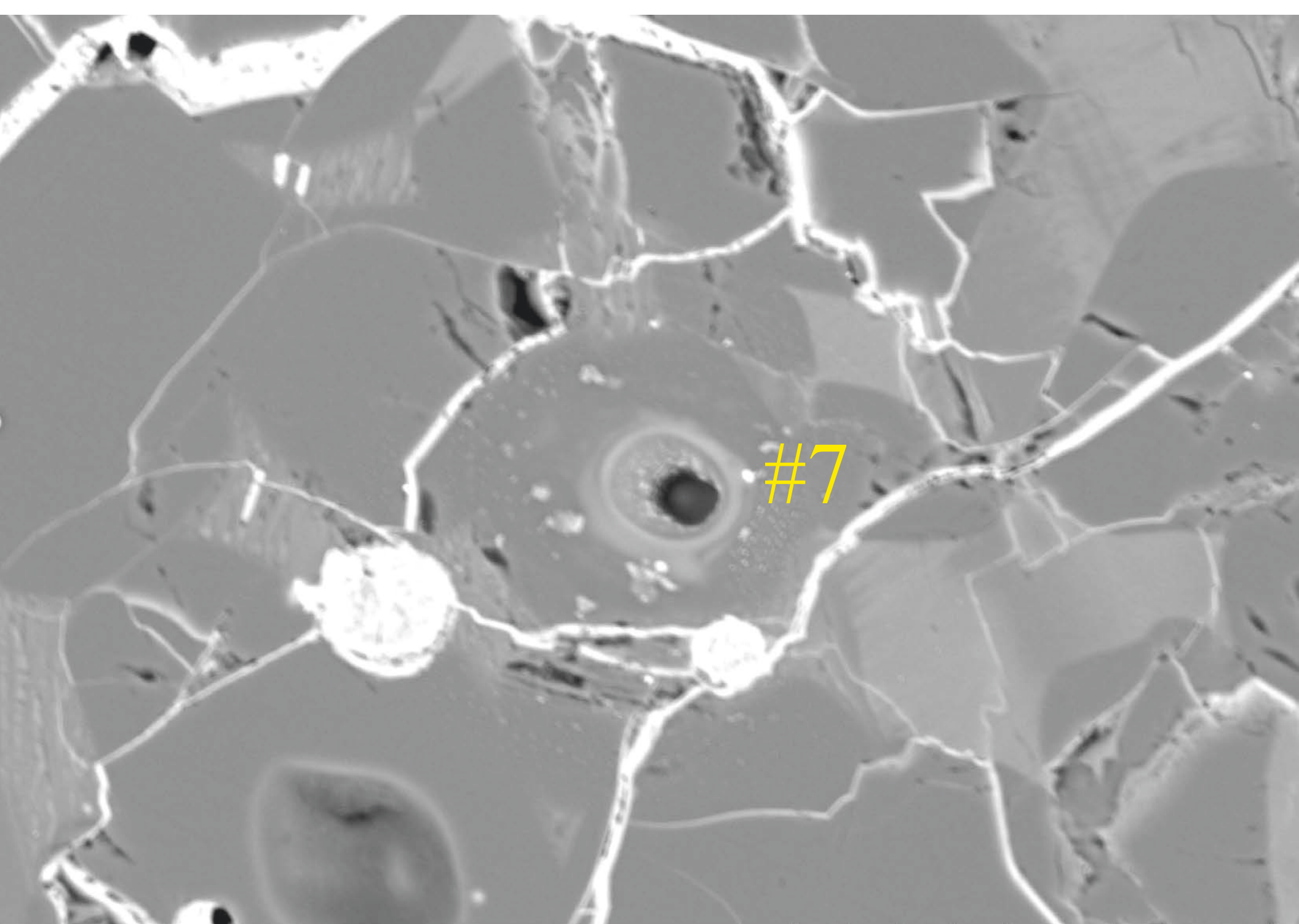


#2

Tiny vein of
weathering products



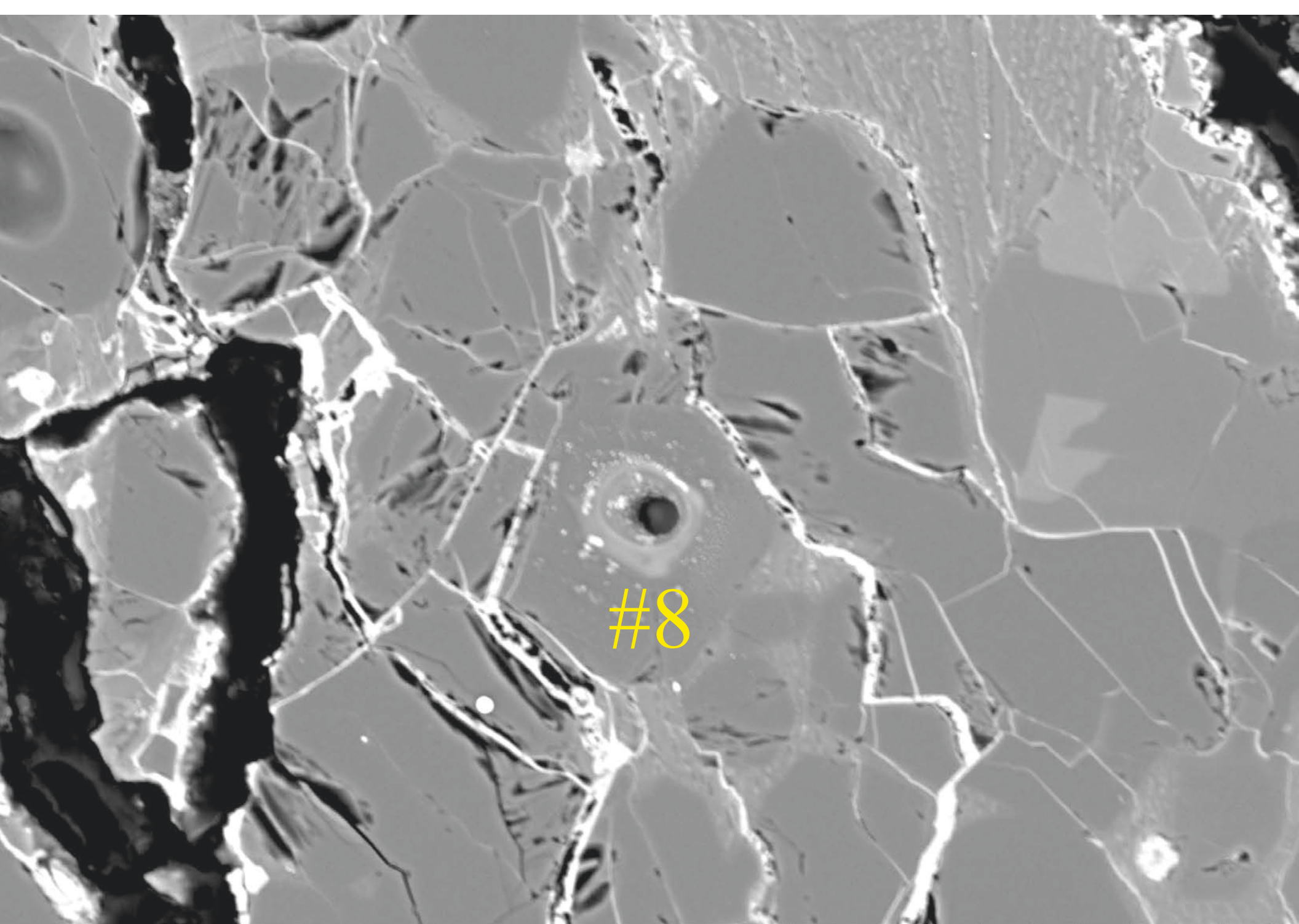




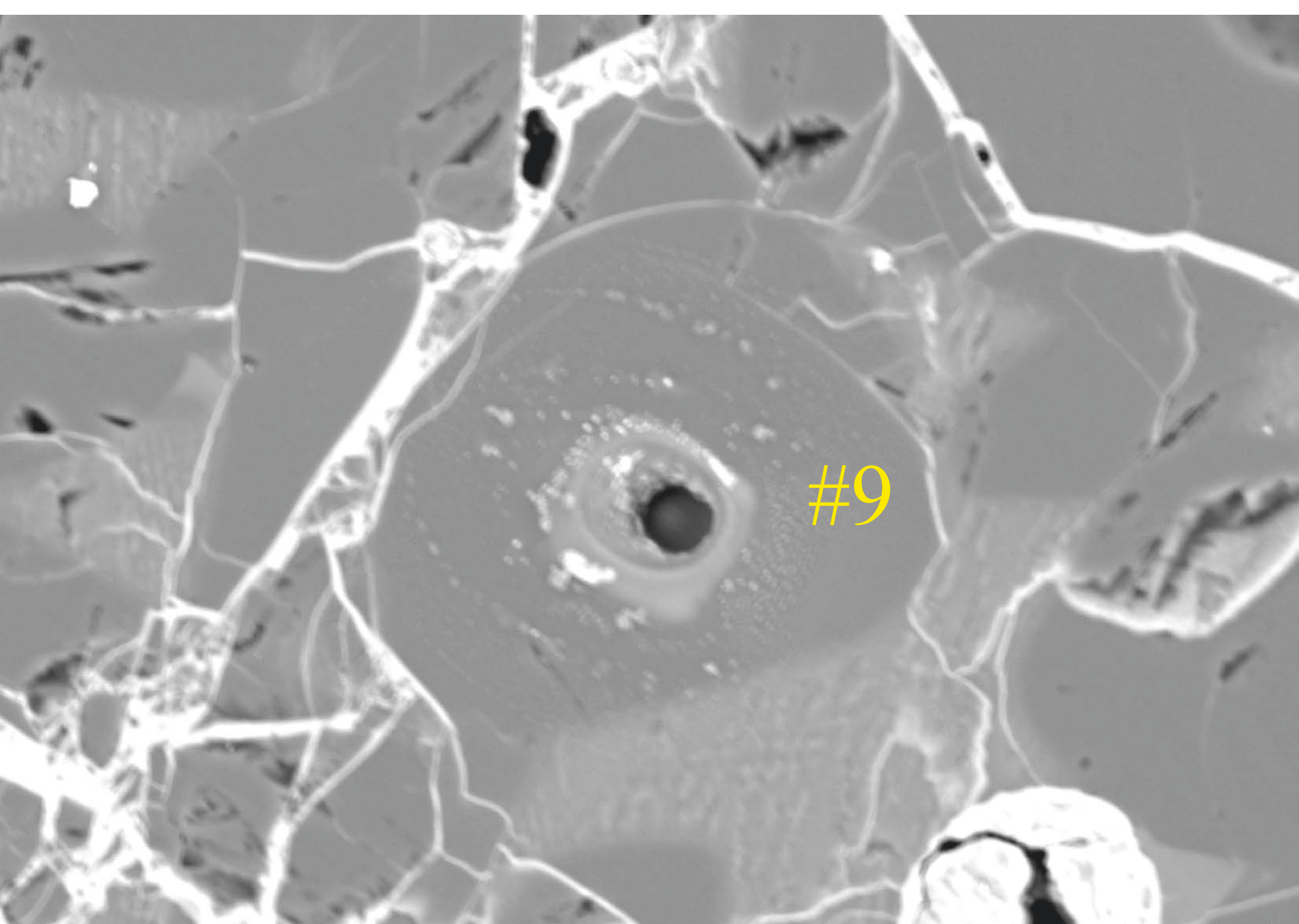
#7

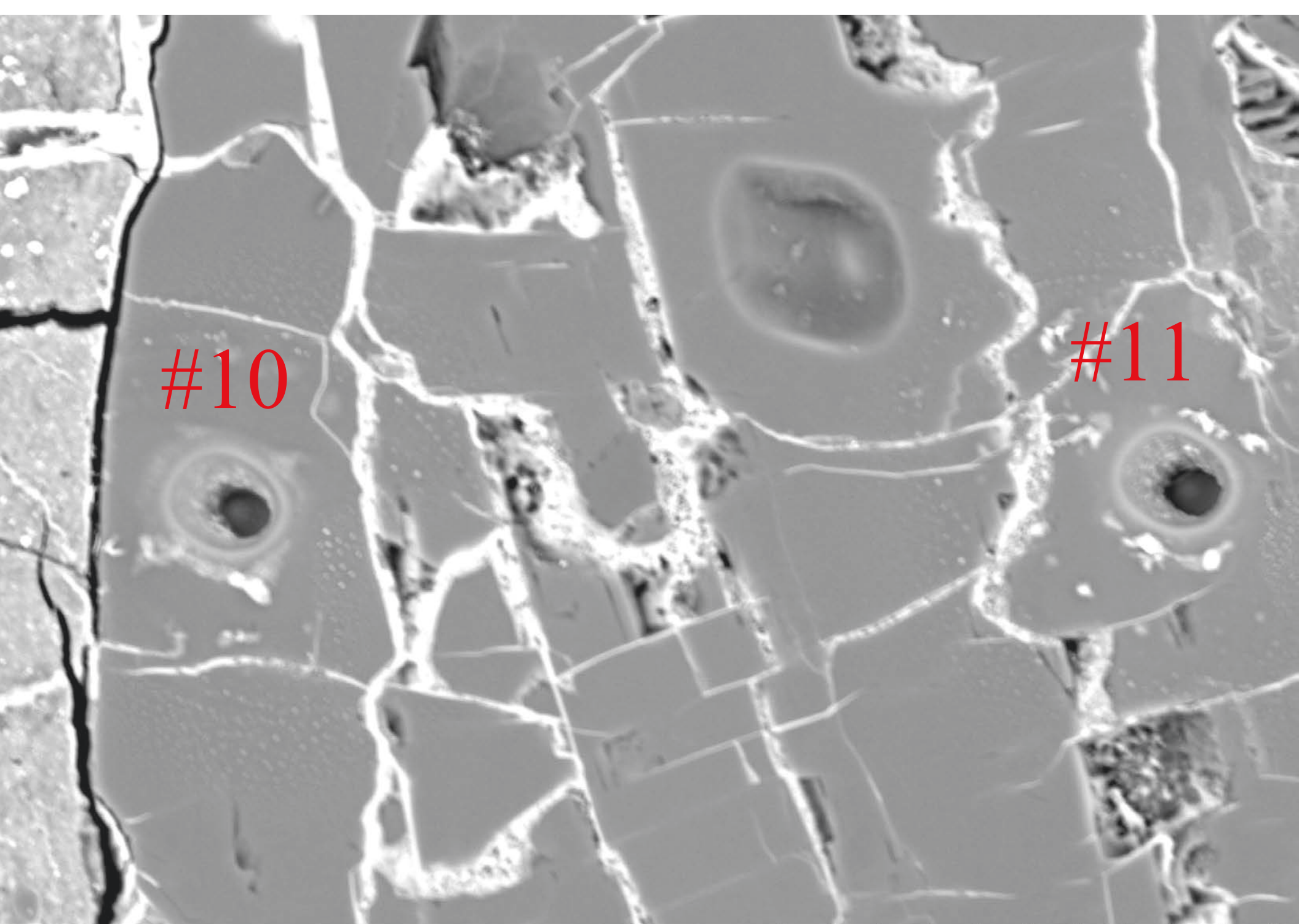
15.0kV x1.30k BSECOMP

40.0um



#8

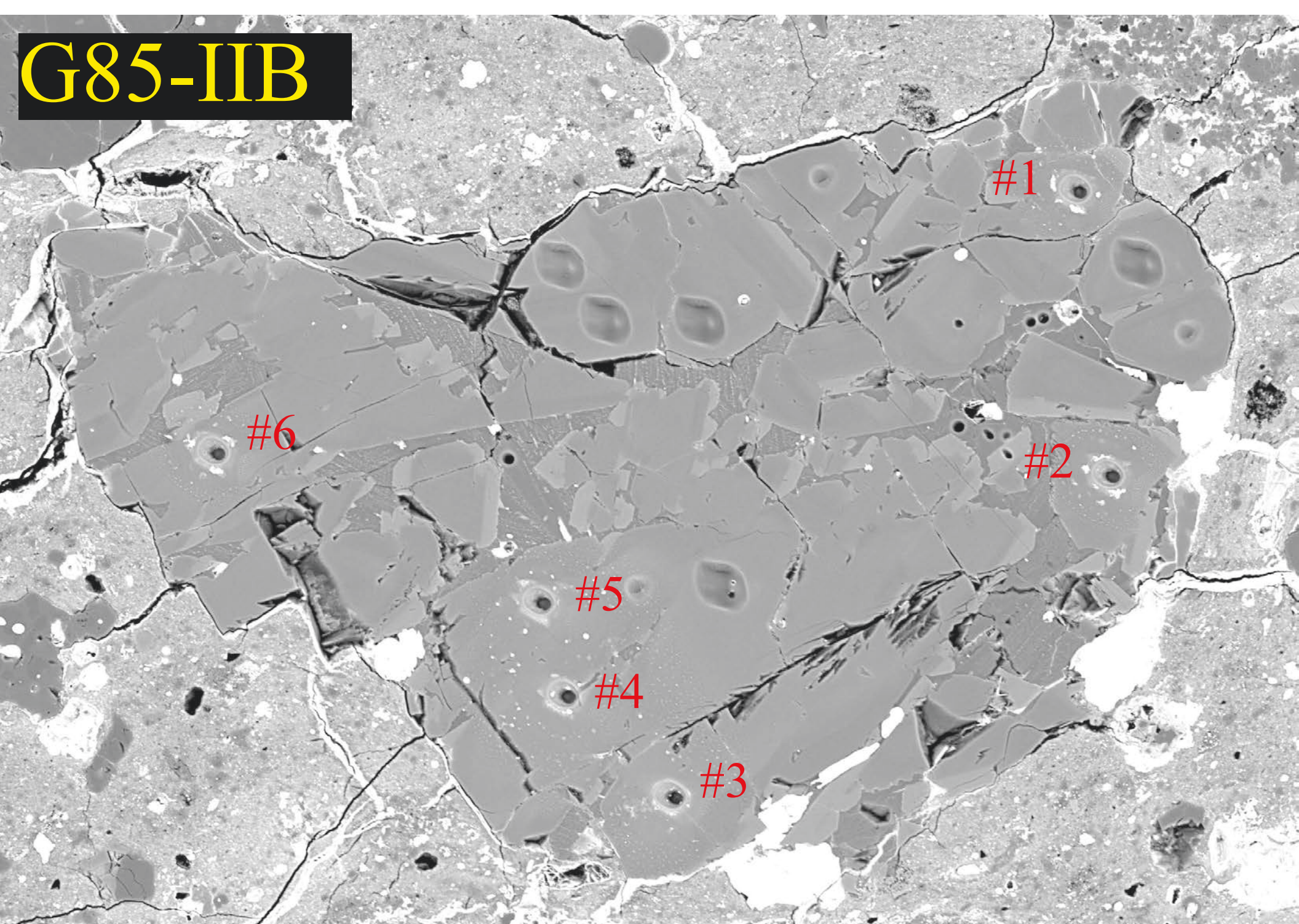




#10

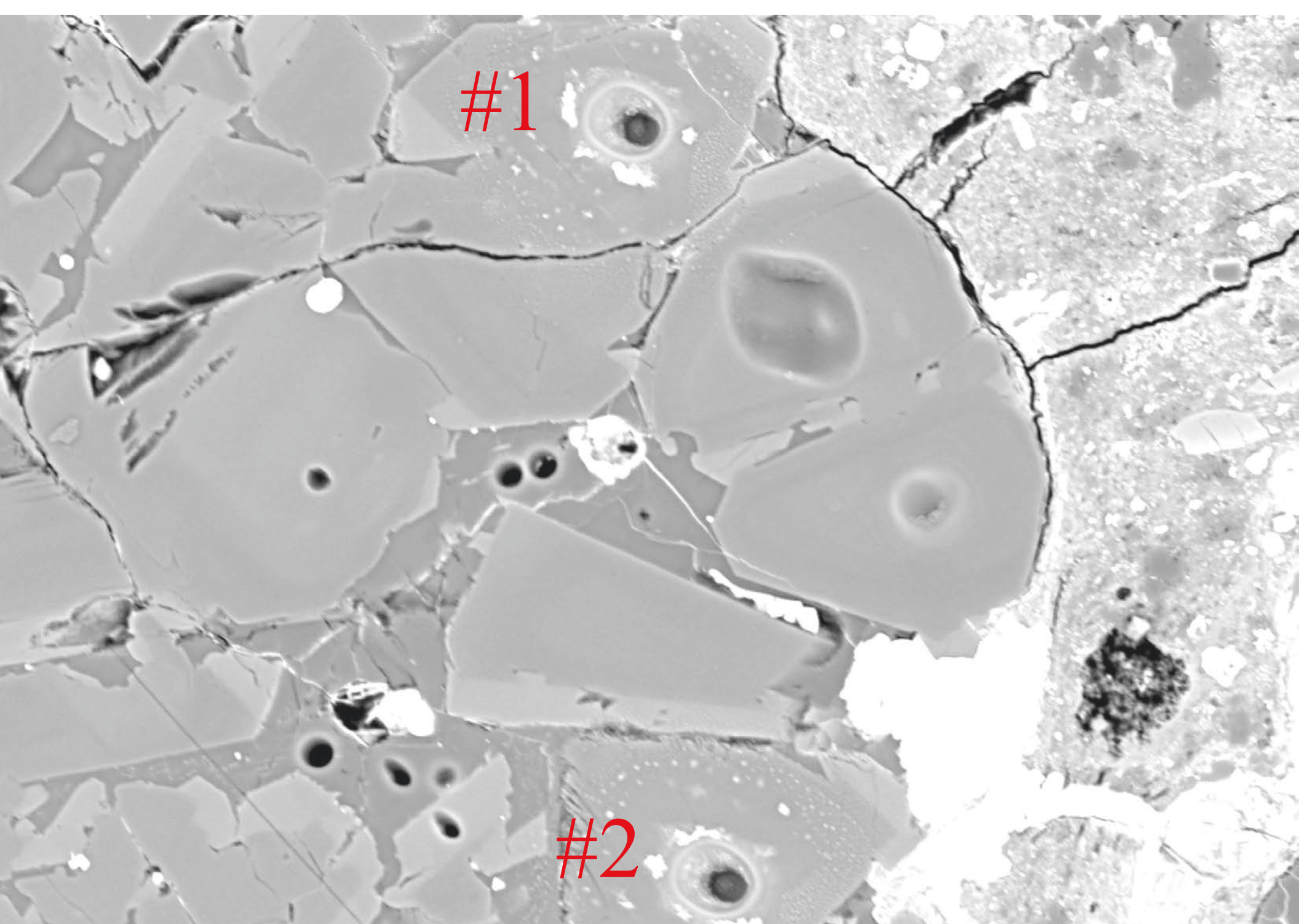
#11

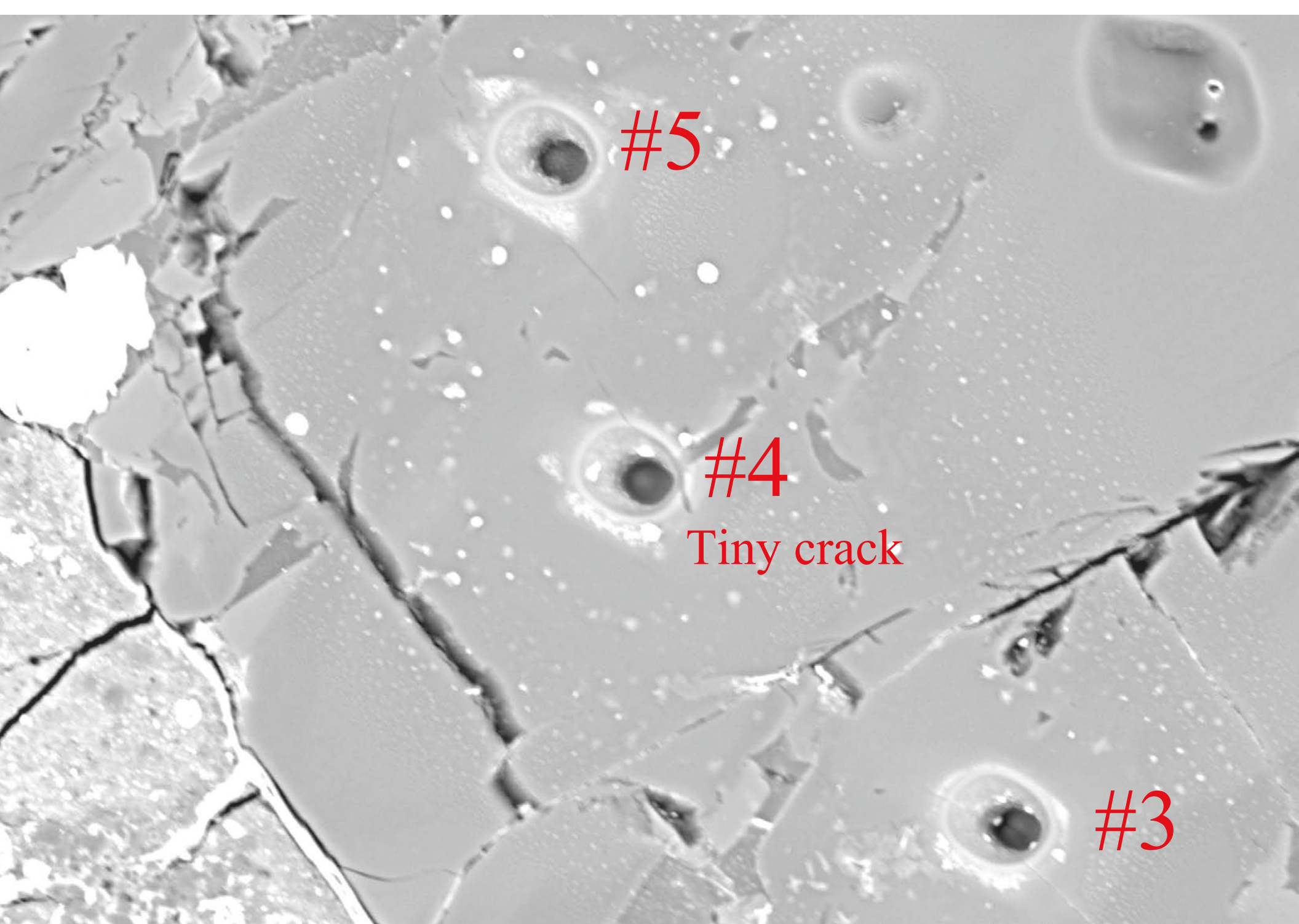
G85-IIB



15.0kV x320 BSECOMP

100um



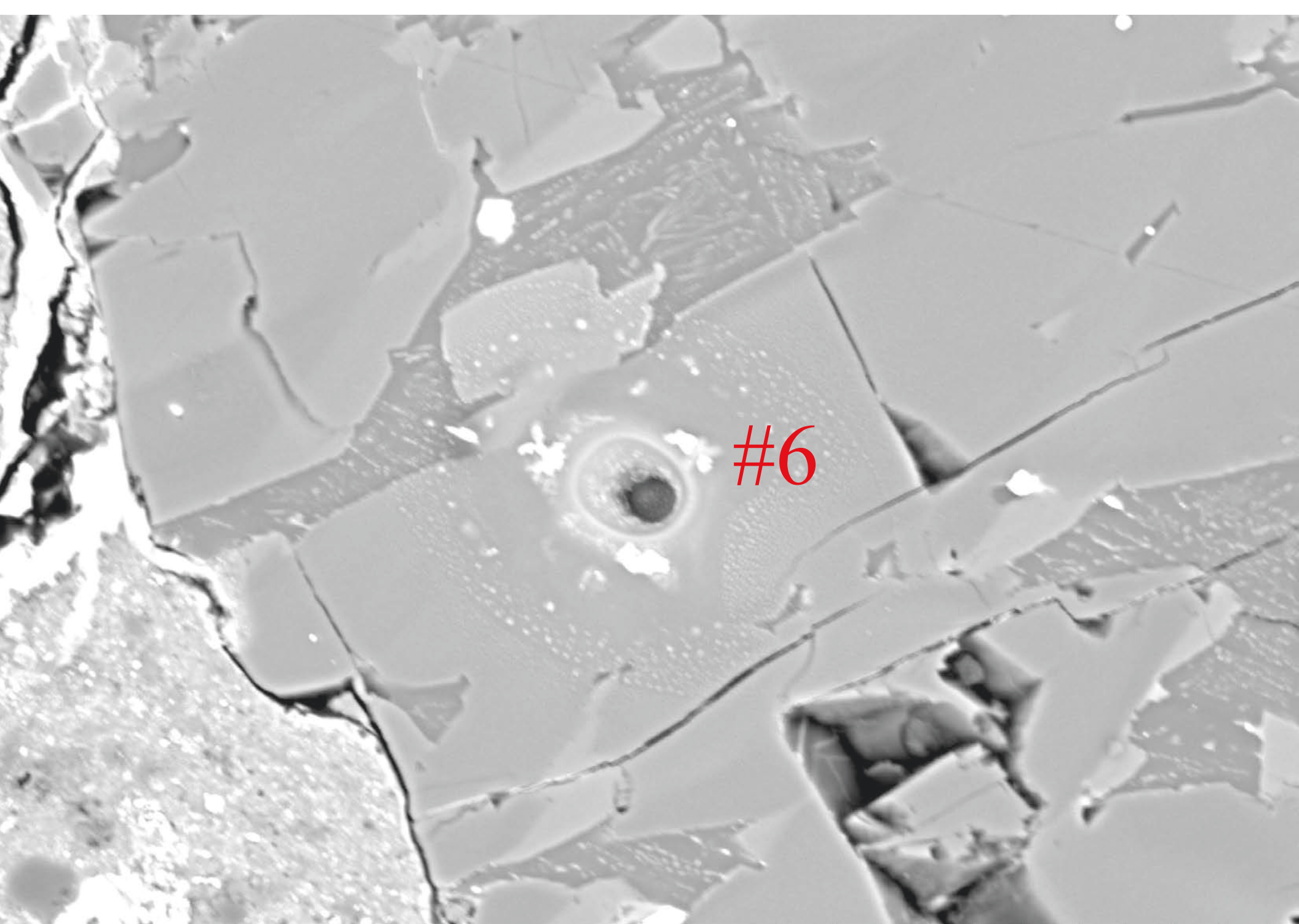


#5

#4

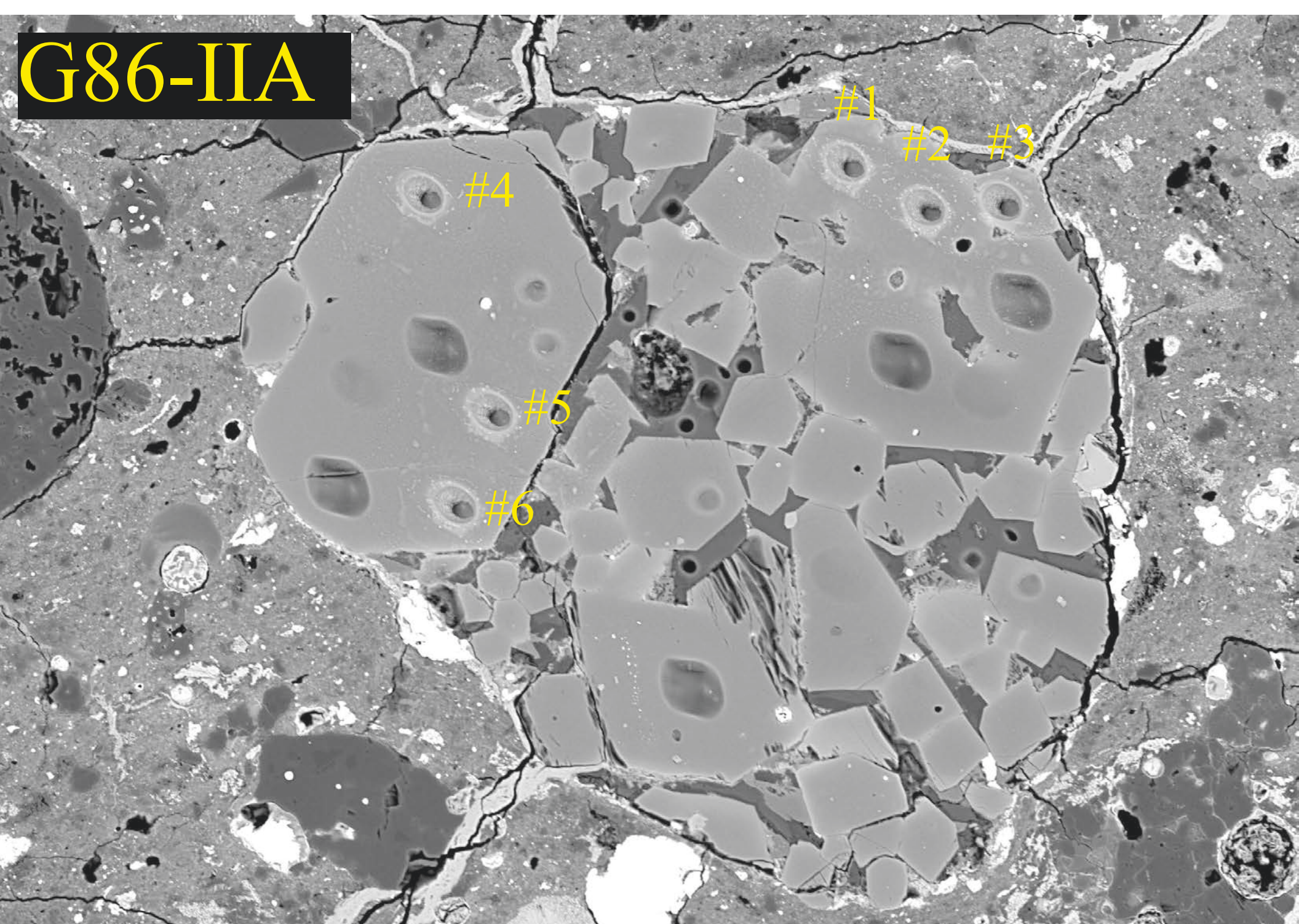
Tiny crack

#3



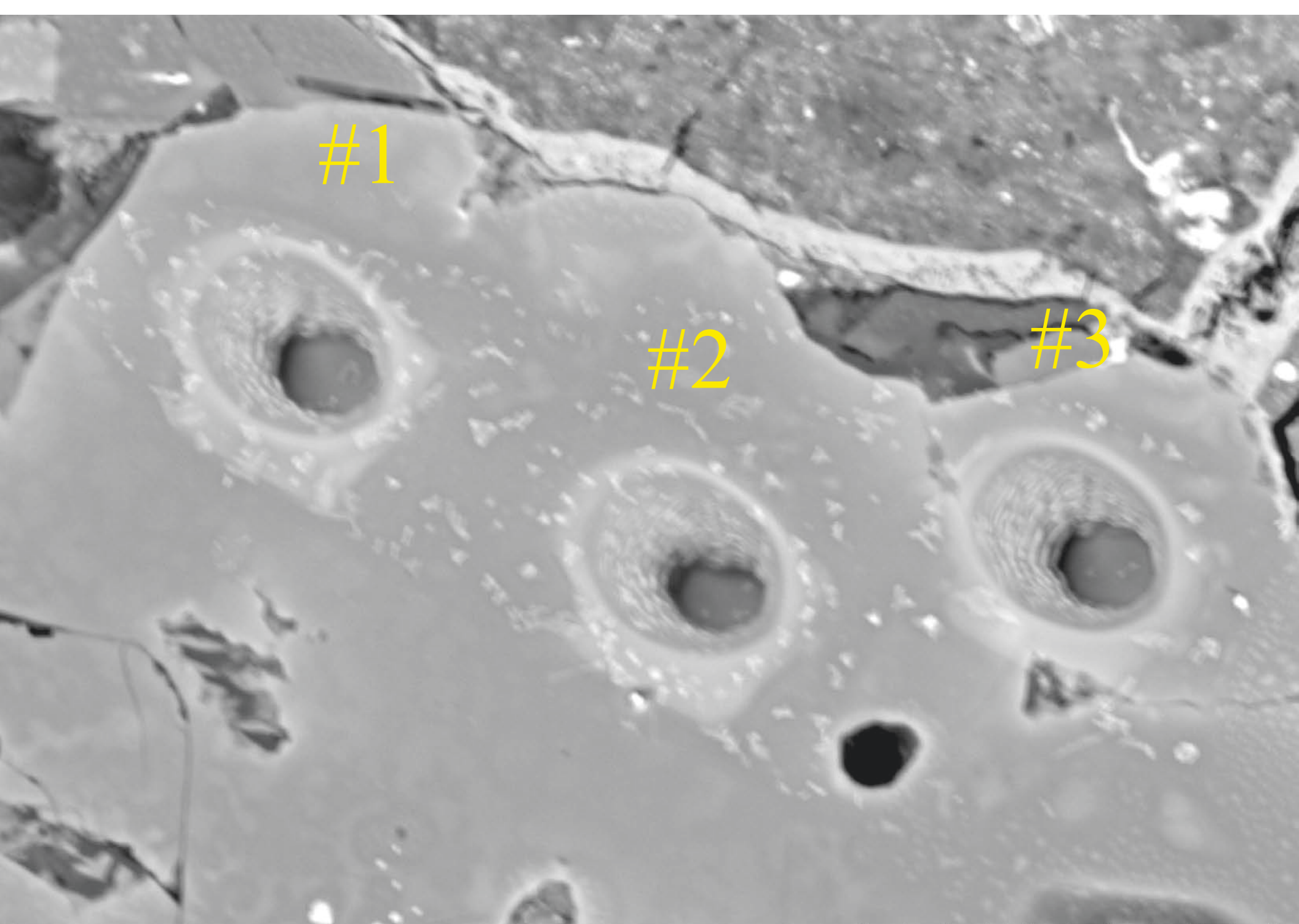
#6

G86-IIA



15.0kV x400 BSECOMP

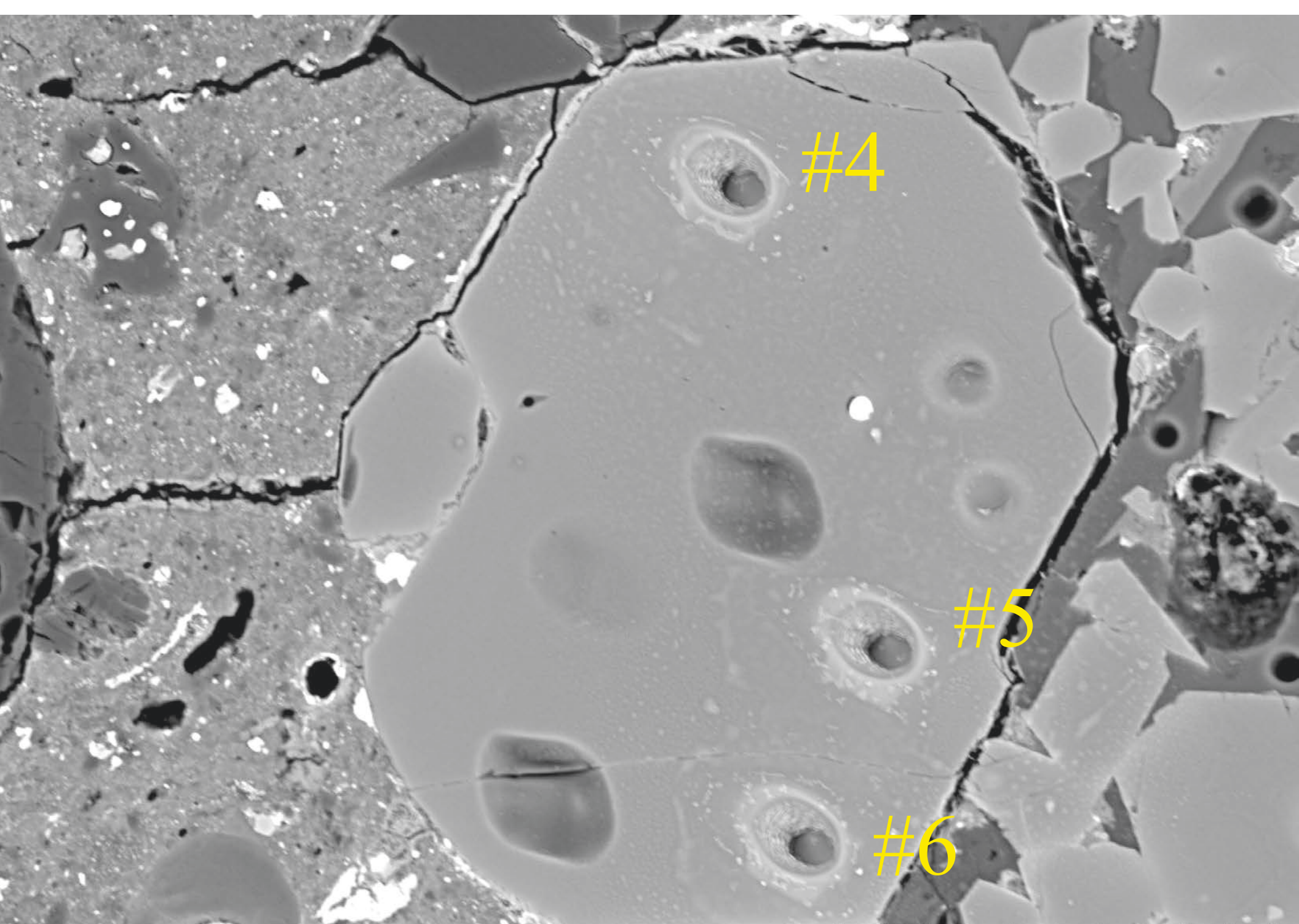
100um



#1

#2

#3

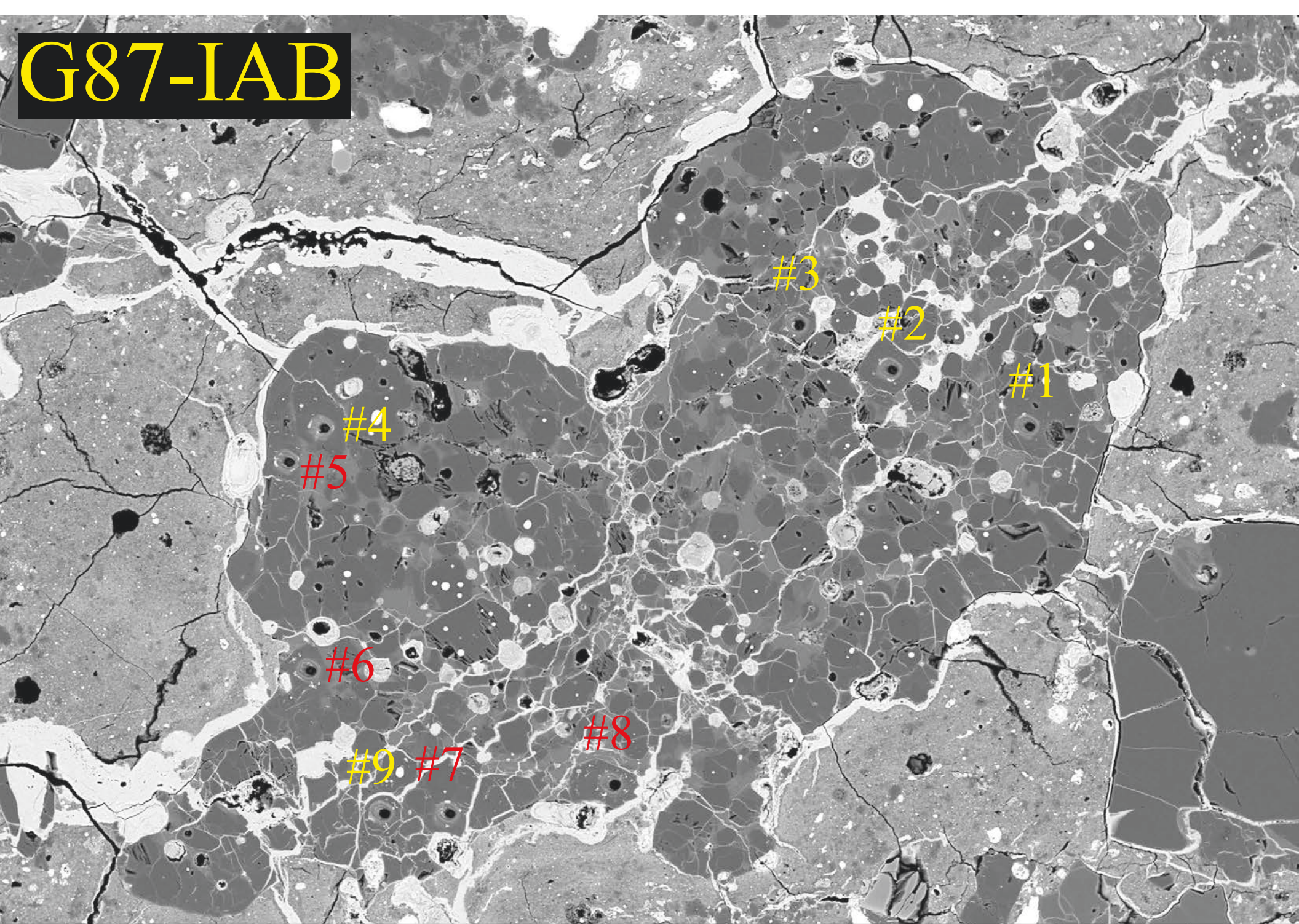


#4

#5

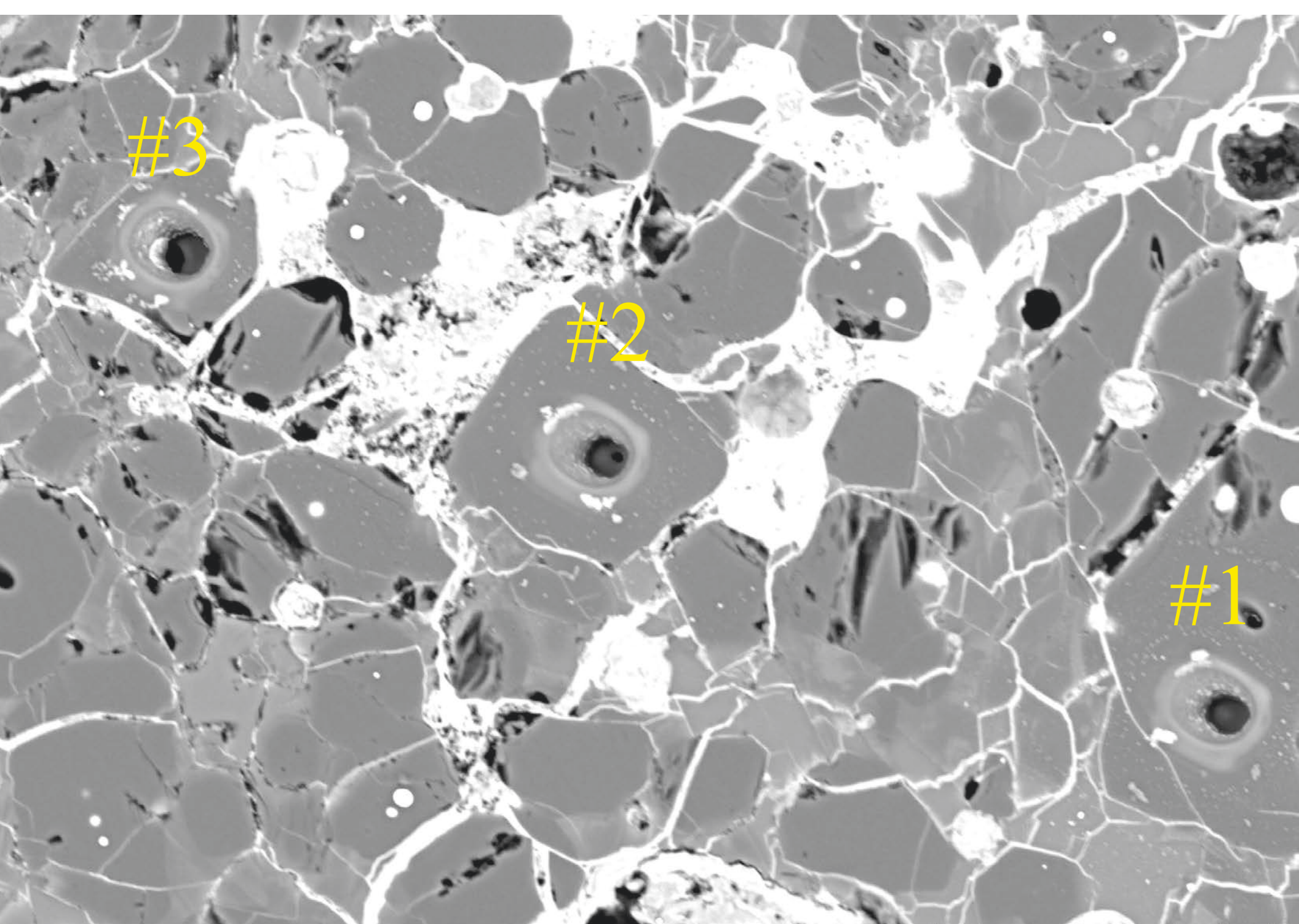
#6

G87-IAB



15.0kV x210 BSECOMP

200um



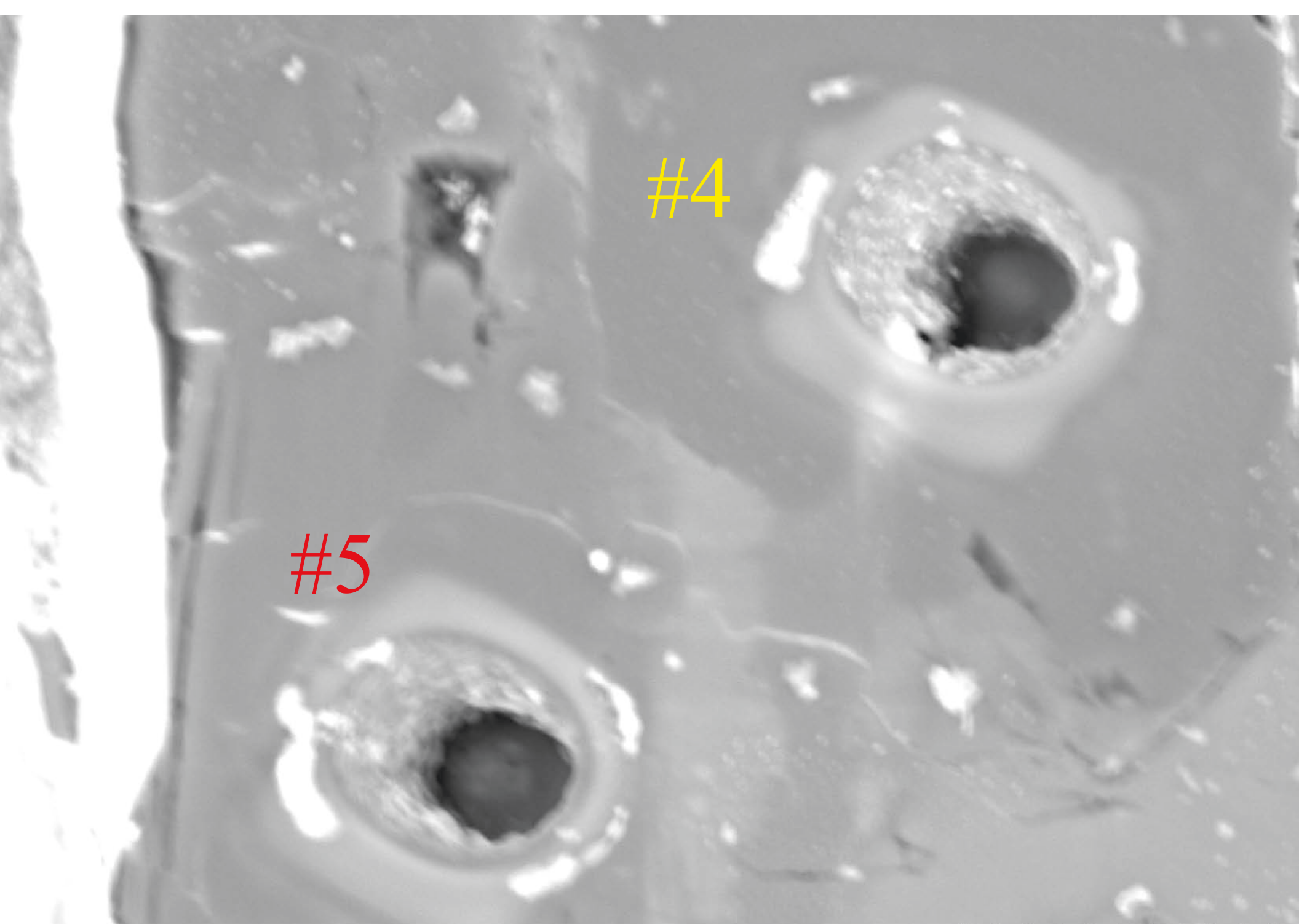
#3

#2

#1

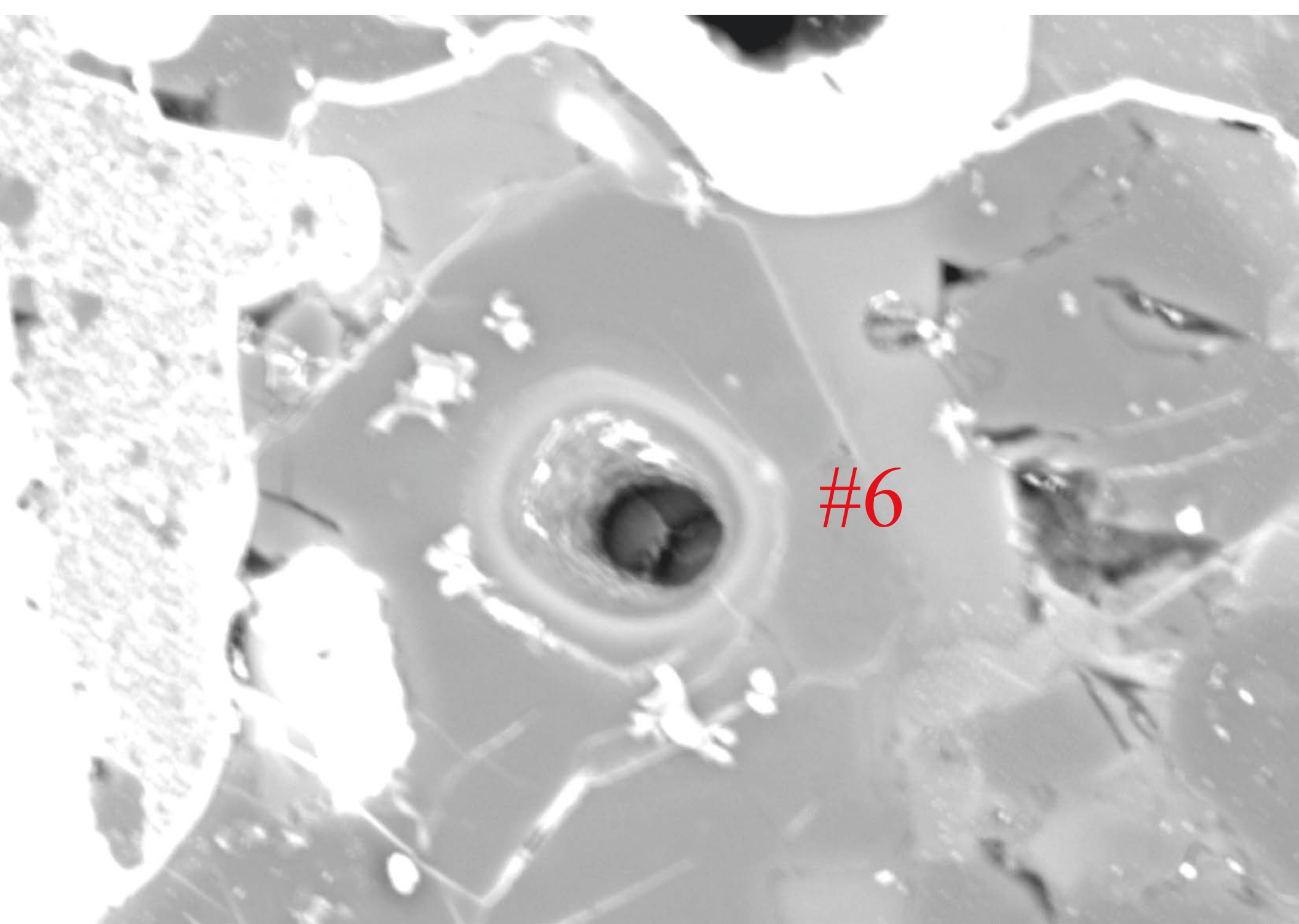
Overlap another phase
beneath, rejected

#3

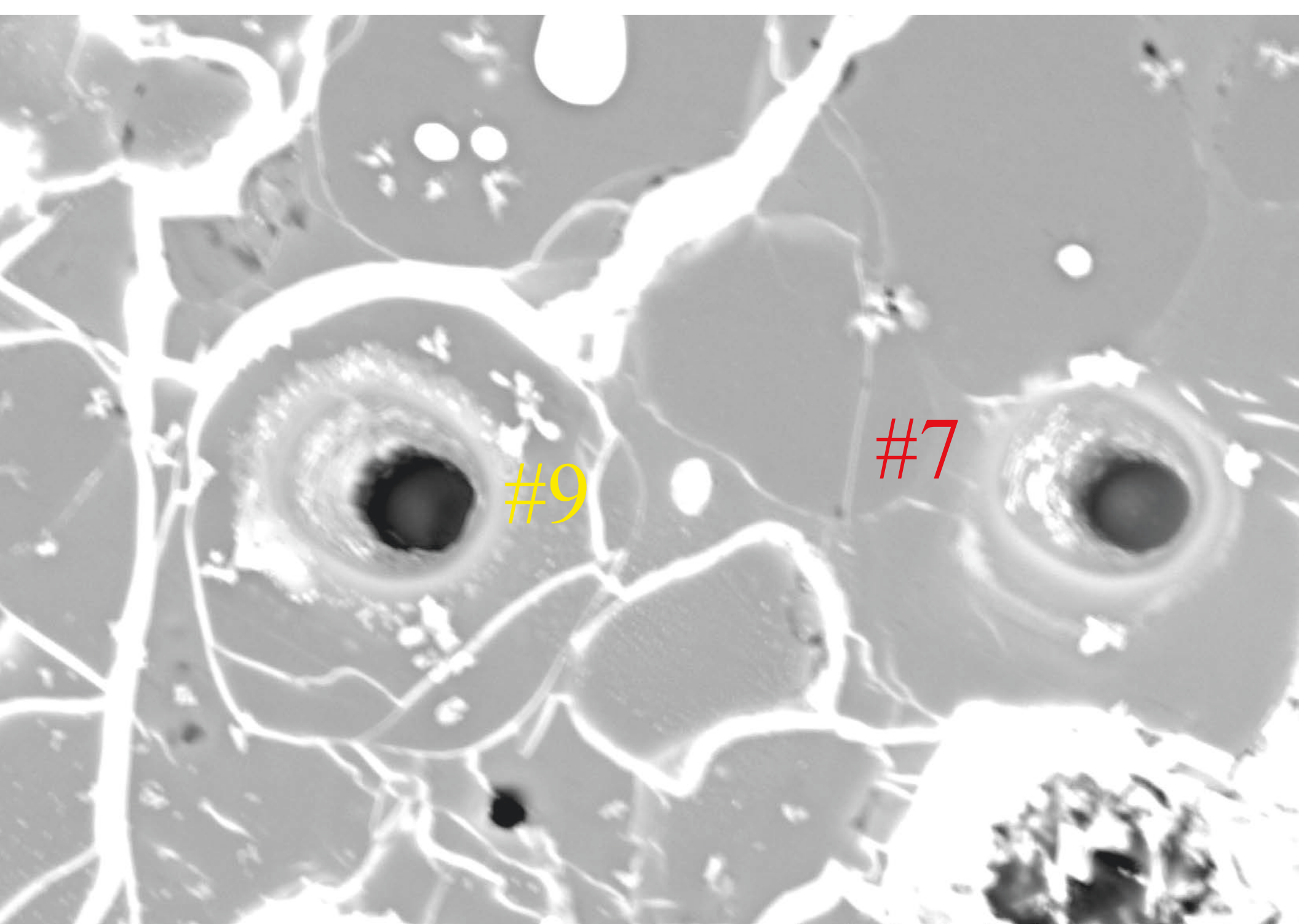


#4

#5

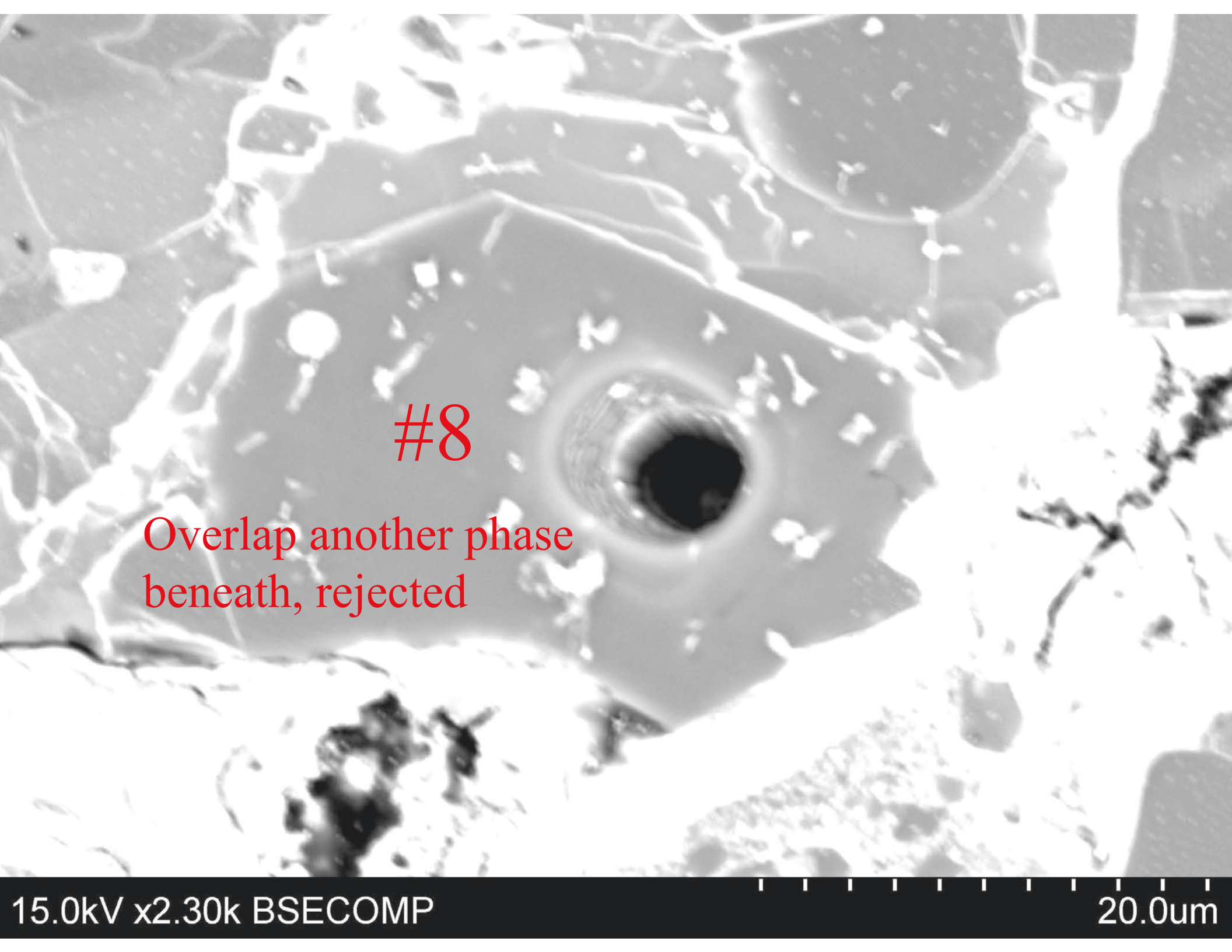


#6



#9

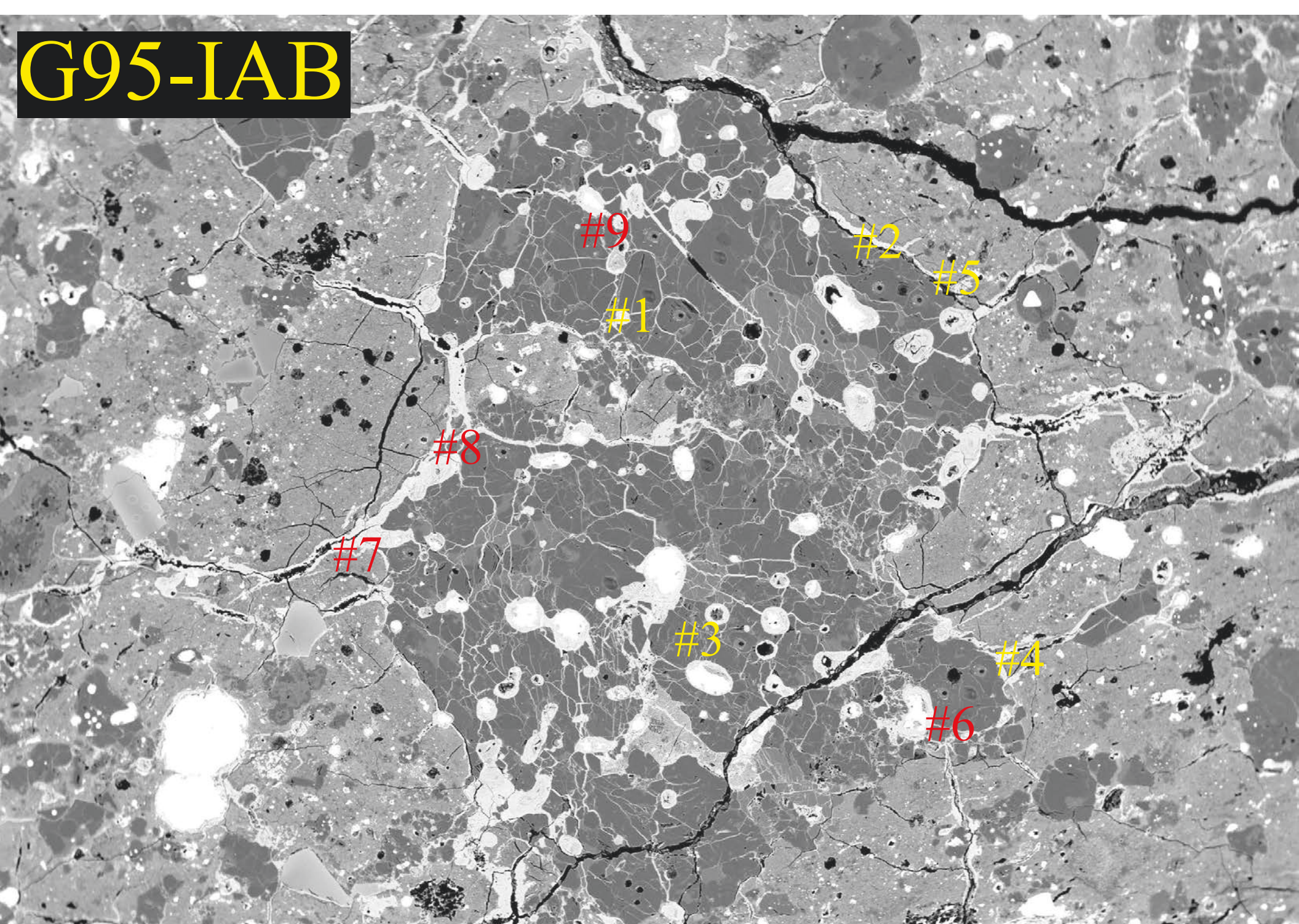
#7

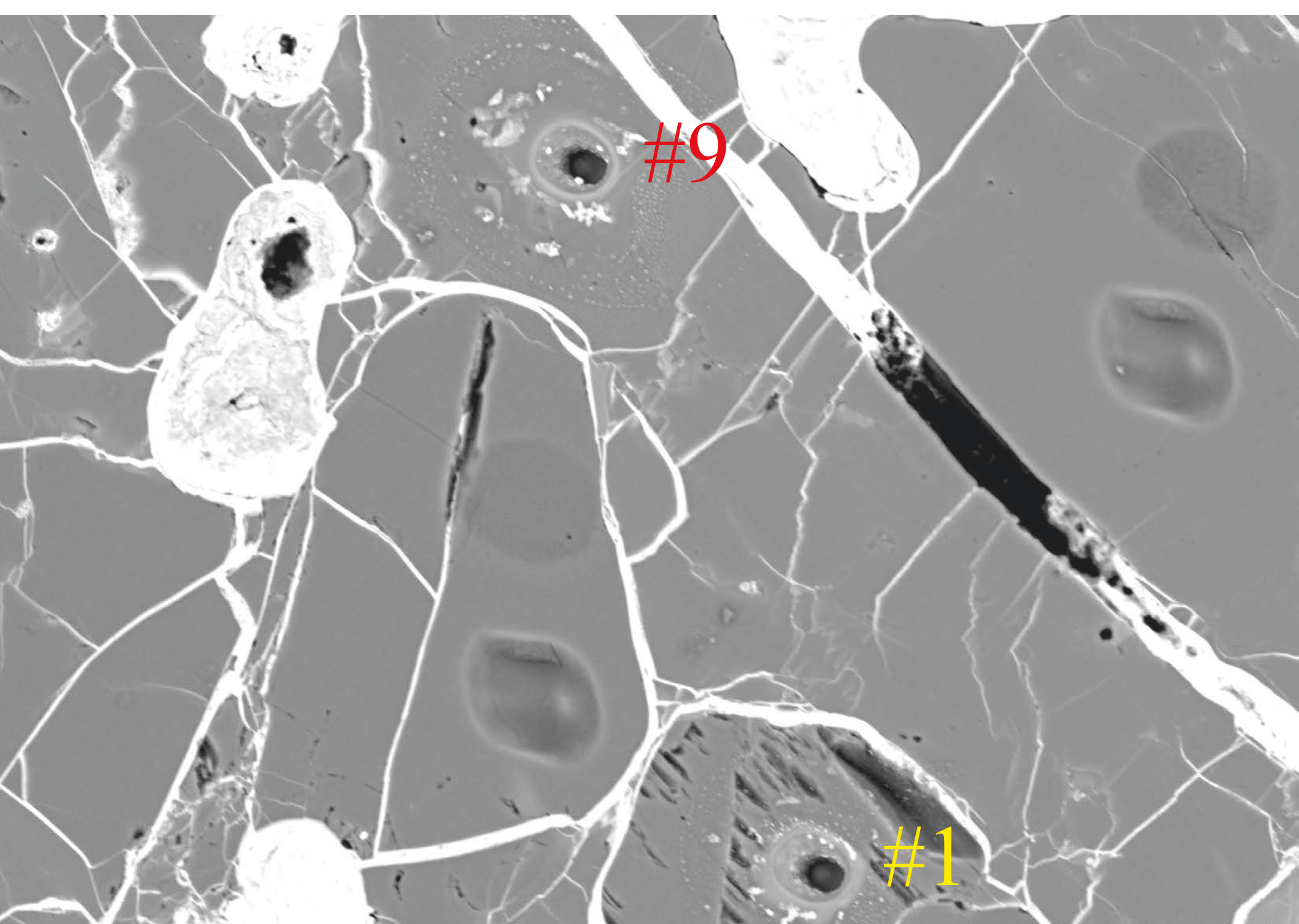
This is a grayscale scanning electron micrograph (SEM) showing a complex microstructure. The central feature is a large, dark, circular void or hole, surrounded by a lighter, textured ring. This central feature is set against a larger, irregularly shaped, light-gray region. The background is a highly textured, light-gray surface with various smaller features and grain boundaries. The overall appearance is that of a cross-section of a material, possibly a metal or ceramic, showing internal structure and defects.

#8

Overlap another phase
beneath, rejected

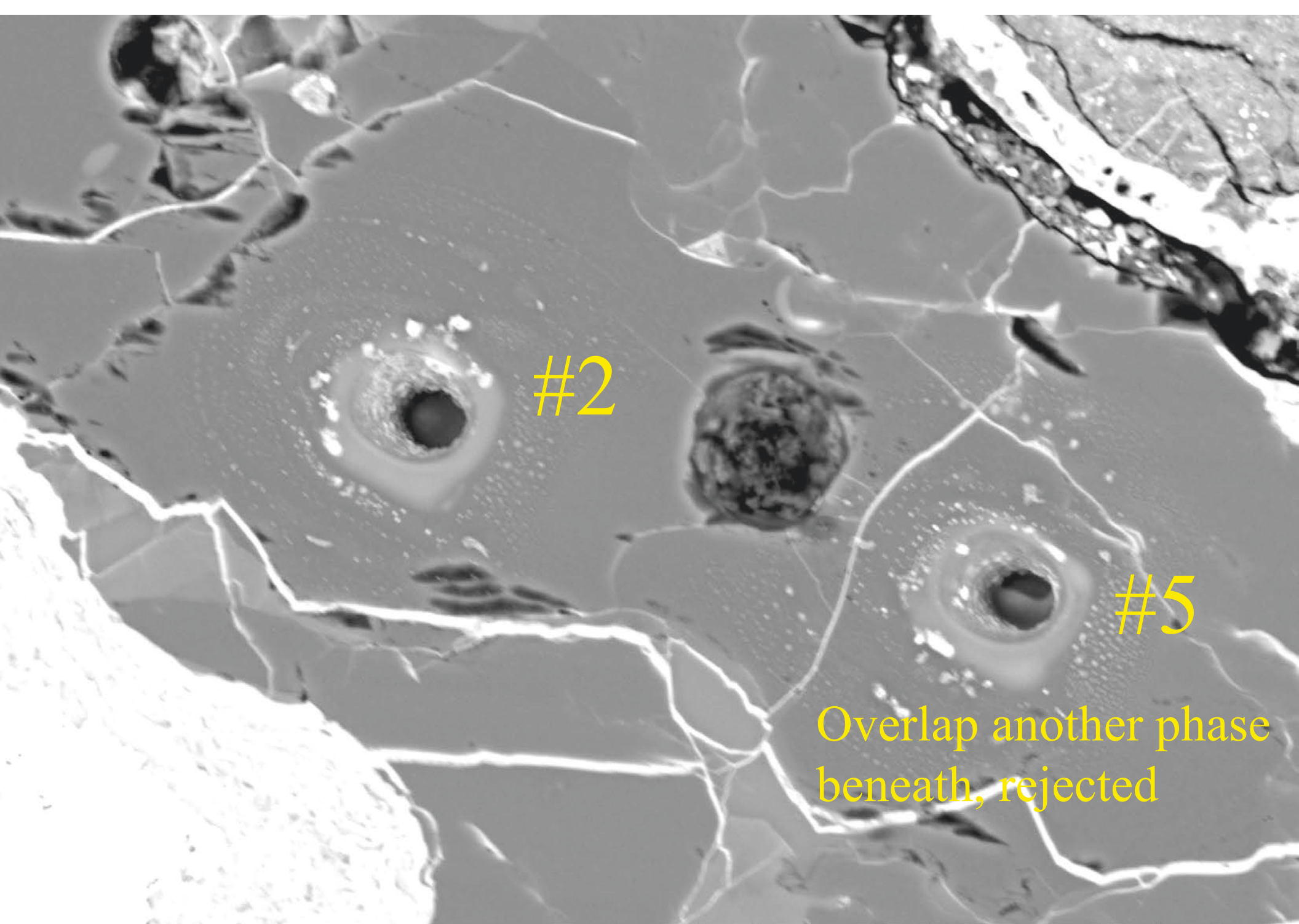
G95-IAB





#9

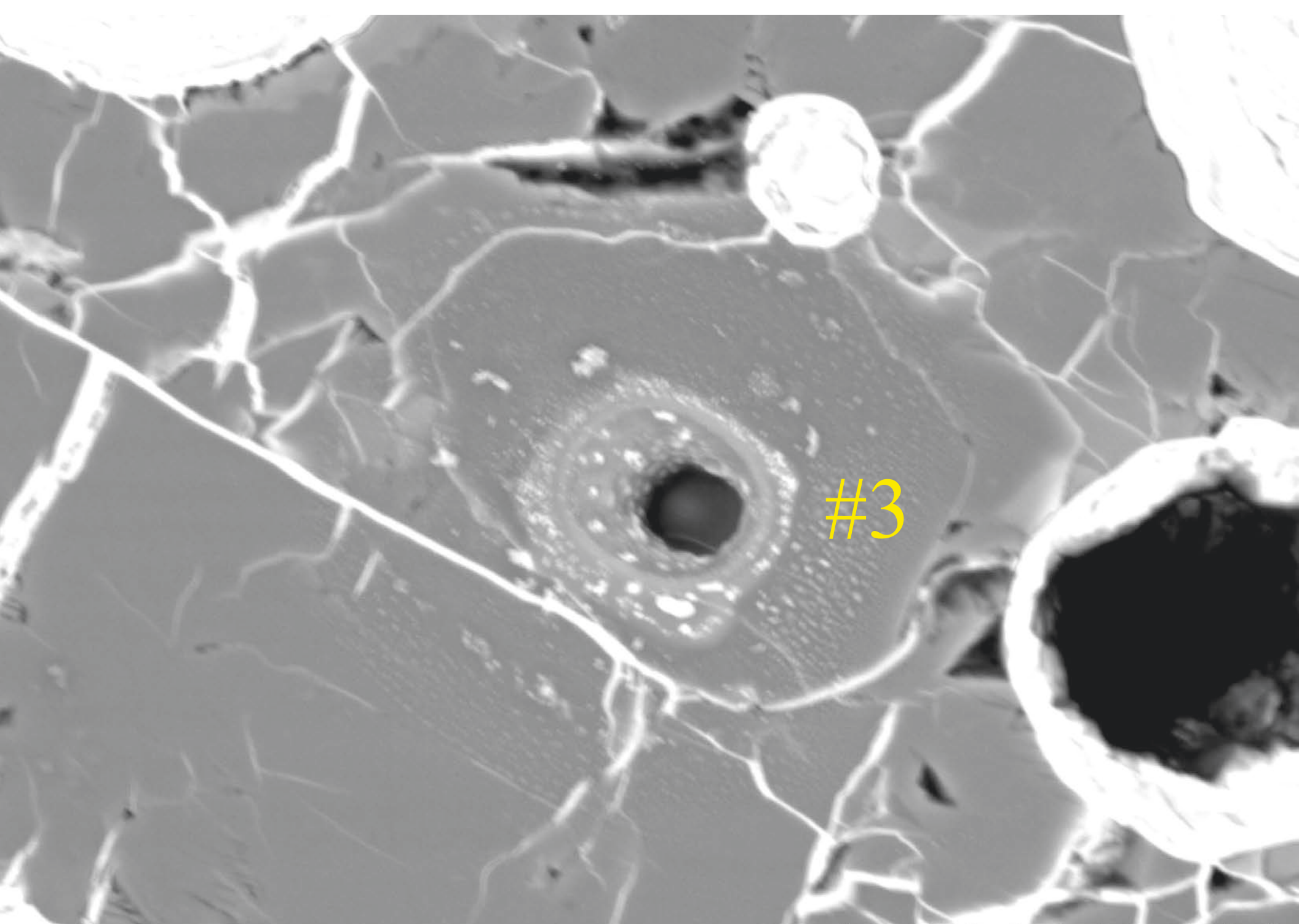
#1



#2

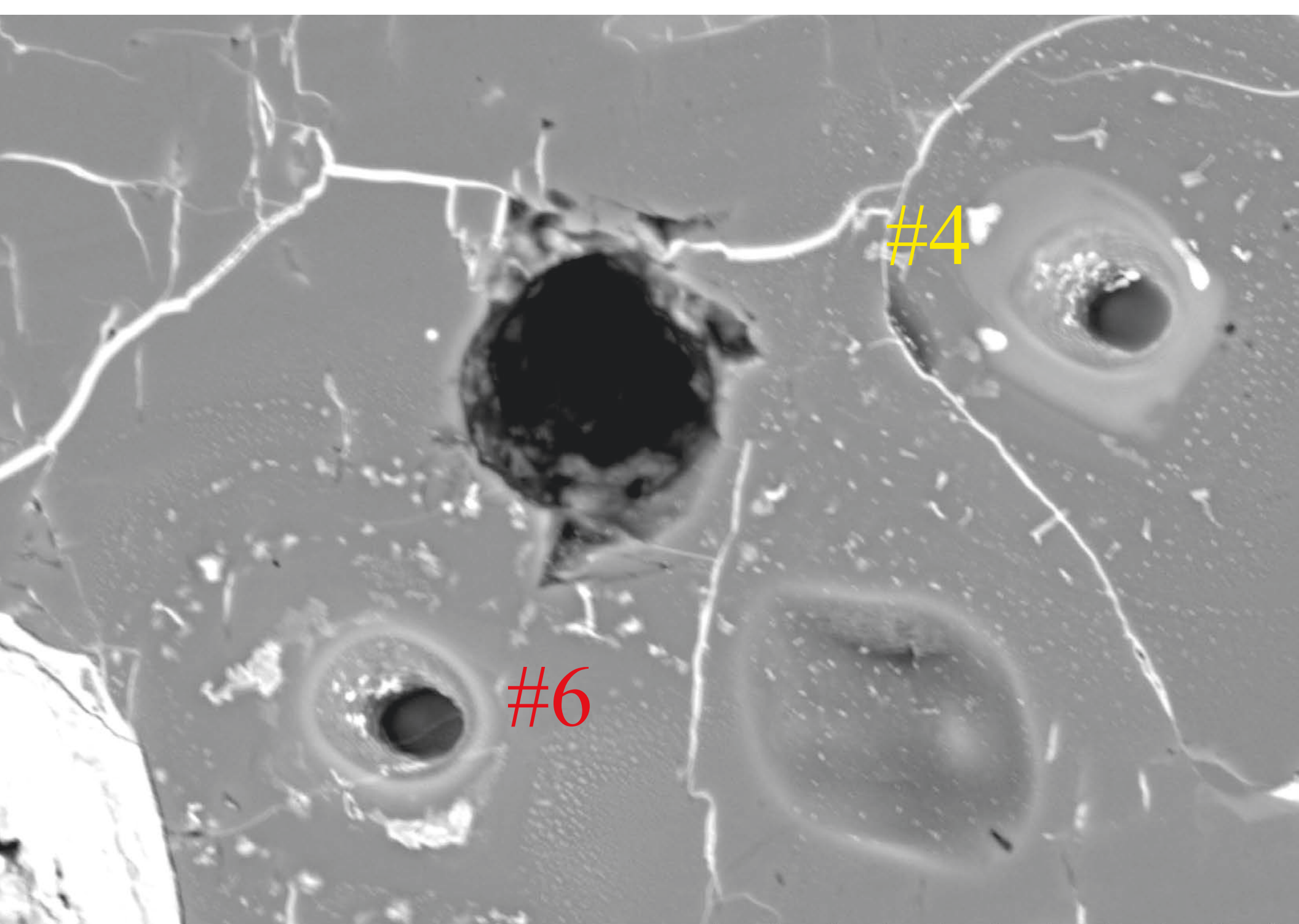
#5

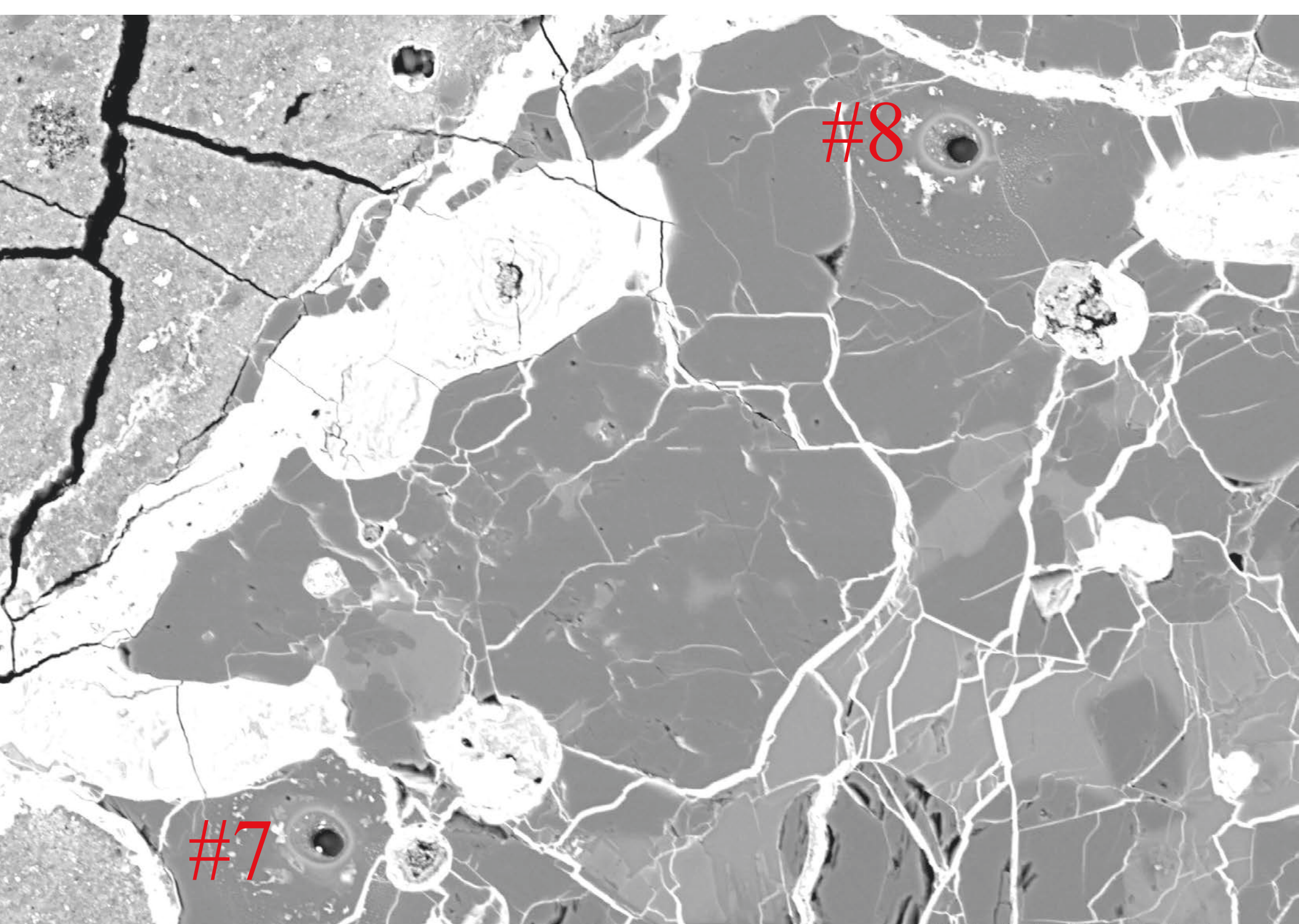
Overlap another phase
beneath, rejected



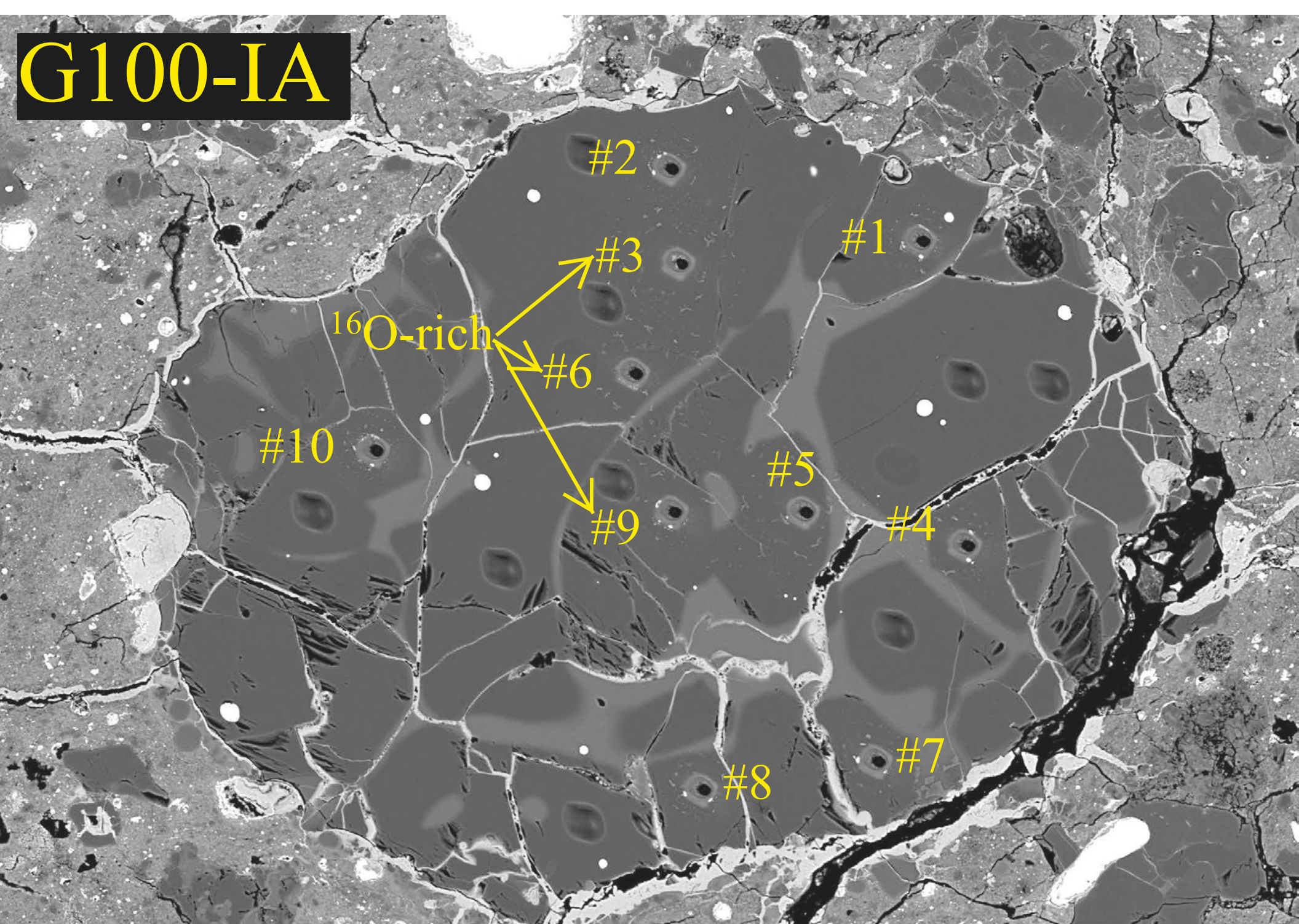
15.0kV x2.10k BSECOMP

20.0um

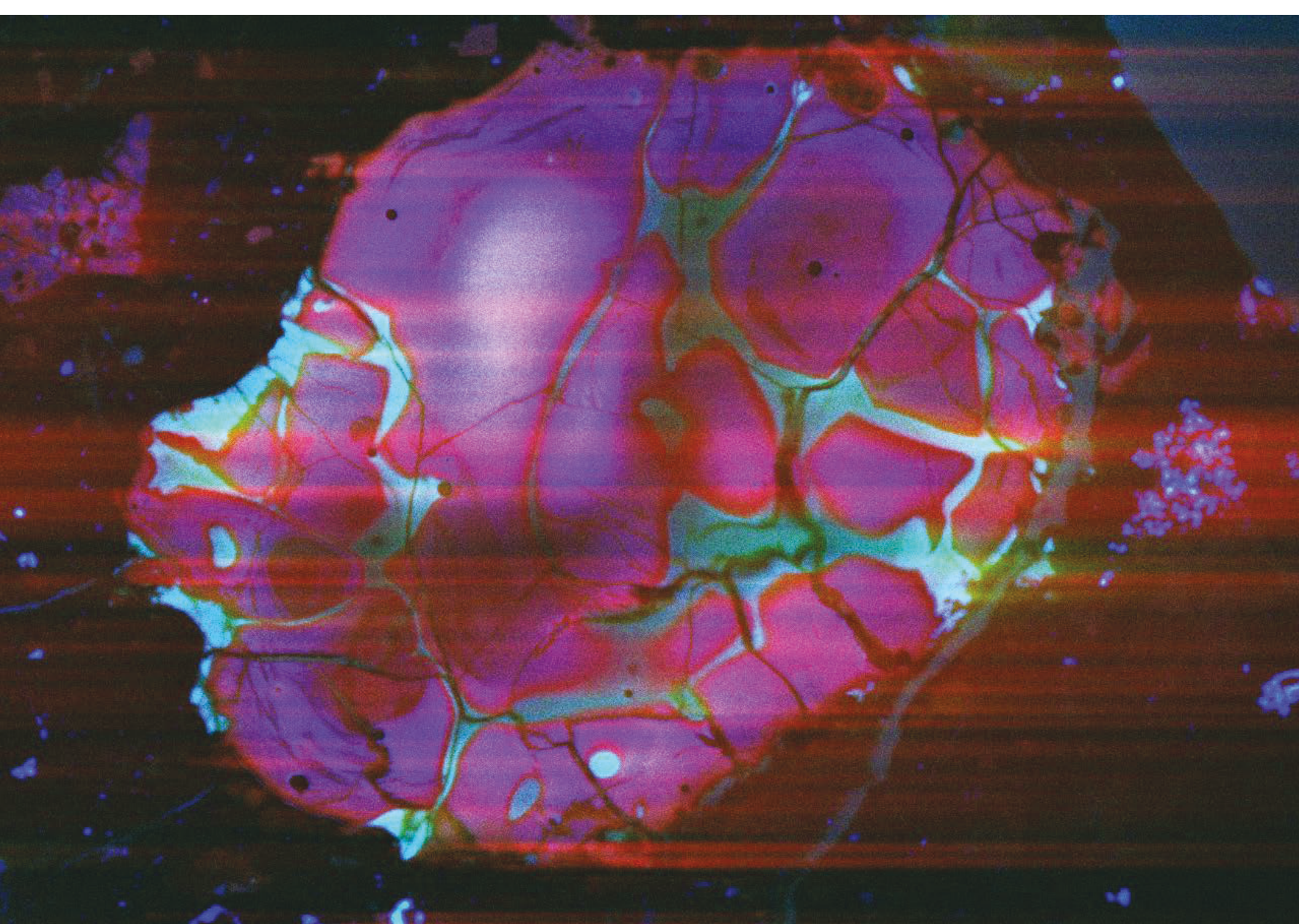


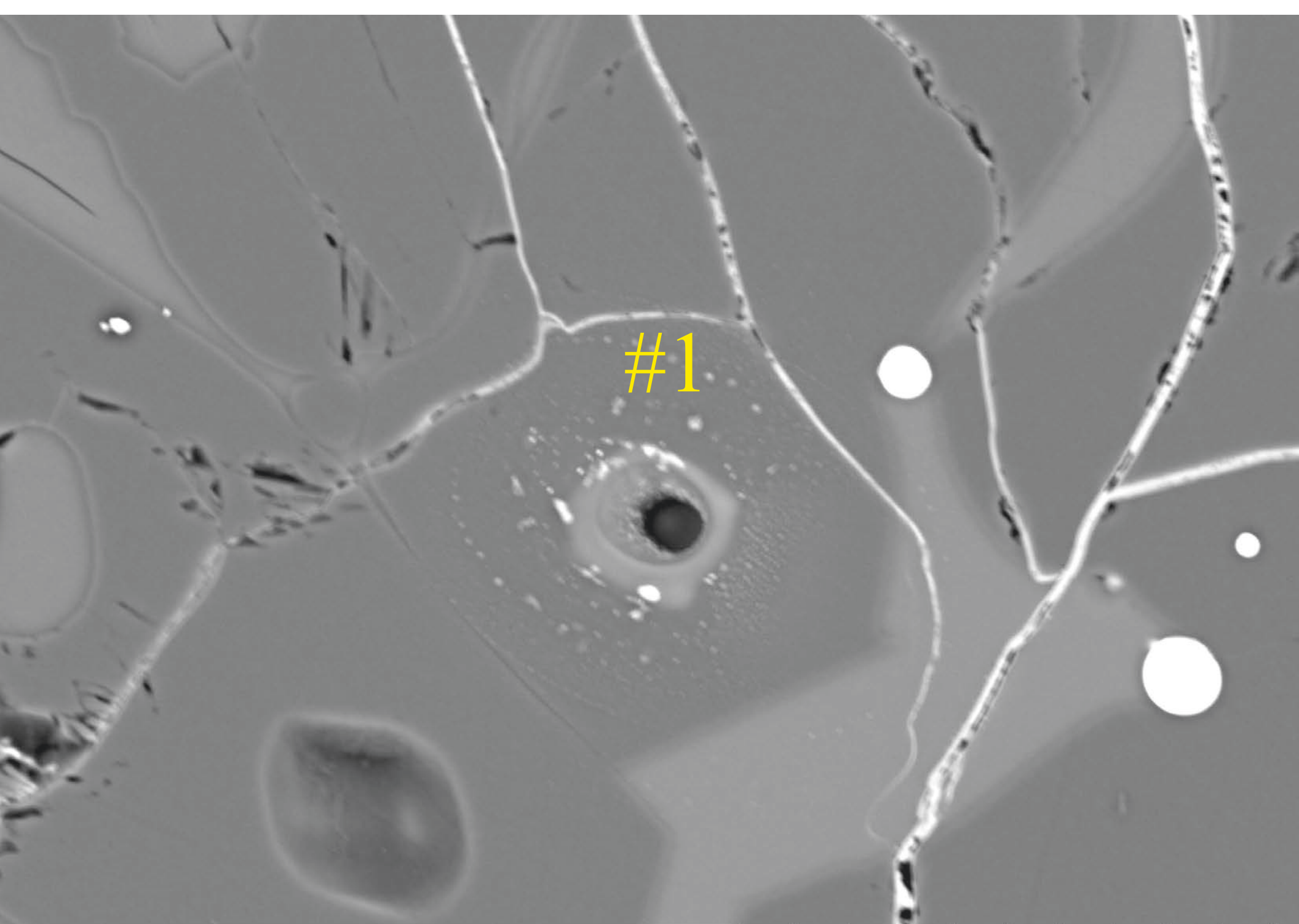


G100-IA

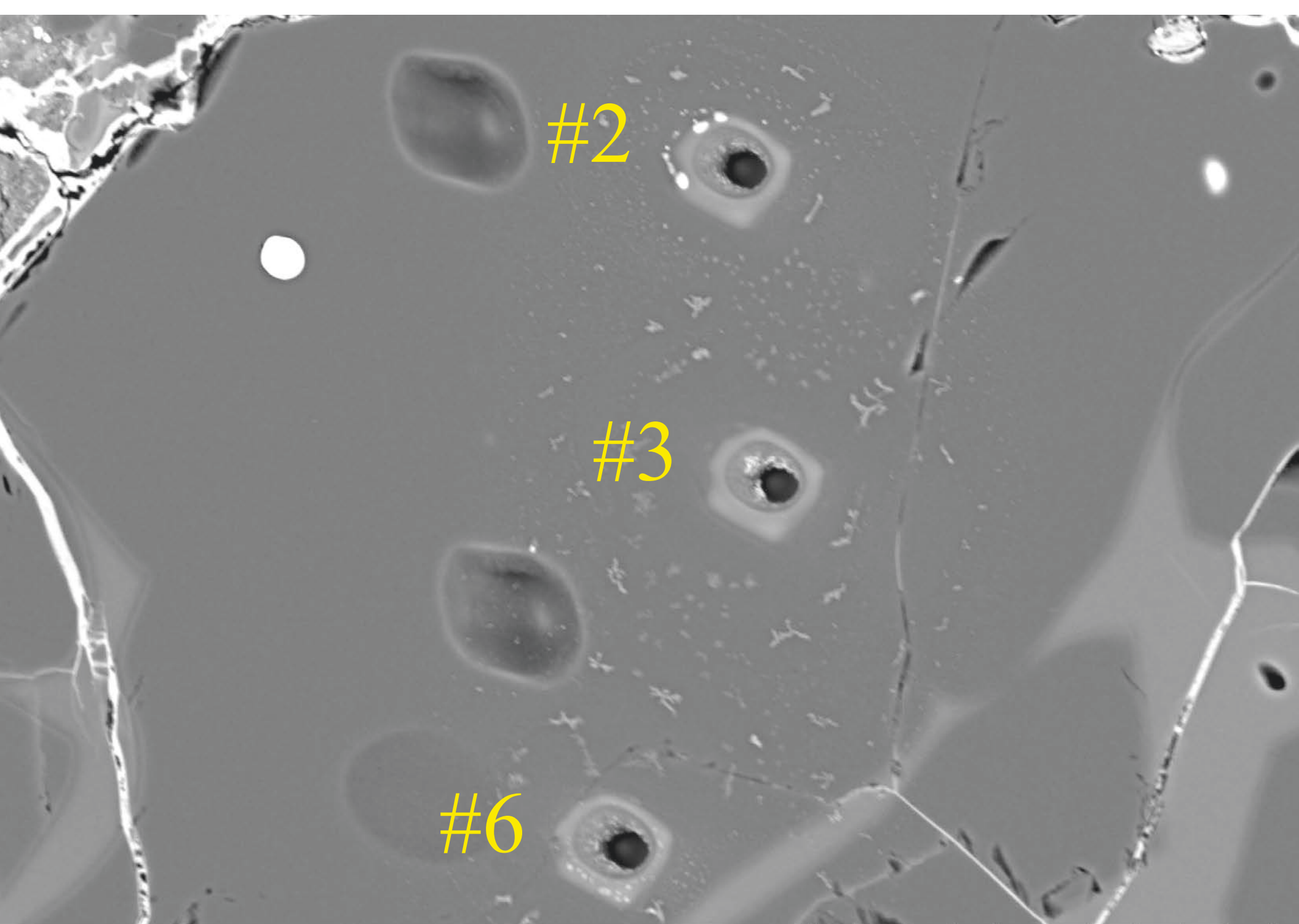


^{16}O -rich





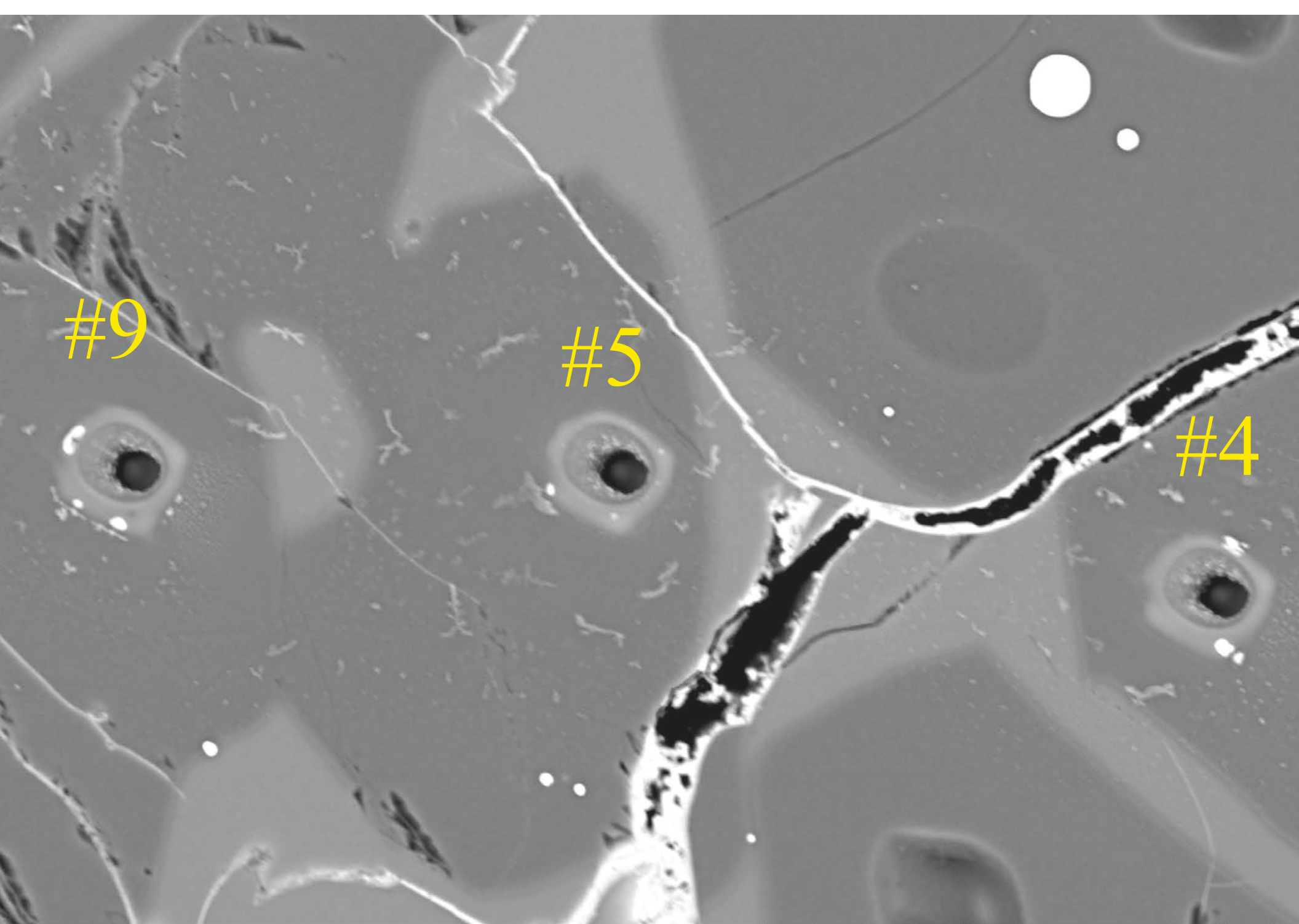
#1



#2

#3

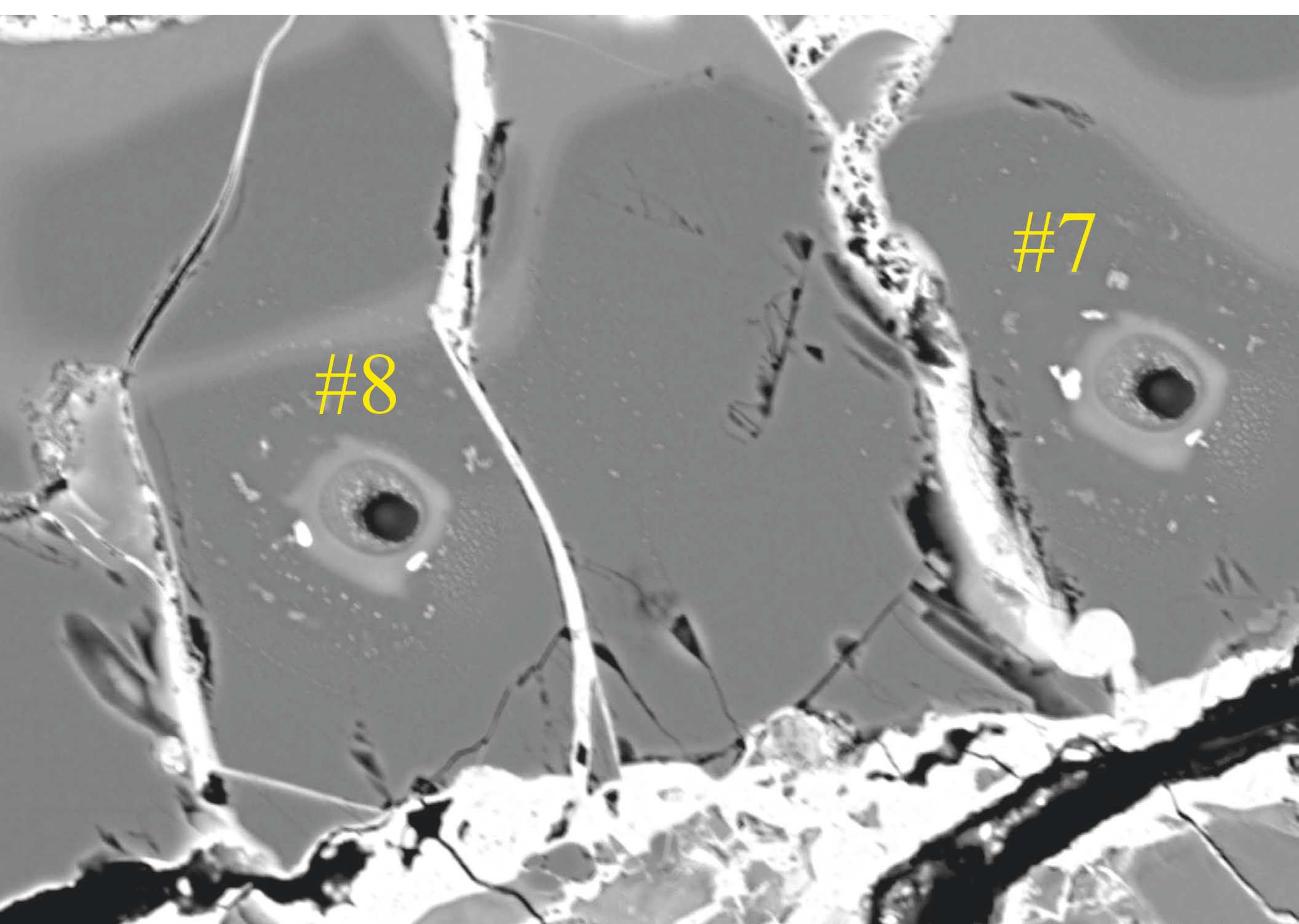
#6



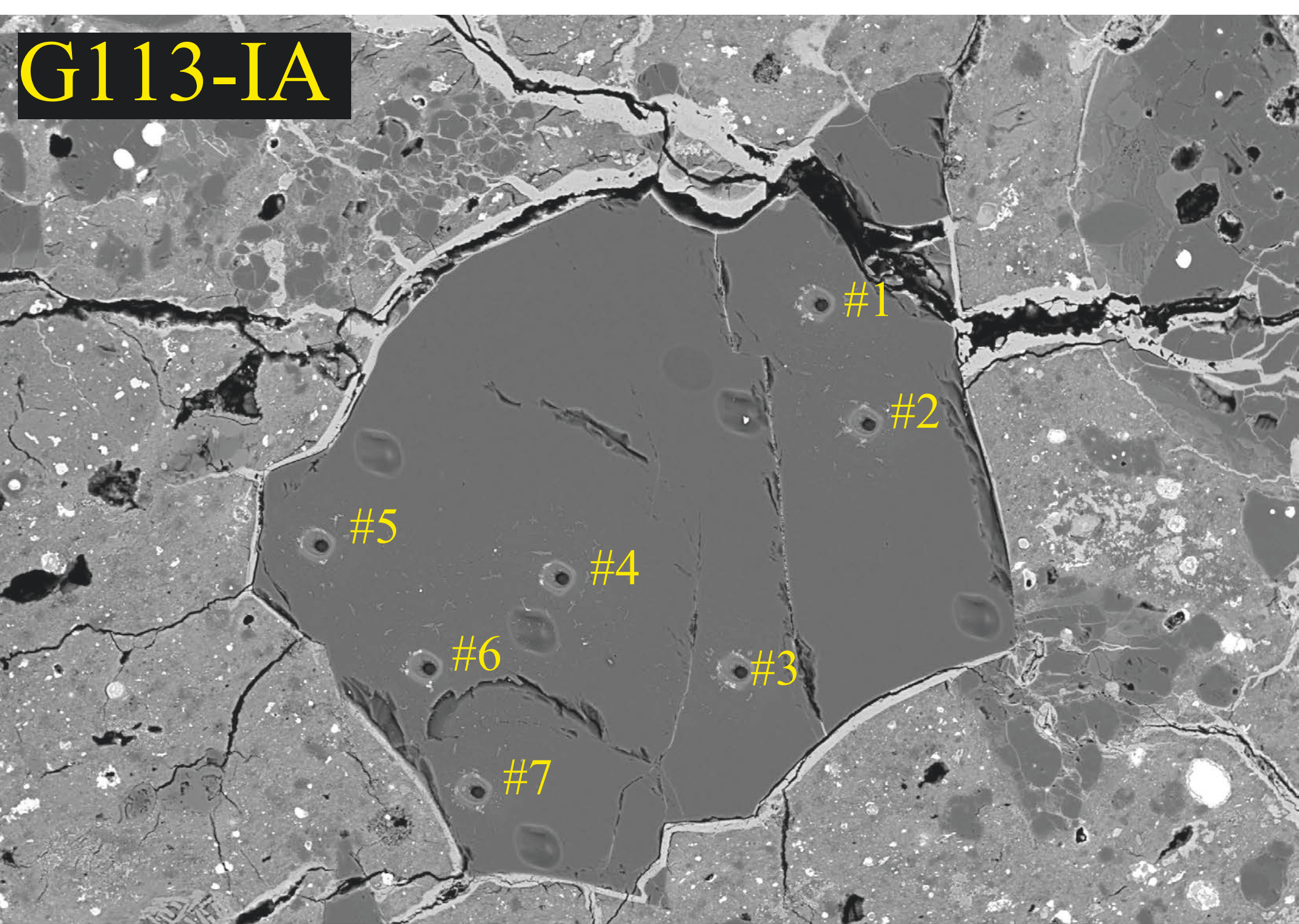
#9

#5

#4

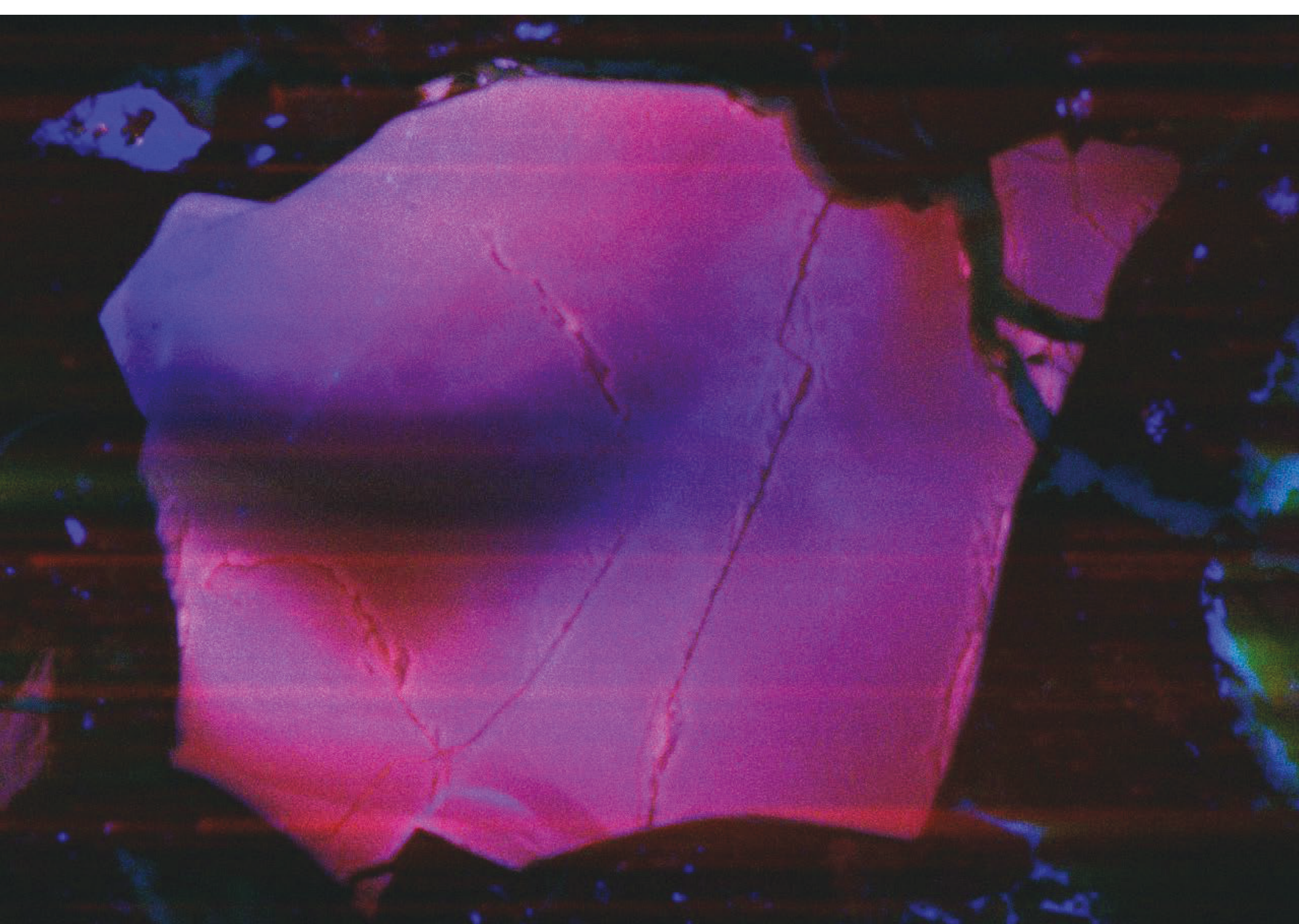


G113-IA



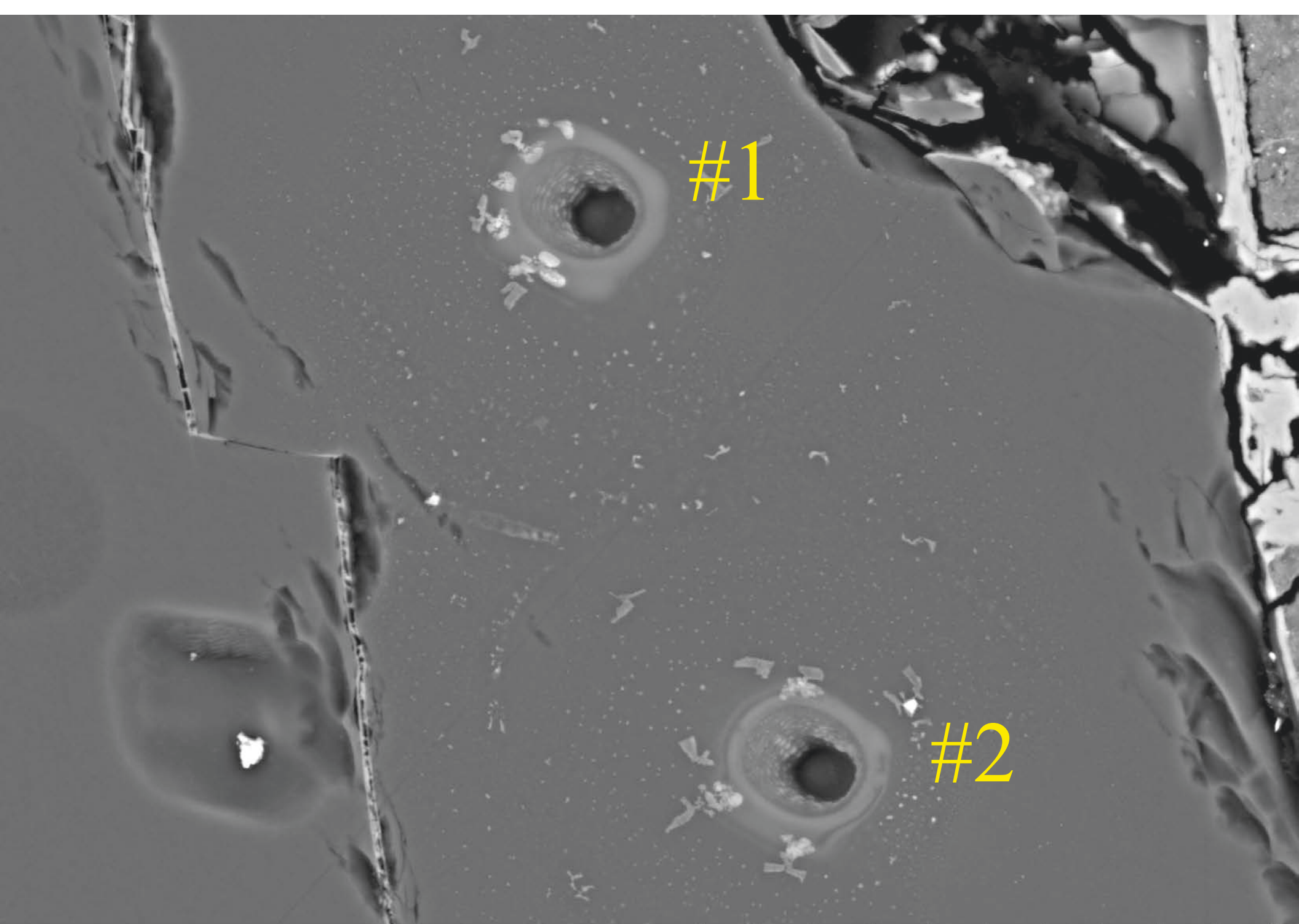
15.0kV x300 BSECOMP

100um



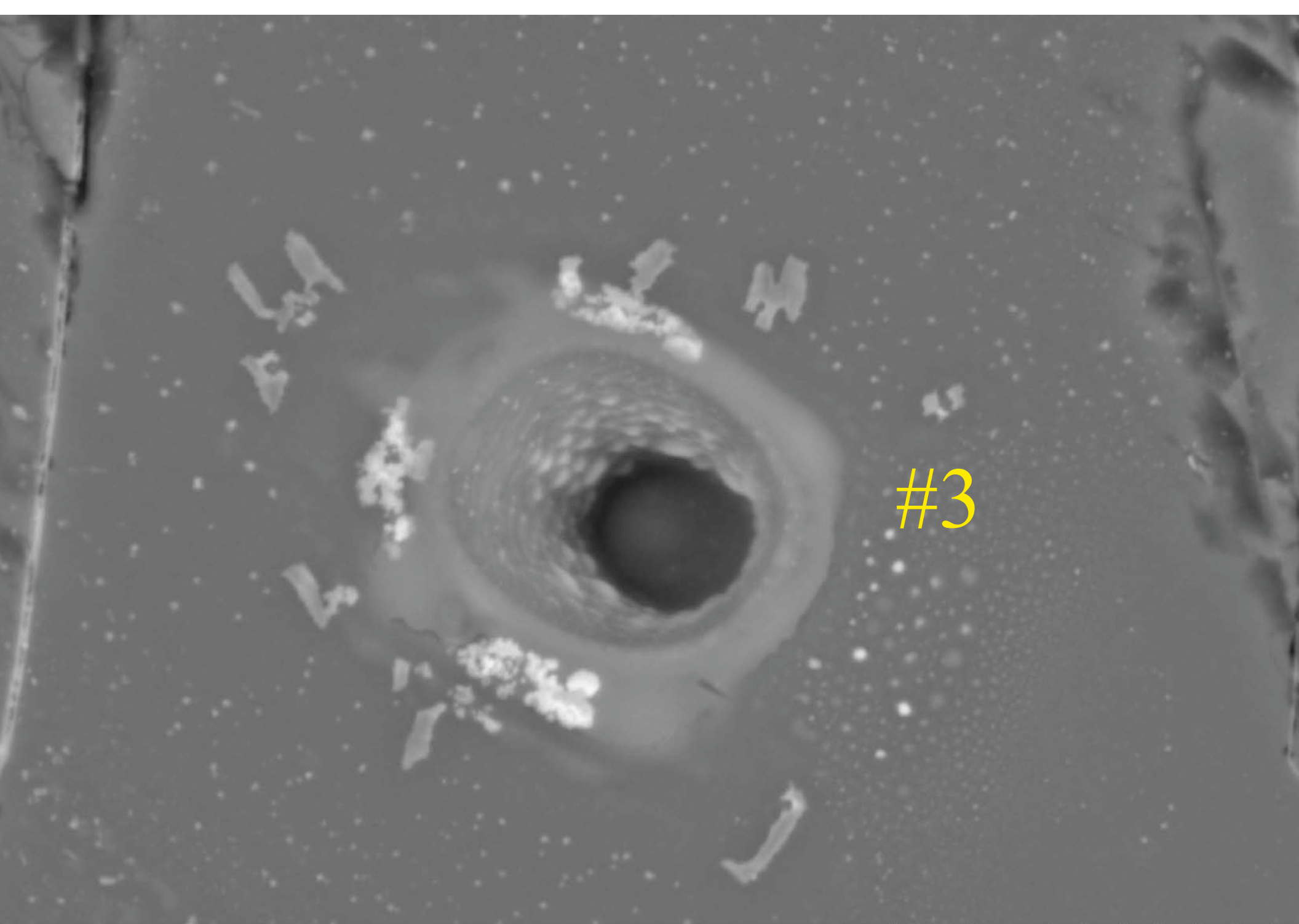
15.0kV x370 OTHER2 10/22/2008

100um



#1

#2



#3

15.0kV x3.70k BSECOMP

10.0um

