

1 Revision 1

2 A new UHP unit in the Western Alps: first occurrence of coesite
3 from the Monviso Massif (Italy)

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ABSTRACT

15 The Western Alps are one of the most studied exhumed subduction-accretionary complexes
16 worldwide. Ultra-high pressure (UHP) metamorphism has been documented therein since the
17 1980's. We now report the first discovery of coesite in the meta-ophiolitic suite of the Monviso
18 Massif, corresponding to the fourth UHP unit defined on the Western Alps. Previous petrographic
19 studies and results from thermodynamic modelling already suggested that these Alpine units may
20 have experienced UHP metamorphism, but no occurrences of index minerals, such as coesite, have
21 been reported to date. The newly discovered coesite inclusions from the Monviso Massif occur as
22 intact single crystals (10-60 μm) hosted by garnet. The observations suggest that they have escaped
23 re-equilibration, and maintained all the original features from the trapping time. The reduced size of
24 the crystals and the lack of re-equilibration significantly differ from the typical textural features

25 described in past findings (i.e., radial cracks, palisade texture of quartz surrounding coesite relicts).
26 Detailed garnet inclusions analysis and thermodynamic modelling constrained the metamorphic
27 peak conditions at $P=2.8-2.9$ GPa and $T=500-520$ °C, within the coesite stability field.

28 The Lago Superiore Unit represent the fourth UHP unit discovered on the Western Alps. The UHP
29 metamorphism on the Western Alps was considered rare and due to process of unusual units escape
30 from mantle-depth. In our view, the implication of our discovery will take new insight to UHP
31 processes that seems to be more common than expected. Further tectonic reconstructions should
32 take into account the common features observed in the UHP units, for better constrain the
33 subduction- and exhumation-related mechanism that drove the actual stacking of mountain belts.

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INTRODUCTION

36 The ground-breaking finding of natural coesite (SiO_2) in the Western Alps, made by [Chopin \(1984\)](#),
37 revolutionised the geodynamic models of subduction-accretionary complexes. This finding firstly
38 proved that rocks can be subducted to experience mantle conditions (>80 km) and then exhumed
39 ([Chopin, 2003](#); [Gilotti, 2013](#)). The discovery of such ultrahigh-pressure (UHP) mineral-bearing
40 rocks also extended the possible depths covered by metamorphic cycles of at least one order of
41 magnitude (e.g., [Chopin, 2003](#)) or, alternatively, opened the possibility for invoking non-lithostatic
42 pressure variations (e.g., [Tajčmanová et al., 2021](#)).

43 Despite more than three decades of research in the field of UHP and the reconnaissance of ca. 20
44 UHP units worldwide (e.g., [Gilotti, 2013](#); [Gonzalez et al., 2020](#)), mainly distributed in Phanerozoic
45 subduction-accretionary complexes, the discovery of new UHP units remains a rare event.

46 This is particularly true for the Western Alps, where only two additional UHP unit has been
47 reported after the very first discovery ([Reinecke, 1991](#); [1998](#); [Frezzotti et al., 2011](#); [Manzotti et al.,](#)
48 [2022](#); **Figure 1a**). Although other direct evidence is lacking, the possible occurrence of other UHP
49 units in the Western Alps has been widely inferred through indirect methods, including
50 thermodynamic modelling and microstructural observations ([Angiboust et al., 2012](#); [Gilio et al.,](#)

51 2020; Ghignone et al., 2021). Groppo et al. (2016) further supported the possible attribution of a
52 Western-Alpine origin to unknown-source coesite-bearing rocks unearthed at an archaeological site
53 nearby.

54 In this paper, we report a new occurrence of intact garnet-inclusions of coesite (10-60 μm) within
55 para-derivative micaschists belonging to the meta-ophiolitic suite of the Monviso Massif (MM) –
56 Western Alps. This discovery constrains the peak pressure conditions reached by the unit within the
57 coesite stability field, and possibly implies that ultrahigh-pressure metamorphism (UHPM) in the
58 Western Alps is more common than expected.

59 GEOLOGICAL BACKGROUND

60 The Western Alps (**Figure 1a**) represent part of an exhumed subduction complex (Bousquet et al.,
61 2008; Butler et al., 2013; Schmid et al., 2017) consisting of an assemblage of high (HP) and
62 ultrahigh-(UHP) pressure continent- (Adriatic and European margins) and ocean-derived units (i.e.,
63 Piedmont Zone, the former Tethys ocean). The UHP units cropping out in the Western Alps are
64 narrow lens-shaped bodies with a magnitude dimension within the ones of kilometre (Compagnoni
65 and Rolfo, 2003; Groppo et al., 2009; Manzotti et al., 2022) that strongly differ from the hundreds
66 to thousands of kilometres of the Norwegian Caledonides (e.g., Wain 1997) or the Dabie Shan (e.g.,
67 Rolfo et al. 2004).

68 To date, three UHP unit have been recognized with verified observations of UHP mineral
69 assemblages (**Figure 1a** for location): the Brossasco-Isasca (BIU, Chopin 1984) and the Chasteiran
70 units (CU, Manzotti et al., 2022) belonging to the continent derived Dora Maira Massif and the
71 Lago di Cignana Unit (LCU, Reinecke, 1991; 1998) within the ocean-derived Piedmont Zone. The
72 Brossasco-Isasca and the Chasteiran units consist respectively of a polymetamorphic continental
73 basement covered by a monometamorphic metasedimentary succession (e.g., Compagnoni and
74 Rolfo, 2003; Compagnoni et al., 2012) and of thin (few tens of metres thick) graphite-rich, garnet–
75 chloritoid micaschists (Manzotti et al., 2022). The Lago di Cignana Unit is made up of a meta-
76 ophiolitic basement covered by its thin oceanic metasedimentary succession (i.e. eclogite-facies

77 Piedmont Zone, [Groppo et al., 2009; 2019](#)). Peak P–T conditions for the Brossasco-Isasca Unit are
78 in the coesite–eclogite facies (diamond stability field, [Hermann, 2003; Groppo et al., 2019](#)): P=4.0-
79 4.3 GPa and T=730 °C. Peak P–T conditions for Lago di Cignana and Chasteiran units are in the
80 coesite-eclogite stability field as well, but at significantly lower Pressure: P=3.2 GPa, T=590-605
81 °C (Lago di Cignana Unit), P=2.7–2.8 GPa, T= 510–530 °C (Chasteiran Unit).

82 The Monviso Massif (MM, **Figure 1b**) consists of eclogite-facies units of the Piedmont Zone,
83 constituted by a meta-ophiolitic suite (i.e., serpentinized metaperidotite + Fe-Ti and Mg-Al
84 metagabbro) and covered by a discontinuous metasedimentary sequence. The latter mainly consist
85 of calcschist, with subordinate effusive metabasalt, quartzite, metapelites (i.e. micaschist), mafic
86 paraderivates and grey marbles along the basement\cover transition (e.g., [Lombardo et al., 1978;](#)
87 [Lombardo et al., 2002; Balestro et al., 2017; Ghignone et al., 2021, De Togni et al., 2021](#)). It is
88 subdivided in two tectono-metamorphic units (**Figure 1b**), which experienced different Alpine HP
89 eclogitic peaks: the Monviso Unit (MU), with P=2.1-2.2 GPa and T=480-500 °C ([Angiboust et al.,](#)
90 [2012](#)), and the Lago Superiore Unit (LSU), with P=2.6-2.8 GPa and T=530-550 °C ([Gilio et al.,](#)
91 [2020](#)). For further tectono-stratigraphic subdivision of the Monviso Massif see [Balestro et al.](#)
92 (2014).

93 The Lago Superiore and Lago di Cignana units show similarities in i) the lithostratigraphic setting
94 of the meta-ophiolitic suite, ii) the structural position within the Western Alpine belt, iii) the
95 tectonic and metamorphic relationships with the adjacent units (e.g., [Angiboust et al., 2012;](#)
96 [Balestro et al., 2017](#) and references therein).

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98

MATERIAL AND METHODS

99 The newly discovered coesite-bearing rocks belong to the metasedimentary succession of the Lago
100 Superiore Unit. BR12 sample (object of this study) was collected in the northern sector of the
101 Monviso Massif, at Colle del Baracun (high Pellice Valley; 44°46'23"N; 7°3'44"E; **Figure 1b** for

102 sample location; see [Festa et al., 2015](#); [Balestro et al., 2017](#) for a more detailed description of the
103 area).

104 Classical 30 μm -thick sections were used for optical microscope observations, while sections used
105 for μ -Raman investigations and microprobe (SEM-EDS) analysis are 300 μm -thick, doubled
106 polished and uncovered.

107 SEM-EDS analyses were performed to obtain point data, X-ray and high-resolution multispectral
108 quantitative maps of the entire thin section. Compositional data were collected using a SEM JEOL
109 IT300LV, EDS Oxford Instruments Inca Energy 200, X-act SDD detector. Working conditions
110 were $E=15$ kV, I probe = 5 nA, EDS process time=1 μs , 10^5 counts/s, livetime= 50 s (data points),
111 dwell time 5 μs , pixel live time 3000 μs , 126 frames (X-ray maps), dwell time 5 μs , pixel live time
112 400 μs , 226 frames (multispectral map). Multispectral maps (almost 4 x 2 cm) were quantified
113 through Quantmap (Aztec Suite, v.3.3).

114 Compositional point data were recalculated using the functions proposed by [Lanari et al. \(2014;](#)
115 [2019\)](#).

116 HORIBA instrument, coupled with a Jobin Yvon HR800 spectrometer and a CCD detector was
117 used for Raman measurements, equipped with a computer-controlled automated X–Y stage. A 532-
118 nm laser was focused onto specimens with a 100X microscope objective (N.A.=0.9) and Raman
119 shifted light was statically dispersed with 1800 groove/mm gratings. The spectrometer was
120 calibrated with a silicon standard. Spectral accuracy and linearity were checked throughout each
121 analytical session by measuring the 520.5 cm^{-1} Raman band of a silicon standard, and the Raman
122 bands of a synthetic quartz reference material. All Raman spectra were acquired for 30 s, 4
123 repetitions, and measured at room conditions, with a laser spot of 2 μm .

124 The P–T isochemical phase diagram (pseudosection modelling) approach was applied to the studied
125 sample. Bulk rock compositions (**Table 1**) were calculated by combining the mineral proportions
126 obtained from the quantitative modal estimate of SEM-EDS multispectral map with mineral
127 chemistry. Natural mineral standards were used to calibrate the raw data, by applying the ΦpZ

128 correction (Pouchou and Pichoir, 1988). The multispectral map of the entire thin section was used
129 to derive the effective bulk composition. Point analyses of each phase were recalculated as atoms
130 per formula unit (apfu). Representative SEM-EDS analyses are reported in **Table S1** for garnet
131 (core, mantle and rim), white mica (phengite and muscovite), chloritoid, albite, chlorite and biotite.
132 The fractionation effects on the bulk composition due to the growth of zoned garnet porphyroblasts
133 were considered. In particular, we removed the garnet core composition (5%, see below for details)
134 from the bulk. The pseudosection was then calculated to model the peak P–T conditions of the
135 measured bulk composition (MBC) minus the garnet core. It was computed in the system
136 MnNCKFMASH (MnO–Na₂O–CaO–K₂O–FeO–MgO–Al₂O₃–SiO₂–H₂O) using Perple_X 6.9.1
137 (Connolly, 1990, 2005, 2009), the internally consistent thermodynamic database of Holland and
138 Powell (2011) and the equation of state for H₂O of Holland and Powell (1998).
139 Fluid-saturated conditions were assumed, and the fluid was considered as pure H₂O (aH₂O = 1).
140 This last assumption is realistic for the studied sample, because of the large occurrence of hydrous
141 phases, and the absence of primary carbonates and sulphides. SiO₂ was considered as normal
142 component (not in excess), because of the low occurrence of quartz both in the matrix and in garnet
143 inclusions. Fe³⁺ was disregarded in the calculated pseudosections, because Fe³⁺-rich oxides are
144 absent and the amount of Fe³⁺ in the analyzed minerals is negligible. The occurrence of amorphous
145 carbon further confirms low oxidation conditions. However, we investigated the Fe³⁺ influence on
146 P–T calculation through the realization of isobaric T–X(Fe₂O₃) and isothermal P–X(Fe₂O₃)
147 pseudosections, reported in Supporting Information (**Figure S1 and S2**). The following solid
148 solution models were used: chlorite, chloritoid, garnet, white mica (White et al., 2014),
149 clinopyroxene (Green et al., 2007), amphibole (Green et al., 2016). Quartz, lawsonite, kyanite and
150 zoisite were considered as pure phases.

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PETROGRAPHY AND μ -RAMAN CHARACTERIZATION

153 The sample BR12 consists of a coesite-bearing garnet micaschist, collected within the oceanic
154 meta-sedimentary suite (e.g., Festa et al., 2015). The coesite-bearing garnet micaschist outcrop
155 within meter-thick discontinuous metapelitic levels showing different textural features, from fine-
156 grained (**Figure 2a, b**) to conglomeratic (**Figure 2c**) terms.

157 The analysed lithotype is characterized by a pervasive foliation, mainly defined by white mica,
158 wrapping garnet porphyroblasts (**Figure 3a**). The eclogitic assemblage consists of coesite (<1%),
159 garnet (~10%), phengite (~40%), chloritoid (~1%) and accessory rutile (~6%). Muscovite +
160 paragonite ± biotite and albite + muscovite + paragonite lozenge-shaped pseudomorphs (<1%) after
161 glaucophane and jadeite, respectively (see e.g., Chopin et al., 1991; Groppo et al., 2019), locally
162 occur in fractured garnets (**Figure 3b**). A retrograde mineral assemblage is represented by
163 muscovite (~20%), albite (~10%), chlorite (~4%), biotite (<1%) and accessory titanite (<1%). In
164 addition, minor amounts of amorphous carbon, quartz, apatite, zircon, allanite and opaque iron
165 oxides are observed. The larger garnet porphyroblasts (1-3 mm) hold a microfolded relict foliation
166 defined by amorphous carbon, chloritoid and minor white mica (**Figure 4b**). K-white mica is the
167 most abundant mineral in the sample, showing a strong zoning in phengite (Si = 3.40–3.65 apfu)
168 and muscovite (Si = 3.17–3.33 apfu). Chloritoid (XMg=0.17–0.23) occurs as 100–200 µm sized
169 inclusions within garnet, and is absent in the matrix. Chlorite (XMg=0.52–0.68) and biotite
170 (XMg=0.47–0.58) replace garnet along cracks and rims, but also locally occur in the matrix.
171 Together with paragonite, they also occur within lozenge-shaped pseudomorphs after glaucophane
172 (muscovite + paragonite ± biotite) and jadeite (paragonite + muscovite + albite; **Figure 3b**). Albite
173 (An₀₋₆) is quite abundant in the rock matrix, replacing former paragonite-rich domains. Quartz is
174 rarely present in the rock matrix (~1%). Conversely, quartz and coesite are relatively abundant as
175 inclusions in the garnet (**Figure 3c**). Lawsonite relicts (or paragonite + epidote pseudomorphs after
176 lawsonite) were observed neither in the matrix nor as inclusions in garnet. This observation is
177 confirmed by the very low amount of Ca in the bulk rock (see **Table 1**).

178 Quantitative X-Ray maps (**Figure 3d, e**) of two selected coesite-bearing garnet porphyroblasts
179 exhibit compositional zoning, characterized by three main concentric shells: a wide core (Alm₄₇₋₅₆
180 Sps₃₂₋₄₃ Prp₃₋₅ Grs₃₋₆), a discordant mantle (truncation plane in the syn-tectonic grow of
181 different garnet shells, *sensu* [Passcheier and Trouw, 2005](#), Alm₅₇₋₇₄ Sps₇₋₃₂ Prp₄₋₁₂ Grs₂₋₆) and
182 a relatively thin discontinuous rim (10-50 μm thick, Alm₄₈₋₆₆ Sps₁₆₋₂₃ Prp₁₋₉ Grs_{8h-23}). Such
183 concentric shells are well-shown in **Figure 3d**, representing a garnet cut through the core, while in
184 **Figure 3e** a non-equatorial cut through garnet (without the core) is reported. The compositional
185 profiles of the selected garnets are reported in **Figure 3f and 3g**. Spessartine decreases from core to
186 mantle with a typical bell-shaped profile, and then tends to slightly increase at the rim. The opposite
187 trend applies to almandine, which firstly increases and then decreases towards the rim. Pyrope and
188 grossular have relatively low abundances: pyrope slightly increases from core to mantle, whereas it
189 dramatically decreases at the rim; grossular roughly remains constant from core to mantle and
190 increases at the rim (**Figure 3f, 3g**).

191 Several mineral inclusions are present in the garnet, as detected via μ -Raman and microprobe
192 (**Figure 4a and 4b**; see **Table S1**). SiO₂ polymorphs, amorphous carbon, rutile and zircon were
193 found in each garnet shell. Chloritoid was detected in both the garnet core and mantle, as well as
194 glaucophane and jadeite pseudomorphs. SiO₂ inclusions occur as: i) monomineralic quartz
195 inclusions, ii) polycrystalline quartz inclusions, and iii) monomineralic coesite inclusions. Quartz
196 inclusions consist of 10-80 μm sized isolated crystals within non-fractured or re-equilibrated
197 portions of the garnets. Polycrystalline inclusions are 50-100 μm sized quartz aggregates,
198 surrounded by typical radial cracks filled by quartz and minor chlorite. Coesite inclusions consist of
199 10-60 μm sized monocrystalline grains surrounded by garnet (few tens of μm below the section
200 surface), with no quartz occurrence at the coesite-garnet interface (**Figure 4c, 4d**). Some inclusions
201 of coesite exhibit well developed facets (**Figure 4c**), while others show a more rounded shape
202 (**Figure 4d**). The presence of coesite is testified by μ -Raman analyses, considering and avoiding
203 possible artefacts or misidentification ([Keller and Ague, 2022](#)). The Raman spectra show the typical

204 peaks of coesite, with a shift of few cm^{-1} . The main peak is located at 522 cm^{-1} (instead of 521 cm^{-1})
205 1), and the secondary peaks at 426, 270 and 178 cm^{-1} (**Figure 4e**; **Table S2**, Boyer et al., 1985).
206 The quartz inclusions hosted in the garnet core are also affected by this shift. The main Raman peak
207 is at 471 cm^{-1} (instead of 464 cm^{-1}), and the secondary peaks occur at 134, 216, 355 and 394 cm^{-1}
208 (**Table S2**).

209

210

COESITE-RELATED METAMORPHIC CONDITIONS

211 The P–T isochemical phase diagram approach was applied to the analyzed sample (see above
212 Material and Methods for details). The pseudosection (**Figure 5**) is dominated by four-to-seven
213 variant fields. Garnet and white mica are predicted to be stable across the whole P–T region of
214 interest; lawsonite is stable at $T < 480 \text{ }^\circ\text{C}$ and chloritoid stability field is limited to $T < 530 \text{ }^\circ\text{C}$.

215 The observed coesite-related mineral assemblage (peak-P) consists of garnet mantle + phengite +
216 glaucophane + jadeite + rutile + coesite, and the vol. % of each modelled phase is reported in
217 **Figure 5**. Glaucophane and jadeite are not preserved, but their former occurrence in the peak-P
218 assemblage is testified by fine-grained pseudomorphs of muscovite + paragonite (\pm biotite) and
219 paragonite + muscovite + albite, respectively.

220 The peak-P assemblage covers a relatively narrow P–T range at $P > 2.7 \text{ GPa}$ and T between 490 and
221 $540 \text{ }^\circ\text{C}$, above the coesite/quartz transition (**Figure 5**). Further constraints are supplied by the
222 intersection of the compositional isopleths of the garnet mantle (average composition:
223 $\text{Alm}_{73}\text{Grs}_{4}\text{Prp}_{10}\text{Sps}_{13}$), which cross each other in a narrow P–T range, within the garnet +
224 phengite + chloritoid + glaucophane + jadeite + coesite field ($2.8\text{--}2.9 \text{ GPa}$ and $500\text{--}520^\circ\text{C}$, **Figure**
225 **5**). The modelled chloritoid compositional isopleths, corresponding to the highest measured XMg
226 values ($\text{XMg} = 0.20\text{--}0.22$), cross Grt isopleths in the same P–T range.

227 Because of the difficulties in assign the measured phengite compositions to a specific generation
228 (i.e. prograde or syn peak-P), the modelled phengite compositional isopleths were not used to
229 further constrain the peak P–T conditions.

230 The influence of Fe^{3+} on the calculated pseudosection was explored through the calculation of
231 isothermal (**Figure S1**) P–X(Fe_2O_3) and isobaric (**Figure S2**) T–X(Fe_2O_3) pseudosections.
232 X(Fe_2O_3) corresponds to $\text{Fe}_2\text{O}_3/(\text{Fe}_2\text{O}_3+\text{FeO})$. The P–X(Fe_2O_3) and T–X(Fe_2O_3) pseudosections
233 were calculated at 510°C and 2.8 GPa, respectively, that are the P–T conditions estimated for the
234 peak-P in the Fe^{+3} -absent system. Based on the observed stability field of the peak-P assemblage
235 (garnet + phengite + chloritoid + glaucophane + jadeite + coesite) and the garnet and chloritoid
236 isopleths, X(Fe_2O_3) which can be involved in the bulk is constrained at maximum values lower than
237 0.05. Overall, the results of the T–X(Fe_2O_3) and P–X(Fe_2O_3) pseudosections show that the P–T
238 conditions inferred in the Fe^{+3} -absent system is reliable, as confirmed by direct observation in the
239 mineralogical content.

240

241

DISCUSSION

242 The mineral inclusions preserved in the successive garnet shells reflect the three main metamorphic
243 stages of garnet growth and constrain the (U)HP metamorphic evolution of the Lago Superiore Unit
244 in the northern sector of the Monviso Massif. Quartz, chloritoid and rutile inclusions in the garnet
245 core demonstrate a first prograde stage compatible with HP conditions below the coesite/quartz
246 transition. A second stage, corresponding to the peak-P, with inclusions of coesite, chloritoid and
247 jadeite and glaucophane pseudomorphs in the garnet mantle, indicates UHP conditions above the
248 coesite/quartz transition. A third stage, related to a retrograde path still in HP conditions,
249 corresponds to the growth of garnet rims trapping quartz as inclusions. The pseudosection
250 constrains the peak-P above the coesite/quartz transition, giving P-T conditions of 2.8-2.9 GPa and
251 500-520 °C (**Figure 5**). These results, now supported by the direct observation of non-re-
252 equilibrated coesite (and polycrystalline quartz after coesite), confirm the Lago Superiore Unit peak
253 P-T estimates above the coesite/quartz transition, previously inferred from thermodynamic
254 modelling only ([Angiboust et al., 2012](#); [Gilio et al., 2020](#)). The slight T difference (~30°C) for
255 peak-P conditions, compared with previous P-T estimations for the Lago Superiore Unit ([Angiboust](#)

256 [et al., 2012](#); [Gilio et al., 2020](#)), may be the result of the effect of local bulk variations, or to different
257 stable mineral assemblage considered.

258 Our peak P-T estimation are remarkably similar to those obtained by [Manzotti et al. \(2022\)](#) for the
259 Chasteiran Unit (Dora Maira Massif), outcropping in a lower structural position respect to the meta-
260 ophiolites.

261 In addition, seen their peak P-T remarkable similarities (**Figure 6**), it is possible to attribute the
262 previously described unknown-source coesite-bearing rocks of [Groppo et al. \(2016\)](#) to the Lago
263 Superiore Unit, despite slight differences in mineralogical composition.

264

265

IMPLICATIONS

266 The “classic” coesite inclusions found in Western Alpine UHP units (e.g., [Chopin, 1984; 2003](#);
267 [Reinecke, 1991; 1998](#)) are typically relicts (> 80 μ m) that have only partially escaped re-
268 equilibration, occurring in polycrystalline quartz, with the typical palisade texture, or inside garnets
269 affected by radial cracks. Conversely, the coesite inclusions found in the Lago Superiore Unit occur
270 as intact single crystals (10-60 μ m) hosted by garnet. Possibly, due to their limited size, they
271 escaped re-equilibration and preserved the original features of the trapping time. Similar micro-
272 textures are described in the Lago di Cignana Unit by [Taguchi et al., \(2021\)](#), in the Chasterian Unit
273 by [Manzotti et al. \(2022\)](#) and by [Schönig et al. \(2022\)](#) in detrital coesite-bearing rocks deposited in
274 sedimentary basins worldwide. A consistent shift in the Raman spectra (**Figure 4e** and **Table S1**) is
275 found as a proof of the residual strain preserved in the elastic isolated inclusions ([Murri et al., 2018](#)
276 and references therein).

277 In this light, the polycrystalline quartz inclusions found in the studied sample are here interpreted as
278 re-equilibrated former coesite inclusions, affected by re-crystallization (i.e., palisade texture) and
279 radial cracks, similar to the ones observed and described in the Brossasco-Isasca, Chasteiran and
280 Lago di Cignana units.

281 In agreement with the interpretation of [Taguchi et al. \(2021\)](#), we thus infer that the different fate
282 (i.e., preservation or re-equilibration) of coesite inclusions could be influenced by the rheological
283 behaviour of the hosting mineral (e.g., [Mazzucchelli et al., 2018](#); [Zhong et al., 2020](#) and references
284 therein). At the coesite/quartz phase transition, the garnet likely behaved elastically in
285 correspondence of coesite inclusions of small size, while it exhibited a brittle behaviour (i.e., radial
286 cracks) at the contact with larger inclusions. The possible size-dependent preservation fate of
287 inclusions in garnet is a challenging topic and needs further deepening.

288 Within the tectono-metamorphic Western Alpine evolution, we have now evidence that the UHP
289 peak conditions reached at the Lago Superiore Unit are similar, along the same gradient, to those of
290 the Lago di Cignana Unit ([Groppo et al., 2009](#)), located ca. 100 km to the north. Between them, in
291 the Susa Valley, similar peak P-T conditions were calculated for the eclogite-facies meta-ophiolite
292 (SV, [Ghignone et al., 2021](#)), though direct coesite (or other UHP minerals) observations are lacking.
293 These units represent detached slices of the down-going Alpine Tethys oceanic slab (i.e. Piedmont
294 Zone), preserving internal stratigraphic coherency, currently tectonically sandwiched within the
295 eclogite-facies meta-ophiolites. This may thus point towards the hypothesis of a dismembered
296 coherent oceanic slab along the whole Western Alps ([Bucher et al., 2005](#); [Angiboust et al., 2012](#);
297 [Ghignone et al 2021](#)).

298 According with [Manzotti et al. \(2022\)](#), the Chasteiran Unit represent a sliced portion of the
299 european continental margin, now stacked within the Dora Maira Massif. The similar peak P-T
300 conditions with the Lago Superiore Unit testifies their similar tectono-metamorphic evolution,
301 likely sharing a common return point.

302 In this view, the Brossasco-Isasca Unit represents a *unicum* in the Western Alps, due to the strong
303 differences in the peak P-T conditions with respect to the other UHP units.

304 Newly discovered UHP units will surely renew the interest on debated and poorly understood
305 processes about the formation and the exhumation of UHP units. Their main common feature (i.e.

306 tiny lens-shaped) will be a crucial observation to take in account for further investigation on the
307 tectonic processes driving the present-day Western Alpine setting.

308

309

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318

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497

498 **FIGURE CAPTIONS**

499 **Figure 1:** a) Tectonic map of the Western Alps (modified after [Balestro et al., 2017](#), [Ghignone et](#)
500 [al., 2020](#), [Scaramuzzo et al., 2022](#) and [Manzotti et al., 2022](#)). Yellow stars indicate UHP coesite-
501 bearing unit locations: Lago di Cignana Unit (LCU), Brossasco-Isasca Unit (BIU) and Chasteiran
502 Unit (CU). Codes: Br: Briançonnais, DM: Dora Maira, GP: Gran Paradiso, MM: Monviso Massif,
503 PF: Penninic Front, SL: Sesia-Lanzo. b) Structural sketch map of the Monviso Massif (MM,
504 modified after Balestro et al. 2017

505

506 **Figure 2:**). Images of the outcropping coe-bearing rocks at the Colle del Baracun. a) Fine-grained
507 Grt-micaschist (44°46'19"N; 7°03'51"E). b) Metaconglomeratic term of the Grt-micaschist

508 (44°46'23''N; 7°3'44''E). c) Detail of the Grt-micaschist at the mesoscale (44°46'19"N;
509 7°03'47"E). We hope for a respectful behaviour for this outcrop and for the whole area.

510

511 **Figure 3:** a) BSE map of the BR12 section. b) Ab+Ms+Pg pseudomorphs after Jd. c) Microphoto
512 (Plane Polarized Light, PPL) of polycrystalline Qz showing typical palisade texture, with radial
513 cracks, in Grt mantle. d) and e) X-ray maps of two Coe-bearing garnets; map indicates molar
514 percent of spessartine (Xsps). f) and g) Compositional profile of the Grt in d) and e), respectively.
515 Red and yellow stars in all the figures indicate the position of Coe and polycrystalline Qz,
516 respectively. Mineral abbreviations after [Whitney and Evans \(2010\)](#).

517

518 **Figure 4:** a) and b) Microphotos of two Coe-bearing garnets, showing the microstructural position
519 of Coe and other inclusions in each Grt, in Plane Polarized Light (PPL). c) and d) Close-up images
520 in PPL of Coe inclusions in garnet. e) Raman spectra of the Coe inclusions of c) and d),
521 respectively. Peaks marked with the value (cm^{-1}) are assigned to coesite, while peaks marked with
522 asterisk are referred to garnet host mineral. Garnet marked peaks values (Sp80_1 spectrum): 349,
523 374, 503, 555, 632, 863, 916 and 1041 (cm^{-1}). Please note that 1041 cm^{-1} peak is shared between
524 garnet and coesite.

525

526 **Figure 5:** P–T pseudosection modelled for sample BR12 using the measured bulk composition
527 (Table 1) to constrain the P–T conditions for the growth of Grt mantle (peak-P).

528

529 **Figure 6:** Peak P-T conditions of the LSU (1a: Angiboust et al., 2012; 1b: Gilio et al., 2020; 1c:
530 Groppo and Castelli, 2010; 1d: Messiga et al., 1999) compared with LCU (2: Groppo et al., 2009),
531 SV (Susa Valley, 3: Ghignone et al., 2021), CU (4: Manzotti et al., 2022), BIU (5: Groppo et al.,

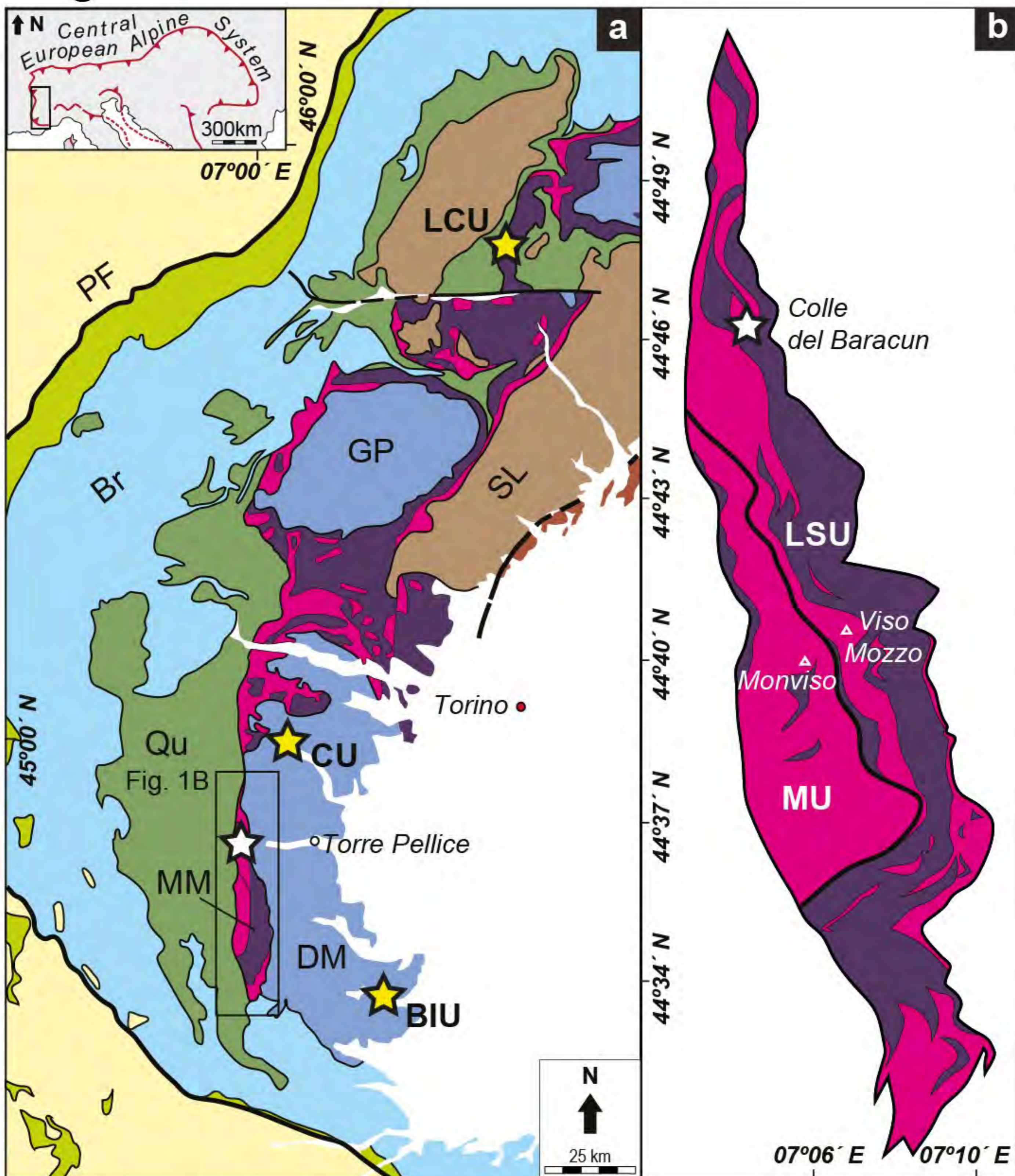
532 2019), and the unknown UHP Coe-bearing unit supposed by (6) Groppo et al. (2016). Red square
533 with the star indicates the position of the calculated peak P-T conditions for the LSU in this study.

534

535 **Table 1:** Effective bulk compositions (wt%) used to calculate the pseudosection for the BR12
536 sample.

<i>MBC = measured bulk composition (wt%);</i>										
<i>MBC-grt-C = effective bulk composition after fractionation of garnet core</i>										
<i>Bulk Type</i>	<i>SiO2</i>	<i>Al2O3</i>	<i>FeO</i>	<i>MnO</i>	<i>MgO</i>	<i>CaO</i>	<i>Na2O</i>	<i>K2O</i>	<i>tot</i>	
<i>BR12</i>	MBC-pr	64.30	16.02	6.71	0.60	4.91	0.24	1.73	5.49	100.00

Figure 1



Adria-derived continental Units

- Southern Alps Units
- Austroalpine s.l.

Tethys-derived meta-ophiolite Units

- Blueschist-facies Piedmont Zone
- a Eclogite-facies Piedmont Zone (a: covers, b: basement)
- b

Europe-derived continental Units

- Eclogite-facies Briançonnais Units
- Blueschist-facies Briançonnais Units

- Valaisan Ocean Unit

- Helvetic-Dauphinois Units

- Faults and contacts
- Coesite-bearing UHP terrains
- Sample location of this study

Figure 2

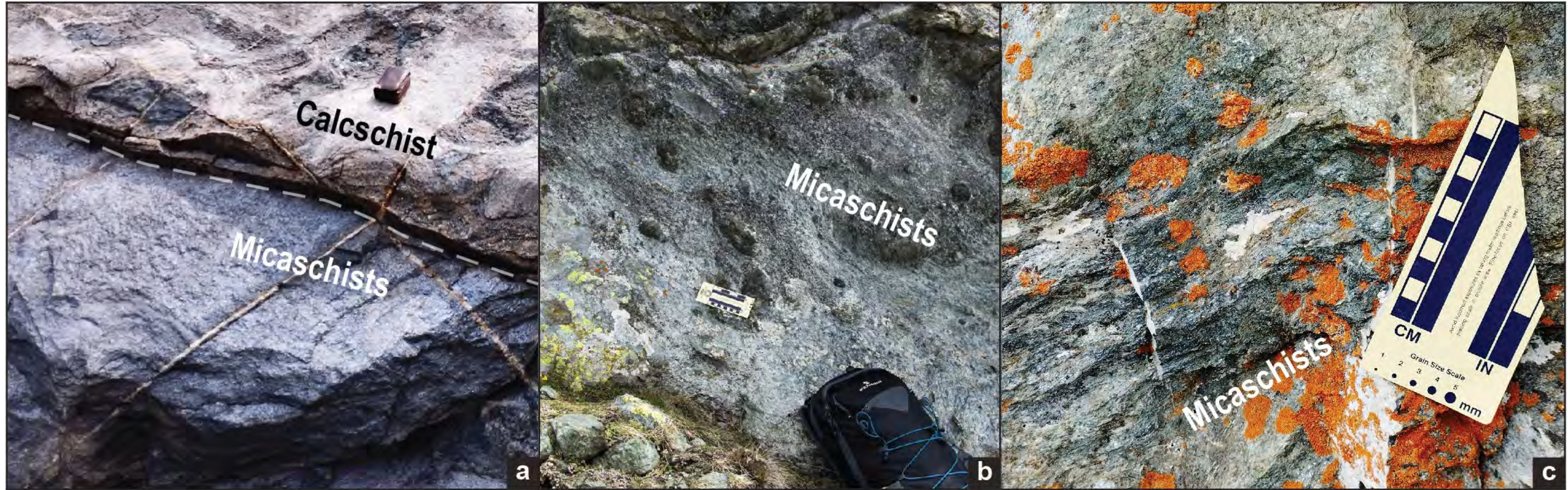


Figure 3

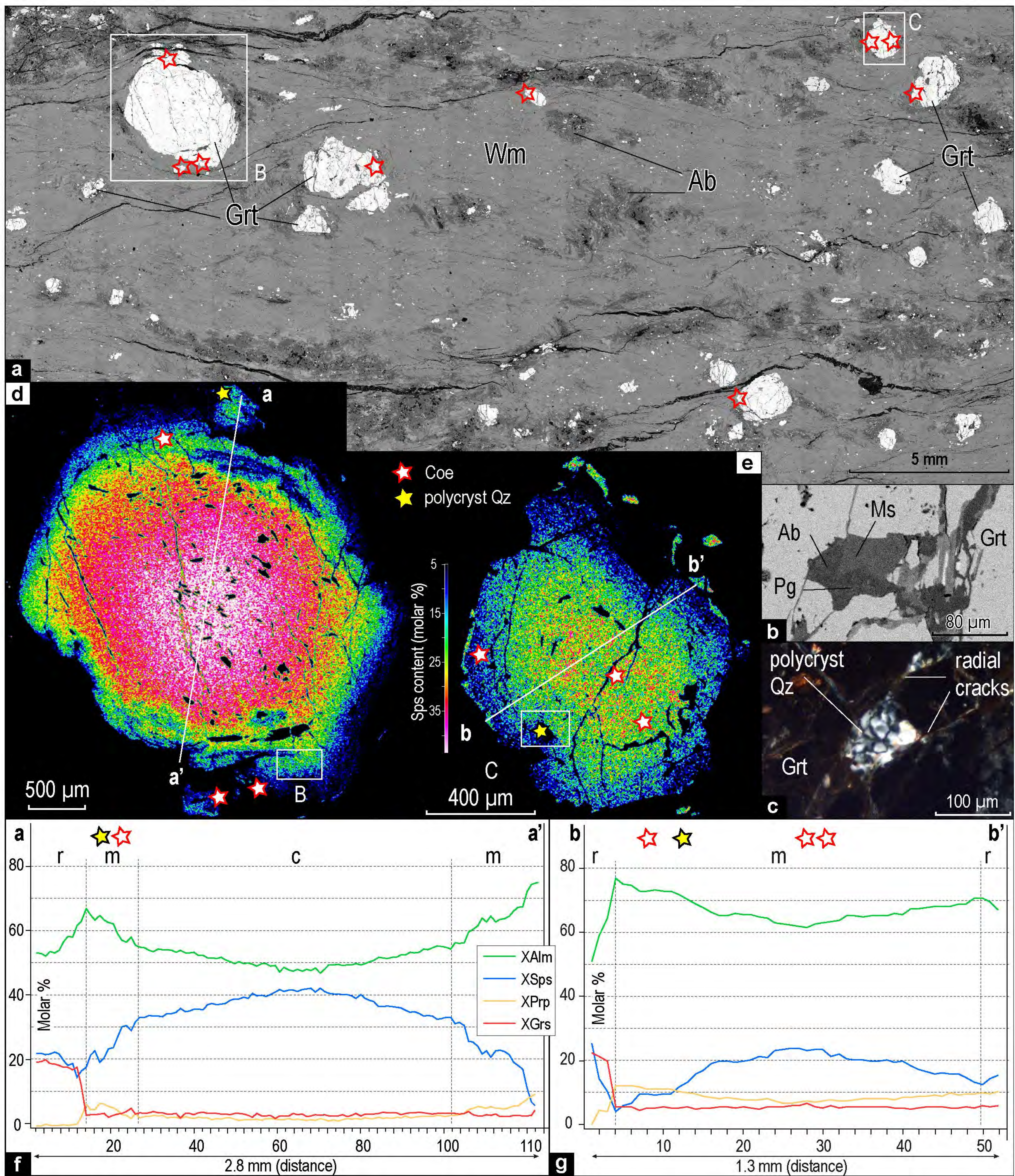


Figure 4

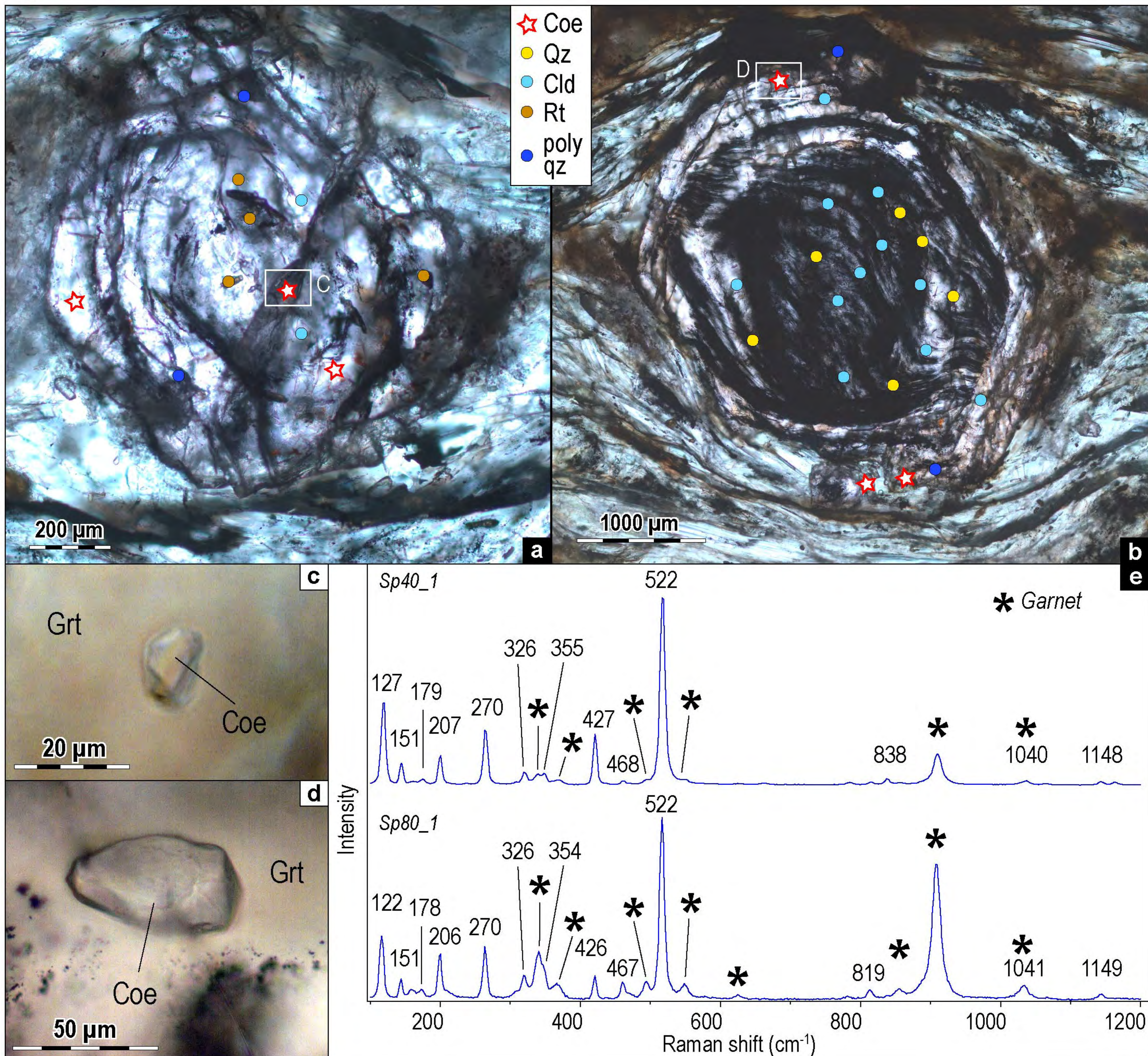


Figure 5

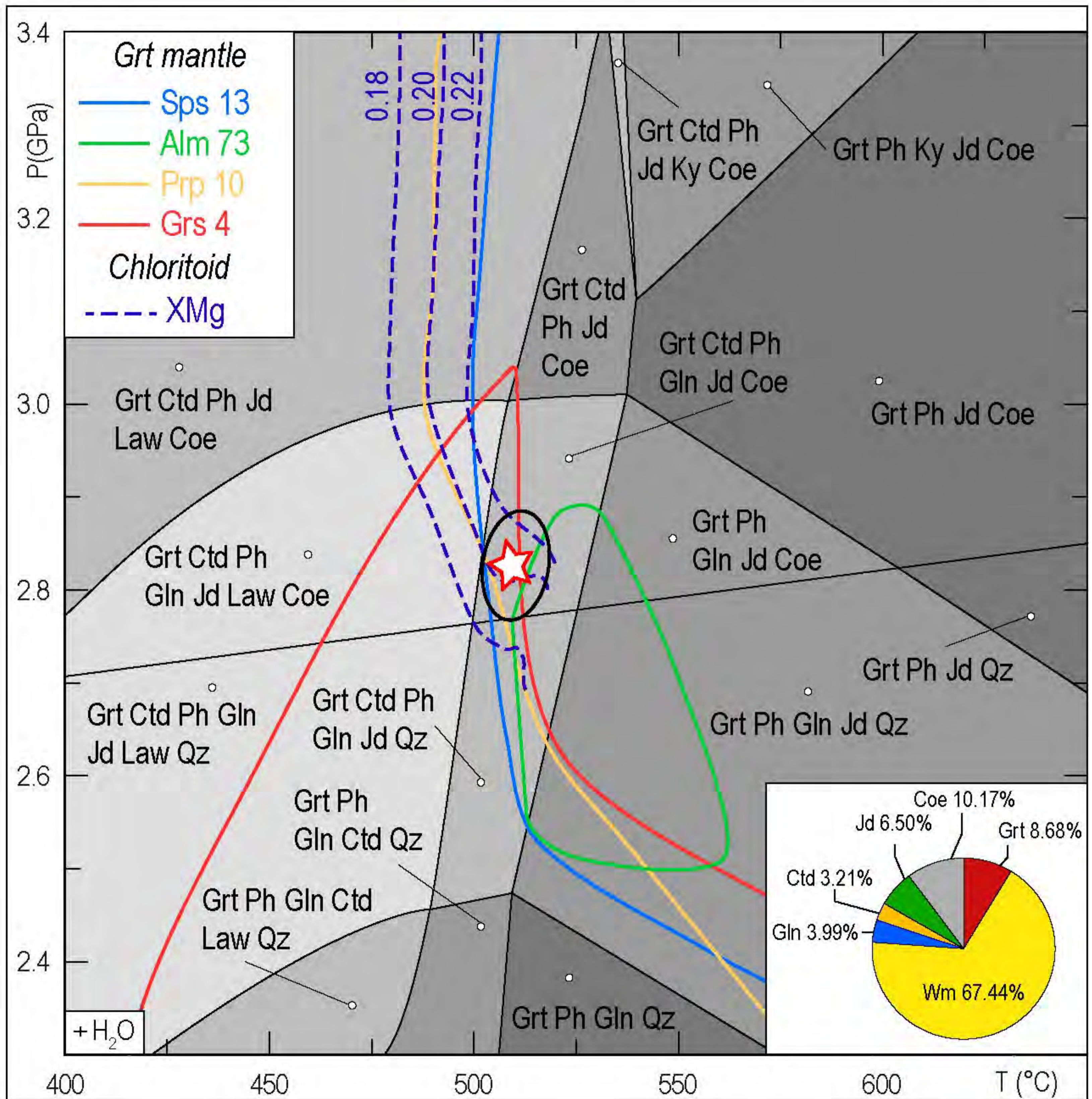


Figure 6

