



Carboniferous tectono-metamorphic evolution of the Variscan crust in the Belledonne-Pelvoux area.

Kévin Fréville, Pierre Trap, Jonas Vanardois, Jérémie Melletton, Michel Faure,
Olivier Bruguier, Marc Poujol, Phillippe Lach

► To cite this version:

Kévin Fréville, Pierre Trap, Jonas Vanardois, Jérémie Melletton, Michel Faure, et al.. Carboniferous tectono-metamorphic evolution of the Variscan crust in the Belledonne-Pelvoux area.. Bulletin de la Société Géologique de France, In press, 10.1051/bsgf/2022008 . insu-03678397v1

HAL Id: insu-03678397

<https://insu.hal.science/insu-03678397v1>

Submitted on 25 May 2022 (v1), last revised 22 Aug 2022 (v2)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

1 **Carboniferous-Permian tectono-metamorphic evolution of the Pelvoux massif (External**
2 **Crystalline Massif, Western Alps), with discussion on flow kinematics of the Eastern-**
3 **Variscan Shear Zone.**

4
5 **Évolution tectono-métamorphique Carbonifère-Permien du massif du Pelvoux (Massif**
6 **cristallin externe, Alpes occidentales), avec discussion sur la cinématique de fluage de la**
7 **zone de cisaillement Est Varisque.**

8
9 **Kévin Fréville^{1,2,3}, Pierre Trap², Jonas Vanardois², Jérémie Melletton³, Michel Faure¹, Olivier**
10 **Bruguier⁴, Marc Poujol⁵, Philippe Lach³**

11
12 ¹ UMR 7327, Institut des Sciences de la Terre d'Orléans, Université d'Orléans, CNRS, 45071
13 ORLEANS Cedex 2, France.

14 ² UMR 6249 Chrono-environnement, Université de Franche-Comté, 16 route de Gray, 25030
15 Besançon Cedex, France

16 ³ BRGM-French Geological Survey, 3 Avenue Claude Guillemin, 45100, Orléans, France.

17 ⁴ Géosciences Montpellier, Université de Montpellier, CNRS, Place Eugène Bataillon, 34095
18 Montpellier Cedex 5, France

19 ⁵ Univ. Rennes, CNRS, Géosciences Rennes -UMRS 6118, F-35000 Rennes, France
20 Corresponding author: kevin.freville@gmail.com

21
22 **Keywords:** Variscan belt, Western Alps, Belledonne-Pelvoux, East-Variscan Shear Zone,
23 migmatite, transpression.

24
25 **Mot clés :** Chaîne Varisque, Alpes Occidentales, Belledonne-Pelvoux, Zone de Cisaillement
26 Est varisque, migmatite, transpression.

27

28

29

30

31

32

33

34 **Abstract**

35
36 Based on new structural, petrological and U-Th-Pb geochronological data, a reappraisal of the
37 Variscan tectono-metamorphic history of the Pelvoux massif (External Crystalline Massif,
38 French Alps) is proposed with the aim to understand the flow pattern and kinematics of the
39 Variscan partially molten crust and the Eastern Variscan Shear Zone. The Pelvoux massif
40 consists of high-grade metamorphic rocks of middle to lower crust, mostly migmatites, that
41 record a prominent syn-metamorphic deformation event (D_2) characterized by a pervasive NE-
42 SW striking, steeply dipping, S_2 foliation, and a network of anastomosed NS and NW-SE
43 trending shear zones, the kinematics of which indicates a sinistral transpression. Relics of an
44 early synmetamorphic event (D_1/M_1) related to crustal thickening and top-to-the east nappe
45 stacking are also reported. Both the D_1 and D_2 features are interpreted as reflecting a NW–SE
46 shortening event, firstly marked by dominant nappe stacking, and secondly overprinted by a
47 sinistral transpression that started at peak metamorphism with the onset of crustal partial
48 melting at ca. 650°C during the late Visean (ca 335–330 Ma). Ongoing sinistral D_2 transpression
49 in the partially molten middle-lower crust of the Pelvoux involved strain partitioning between
50 C and C' shear zones and horizontal longitudinal flow in the range 330–300 Ma. Along the
51 anatetic front, vertical shortening and top-to-the NW shearing (D_3) is coeval with D_2 and argue
52 for south-eastward motion of the partially molten crust. The contemporaneity between NW-SE
53 directed transpressional flow and vertical shortening is supported by our radiometric data of D_2
54 and D_3 and attests for strain partitioning between the suprastructure and infrastructure during
55 horizontal crustal flow under transpressive regime. The exhumation of deep-seated rocks during
56 sinistral transpression followed a near isothermal (ca. 700 °C) evolution down to pressure of
57 ca. 0.5 GPa in the period 325–306 Ma. The sinistral transpression recorded in the Pelvoux massif
58 might corresponds to an antithetic shear zone coeval with the dextral East-Variscan Shear Zone,
59 proposed for this part of the Variscan orogen.

60

61

62 **Résumé**

63

64 Sur la base de nouvelles données structurales, pétrologiques et géochronologiques U-Th-Pb,
65 une réévaluation de l'histoire tectono-métamorphique varisque du massif du Pelvoux (Massif
66 cristallin externe, Alpes françaises) est proposée dans le but de comprendre le style et la
67 cinématique du fluage de la croûte varisque partiellement fondu et de la Zone de

68 Cisaillement Est Varisque. Le massif du Pelvoux est constitué de roches métamorphiques de
 69 haut grade, de la croûte moyenne à inférieure, principalement des migmatites, qui enregistrent
 70 un événement de déformation syn-métamorphique prédominant (D_2) caractérisé par une
 71 orientation NE-SW, une foliation S_2 à fort pendage et un réseau anastomosé de zones de
 72 cisaillement d'orientation NS et NW-SE dont la cinématique indique une transpression
 73 senestre. Des reliques d'un événement synmétamorphique précoce (D_1/M_1) lié à
 74 l'épaississement de la croûte et à l'empilement des nappes à vergence Est sont retrouvées. Les
 75 caractéristiques de D_1 et D_2 sont interprétées comme reflétant un événement de
 76 raccourcissement NW – SE, d'abord marqué par l'empilement dominant des nappes, qui
 77 évolue ensuite en une transpression senestre, initiée au pic du métamorphisme avec le début
 78 de l'anatexie crustale dès 650°C, à la fin du Viséen (335-330 Ma). Dans la croûte
 79 partiellement fondu, la déformation transpressive senestre D_2 se partitionne avec la
 80 formation de zones de cisaillement C et C' qui accommodent le fluage longitudinal entre 330
 81 et 300 Ma. Le long du front anatectique, un raccourcissement vertical accompagné d'un
 82 cisaillement vers le NW (déformation D_3) sont contemporains de D_2 et participent aussi à
 83 l'échappement vers le sud-est de la croûte partiellement fondu. La contemporanéité entre le
 84 fluage transpressif dirigé NW-SE (D_2) et le raccourcissement vertical à cinématique NW (D_3)
 85 est étayée par nos données radiométriques. L'exhumation des roches profondes lors de la
 86 transpression senestre a suivi une évolution quasi isotherme (~ 700 ° C) jusqu'à une pression
 87 d'environ 0,5 GPa dans la période 325-306 Ma. La transpression senestre enregistrée dans le
 88 massif du Pelvoux pourrait correspondre à une zone de cisaillement antithétique
 89 contemporaine de la zone de cisaillement dextre Est-Varisque.

90

91 1. Introduction

92 Together with the Maures-Corsica-Sardinia massifs, the External Crystalline Massifs
 93 (ECMs), exposed in the Helvetic zone of the Western Alpine belt represent the Eastern Branch
 94 of the Variscan orogen (Fig. 1). In spite of several geodynamic interpretations (Corsini &
 95 Rolland, 2009; Faure et al., 2014; Faure and Ferrière, 2022; Fernandez et al., 2002; Guillot &
 96 Ménot, 2009; Oliot et al., 2015; Rossi et al., 2009; Von Raumer et al., 2013), the timing of the
 97 main tectono-metamorphic events in the ECMs, and the correlations between these massifs
 98 remain poorly constrained mainly because of a strong imprint by late-orogenic transpressional

99 tectonics during Carboniferous time and intense partial melting and plutonism in the mid-lower
100 crust at that time. Widespread Carboniferous crustal partial melting in response to thermal
101 relaxation (i.e. Alcock et al., 2015; Barbey et al., 2015; Villaros et al., 2018) triggered horizontal
102 flow of the lower and middle crust (Vanderhaeghe et al., 2020, Cochelin et al., 2017) and strain
103 partitioning along strike-slip shear zone and exhumation of migmatitic domes (Vanderhaeghe
104 et al., 1999; Ledru et al., 2001). In the ECMs, the structural and kinematic feature associated
105 with partial melting and magmatism are still elusive.

106 The Eastern Crystallin Massifs (ECMs) stand out as a complex portion of the European
107 Variscan Belt that was built along a major crustal-scale wrenching corridor, named the East
108 Variscan Shear Zone EVSZ (Fig. 1A; EVSZ; Carosi et al., 2012; Corsini & Rolland, 2009;
109 Guillot & Ménot, 2009; Padovano et al., 2012, 2014; Rolland et al., 2009; Simonetti et al.,
110 2018). The EVSZ is considered as the main structure that accommodated the shaping of the
111 variscan eastern orocline (Fig. 1A; Ballèvre et al., 2018; Bellot, 2005; Matte, 2001). A series
112 of multidisciplinary studies have provided many structural, petrological, and radiometrical data
113 in that part of the East Variscan branch that was affected by the EVSZ (Guillot and Menot,
114 2009), i.e. the Aiguilles-Rouges and Mont-Blanc massif (Von Raumer et al., 2013; Von Raumer
115 and Bussy, 2004, Simonetti et al., 2020a), the Belledonne-Pelvoux massifs (Guillot and Menot,
116 2009), the Argentera Massif (Simonetti et al., 2018, 2021), the Maures-Tanneron massif
117 (Rolland et al., 2009, Schneider et al., 2014; Gerbault et al., 2018, Simonetti et al., 2020b), and
118 Sardinia (Carosi et al., 2012) showing that the EVSZ was responsible for complex strain
119 partitioning in time and space during Carboniferous. Simonetti et al. (2020a) proposed the first
120 detailed picture of the EVSZ with the position, orientation and kinematics of the major branches
121 constituting the regional-scale anastomosed system (Fig. 1B). Because not all ECMs are
122 considered in the EVSZ system, the location, thickness and internal strain pattern of the EVSZ
123 remains elusive as well as the variations of strain regimes and kinematics that are expected to
124 exist at lithospheric scale.

125 In this contribution we focus on the Belledonne-Pelvoux area that is a large but still poorly
126 understood portion of the ECMs, and absent from the reconstruction of the EVSZ anastomosed
127 system (Fig. 1B). The Pelvoux massif displays a well exposed section of the late-Variscan low
128 and middle crust mainly composed of migmatites and granites formed in response to a crustal
129 melting event developed at the end of a HT low-to-medium pressure Carboniferous
130 metamorphism (Pecher, 1970; Le Fort, 1973). There, a sinistral kinematics was documented
131 (Strzerynski et al., 2005) making it unique in the transpressive framework of the ECMs where

132 dextral shearing dominates (Carosi et al., 2012; Corsini & Rolland, 2009; Guillot & Ménot,
 133 2009; Padovano et al., 2012, 2014; Rolland et al., 2009; Simonetti et al., 2018, 2020a).

134 Presently, the Pelvoux massif lacks large-scale structural analysis combined with
 135 quantified tectono-metamorphic evolution using modern petrological methods. Simonetti et al.
 136 (2018; 2020a, 2020b) suggested that dextral transpression in the ECMs was initiated at ca. 320
 137 Ma with the exception of the Argentera massif where it could have started at ca. 330-340 Ma.
 138 In the Pelvoux massif, rare geochronological data document the protolith age of some
 139 orthogneiss, but the syn-metamorphic deformation is still undated. A study of the Pelvoux
 140 massif will help integrating the sinistral kinematics in the general framework of the dextral
 141 transpression model of the EVSZ (e.g. Simonetti et al., 2020a) and of the whole Variscan belt
 142 (e.g. Ballèvre et al., 2018; Edel et al., 2018).

143 In this article, we present (i) the detailed finite strain pattern at the transition from the upper
 144 crust and the former partially molten crust that crops out in the Pelvoux massif and (ii)
 145 microstructural, petrological and geochronological analyses on samples from the unmolten and
 146 molten crust. These results allow us to discuss (i) the P-T-D-t evolution recorded in some high-
 147 grade metamorphic rocks; (ii) the geometrical and temporal relationships between deformation,
 148 metamorphism, partial melting, and magma emplacement; (iii) the kinematics of ductile flow
 149 in the mid-crust. Our findings are compared to those recently obtained on the adjacent
 150 Belledonne massif by Fréville et al. (2018) and Jacob et al. (2021) and enable us to propose a
 151 tectono-metamorphic evolution model of the Pelvoux that may represent an antithetic branch
 152 of the EVSZ.

153

154 **Geological setting.**

155

156 *2.1. Overview of the Variscan Belt in the Alpine Crystalline massifs*

157 The Variscan belt formed in response to collision between Gondwana and Laurussia
 158 continents, and several Gondwana-derived microcontinents during the Late Devonian to Early
 159 Carboniferous (Fig. 1A), ([Autran and Cogné, 1980](#); [Paris and Robardet, 1990](#); [Franke, 2000](#);
 160 [Tait et al., 1997, 2000](#); [Matte, 1991, 2001, 2007](#); [Von Raumer et al., 2003](#); [Faure et al., 2005](#);
 161 [Stampfli et al., 2013](#)). From Late Visean to Early Permian, thermal relaxation and mafic to
 162 felsic plutonism enhanced a widespread partial melting of the thickened low-middle crust, that

163 modified gravity vs boundary stress balance and enhanced a complex intracontinental strain
 164 partitioning in a global transpressive regime (e.g. Rabin et al., 2015; Cochelin et al., 2017; Henk
 165 et al., 2000).

166 In its present geometry, the External Crystalline Massifs (ECMs) of the Alps form an
 167 arcuate, concave to the East, branch of the Variscan belt that includes, from North to South, the
 168 *Aar-Gothard, Aiguilles Rouges-Mont Blanc, Belledonne, Grandes Rousses, Pelvoux, and*
 169 *Argentera* massifs (Fig. 1B) (e.g. Barfety et al., 2000; Guillot and Ménot, 2009). A first-order
 170 three-fold subdivision, previously proposed by Bordet and Bordet (1963), and Guillot and
 171 Ménot (2009) (Fig. 1B), defines the Western, Central and Eastern domains.

172 The Western domain consists of slightly metamorphosed micaschists and
 173 metagreywackes considered as a turbiditic series of Ordovician age (Bordet and Bordet, 1963;
 174 Fréville et al., 2018). The central domain, including the SW part of the Aiguilles Rouges, the
 175 SW part of Belledonne massifs, and the western part of the Pelvoux massif or Cortical Pelvoux
 176 area (Le Fort, 1973; Fig. 2) is made of a stack of several litho-tectonic units, namely from top
 177 to bottom: (i) the Cambro-Ordovician Chamrousse ophiolite (Carme, 1965a; Carme, 1965b;
 178 Carme, 1970; Bodinier et al., 1981; Ménot, 1987; Pin and Carme, 1987; Ménot, 1988a; Ménot,
 179 1988b); (ii) an amphibolitic facies gneiss, micaschists and volcano-sedimentary rocks (VSU,
 180 *Riouperoux-Livet* and *Allemont* units) overlain by (iii) a weakly metamorphosed and
 181 deformed conglomerate, black schist, and acidic volcanic rocks, named the *Taillefer* unit
 182 (Gibergy, 1968; Ménot, 1988; Fréville et al. 2018).

183 The Eastern part of the ECMs consists of high-grade rocks of the mid-lower crust with
 184 migmatites enclosing several lenses of HP granulites and retrogressed eclogites that crop out in
 185 the *Argentera* massif, the Inner Pelvoux area, the NE Belledonne area, the major part of the
 186 *Aiguilles Rouges-Mont Blanc* massif, and the *Aar-Gothard* massif. (Fig. 1B, Paquette et al.,
 187 1989; Abrecht and Biino, 1991; Lombardo et al., 1997; Von Raumer and Bussy,
 188 2004; Ferrando et al., 2008; Compagnoni et al., 2010; Rubatto et al., 2010; Jacob et al., 2021).
 189 These three crustal domains are juxtaposed along the Synclinal-Median Fault (SMF) and the
 190 Rivier-Belle Etoile Fault (RBEF, Fig. 1B)

191

192 2.2. Impact of the post-variscan reworking in the Belledonne-Pelvoux area

193

194 The Jurassic rifting, coeval with the opening of the Liguro-Piemonte ocean, was
 195 responsible for the development of brittle normal faults associated with the local tilting of the
 196 Paleozoic basement. It was responsible for the individualization of several Liassic blocks. These

197 are the *La Mure* and *Le Taillefer* blocks within the Belledonne massif, and *Le Rochail*,
 198 *L'Emparis*, *La Meije*, and *Le Combeynot* blocks in the Pelvoux massif (Fig. 2) (Lemoine et al.,
 199 1986; Barfety et al., 1988; Lemoine, 1988). The Miocene Alpine deformation inverted the
 200 Jurassic normal faults and was responsible for the development of localized NW-SE trending
 201 shear zones with a top-to-the NW ductile shearing (Bellahsen et al., 2014; Bellanger et al., 2014,
 202 2015; Boutoux et al., 2014). The Alpine shortening in the Paleozoic basement was coeval with
 203 a weak metamorphic overprint in the prehnite-pumpellyite to greenschist facies. Outside these
 204 localized Alpine shear zones, the markers of the Pre-Alpine tectono-metamorphic events are
 205 particularly well-preserved in the Belledonne-Pelvoux area.

206

207 2.3. Summary of previous P-T-t data on the Pelvoux Massif

208

209 In the literature, the Pelvoux massif is described as two-fold, with the Cortical and the
 210 Inner Pelvoux domains, the boundary of which is mainly reworked by alpine faulting (Le Fort,
 211 1973). The Cortical Pelvoux, located in the western part, consists of an alternation of
 212 volcaniclastic rocks and micaschists with migmatitic gneisses at the base of these series (Fig.
 213 2). Barrovian metamorphism is attested by kyanite-staurolite bearing micaschists documented
 214 in the Cortical Pelvoux (Le Fort, 1973) but quantitative thermobarometric estimates are not
 215 available. In the adjacent SW Belledonne, a MP-HT barrovian metamorphism (M_1) is
 216 documented with P-T conditions at ca. 0.5-0.6 GPa, 600 °C, recorded in staurolite-bearing
 217 micaschists and up to ca. 0.8 GPa, 680 °C for the migmatitic gneiss in lowest unit (Guillot and
 218 Ménot, 1999; Fernandez et al., 2002; Fréville et al., 2018). The M_1 metamorphism is coeval
 219 with a D_1 deformation characterized by the development of a westward dipping foliation S_1 and
 220 E-W stretching L_1 lineation interpreted as an eastward nappe stacking event (Fréville et al.,
 221 2018). At upper structural level in the Cortical Pelvoux, a series of micaschists and
 222 volcaniclastic rocks is overlain by black schists and conglomerates, similar to the *Taillefer* unit
 223 observed in SW Belledonne (Barfety et al., 2000; Guillot and Ménot, 2009) (Fig. 2).

224 The Inner Pelvoux is composed of i) migmatites that developed through partial melting
 225 of paragneiss, orthogneiss and amphibolite, and ii) several generations of granitoids (Pecher,
 226 1970; Le Fort, 1973). Some mafic lenses (e.g. *Peyre-Arguet*, Fig. 2) within migmatitic
 227 paragneiss record amphibolite facies P-T conditions of 0.7 ± 0.1 GPa, 650 ± 50 °C, and a low-
 228 pressure granulite facies of 0.5 ± 0.1 GPa, 800 ± 50 °C, followed by a retrogressive evolution
 229 in the greenschist facies conditions (Grandjean et al., 1996). Granulitic conditions have also

been inferred from the migmatitic gneiss (Pecher, 1970; Pecher and Vialon, 1970) but without any phase diagram quantification. Two episodes of partial melting are recognized with a first low-temperature, cordierite-free migmatite, and a high-temperature – low-pressure, cordierite-bearing migmatite (Bogdanoff et al., 1991). In the Inner Pelvoux, the foliation is mostly steeply dipping to vertical, but superimposed deformation has been invoked (Pecher, 1970; Le Fort, 1973) and the relationships between partial melting and deformation are still unclear.

Two groups of granitoids are distinguished, namely two-mica granites and monzonitic granites (Barféty et al., 1982; Debon and Lemmet, 1999). Presently, only the two-mica Rochail and Combeynot granites, and the Turbat-Lauranoure monzonite have been dated with proposed emplacement age at 343 ± 11 Ma, 312 ± 7 Ma and 302 ± 2 Ma, respectively (U-Pb on zircon; Canic, 1998; Guerrot and Debon, 2000). N-S to NW-SE striking, syn-magmatic sinistral C-S fabrics are described in granitic plutons (Strzerynski et al., 2005) but the geometrical and kinematic relationships with their migmatitic host rocks are poorly understood.

243

244 3. Structural analysis

245

246 3.1. Strain patterns in the metamorphic and migmatitic pile

247

248 At the scale of the entire Pelvoux massif, field observations show that the dominant
249 macroscopic ductile structure is a steeply dipping foliation, ascribed here to the D₂ event (Fig.
250 3 and 4). Due to its pervasive character, the D₂ event will be presented first.

251

252 3.1.1 The D₂ submeridian sinistral shearing

253

254 The majority of this D₂ planar structure is represented by a gneissic (i.e. solid-state
255 deformation), and a migmatitic foliation (i.e. suprasolidus deformation). It ranges from NW-SE
256 to NE-SW with the occurrence of three main directional populations: ~N30°E, ~N140°E and
257 ~N170°E (Figs. 3 and 4). The ~N30°E foliation is less represented than the two other directions
258 and is referred to as S₂ in the following. S₂ is axial planar to upright folds F₂ that deforms an
259 earlier weakly dipping S₁ foliation (see below). S₂ developed in response to an E-W to NW-SE
260 bulk shortening (Figs. 5A and 5B). In the Inner Pelvoux, S₂ consists of a migmatitic layering
261 that almost totally transposes S₁ that is only preserved within F₂ folds hinges (see next
262 paragraph and Fig. 5C).

263 The two most developed D₂ planar fabrics are striking N170°E and N140°E with a high
 264 ($>70^\circ$) dip angle (Fig. 3). Both sets show melt-present and solid-state deformation features (Fig.
 265 5D). When the three directional populations of planar fabrics, i.e. ~N30°E, ~N140°E and
 266 ~N170°E are observed on the same outcrops, the cross-cutting relationships clearly indicate
 267 that the ~N170°E planar surface is a shear plane that reworks the ~N30°E directed foliation,
 268 and that both ~N30°E and ~N170°E trending planar surfaces are reworked by the ~N140°E
 269 shear zone, as portrayed in Figure 7.

270 In the northern and eastern portions of the Emparis and La Meije Blocks, the N170°E
 271 trending and highly penetrative planar surface forms 100 meters to several kilometers wide
 272 shear zones (Figs. 3 and 4) along which a southward low-angle plunging L₂ stretching lineation
 273 is observed (Fig. 3B). A sinistral kinematics is deduced from the observation of sigmoidal
 274 minerals or aggregates and the deflection of S₂ (Figs. 3, 5E, 5F, 6A). In the southern part of the
 275 Pelvoux massif, similar meter to kilometers sized sinistral high-strain corridors strike mostly
 276 ~N140°E (Fig. 3). Where the NW-SE planar fabric becomes preponderant, the N-S surface is
 277 only preserved within centimeter to meter scale lenticular bodies (Fig. 7A). The mineral and/or
 278 stretching lineations are rarely observed; but when it is the case, they are sub-horizontal or
 279 moderately plunging (Fig. 3). In some places, within stromatic migmatite, the oblate shape of
 280 mafic restites suggests that flattening strain without the development of a preferred stretching
 281 direction was dominant (Fig. 6B). At the outcrop scale, some conjugate dextral and sinistral
 282 shear bands are also observed (Fig. 6C). Considering the geometric and kinematic features of
 283 the D₂ structures, it appears that the N170°E and N140°E planar surfaces might be considered
 284 as C₂ and C'₂ shear planes that developed synchronously with S₂ in a bulk sinistral strike-slip
 285 regime. This S₂, C₂, C'₂ anastomosing system is observed from kilometer to meter scale (Figs.
 286 3). The presence of leucosome within the S₂, C₂ and C'₂ shear bands attests for the onset of D₂
 287 in a partially molten rock, under supra-solidus conditions (Fig. 5). Diatexit commonly shows
 288 rafts and schollens with a high aspect-ratio parallel to the migmatitic foliation arranged either
 289 on the C₂ or C'₂ trends (Figs. 6D, 6E and 6F). In some places, cm-scale elongated cordierite
 290 aggregates are preferentially aligned along C₂ and C'₂ planes (Fig. 6F) indicating that low-
 291 pressure/high-temperature partial melting was coeval with the D₂ sinistral strike-slip. The D₂
 292 planar surface is also reported within garnet-bearing amphibolites (Fig. 7B) that are interpreted
 293 as retrogressed HP granulites ([Grandjean et al., 1996](#)).

294

295 3.1.2 The relictual D₁ structure

296

297 The D₂ anastomosed system reworks a nearly horizontal or westward shallowly dipping
 298 early foliation, named S₁ (Figs. 3 and 4). Within the Inner Pelvoux, the relictual S₁ foliation
 299 corresponds to a gneissic layering and lithological alternations, the attitude of which marks
 300 large scale F₂ folds. This is exemplified by the attitude of the La Lavey amphibolite formation
 301 in the La Meije block where a low angle (20-40°) S₁ foliation is observed (Fig 3). In the Inner
 302 Pelvoux, the S₁ foliation only remains as isolated F₂ fold hinges (Figs. 5A and 5B). In the
 303 Cortical Pelvoux, a S₁ gneissic layering with a low-angle dip is also recognized. It is worth
 304 noting that L₁ lineation is very rare with no clear preferred direction. Generally, the
 305 superimposition of S₂ and S₃ over S₁ makes the latter difficult to depict in the outcrop. Relics
 306 of S₁ are best recognized at the cm-scale (thin section) (Fig. 8B).

307

308 3.1.3 Late horizontal shearing: D₃ structure

309 A flat-lying foliation (S₃) superimposed on both the D₁ and D₂ fabrics is observed in the
 310 Inner Pelvoux, at m-cm scale, and attributed here to a D₃ deformation (Fig. 3, 4 and 8). The D₂
 311 planar fabric elements (S₂-C₂-C'₂) are involved in the formation of S₃ axial planar F₃ folds, and
 312 C₃ shear bands with top-to-the-NW kinematics (Figs. 8 and 9). The attitude of leucosome that
 313 parallels S₃ and the horizontal axial plane of F₃ folds argue for melt migration during D₃ (Figs.
 314 9A and B). The melt-bearing S₃ foliation cuts across S₂ the upper structural level of the *La*
 315 *Meije* block.

316 In the *Le Rochail* block, a similar D₃ strain pattern is observed with centimeter-scale F₃
 317 folds, with sub-horizontal axial planes that rework the subvertical S₂ foliation. F₃ fold axes are
 318 weakly plunging toward the NW. In the Cortical Pelvoux, a kilometer-scale D₃ decreasing strain
 319 gradient can be observed from west to east. The S₃ becomes more penetrative and presents a
 320 mylonitic fabric in which a N150-160°E stretching lineation L₃ is observed (Figs. 3 and 8D).
 321 Along the L₃ stretching lineation, kinematic criteria (sigmoidal structures, pressure shadow, and
 322 shear bands) indicate a top-to-the northwest sense of shear whatever the observation scale (Figs.
 323 8 and 9). A-type folds with axes parallel to L₃ lineation can be also observed. Accordingly, a
 324 similar stretching direction is documented by Jacob (2022) and Jacob et al. (2022) in the La
 325 Meije Block with the observations of a syn-migmatitic flat-lying foliation documenting a N150-
 326 N180 directed horizontal flow that reworks early D₁ and D₂ fabrics.

327

328 3.2. Strain patterns in the felsic plutons

329

330 Within the granitic bodies of the Inner Pelvoux area (e.g. Turbat-Lauranoure, Etages, La
 331 Bérarde-Promontoire plutons), the S₁, S₂ and S₃ were not identified but the two C₂ (~N170°E)
 332 and C'₂ (N140°E) structures are recognized. The preferred orientation of feldspar, biotite and
 333 shape ratio of mafic enclaves define a ~N160-170°E striking subvertical magmatic foliation.
 334 When observed, the stretching lineation is sub-horizontal and trends NNW-SSE as previously
 335 described by Strzerynski et al. (2005). In agreement with these authors, we also document the
 336 presence of N135-140°E striking and vertical ductile shear bands. These shear-bands rise to C-
 337 S -like structures, which reflect a sinistral strike-slip shearing, as best exemplified in the
 338 Bérarde-Promontoire and Etages granites (Fig. 3). In agreement with Strzerynski et al. (2005),
 339 we consider that the sinistral kinematics was coeval with pluton emplacement. These C₂ and
 340 C'₂ planar surfaces that developed under supra-solidus magmatic conditions, appear in
 341 continuity with the D₂ structures observed in the country rocks, indicating a syn-D₂
 342 emplacement of those plutons.

343 In the northern part of the Cortical Pelvoux, the Rochail granite shows a sub-horizontal
 344 magmatic foliation inferred from biotite arrangement (Barféty et al., 1988) and does not show
 345 subsolidus deformation. The D₂ deformation was not observed in the pluton, and the S₃ foliation
 346 wraps around the granite (Fig. 4A). This may indicate that the flat-lying magmatic foliation
 347 could be ascribed to S₁ (see discussion below in section 5).

348 **4. Petro-chronological results**

349 This section presents U-Th-Pb radiometric analyses of monazite and zircon grains from
 350 (1) mylonitic gneiss (samples *MCE379* and *MCE382b*), (2) Al-rich metapelites (samples
 351 *MCE339v*, *MCE338* and *MCE328*), (3) migmatites (samples *MCE314*, *MCE330*, *MCE140b*
 352 and *MCE313b*) and (4) metamafics (sample *MCE304v2*) sampled in the Cortical and Inner
 353 Pelvoux (Fig. 2; Table 1). A petrological description is given for each sample (Fig. 10). Before
 354 isotopic analyses, cathodoluminescence (CL) and back-scattered electron (BSE) images were
 355 acquired for all zircon and monazite grains, respectively, using a scanning electron microscope
 356 (SEM) in order to check spot locations with respect to the internal microstructures, inclusions,
 357 fractures and physical defects. For monazite, U-Th-Pb analyses were performed by LA-ICP-
 358 MS directly in thin section at the University of Montpellier (samples *MCE338*, *MCE314* and
 359 *MCE382b*) and at BRGM (Bureau de Recherche Géologique et Minière) (*MCE328*, *MCE339v*
 360 and *MCE379*) (Table S₁). The analytical protocol for the University of Montpellier followed

361 the procedure described in Bruguier et al. (2017) and is presented in Table S2. Manangotry
 362 ([Poitrasson et al., 2000](#)) and Moacyr ([Goncalves et al., 2016](#)) monazites used as calibration and
 363 quality control reference materials yielded concordia ages of 552 ± 2 Ma (MSWD=2.2, n=38)
 364 and 507 ± 2.5 Ma (MSWD=0.02, n=14), respectively. The analytical protocol for the BRGM is
 365 presented in Table S3 and the Madmon and Namaqualand monazites used as quality control
 366 reference materials yielded concordia ages of 514 ± 7 Ma (MSWD=1.4, n=10) and 994 ± 17
 367 Ma (MSWD=1.3, n=10), respectively.

368 The zircon U-Pb analyses were performed at BRGM (Sample *MCE330*, *MCE 304v2*
 369 and *MCE313b*) and at GeOHeLiS analytical platform (University Rennes 1) (Sample
 370 *MCE140b*, Table S1, S4). Zircon grains were obtained by a conventional mineral separation.
 371 The selected grains (~100-200 μm size) were mounted in epoxy resin and polished down to
 372 expose their near equatorial sections. The analytical protocol for the BRGM is presented in
 373 Table S3 and the Plešovice zircon (Sláma et al., 2008) used as quality control reference material
 374 yielded a concordia age of 340 ± 3 Ma (MSWD=1.5, n=24). The analytical protocol for the
 375 GeOHeLiS analytical Platform is presented in Table S4 and the Plešovice zircon (Sláma et al.,
 376 2008) used as quality control reference material yielded a concordia age of 337.6 ± 2.0 Ma
 377 (MSWD=0.23, n=15). See Manzotti et al. (2016) for more details on the analytical protocol.

378 Two Al-rich metapelitic samples (*MCE339v* and *MCE338*) were investigated for their
 379 metamorphic evolutions through petrology and phase diagram calculations. Electron
 380 microprobe analysis has been performed at the University of Orléans on a CAMECA SX-FIVE.
 381 The P-T metamorphic conditions were obtained through calculations of pseudosection
 382 diagrams using Perple_X 6.9.1. software ([Connolly and Pettrini, 2002](#); [Connolly, 2005](#);
 383 hpver62 database from Holland and Powell, 2011). The considered system was MnO-Na₂O-
 384 CaO-K₂O-FeO-MgO-Al₂O₃-SiO₂-H₂O (MnNCKFMASH). Solution models used in the
 385 calculations were garnet, biotite, white mica, staurolite, cordierite, chlorite, chloritoid and melt
 386 (White et al., 2014) as well as plagioclase (Fuhrman & Lindsley, 1988) and ilmenite (White et
 387 al., 2000). Whole rock major element compositions (Table 2) were obtained using a
 388 PANalytical AxiosmAX X-Ray Fluorescence (XRF) Spectrometer at Lausanne University,
 389 Lausanne, Switzerland. The P-T conditions of biotite, muscovite and plagioclase equilibrium
 390 were estimated using the third model quality factor Qcmp described in Duesterhoeft & Lanari
 391 (2020) in order to have a quantitative approach. This factor calculates the fitting between the
 392 mineral composition and the composition modelled and takes account of the relative analytical
 393 uncertainty of the extracted compositions. The comparison of mineral composition was
 394 restricted to MnO, MgO, FeO, SiO₂ and Al₂O₃ contents for biotite, of Na₂O, K₂O, CaO, Al₂O₃,

395 FeO, MgO and SiO₂ contents for muscovite, and of CaO, K₂O, Na₂O, SiO₂ and Al₂O₃ contents
 396 for plagioclase.

397

398 *4.1. Gneissic mylonites (samples MCE379 and MCE382b)*

399

400 The sample *MCE379* is a gneiss from the volcano-sedimentary unit of the northern part
 401 of the Cortical Pelvoux where the main planar fabric is a composite S₁₋₃ foliation (Fig. 4A). It
 402 is composed of Qtz + Kfs + Bt with rare garnet and muscovite occurrences and few late white
 403 micas (Fig. 10A). It is structured by D₁ shear planes oriented N120°E/30NW, kinematic is not
 404 clear because of D₃ superimposition. Quartz ribbons show undulose extinction and Grain
 405 Boundary Migration recrystallization (GBM; Stipp et al., 2002). Monazite is located either in
 406 the quartzo-feldspathic matrix (Fig. 10B) or as an undeformed inclusion in biotite marking the
 407 S₁ foliation (Fig. 10C and D). Monazite grains do not show any zonation in BSE images (Fig.
 408 S1) and have U, Pb and Th contents ranging between 1322-3462 ppm, 869-2110 ppm and
 409 22326-72038 ppm, respectively, with Th/U ratios between 8.1 and 27.8 (Table S1). Twenty-
 410 nine analyses were performed on 26 monazite grains within the matrix. Except two discordant
 411 analyses, all analyses yield a concordant date at 334.8 ± 3.2 Ma (n = 27; MSWD_(C+E) = 1.3)
 412 (Fig. 12A).

413 Sample *MCE382b* is a gneiss coming from the same area as sample *MCE379* (Fig. 2).
 414 It is composed of Qtz + Kfs + Bt + Grt + late Ms (Fig. 10E). In this sample, D₃ strain is higher
 415 than in sample *MCE379* and the D₃ mylonitic planar fabric is oriented N133°E;30NE with a L₃
 416 stretching lineation trending N120°E. C-S structures and sigmoidal quartz aggregates indicate
 417 top-to-the-NW kinematics (Fig. 10E). Quartz crystals are stretched and form quartz-ribbons
 418 with undulose extinction and GBM recrystallization.

419 Fourteen monazite grains from sample *MCE382b* have been analyzed *in situ*, they do
 420 not show any zonation (Fig. S1) but display two habitus: monazite included in large biotite
 421 marking the S₃ foliation (group 1; Fig. 10G and H) and monazite located inside the quartzo-
 422 feldspathic matrix (group 2; Fig. 10F). Monazite grains from the quartzo-feldspathic matrix
 423 (group 2) have U, Pb and Th contents between 740-1016 ppm, 1198-1796 ppm and 15803-
 424 26505 ppm, respectively, and Th/U ratios of 19.4-36.9 (Table S1). Monazite inclusions within
 425 large biotite marking the S₃ foliation (group 1) have higher U contents (1241-1997 ppm),
 426 similar Pb and Th contents (1063-1478 ppm and 11914-21818), and lower Th/U ratios (6.1-
 427 16.4). Two ages can be identified (Fig. 11B), the oldest one is calculated from 7 monazite grains
 428 located in the matrix (group 2) that provide a concordant date at 334.5 ± 3.4 Ma (MSWD_(C+E)

429 = 0.88). The second one is obtained from 4 grains included within large biotite (group 1)
 430 yielding a concordant date at 306.0 ± 3.5 Ma ($\text{MSWD}_{(\text{C+E})} = 0.39$).

431

432 *4.2. Al-rich metapelites (samples MCE339v, MCE338 and MCE328)*

433

434 Sample *MCE339v* is a micaschist composed of Qtz + Grt + Ky + St + Bt + Ms + Pl (Fig.
 435 11A) sampled in the middle part of the Cortical Pelvoux (SW of Entraigues village, Fig. 2). It
 436 is structured by a pervasive D_2 shear zone oriented N0°E;70E with a horizontal stretching
 437 lineation trending N0. Staurolite and kyanite are relictual and are strongly affected by the D_2
 438 shearing. An old foliation, probably S_1 , is preserved in kyanite and garnet (Fig. 11B). Micas
 439 and quartz layers form sinistral sigmoids wrapping around garnet porphyroblasts.

440 Garnet grains show a slight zonation (Fig. 13A) with a core composed of ca. 64% of
 441 almandine, 5% of pyrope, 18.5% of grossular and 12.5% of spessartine, and a rim composed of
 442 74% of almandine, 12% of pyrope, 13% of grossular and 1% of spessartine (Table 3). Mineral
 443 compositions were modified by diffusion processes, as suggested by the smooth compositional
 444 zoning (Fig. 13A). Plagioclase is an oligoclase with Ab_{76} , and biotite presents a stable
 445 composition at $X_{\text{Fe}} 0.57$ (Table 3). A phase equilibrium diagram was calculated for this sample
 446 with a H_2O content at 1.33 % wt, which corresponds to the saturation of the sample at the
 447 solidus conditions as estimated from a T-X $_{\text{H}_2\text{O}}$ diagram (Fig. 13B). The obtained phase diagram
 448 defines a large stability field corresponding to the mineral assemblage of sample *MCE339v*
 449 (Qtz + Grt + Ky + St + Bt + Ms + Pl) with temperature and pressure conditions below 600 °C
 450 and 0.7 GPa, respectively (Fig. 13C). The phase diagram fails to reproduce the garnet core
 451 composition, perhaps due to diffusion process and modification of the initial composition of
 452 the garnet core. The Qcmp factor of the plagioclase composition only slightly varies, and its
 453 maximal value is 99.8% of fitting with the reference composition (Fig. 13C). This highest Qcmp
 454 value (Duesterhoeft et Lanari, 2020) indicates P-T conditions inferior to 650 °C and 0.6 GPa
 455 and is well expressed in the stability field of the mineral assemblage (Fig. 13C). The Qcmp
 456 factor of the biotite reaches a value of 95% of fitting with the reference composition and
 457 indicates temperatures between 525 and 750 °C and pressure conditions between 0.4 and 0.7
 458 GPa and only expressed in the stability field of the mineral assemblage at around 550 °C and
 459 0.5 GPa (Fig. 13D). These results must be taken with caution due to potential diffusion
 460 processes that might have affected the mineral compositions and analytical uncertainties on the
 461 reference compositions.

462 Monazite grains from sample *MCE339v* do not show any zonation, however two
 463 populations are recognized: the first one (group 1) is composed of monazite grains not oriented
 464 within the S_2 foliation and often included in quartz and sometimes in kyanite (Fig. 11B),
 465 displaying U, Pb and Th contents at 2985-6844 ppm, 1894-4304 ppm and 20221-45439 ppm,
 466 respectively, and medium Th/U ratios (5.1-7.6). The second population (group 2) is composed
 467 of monazite grains oriented parallel to the main S_2 foliation in mica-rich layers (Fig. 11C), with
 468 higher U and Pb contents ranging at 7069-8247 ppm and 4006-4827 ppm, Th varying in the
 469 range 33668-50915 ppm. The Th/U ratios are in the range 4.8-6.7 (Table S1). Analyses
 470 performed on monazite grains from the first group yield a concordant date at 346.6 ± 4.8 Ma (n
 471 = 7; MSWD_(C+E) = 0.51) (Fig. 11C), whereas analyses from the second group of monazite grains
 472 provide a concordant date at 319.2 ± 6.1 Ma (n = 4; MSWD_(C+E) = 0.78).

473

474 Sample *MCE338* is a metapelite sampled in the middle of the Cortical Pelvoux (Fig. 2).
 475 It is composed of Qtz + Pl + Ms + Bt + Grt + Sill with scarce tourmaline (Fig. 11D). The main
 476 planar fabric is a S_1 foliation showing numerous variscan sigmoidal and C-S structures
 477 reoriented by the alpine tectonics. Garnet grains are boudinaged by D₁ with boudin necks filled
 478 by biotite, quartz and sillimanite (Fig. 11D). Fibrolitic sillimanite is localized in D₁ structures
 479 and in D₁ sigmoid tails, suggesting a syn-D₁ crystallization. A phase equilibrium diagram was
 480 calculated for this sample. (Fig. 14). H₂O amount was defined at 1.47 % wt, which corresponds
 481 to the saturation of the sample at the solidus conditions of the mineral assemblage and was
 482 estimated from a T-X_{H2O} pseudosection (Fig. 14B). Garnet grains show a slight zonation (Fig.
 483 14A) with a core composed of ca. 71% of almandine, 12.5% of pyrope, 5.5 % of grossular and
 484 11% of spessartine, and a rim composed of 68.5% of almandine, 8.5% of pyrope, 4% of
 485 grossular and 19% of spessartine (Table 3). Plagioclase is homogeneous in composition with
 486 Ab₇₅, and biotite presents a stable composition at X_{Fe} 0.56 (Table 3). The resulting
 487 pseudosection (Fig. 12B and C) indicates a stability field with the mineral assemblage
 488 corresponding to the one observed in the sample (i.e. Pl + Grt + Ms + Bt + Sill + Qtz). Due to
 489 its low proportion and variability, grossular was not used to constrain the P-T conditions. The
 490 almandine, pyrope and spessartine isopleths of the garnet core cross-cut at 565 ± 30 °C and 0.46
 491 ± 0.04 GPa in the stability field of the observed mineral assemblage (Fig. 12B). Regarding the
 492 low volume of garnet in this sample (i.e. inferior to 3 vol%), we did not calculate a new
 493 pseudosection removing the garnet core bulk composition. Isopleths from the garnet rims cross-
 494 cuts at 450 ± 30 °C and 0.36 ± 0.02 GPa (Fig. 12B). The best Qc_{mp} values of the biotite and
 495 plagioclase do not perfectly fit with these P-T conditions, but their Qc_{mp} remains high at the

496 P-T conditions defined by the garnet core composition (Fig. 14D and F). The best Qcmp factor
 497 of the muscovite might indicate a higher-pressure stage around 0.7-0.8 GPa before the P-T
 498 conditions defined by the garnet core (Fig. 14E).

499 In the sample *MCE338*, monazite grains are included in quartz, in biotite and in
 500 muscovite-biotite layers (Fig. 11E and F). They are mainly parallel with the S₁ foliation (Fig.
 501 11F) and sometimes show syn-D₁ kinematic criteria (Fig. 11E). They do not show zonation on
 502 BSE images (Fig. S1). Twenty-eight analyses display U, Pb and Th contents ranging between
 503 1486-5802 ppm, 786-3070 ppm and 7372-33214 ppm, respectively, with constant Th/U ratios
 504 (4.2-6.1; Table SE1). By removing discordant data (ja8, ja11, ja15, ja20, ja24, ja27, ja28 and
 505 ja29; Table SE1), as well as the younger and older analyses (ja13 and ja5 respectively; Table
 506 SE1), the remaining data points provide a concordia date of 333.2 ± 1.6 Ma ($n = 18$; MSWD_(C+E)
 507 = 0.83) (Fig. 11D).

508

509 Sample *MCE328* is a micaschist from the southern part of the Cortical Pelvoux (Fig. 2).
 510 It is composed of quartz, muscovite, biotite, staurolite and kyanite (Fig. 11G). The main planar
 511 fabric of this sample is a composite S₁₋₃ foliation oriented N160°E;25E with a subhorizontal L₃
 512 stretching lineation trending N160°E. The quartz and micas sigmoidal aggregates indicate a D₁
 513 top-to-the-NW sense of shear, while D₃ shear bands indicate top-to-the-SE kinematics (Fig.
 514 11G). Kyanite and staurolite, often surrounded by a white mica-corona, are deformed by the D₃
 515 shear bands. Biotites are commonly chloritized. Monazite grains are mainly located in the
 516 quartz-matrix or in biotite marking the S₁ foliation and are typically oriented parallel to the S₁
 517 foliation (Fig. 11H). Some monazite grains also seem included in staurolite (Fig. 11I). They do
 518 not show chemical zoning (Fig. S1). The analyzed grains display U, Pb and Th contents ranging
 519 between 3761-8639 ppm, 2160-5277 ppm and 24475-45307 ppm, respectively, and constant
 520 Th/U ratios (5.2-7.1 except one data at 4.0; Table S1). As the whole, 17 analyses were
 521 performed, among them, 14 are concordant and yield a concordia date of 330.7 ± 3.1 Ma
 522 (MSWD_(C+E) = 1.4) (Fig. 11E).

523

524 4.3. Migmatites (samples *MCE314*, *MCE330*, *MCE140b* and *MCE313b*)

525

526 The cordierite bearing migmatite *MCE314* has been sampled in the Inner Pelvoux
 527 massif (Fig. 2). It is composed of quartz, K-feldspar, muscovite, chloritized biotite and pinitized
 528 cordierite. This sample exhibits a highly dipping and N140°E striking S₂ foliation defined by
 529 quartz aggregates and phyllosilicates. Subsolidus deformation is rare, and S₂ foliation is mainly

530 a suprasolidus planar fabric. The alpine tectonics induced a low-grade retrogression as shown
 531 by chlorite around biotites, and sericite around K-feldspar. Unfortunately, because of alpine
 532 retrogression and strong pseudomorphosis of cordierite, pseudosection calculation was not
 533 possible. One may consider that cordierite-bearing migmatites are generally formed under low-
 534 pressure and high temperature conditions at ca. 0.4-0.6 GPa; 750-850 °C (Barbey et al., 1999;
 535 Kalt et al., 1999).

536 Monazite grains, located within the quartzo-feldspathic matrix, are not zoned and
 537 display heterogeneous U and Th contents (3437-10171 ppm and 5909-86534 ppm,
 538 respectively), relatively constant Pb content (1210-5516 ppm), and heterogeneous Th/U ratios
 539 (1.3-20.2) (Table S1). Despite this chemical heterogeneity, all analyses are concordant or sub-
 540 concordant (except jb7; Table S1), and yield a concordia date of 307.5 ± 1.9 Ma ($n = 18$;
 541 $\text{MSWD}_{(\text{C+E})} = 1.4$) (Fig. 11F).

542

543 The Roux migmatite (*MCE330*), located in the Cortical Pelvoux, is a migmatitic gneiss
 544 developed at the base of the VSU (Fig. 2 and 4B). It is composed of quartz + K-feldspar +
 545 plagioclase + Biotite + Muscovite and is the equivalent of the Allemont migmatites from the
 546 SW Belledonne area (Fréville et al., 2018). The *MCE330* migmatite shows a N110°E40 solid-
 547 state protomylonitic foliation that erased syn-melting fabrics (Fig. 9F). The preferred
 548 orientation of mica and quartz-feldspar aggregates defines S-C fabrics that we attribute to D_3 .
 549 The CL images of the analysed zircon grains show inherited cores with a typical magmatic
 550 concentric oscillatory zoning and metamorphic rims (Fig. S1). Zircon cores and rims have
 551 similar U and Pb contents ranging between 247-2605 ppm and 12-140 ppm, respectively (Table
 552 S1). Thirty analyses have been performed on 30 zircon grains (Fig. 13A). In the Tera-
 553 Wasserburg diagram, analyses mainly cluster into two groups. The first one, includes 13
 554 concordant analyses on zircon cores, indicate a late Neoproterozoic age of crystallization.
 555 Among them 9 analyses yield a concordant date at 590.6 ± 6.2 Ma ($\text{MSWD}_{(\text{C+E})} = 0.95$). Two
 556 zircon cores show concordant and sub-concordant dates at ca. 1700 Ma and 1800 Ma (Fig.
 557 13A), and two single analyses yield concordant dates at ca. 405 and 380 Ma. The second cluster
 558 includes 12 analyses performed on zircon rims and yields a concordia date at 330.5 ± 3.1 Ma
 559 ($\text{MSWD}_{(\text{C+E})} = 0.92$) (Fig. 13A).

560

561 The Etages migmatite (*MCE140b*), located in the Inner Pelvoux, forms the country rock
 562 of the Etages granite (Fig. 2 and 4A). Composed of chloritized biotite, feldspars and quartz this
 563 rock shows a slight C_2 orientation, and it was also superimposed by a low-temperature alpine

564 deformation (Fig. 4A). Euhedral zircon crystals with elongated shapes present oscillatory
 565 zonings in CL (Fig. S1). Twenty-eight zircon grains were analysed and they form two age
 566 groups (Fig. 13B). The first one is composed of four analyses forming a concordant cluster with
 567 low U, Pb and Th contents and Th/U ratios ranging from 0.08 to 0.5 (Table S1), that yields a
 568 concordant date at 317 ± 3.6 Ma ($\text{MSWD}_{(\text{C+E})} = 0.38$) (Fig. 13B). The second group is composed
 569 of 22 analyses with higher U, Pb and Th contents than the first group, but with similar Th/U
 570 ratios ranging from 0.06 to 0.5 (Table S1). Among this group, numerous analyses show lead
 571 loss (Fig. 13B) but ten analyses define a concordant date at 297.8 ± 2.1 Ma ($\text{MSWD}_{(\text{C+E})} = 0.66$)
 572 (Fig. 13B). In addition, one analysis shows a concordant date at ca. 460 Ma.

573

574 The Peyre-Arguet cordierite-bearing migmatite (*MCE313b*) displays a C'_2 foliation
 575 along which the cordierite grains are aligned. Zircon grains display patchy and oscillatory
 576 zoning (Fig. S1). Nineteen grains have been analysed and they broadly scatter along the
 577 Concordia between 650 and 280 Ma. The most abundant age population is defined by 12
 578 analyses ranging from 481 to 419 Ma with low U (292-1043 ppm) and Pb (19-66 ppm) contents
 579 (Table SE1). Among this group, 7 analyses yield a concordant date of 451.4 ± 5.2 Ma
 580 ($\text{MSWD}_{(\text{C+E})} = 0.66$) (Fig. 13C).

581

582 4.4. Peyre-Arguet garnet amphibolite (sample MCE304v2)

583

584 The Peyre-Arguet meta-mafic (*MCE304v2*) is a garnet-bearing amphibolite from the
 585 Inner Pelvoux (Fig. 2) that consists of an amphibole, quartz, plagioclase and garnet assemblage
 586 that recorded D_2 deformation. Relics of clinopyroxene have been described by Barféty et al.
 587 (1982) and Jacob et al. (2022). Rutile grains are included within garnet and are replaced by
 588 ilmenite in the matrix. Garnet grains are surrounded by plagioclase-amphibole coronas. CL
 589 images of zircon included in garnet cores show cores with concentric oscillatory zoning
 590 surrounded by near homogeneous rims (Fig. S1). Zircon cores have high U (102-1349 ppm)
 591 and Pb (6.8-89.6 ppm) contents compared to rims (U: 3-72 ppm; Pb: 0.1-3.3 ppm) (Table SE1).
 592 Twenty-nine analyses have been performed on 29 zircon grains that define two clusters (Fig.
 593 13D). The first one, composed of 12 concordant analyses from zircon cores, yields a concordant
 594 date at 471.3 ± 5 Ma ($\text{MSWD}_{(\text{C+E})} = 1.06$; $n = 11$) (Fig. 13D). The second cluster is formed by
 595 11 analyses performed on zircon rims that define a lower intercept at 329.6 ± 9.2 Ma ($\text{MSWD} = 0.85$).
 596 Among them, 8 analyses yield a concordant date at 326.9 ± 9.1 Ma ($\text{MSWD} = 0.85$)
 597 (Fig. 13D). Several analyses show concordant dates at ca. 379, 385, 409 and 432 Ma, which

598 probably reflect a mixture between an old core (~ 470 Ma) and a younger rim (~ 327 Ma) and
 599 are probably therefore without geological meaning.

600

601 **5. Discussion**

602 *5.1. Pre-Variscan history*

603

604 Inherited dates at 451.4 ± 5.2 Ma and 460 ± 10 Ma were obtained from magmatic zircon grains
 605 of the Peyre-Arguet and Etages migmatites (samples *MCE313b* and *MCE140b*; Fig. 13; Table
 606 S1). This Ordovician record is interpreted as the emplacement age of felsic laccoliths, i.e. the
 607 protolith of orthogneisses. Numerous orthogneiss-derived from Ordovician protoliths are well
 608 documented in the entire Variscan belt (e.g. [Melleton et al., 2010](#); [Lardeaux et al. 2014](#)) as
 609 within the ECMs (e.g. [Schaltegger, 1993](#); [Sergeev and Steiger, 1993](#); [Bussy and von Raumer,](#)
 610 [1994](#); [Bussy et al., 2011](#); [Bussien Grosjean et al., 2017](#)). Even though a continental magmatic
 611 arc setting is sometimes suggested, presently, the preferred interpretation for the Ordovician
 612 magmatism is rather a rifting episode related to the opening of the Variscan oceans (e.g. [Von](#)
 613 [Raumer et al., 1999](#), [Von Raumer et al., 2013](#); [Vanderhaeghe et al., 2020](#)).

614 Similarly, the magmatic zircon cores from the Peyre-Arguet amphibolite (sample
 615 *MCE304v2*) display an inherited date of 471.3 ± 5 Ma that likely represents the intrusion age
 616 of a mafic protolith during the Ordovician crustal thinning, in agreement with inheritance
 617 recorded in other metabasites from the ECMs ([Paquette et al., 1989](#); [Oberli et al., 1994](#); [Rubatto](#)
 618 [et al., 2001](#); [Bussy et al., 2011](#); [Jacob et al., 2021, 2022](#); [Vanardois et al., 2022](#)).

619 Older detrital and inherited zircon ages from pre-Neoproterozoic to Cambrian were also
 620 obtained (Fig. 13). Lack of Mesoproterozoic dates (>1500 Ma; Fig. 13A) point to a
 621 Gondwanan origin, i.e. the West African Craton (e. g. [Melleton et al., 2010](#); [Linnemann et](#)
 622 [al., 2014](#); [Gärtner et al., 2017](#)), and NE Africa-Arabia, Baltica and Amazonia ([Stephan et al.,](#)
 623 [2019](#)) as possible source regions. In the Cortical Pelvoux, the Roux migmatite (*MCE330*) did
 624 not record any Ordovician inheritance, but magmatic zircon cores rather indicate a
 625 Neoproterozoic magmatism at 590.6 ± 6.2 Ma (Fig. 13A). The Roux migmatite did not originate
 626 from the partial melting of an Ordovician intrusive protolith but from that of a metasedimentary
 627 protolith probably related to Pan-African (750-600 Ma) or Cadomian (590-540 Ma) orogeneses
 628 ([Linneman et al., 2014](#)). Similar metasedimentary rocks in the SW Belledonne display inherited

629 zircons at ca. 590 Ma (Fréville et al., 2018). These Pan-African and Cadomian inherited zircon
 630 ages are common in the South-Western Variscan belt (e.g. Roger et al., 2004; Melleton et al.
 631 2010; Schnaperelle et al., 2020) with a possible source region linked to the north-eastern
 632 Gondwana margin (Linnemann et al., 2014; Couzinié et al., 2014; Von Raumer et al.,
 633 2015; Chelle-Michou et al., 2017).

634

635 5.2. Carboniferous crustal thickening (D_1 deformation)

636

637 The mineral assemblage Qtz + Bt + Ms + Pl + Grt + Ky + St from sample *MCE339v*
 638 defines a large stability field with P-T conditions lower than 0.75 GPa and 625 °C (Fig. 13C).
 639 A set of old monazite grains, some being included in kyanite, yield a concordant date at 346.6
 640 ± 4.8 Ma that gives a time constraint for prograde metamorphism (Fig. 16b). In the sample
 641 *MCE338*, the main assemblage Qtz + Ms + Bt + Pl + Grt + Sill (Fig. 11D) gives P-T conditions
 642 between 550-700 °C and 0.35-0.80 GPa (Fig. 16a). The highest Qcnp factors for muscovite
 643 and biotite give a P-T refinement at ca. 0.6 GPa and 650 °C (Fig. 16a). Garnet grains are also a
 644 part of the mineral assemblage and mark the same planar fabric than micas (Fig. 11D), but their
 645 core compositions are best modelled at lower-grade conditions (0.45 GPa and 575 °C; Fig. 14c).
 646 Garnet core shows a perfect homogeneous composition (Fig. 14A) that might be the result of
 647 diffusion process, which could explain the lower grade metamorphic conditions defined by the
 648 garnet core composition. Garnet rim composition yields P-T conditions at 0.35 GPa and 450 °C
 649 (Fig. 14c). The mineral composition modelling highlights a retrograde P-T path from the peak
 650 of metamorphism at ca. 0.6 GPa and 650 °C to the end of the retrograde path at 0.35 GPa and
 651 450 °C (Fig. 16a). In the corresponding sample (*MCE338*), monazite grains are often localized
 652 within biotite-muscovite layers (Fig. 11F) and yield a concordant date of 332.2 ± 1.6 Ma (Fig.
 653 12D), which is therefore interpreted as the age of the peak of M_1 metamorphism. These two
 654 samples present near similar P-T paths (Fig. 16c) with metamorphic conditions slightly higher
 655 in the sample *MCE338*, which is consistent with its deeper position into the crust (see Fig. 4B).

656 In sample *MCE339v*, the relictual S_1 foliation preserved in garnet and kyanite is dated
 657 by monazite at 346.6 ± 4.8 Ma. Similarly, the S_1 foliation in the sample *MCE338* is defined by
 658 the alignment of micas and by the orientation of monazite and is dated at 332.2 ± 1.6 Ma.
 659 Similar ages are obtained in samples *MCE379*, *MCE382b* and *MCE328* with a main S_1 foliation
 660 with syn-kinematic monazite grains (Fig. 10, 11 and 12). These results indicate that a D_1
 661 deformation was active at ca. 345-330 Ma (Fig. 16d).

662 A similar D₁/M₁ event is documented in the SW Belledonne area with the well-
 663 preserved low angle S₁, holding a E-W trending L₁ stretching lineation, interpreted as due to an
 664 eastward nappe stacking event responsible for crustal thickening coeval with the barrovian
 665 metamorphism (M₁) (Fernandez et al., 2002; Guillot et al., 2009; Guillot and Ménot, 2009;
 666 Fréville et al., 2018). In SW Belledonne massif, the peak of M₁ metamorphism is dated on
 667 monazite (LA-ICP-MS) and zircon (SIMS) at around 337 ± 7 Ma and 338 ± 5 Ma respectively
 668 (Fig. 16d; Fréville et al., 2018). The D₁/M₁ barrovian evolution culminated with the partial
 669 melting as observed at the bottom of the VSU in the Cortical Pelvoux and SW Belledonne
 670 (Gidon et al., 1980; Barféty et al., 1988; Guillot et al., 2009; Fréville et al. 2018; this study) as
 671 exemplified by the “Roux migmatite” that yields a similar concordant age at 330 ± 3 Ma (Fig.
 672 13A) obtained on metamorphic rims of zircons (sample *MCE330* in this study).

673 The deposition age of the SW Belledonne VSU is dated at 352 ± 1 Ma from a
 674 plagioclase-rich leucocratic sill (Fréville et al., 2018). Based on the lithological similarities of
 675 these volcano-sedimentary rocks in SW Belledonne and Cortical Pelvoux, we propose that the
 676 volcano-sedimentary rocks of the Cortical Pelvoux deposited during the late-Devonian early-
 677 Carboniferous rifting and therefore predated the D₁ crustal thickening.

678 Retrogressed eclogites and HP granulites are well documented in others ECMs (e.g.
 679 Albrecht et al., 1991; Von Raumer and Bussy, 2004; Ferrando et al., 2008; Jouffray et al., 2020;
 680 Jacob et al., 2021; Vanardois et al., 2022) and yield zircon and rutile ages at ca. 340-330 Ma
 681 (Rubatto et al., 2010; Vanardois et al., 2022). Recently, M₁ high-pressure peak condition
 682 recorded within retrograded eclogites of the NE Belledonne and Inner Pelvoux was constrained
 683 at ca. 340-330 Ma (Jacob et al., 2021, 2022). In the Inner Pelvoux, the Peyre-Arguet mafic HP
 684 granulite (Barféty et al., 1982) recorded a metamorphic age at 326.9 ± 9.1 Ma (Fig. 13D),
 685 confirming that a D₁/M₁ crustal thickening event at 350-330 Ma is recorded in both the Pelvoux
 686 and Belledonne massifs (Fig. 16e). Consistently, the sub-horizontal magmatic foliation we
 687 recognized in the Rochail granite and dated at 343 ± 11 Ma age (Guerrot and Debon, 2000) is
 688 interpreted as a S₁ foliation that resulted from crustal thickening.

689

690 5.3. Sinistral transpression and longitudinal flow (D₂ and D₃ deformations)

691

692 In the Cortical Pelvoux, the D₂ tectono-metamorphic event corresponds to a NW-SE
 693 shortening responsible for folding of the S₁ and formation of the N30°E striking S₂ foliation,
 694 also documented in the SW Belledonne (Fréville et al., 2018), in the course of D₁ contraction.
 695 In sample *MCE339v*, from the central part of the Cortical Pelvoux, the S₂ foliation is defined

696 by the preferential alignment of biotite for which the highest Qcmp factor indicates temperature
 697 conditions above 525 °C and allows us to refine the P-T condition of biotite-bearing S₂ foliation
 698 at around 0.5 GPa and 550 °C near the kyanite-sillimanite transition (Fig. 13D). Monazite grains
 699 included in the biotite-layers (Fig. 11C) yield an age at 319.2 ± 6.1 Ma (Fig. 11C) providing a
 700 time constraint for D₂ transpression (Fig. 16b).

701 In the Inner Pelvoux, D₂ structures are ubiquitous with the development of penetrative
 702 and steeply dipping planar surfaces, such as the S₂ foliation, and C₂-C'₂ sinistral shear zones,
 703 and weakly plunging lineations formed under sinistral strike-slip regime (Fig. 17A). The syn-
 704 D₂ cordierite-bearing migmatite *MCE314* shows U-Th-Pb data obtained on monazite grains that
 705 form a cluster with an intercept at 307.5 ± 1.9 Ma (Fig. 11F). It suggests that the partially molten
 706 crust was under high temperature and low-pressure conditions at ca. 308 Ma (Fig. 16c), giving
 707 another time constraint for the D₂ deformation. In the Etages migmatite (*MCE140b*), four zircon
 708 grains yield a concordant date at 317 ± 4 Ma (Fig. 13B) that we also relate to the D₂
 709 transpression. The Etages migmatite *MCE140b* also gives a concordant date at 297.8 ± 2.1 Ma,
 710 like the age of the Etages and the Bérarde-Promontoire syn-D₂ plutons (this study; [Strzerynski et al., 2005](#)) dated at ca. 303-299 Ma ([Fréville, 2016](#)). Hence, we propose that the timing of the
 711 D₂ transpression ranged from at least ca. 320 Ma to 298 Ma (Fig. 16d), but it might have started
 712 as early as 330 Ma (Fig. 16e). In the SW and NE Belledonne massif, the onset of the D₂
 713 transpression with the development of S₂ occurred after the peak of pressure at 330 Ma ([Fréville et al., 2018; Jacob et al., 2021](#)), a period that corresponds to the onset of partial melting in the
 714 lower crust. In both Pelvoux and Belledonne massifs, the transpression is more pervasive in the
 715 anatetic crust (Fréville et al., 2018; this study). Melt-enhanced strength drop may have
 716 impacted stress distribution and initiated transpressional strain in the deep crust with the
 717 preferential appearance of the steeply dipping S₂ cleavage in the partially molten middle-lower
 718 crust, while NW-SE contraction was accommodated by upright to SE-verging D₂ folding in the
 719 upper-middle crust (Fig. 17).

722 Near the anatetic front, we have recognized a S₃ sub-horizontal planar fabric affecting
 723 the former S₁ and S₂ foliations (Fig. 8, 9 and 17). In sample *MCE382b* located in the Cortical
 724 Pelvoux, 4 monazite grains included in undeformed biotite marking the S₃ foliation (Fig. 10G
 725 and H) yield a concordant date at 306 ± 3.5 Ma (Fig. 11B). The record of the D₃ deformation
 726 in monazite is probably dependent on D₃ strain localization. Thus, we propose that the ca. 306
 727 Ma age is a reliable one for the D₃ deformation in the Cortical Pelvoux (Fig. 16d). Our results
 728 suggest that during the Late Carboniferous, the D₂ and D₃ deformations were partly
 729 synchronous (Fig. 16d) and therefore attest for strain partitioning during a same tectonic event

730 responsible for longitudinal flow of the middle-lower crust. We interpret the top-to-the NW
731 shearing along S_3 as a local accommodation of a southeastward horizontal flow of the partially
732 molten lower crust during sinistral transpression. Recently, Jacob (2022) and Jacob et al. (2022)
733 also show that in the central Inner Pelvoux (La Lavey area) the S_1 foliation is reworked by a
734 syn-migmatitic flat-lying foliation showing evidence for a NW-SE, i.e. N150-N180 directed
735 horizontal flow. These authors argue that the horizontal flow was coeval with a sinistral
736 shearing along a N140-N170 directed high-strain corridor (D_2) characterized by a vertical
737 shortening of the D_2 planar fabrics by the syn-magmatic flat-lying foliation. This is consistent
738 with our own field observations of the S_3 foliation, made in the same La Meije block, a few
739 kilometers to the SE (Fig. 3). The contemporaneity between NW-SE directed transpressional
740 flow and vertical shortening in that part of the la Meije block is supported by our radiometric
741 data of D_2 and D_3 and attests for strain partitioning between the suprastructure and infrastructure
742 during horizontal crustal flow under transpressive regime as commonly described in the
743 Variscan belt (Aguilar et al., 2014; Cochelin et al., 2017, 2021; Rabin et al., 2015; Trap et al.,
744 2017).

745

746 5.4. Kinematic flow at the scale of the EVSZ

747

748 At large scale, the shape and strike of the EVSZ and how it connects to other major shear
749 zones of the Variscan belt framework is not straightforward (e.g. Ballèvre et al., 2018; Chardon
750 et al., 2020; Simonetti et al., 2020a). In most of previous studies, the authors proposed that the
751 EVSZ runs from the Aar-Gothard, Aiguilles-Rouges-Mont-Blanc, Belledonne massifs, and to
752 the Argentera, Maures-Tanneron and Corsica-Sardinia massifs with a main trend that changes
753 from NE-SW to N-S respectively (Fig. 1; e.g. Guillot et al., 2009; Padovano et al., 2012;
754 Duchesne et al., 2013; Simonetti et al., 2020a) that consider a post-Variscan counterclockwise
755 rotation of the Argentera massif of about 90° that is not recorded within the Permian
756 sedimentary cover (Bogdanoff and Schott, 1977; Sonnette et al., 2014). The major rotational
757 movements described in the internal Alps are accommodated by transtcurrent faults that did not
758 affect the ECMs (Collombet et al., 2002). Any rotation of the Argentera massif may have
759 occurred prior to the deposition of Permian sedimentary rocks deposits and at these times the
760 rotation in the southeastern part of the Variscan belt is clockwise (Edel et al., 2014, 2015).
761 Following the work of Edel et al. (2014, 2018) that consider the rotation of the Maures-
762 Tanneron - Corsica -Sardinia block, we propose an alternative geometry for the EVSZ with the
763 individualization of several branches forming the anastomosed network (Fig. 18).

The large-scale transpression is a strain feature the whole ECMs have in common, with a general dextral kinematics (Von Raumer et al., 1999; Von Raumer and Bussy, 2004; Simonetti et al., 2018, 2020a; Jacob et al., 2021) except in the Pelvoux massif where it is sinistral (this study, Strzerynski et al., 2005; Jacob et al., 2022). Our results argue that the sinistral shearing in the Pelvoux massif was active between at least ca. 320 and 300 Ma. Similar ages have been reported for the dextral transpressional shearing in the Aiguilles-Rouges - Mont-Blanc massifs (Simonetti et al., 2020a; Vanardois, 2021), in the Argentera massif (Sanchez et al., 2011; Simonetti et al., 2018, 2021), in the Maures-Tanneron massifs (Rolland et al., 2009; Corsini and Rolland, 2009), in Sardinia and Corsica (Giacomini et al., 2008; Carosi et al., 2012). Since dextral and sinistral shearing were synchronous, we propose that at the scale of the ECMs, the sinistral shearing in the Pelvoux massif corresponds to an antithetic domain within the dextral dominated shear zone network (Fig. 18). During the Late Carboniferous times, the average antithetic C' shear zone strikes N140-150E in the Pelvoux massif while dextral shear zones trends ca. N30E in the Aiguilles-Rouges-Mont-Blanc massif and Belledonne massif (e.g. Simonetti et al., 2020, Jacob et al., 2021). Vanardois (2021) argue that N30E directed dextral deformation in the Aiguilles-Rouges Massif (Fig. 18) corresponds to 1-2 km wide synthetic C' shear zones in a regional-scale (> 10km) N-S directed shear zone system. The strain pattern of the Aiguilles-Rouges massif is made of a S-C-C' dextral framework with NW-SE-directed S planes, N-S directed C planes and N30E directed C' planes (Fig. 18; Vanardois 2021). In that scheme, the average obtuse angle between synthetic C' and antithetic C' shear direction might be around $105 \pm 10^\circ$ (Fig. 18) that is consistent with geometry and flow kinematics of a typical ductile shear zone (Fossen et al., 2012; Gillam et al., 2013) even if anticlockwise back-rotation between NE-SW dextral corridors is considered.

787

788 Conclusions

789

790 Our field work, structural, thermobarometric, and geochronological results argue that the
 791 Belledonne and Pelvoux massifs share the same Carboniferous tectono-metamorphic
 792 evolution. The Belledonne-Pelvoux area experienced a D₁ event related to crustal thickening
 793 during the Eastward nappe stacking event in response to E-W to NW-SE contraction. The
 794 D₁/M₁ episode ended with the onset of crustal partial melting at ca. 650°C during Late Visean
 795 time. Ongoing NW-SE bulk shortening is responsible for sinistral D₂ shearing in the partially
 796 molten middle-lower crust (i.e. Inner Pelvoux) with the strain partitioning between C and C'
 797 shear zones and horizontal longitudinal flow in the range 330-300 Ma. Field and radiometric

798 data argue for contemporaneity between D₂ and D₃ and attest for vertical strain partitioning
 799 between the suprastructure and infrastructure during horizontal crustal flow and strike-slip
 800 shearing, as commonly described in the Variscan belt. Within the orogen scale dextral East-
 801 Variscan Shear Zone, the sinistral transpression recorded in the Pelvoux massif corresponds to
 802 an antithetic strain domain. The data presented in this paper on the East Variscan Shear Zone
 803 exposed in the Belledone-Pelvoux massifs, should be compared to other late-Variscan shear
 804 zones in order to check for kinematic compatibility and to reconstruct plate-scale kinematics
 805 during late carboniferous time.

806

807 Acknowledgments.

808 The authors thank the Institut des Sciences de la Terre d'Orléans (ISTO), BRGM, the
 809 Laboratoire Chrono-Environnement, and the Observatoire des Sciences de l'Univers en Région
 810 Centre (OSUC) for their financial support. We also gratefully acknowledge the French
 811 RENATECH network and its FEMTO-ST technological facility that partly supports this work.
 812 We thank Laurent Jolivet and Olivier Vanderhaeghe for their comments and editorial work. The
 813 constructive and helpful reviews by Julien Berger and Yann Rolland are acknowledged with
 814 thanks.

815

816 References:

817

- 818 Abrecht J, Biino G. G, Mercolli I, Stille P. 1991. Mafic-ultramafic rock associations in the Aar, Gotthard
 819 and Tavetsch massifs of the Helvetic domain in the Central Swiss Alps: markers of ophiolitic pre-
 820 Variscan sutures, reworked by polymetamorphic events? *Schweiz. Mineral. Petrogr. Mitt.* 71:295–
 821 300.
- 822 Aguilar, C., Liesa, M., Castiñeiras, P., & Navidad, M. (2014). Late Variscan metamorphic and magmatic
 823 evolution in the eastern Pyrenees revealed by U–Pb age zircon dating. *Journal of the Geological
 824 Society*, 171(2), 181–192.
- 825 Alcock, J. E., Catalán, J. R. M., Pascual, F. J. R., Montes, A. D., Fernández, R. D., Barreiro, J. G., ... &
 826 Clavijo, E. G. (2015). 2-D thermal modeling of HT–LP metamorphism in NW and Central Iberia:
 827 Implications for Variscan magmatism, rheology of the lithosphere and orogenic evolution.
 828 *Tectonophysics*, 657, 21–37
- 829 Autran A, Cogné J. 1980. La zone interne de l'orogène varisque dans l'ouest de la France et sa place
 830 dans le développement de la chaîne hercynienne. *Géologie Eur. 26° CGI Paris Mém. BRGM* 108:90–
 831 111.
- 832 Ballèvre M, Manzotti P, Dal Piaz GV. 2018. Pre-Alpine (Variscan) inheritance: A key for the location
 833 of the future Valaisan Basin (Western Alps). *Tectonics* 37:786–817.
- 834 Barbey P, Marignac C, Montel JM, Macaudière J, Gasquet D, Jabbori J. 1999. Cordierite Growth
 835 Texture and the Conditions of Genesis and Emplacement of Crustal Granitic Magmas: the Velay
 836 Granite Complex (Massif Central, France). *J. Petrol.* 40:1425–1441.
- 837 Barbey, P., Villaros, A., Marignac, C., & Montel, J. M. 2015. Multiphase melting, magma emplacement
 838 and PT-time path in late-collisional context: the Velay example (Massif Central, France). *Bulletin de
 839 la Société géologique de France*, 186(2–3), 93–116.
- 840 Barfety JC, Gidon M, Ménot RP, Debon F, Pêcher S, Guillot S, Fourneaux JC, Gamond JF. 2000. Notice
 841 de la carte géologique de la France, feuille Domène (773), scale 1:50 000. Orléans : BRGM.

- 842 Barfety JC, Montjuvent G, Pécher A, Carme F. 1988. Notice de la carte géologique de la France, feuille
 843 La Mure (821), scale 1:50 000. Orléans : BRGM.
- 844 Barfety JC, Pécher A, Vivier G, Demeulemeester P, Poulaïn PA, Vernet J, Fourneaux JC, Bambier A.
 845 1982. Notice de la carte géologique de la France, feuille St-Christophe-en-Oisans (822), scale 1:50
 846 000. Orléans : BRGM.
- 847 Bellahsen N, Mouthereau F, Boutoux A, Bellanger M, Lacombe O, Jolivet L, Rolland Y. 2014. Collision
 848 kinematics in the western external Alps. *Tectonics* 33: 2013TC003453.
 849 <https://doi.org/10.1002/2013TC003453>
- 850 Bellanger M, Augier R, Bellahsen N, Jolivet L, Monié P, Baudin T, Beyssac O. 2015. Shortening of the
 851 European Dauphinois margin (Oisans Massif, Western Alps): New insights from RSCM maximum
 852 temperature estimates and $^{40}\text{Ar}/^{39}\text{Ar}$ in situ dating. *J. Geodyn.* 83:37–64.
 853 <https://doi.org/10.1016/j.jog.2014.09.004>
- 854 Bellanger M, Bellahsen N, Jolivet L, Baudin T, Augier R, Boutoux A. 2014. Basement shear zones
 855 development and shortening kinematics in the Ecrins Massif, Western Alps. *Tectonics* 33:84–111.
- 856 Bellot JP. 2005. The Palaeozoic evolution of the Maures Massif (France) and its potential correlation
 857 with other areas of the Variscan belt: a review. *J. Virtual Explor.* 19:1–24.
- 858 Bodinier JL, Dupuy C, Dostal J, Carme F. 1981. Geochemistry of Ophiolites from Chamrousse
 859 Complexe (Belledonne Massif, Alps). *Contrib Miner. Pet.* 78:379–388.
- 860 Bogdanoff S, Menot R.P, Vivier G. 1991. Les Massifs cristallins externes des Alpes occidentales
 861 françaises, un fragment de la zone interne varisque. *Extern. Cryst. Massifs Fr. West. Alps Part Intern.*
 862 *Variscan Zone* 44:237–285.
- 863 Bordet P, Bordet C. 1963. Belledonne-Grande Rousses et Aiguilles Rouges Mont Blanc: quelques
 864 données nouvelles sur leurs rapports structuraux. -Livre à la mémoire du professeur Fallot.-. *Mém.*
 865 *Hors Sér. Société Géologique Fr.* 1:309–316.
- 866 Boutoux A, Bellahsen N, Lacombe O, Verlaguet A, Mouthereau F. 2014. Inversion of pre-orogenic
 867 extensional basins in the external Western Alps: Structure, microstructures and restoration. *J. Struct.*
 868 *Geol.* 60:13–29.
- 869 Bruguier O, Bosch D, Caby R, Vitale-Brovarone A, Fernandez L, Hammor D, Laouar R, Ouabadi A,
 870 Abdallah N, Mechat M. 2017. Age of UHP metamorphism in the Western Mediterranean : insight
 871 from rutile and zircon inclusions in a diamond-bearing garnet magacryst (Edough Massif, Algeria).
 872 *Earth Planet. Sci. Lett.* 474:215–225.
- 873 Bussy F, von Raumer JF. 1994. U–Pb geochronology of Palaeozoic magmatic events in the Mont-Blanc
 874 Crystalline Massif, Western Alps. *Schweiz. Mineral. Petrogr. Mitt.* 74:514–515.
- 875 Bussy F, Péronnet V, Ulianov A, Epard JL, von Raumer J. 2011. Ordovician magmatism in the External
 876 French Alps: witness of a peri-Gondwanan active continental margin. In Gutiérrez-Marco JC,
 877 Rábano I, García-Bellido D, Eds. *The Ordovician of the World*: Madrid, Instituto Geológico y
 878 Minero de España, Cuadernos del Museo Geominero, v. 14, p. 75–82.
- 879 Carme F. 1970. Age briovérien probable de la majeure partie des séries supposées dévono-dinantianes
 880 et existence d'un cycle orogénique anté-hercynien, sans doute cadomien, dans la chaîne de
 881 Belledonne (Alpes Française). *C R Acad Sc Paris* 271:631–633.
- 882 Carme F. 1965. Sur deux formations, d'origine volcanique, des schistes cristallins anté-houillers de la
 883 chaîne de Belledonne (Alpes Française). *C R Acad Sc Paris* 260:6401–6404.
- 884 Chardon D, Aretz M, Roques D. 2020. Reappraisal of Variscan tectonics in the southern French Massif
 885 Central. *Tectonophysics* 787:228477.
- 886 Carosi R, Montomoli C, Tiepolo M, Frassi C. 2012. Geochronological constraints on post-collisional
 887 shear zones in the Variscides of Sardinia (Italy). *Terra Nova* 24:42–51.
- 888 Chelle-Michou C, Laurent O, Moyen JF, Block S, Paquette JL, Couzinié S, Gardien V, Vanderhaeghe
 889 O, Villaros A, Zeh A. 2017. Pre-Cadomian to late-Variscan odyssey of the eastern Massif Central,
 890 France: Formation of the West European crust in a nutshell. *Gondwana Res.* 46:170–190.
- 891 Cochelin B, Chardon D, Denèle Y, Gumiaux C, Le Bayon B. 2017. Vertical strain partitioning in hot
 892 Variscan crust: Syn-convergence escape of the Pyrenees in the Iberian-Armorian syntax. *Bull. Soc.*
 893 *Geol. Fr.* 188.
- 894 Cochelin B, Lemirre B, Denèle Y, de Saint Blanquat M. 2021. Strain partitioning within bending
 895 orogens, new insights from the Variscan belt (Chiroulet-Lesponne domes, Pyrenees). *Tectonics* 40,
 896 e2020TC006386.

- 897 Collombet, M., Thomas, J. C., Chauvin, A., Tricart, P., Bouillin, J. P., & Gratier, J. P. (2002).
 898 Counterclockwise rotation of the western Alps since the Oligocene: New insights from
 899 paleomagnetic data. *Tectonics*, 21(4), 1032.
- 900 Compagnoni R, Ferrando S, Lombardo B, Radulesco N, Rubatto D. 2010. Paleo-European crust of the
 901 Italian Western Alps: Geological history of the Argentera Massif and comparison with Mont Blanc-
 902 Aiguilles Rouges and Maures-Tanneron Massifs. *J. Virtual Explor.* 36:
 903 <https://doi.org/10.3809/jvirtex.2010.00228>
- 904 Connolly JA. 2005. Computation of phase equilibria by linear programming: A tool for geodynamic
 905 modeling and its application to subduction zone decarbonation. *Earth Planet. Sci. Lett.* 236: 524–
 906 541.
- 907 Connolly J.A, Pettrini K. 2002. An automated strategy for calculation of phase diagram sections and
 908 retrieval of rock properties as a function of physical conditions. *J. Metamorph. Geol.* 20: 697–708.
- 909 Corsini M, Rolland Y. 2009. Late evolution of the southern European Variscan belt: Exhumation of the
 910 lower crust in a context of oblique convergence. *C. R. Geosci.* 341:214–223.
- 911 Couzinié S, Moyen JF, Villaros A, Paquette JL, Scarrow JH, Marignac C. 2014. Temporal relationships
 912 between Mg-K mafic magmatism and catastrophic melting of the Variscan crust in the southern part
 913 of Velay Complex (Massif Central, France). *J Geosci* 59:1-18.
- 914 Debon F, Lemmet M. 1999. Evolution of Mg/Fe Ratios in Late Variscan Pultonic Rocks from the
 915 External Crystalline Massif of the Alps (France, Italy, Switzerland). *J. Petrol.* 40:1151–1185.
- 916 Duchesne, J. C., Liégeois, J. P., Bolle, O., Vander Auwera, J., Bruguier, O., Matukov, D. I., & Sergeev,
 917 S. A. (2013). The fast evolution of a crustal hot zone at the end of a transpressional regime: The
 918 Saint-Tropez peninsula granites and related dykes (Maures Massif, SE France). *Lithos*, 162, 195–
 919 220.
- 920 Duesterhoeft E, Lanari P, 2020. Iterative thermodynamic modelling—Part 1: A theoretical scoring
 921 technique and a computer program (Bingo-Antidote). *J Metamorph Geol* 8:527–551.
- 922 Edel, J. B., Schulmann, K., Lexa, O., & Lardeaux, J. M. (2018). Late Palaeozoic palaeomagnetic and
 923 tectonic constraints for amalgamation ofPangea supercontinent in the European Variscan belt. *Earth-
 924 Science Reviews*, 177, 589–612. <https://doi.org/10.1016/J.EARSCIREV.2017.12.007>
- 925 Faure M, Mezeme E.B, Duguet M, Cartier C, Talbot JY. 2005. Paleozoic tectonic evolution of medio-
 926 europa from the example of the french massif central and massif armoricain. *J. Virtual Explor.* 19:
 927 Paper 5.
- 928 Faure M., Rossi P., Gaché J., Melletton J., Frei D, Li X., Lin W. 2014. Variscan orogeny in Corsica:
 929 New structural and geochronological insights, and its place in the Variscan geodynamic framework.
 930 *Int. J. Earth Sci. (Geol Rundsch)* DOI 10.1007/s00531-014-1031-8.
- 931 Faure M., Ferrière J. 2022. Reconstructing the Variscan terranes in the Alpine basement: facts and
 932 arguments for an Alpidic orocline. *Geosciences*, 12, in press
- 933 Fernandez A, Guillot S, Ménot R.P, Ledru P. 2002. Late Paleozoic polyphased tectonics in the SW
 934 Belledonne massif (external crystalline massifs, French Alps). *Geodin. Acta* 15:127–139.
- 935 Ferrando S, Lombardo B, Compagnoni R. 2008. Metamorphic history of HP mafic granulites from the
 936 Gesso-Stura Terrain (Argentera Massif, Western Alps, Italy). *Eur. J. Mineral.* 20:777–790.
 937 <https://doi.org/10.1127/0935-1221/2008/0020-1891>
- 938 Franke W. 2000. The mid-European segment of the Variscides: tectonostratigraphic units, terrane
 939 boundaries and plate tectonic evolution. *Geol. Soc. Lond. Spec. Publ.* 179:35–61.
- 940 Franke W, Cocks LRM, Torsvik TH, 2017. The Palaeozoic Variscan oceans revisited. *Gondwana Res*
 941 48:257-284.
- 942 Fréville K, 2016. The variscan orogeny in the external crystalline massifs of Belledonne and Pelvoux
 943 (French Western Alps): the role of partial melting and plutonism on the structuration of the
 944 continental crust, (Doctoral dissertation). Orléans, France, Université de Orléans.
- 945 Fréville K, Trap P, Faure M, Melletton J, Xian-Hua L, Wei L, Blein O, Bruguier O, Poujol M. 2018.
 946 New structural, metamorphic and geochronological insights on the Variscan evolution in the Alpine
 947 Belledonne massif (France). *Tectonophysics* 726:14–42.
- 948 Fuhrman ML, Lindsley DH, 1988. Ternary-feldspar modeling and thermometry. *Am Mineral* 73:201–
 949 215.

- 950 Gärtner A, Youbi N, Villeneuve M, Sagawe A. 2017. The zircon evidence of temporally changing
 951 sediment transport— the NW Gondwana margin during Cambrian to Devonian time (Aoucert and
 952 Smara areas, Moroccan Sahara). *Int. J. Earth Sci.* 106:2747–2769.
- 953 Gerbault M, Schneider J, Reverso-Peila A, Corsini M. 2018. Crustal exhumation during ongoing
 954 compression in the Variscan Maures-Tanneron Massif, France - geological and thermo-mechanical
 955 aspects. *Tectonophysics* 746:439–458.
- 956 Gibergy P. 1968. Découverte de “grès à trous” renfermant des schistes noirs de Valbonnais (série
 957 cristallophyllienne des Massifs Cristallins Externes dans les Alpes française). *C R Acad Sc Paris*
 958 267:1251–1254.
- 959 Gidon M, Bonhomme J.-L, Fourneaux J.C, Monjuvent G, Mouterde R. 1980. Notice de la carte
 960 géologique de la France, feuille Saint-Bonnet (845), scale 1:50 000. Orléans : BRGM.
- 961 Gonçalves GO, Lana C, Scholz R, Buick IS, Gerdes A, Kamo SL, Corfu F, Marinho MM, Chaves AO,
 962 Valeriano C, Nalini A Jr. 2016. An assessment of monazite from the Itambé pegmatite district for as
 963 U-Pb isotope reference material for microanalysis and implications for the origin of the “Moacyr”
 964 monazite. *Chem. Geol.* 424:30-50.
- 965 Grandjean V, Guillot S, Pecher A. 1996. Un nouveau témoin de l'évolution métamorphique BP-HT
 966 post-orogénique hercynienne : l'unité de Peyre-Arguet (Haut-Dauphiné). *C. R. Acad. Sci. Sér. 2 Sci.*
 967 *Terre Planètes* 322:189–195.
- 968 Guerrot C, Debon F. 2000. U-Pb zircon dating of two contrasting Late Variscan plutonic suites from the
 969 Pelvoux massif (French Western Alps). *Schweiz. Mineral. Petrogr. Mitt.* 80:249–256
- 970 Guillot S, di Paola S, Ménot R.-P, Ledru P, Spalla M, Gosso G, Schwartz S. 2009. Suture zones and
 971 importance of strike-slip faulting for Variscan geodynamic reconstructions of the External
 972 Crystalline Massifs of the western Alps. *Bull Soc Géol Fr.* 180:483–500.
- 973 Guillot S, Ménot R.P. 2009. Paleozoic evolution of the External Crystalline Massifs of the Western
 974 Alps. *C R Geosci.* 341:253–265.
- 975 Henk A. 2000. Foreland-directed lower-crustal flow and its implications for the exhumation of high-
 976 pressure-high-temperature rocks. *Geol. Soc. Lond. Spec. Publ.* 179: 355–368.
 977 <https://doi.org/10.1144/GSL.SP.2000.179.01.21>
- 978 Jacob J.B. 2022 Quelle place pour les Massifs Cristallins Externes des Alpes occidentales dans
 979 l'orogenèse varisque? PhD Thesis. Université de Grenoble.
- 980 Jacob J.B, Guillot S, Rubatto D, Janots E, Melletton J, Faure M. 2021. Carboniferous high-pressure
 981 metamorphism and deformation in the Belledonne Massif (Western Alps). *J. Metamorph. Geol.*
 982 39:1009-1044, doi:10.1111/jmg.12600.
- 983 Jacob JB, Janots E, Guillot S, Rubatto D, Fréville K, Melletton J, Faure M, 2022. HT overprint of HP
 984 granulites in the Oisans–Pelvoux massif: implications for the dynamics of the Variscan collision in
 985 the external Western Alps. doi.org/10.1016/j.lithos.2022.106650.
- 986 Jouffray F, Spalla M.I, Lardeaux J.M, Filippi M, Rebay G, Corsini M, et al. 2020. Variscan eclogites
 987 from the Argentera-Mercantour Massif (External Crystalline Massifs, SW Alps): a dismembered
 988 cryptic suture zone. *Int. J. Earth Sci.* 109: 1273–1294. <https://doi.org/10.1007/s00531-020-01848-2>.
- 989 Kalt A, Berger A, Blumel P. 1999. Metamorphic Evolution of Cordierite-Bearing Migmatites from the
 990 Bayerische Wald (Variscan Belt, Germany). *J. Petrol.* 40: 601–627.
- 991 Kretz R. 1983. Symbols of rock-forming minerals. *Am. Mineral.* 68:277–279.
- 992 Lardeaux JM, Schulmann K, Faure M, Janouzek V, Lexa O, Skrzypek E, Edel JB, Štípká P. 2014. The
 993 Moldanubian Zone in the French Massif Central, Vosges/Schwarzwald and Bohemian Massif
 994 revisited: differences and similarities. *Geol. Soc. Lond. Spec. Publ.* 405:7–44.
 995 <https://doi.org/10.1144/SP405.14>
- 996 Ledru, P., Courrioux, G., Dallain, C., Lardeaux, J. M., Montel, J. M., Vanderhaeghe, O., & Vitel, G.
 997 2001. The Velay dome (French Massif Central): melt generation and granite emplacement during
 998 orogenic evolution. *Tectonophysics*, 342(3-4), 207-237.
- 999 Le Fort P. 1973. Géologie du Haut-Dauphiné cristallin (Alpes Française): Etudes pétrologique et
 1000 structurale de la partie occidentale (Phd thesis). Université Nancy I.
- 1001 Lemoine M. 1988. Des nappes embryonnaires aux blocs basculés : évolution des idées et des modèles
 1002 sur l'histoire mésozoïque des Alpes occidentales. *G-Alp.* 8:787–797.

- 1003 Lemoine M, Bas T, Arnaud-Vanneau A, Arnaud H, Dumont T, Gidon M, Bourbon M, de Graciansky
 1004 P.-C, Rudkiewicz J.-L, Megard-Galli J, Tricart P. 1986. The continental margin of the Mesozoic
 1005 Tethys in the Western Alps. *Mar. Pet. Geol.* 3:179–199.
- 1006 Linnemann U, Gerdes A, Hofmann M, Marko L. 2014. The Cadomian Orogen: Neoproterozoic to Early
 1007 Cambrian crustal growth and orogenic zoning along the periphery of the West African Craton-
 1008 Constraints from U-Pb zircon ages and Hf isotopes (Schwarzburg Antiform, Germany). *Precambrian*
 1009 *Res.* 244: 236–278. <https://doi.org/10.1016/j.precamres.2013.08.007>.
- 1010 Lombardo B, Colombo F, Compagnoni R, Ghiglione G, Rubatto D. 1997. Relics of pre-Variscan events
 1011 in the Malinvern-Argentera Complex, Argentera Massif, Western Alps. *Quaderni di Geodinamica*
 1012 *Alpina e Quaternaria* 4:66.
- 1013 Manzotti P, Ballèvre M, Poujol M, 2016. Detrital zircon geochronology in the Dora-Maira and Zone
 1014 Houillère: a record of sediment travel paths in the Carboniferous. *Terra Nova* 28:279–288.
- 1015 Matte P. 1991. Accretionary history and crustal evolution of the Variscan belt in Western Europe.
 1016 *Tectonophysics* 196:309–307.
- 1017 Matte P. 2001. The varisacn collage and orogeny (480-290 Ma) and the tectonic definition of the
 1018 Armorica microplate: a review. *Terra Nova* 13:122–128.
- 1019 Matte P. 2007. Variscan thrust nappes, detachment, and strike-slip faults in the French Massi Central:
 1020 Interpretation of lineations. *Geol. Soc. Am. Memoire* 200:391–402.
- 1021 Melleton J, Cocherie A, Faure M, Rossi P. 2010. Precambrian protoliths and Early Paleozoic magmatism
 1022 in the French Massif Central: U–Pb data and the North Gondwana connection in the west European
 1023 Variscan belt. *Gondwana Res* 17:13–25.
- 1024 Ménot RP. 1988a. An overview of the geology of the Belledonne Massif (External Crystalline Massifs
 1025 of western Alps). *Schweiz Miner. Petrogr Mitt* 70:33–53.
- 1026 Ménot RP. 1988b. Magmatisme paléozoïque et structuration carbonifère du massif de Belledonne
 1027 (Alpes françaises). Contraintes nouvelles pour les schémas d'évolution de la chaîne varisque Ouest-
 1028 Européenne. *Mémoire et documents du centre armoricain d'étude structurale des socles*. Rennes.
- 1029 Ménot RP. 1987. Magmatismes et structuration orogénique Paléozoïques de la Chaîne de Belledonne
 1030 (Massifs cristallins externes alpins). Le Domaine Sud - Occidental. *G-Alp.* 63: 55–93.
- 1031 Oberli F, Meier M, Biino GG. 1994. Time constraints on the pre-Variscan magmatic/metamorphic
 1032 evolution of the Gotthard and Tavetsch units derived from U-Pb results. *Schweiz. Mineral. Petrogr.*
 1033 *Mitt.* 74:483–488.
- 1034 Padovano M, Elter F.M, Pandeli E, Franceschelli M. 2012. The East Variscan Shear Zone: new insights
 1035 into its role in the Late Carboniferous collision in southern Europe. *Int. Geol. Rev.* 54: 957–970.
- 1036 Padovano M, Dörr W, Elter FM, Gerdes A. 2014. The East Variscan Shear Zone: Geochronological
 1037 constraints from the Capo Ferro area (NE Sardinia, Italy). *Lithos* 196–197:27–41.
- 1038 Paquette JL, Ménot RP, Peucat JJ. 1989. REE, Sm-Nd and U-Pb zircon study of eclogites from the
 1039 Alpine External Massifs (Western Alps)" evidence for crustal contamination. *Earth Planet. Sci. Lett.*
 1040 96:181–198.
- 1041 Paris F, Robardet M. 1990. Early Palaeozoic palaeobiogeography of the Variscan regions.
 1042 *Tectonophysics* 1977:193–213.
- 1043 Pecher A. 1970. Etude pétrographique de la partie orientale du massif des Ecrins-Pelvoux: le socle
 1044 ancien - Alpes françaises. (Thesis). Faculté des Sciences de l'Université de Grenoble, pp 151.
- 1045 Pecher A, Vialon P. 1970. Présence de gneiss du "faciès granulite" dans le noyau précambrien du massif
 1046 des Ecrins-Pelvoux (Alpes du Dauphiné, France). *C R Acad Sc Paris* 270:666–668.
- 1047 Pin C, Carme F. 1987. A Sm-Nd isotopic study of 500 Ma old oceanic crust in the Variscan belt of
 1048 Western Europe: the Chamrousse ophiolite complex, Western Alps (France). *Contrib. Mineral.*
 1049 *Petrol.* 96:406–413.
- 1050 Poitrasson F, Chenary SR, Shepherd TJ, 2000. Electron microprobe and LA-ICP-MS study of monazite
 1051 hydrothermal alteration: implications for U-Th-Pb geochronology and nuclear ceramics. *Geochim*
 1052 *Cosmochim Acta* 64:3283-3297
- 1053 Rabin M, Trap P, Carry N, Fréville K, Cenki-Tok B, Lobjoie C, Goncalves P, Marquer D. 2015. Strain
 1054 partitioning along the anatetic front in the Variscan Montagne Noire massif (southern French Massif
 1055 Central). *Tectonics* 34: 2014TC003790. <https://doi.org/10.1002/2014TC003790>

- 1056 Roger F, Respaut JP, Brunal M, Matte P, Paquette JL. 2004. Première datation U–Pb des orthogneiss
 1057 oeillés de la zone axiale de la Montagne noire (Sud du Massif central) : nouveaux témoins du
 1058 magmatisme ordovicien dans la chaîne Varisque. *C R Geosci* 336:19–28.
- 1059 Rolland Y, Corsini M, Demoux A, 2009. Metamorphic and structural evolution of the Maures-Tanneron
 1060 Massif (SE Variscan chain): Evidence of doming along a transpressional margin: *Bull Soc Geol Fr*
 1061 3:217–230.
- 1062 Rubatto D, Ferrando S, Compagnoni R, Lombardo B. 2010. Carboniferous high-pressure metamorphism
 1063 of Ordovician protoliths in the Argentera Massif (Italy), Southern European Variscan belt. *Lithos*
 1064 116: 65–76. <https://doi.org/10.1016/j.lithos.2009.12.013>
- 1065 Schaltegger U. 1993. The evolution of the polymetamorphic basement in the central Alps unravelled by
 1066 precise U-Pb zircon dating. *Contrib. Mineral. Petrol.* 113: 466–478.
- 1067 Schnapperelle S, Mezger JE, Stipp M, Hofmann M, Gärtner A, Linnemann U. 2020 Polyphase magmatic
 1068 pulses along the Northern Gondwana margin: U-Pb zircon geochronology from gneiss domes of the
 1069 Pyrenees. *Gondwana Res* 81:291–311.
- 1070 Schneider J, Corsini M, Reverso-Peila A, Lardeaux JM. 2014. Thermal and mechanical evolution of an
 1071 orogenic wedge during Variscan collision: an example in the Maures-Tanneron Massif (SE France).
 1072 *Geol. Soc. Lond. Spec. Publ.* 405:313–331. <https://doi.org/10.1144/SP405.4>
- 1073 Sergeev SA, Steiger RH. 1993. High-precision U-Pb single zircon dating of Variscan and Caledonian
 1074 magmatic cycles in the Gotthard massif, Central Swiss Alps. *Terra Nova* 5:394–395.
- 1075 Simonetti M, Carosi R, Montomoli C, Langone A, D'Addario E, Mammoliti E. 2018. Kinematic and
 1076 geochronological constraints on shear deformation in the Ferriere-Mollières shear zone (Argentera-
 1077 Mercantour Massif, Western Alps): implications for the evolution of the Southern European Variscan
 1078 Belt. *Int. J. Earth Sci.* 107:2163–2189. <https://doi.org/10.1007/s00531-018-1593-y>
- 1079 Simonetti M, Carosi R, Montomoli C, Cottle JM, Law RD. 2020a. Transpressive Deformation in the
 1080 Southern European Variscan Belt: New Insights From the Aiguilles Rouges Massif (Western Alps).
 1081 *Tectonics* 39. <https://doi.org/10.1029/2020TC006153>
- 1082 Simonetti M, Carosi R, Montomoli C, Corsini M, Petroccia A, Cottle JM, Iaccarino S. 2020b. Timing
 1083 and kinematics of flow in a transpressive dextral shear zone, Maures Massif (Southern France). *Int J*
 1084 *Earth Sci* 109:2261–2285. doi.org/10.1007/s00531-020-01898-6
- 1085 Simonetti M, Carosi R, Montomoli C, Lawd RD, Cottle JM. 2021. Unravelling the development of
 1086 regional-scale shear zones by a multidisciplinary approach: The case study of the Ferriere-Mollières
 1087 Shear Zone (Argentera Massif, Western Alps). *J Struct Geol* 149, 104399
- 1088 Sláma J, Košler J, Condon DJ, Crowley JL, Gerdes A, Hanchar JM, Horstwood MSA, Morris GA,
 1089 Nasdala L, Norberg N, Schaltegger U, Schoene B, Tubrett MN, Whitehouse MJ. 2008. Plešovice
 1090 zircon — A new natural reference material for U–Pb and Hf isotopic microanalysis. *Chem. Geol.*
 1091 249:1–35. <https://doi.org/10.1016/j.chemgeo.2007.11.005>
- 1092 Stampfli GM, Hochard C, Vérard C, Wilhem C, Von Raumer JF. 2013. The formation of Pangea.
 1093 *Tectonophysics* 593:1–19.
- 1094 Stephan T, Kroner U, Romer RL. 2019. The pre-orogenic detrital zircon record of the Peri-Gondwanan
 1095 crust. *Geol. Mag.* 156:281–307. doi.org/10.1017/S0016756818000031.
- 1096 Stipp M, Stunitz H, Heilbronner R, Schmid S. 2002. Dynamic recrystallization of quartz: correlation
 1097 between natural and experimental conditions. In: De Meer, S., Drury, M.R., De Bresser, J.H.P.,
 1098 Pennock, G.M.(eds) *Deformation Mechanisms, Rheology and Tectonics: Current Status and Future
 1099 Perspectives*. *Geol Soc London Spec Publ* 200:171–190.
- 1100 Strzerynski P, Guillot S, Courrioux G, Ledru P, 2005. Modélisation géométrique 3D des granites
 1101 stéphaniens du massif du Pelvoux (Alpes, France). *C R Geosci* 337:1284–1292.
- 1102 Tait J, Schatz M, Bachtadse V, Soffel H. 2000. Palaeomagnetism and Palaeozoic palaeogeography of
 1103 Gondwana and European terranes. *Geol. Soc. Lond. Spec. Publ.* 179:21–31.
- 1104 Tait J.A, Bachtadse V, Franke W, Soffel H.C. 1997. Geodynamic evolution of the European Variscan
 1105 fold belt: palaeomagnetic and geological constraints. *Geol. Rundsch.* 86:585–598.
- 1106 Trap P, Roger F, Cenki-Tok B, Paquette JL. 2017. Timing and duration of partial melting and
 1107 magmatism in the Variscan Montagne Noire gneiss dome (French Massif Central). *Int. J. Earth Sci.*
 1108 106:453–476.

- 1109 Vanardois J, 2021. Fusion partielle, transfert de magma et partitionnement de la déformation dans la
1110 croûte tardi-orogénique. Exemple des massifs des Aiguilles-Rouges (Alpes) et de l'Agly (Pyrénées)
1111 dans la chaîne Varisque. PhD Thesis, Université de Franche-Comté, France. pp 487.
- 1112 Vanardois J, Roger F, Trap P, Goncalves P, Lanari P, paquette JL, Marquer D, Cagnard F, Le Bayon B,
1113 Melletton J, Barou F. 2022. Variscan eclogites from Aiguilles-Rouges Massif (Western Alps):
1114 Witnesses of exhumation of deep crust through strike-slip shear zone. *J Metamorph Geol.*
- 1115 Vanderhaeghe, O., Burg, J. P., & Teyssier, C. 1999. Exhumation of migmatites in two collapsed
1116 orogens: Canadian Cordillera and French Variscides. Geological Society, London, Special
1117 Publications, 154(1), 181-204.
- 1118 Vanderhaeghe O., Laurent O., Gardien V., Moyen J.F., Gébelin G., Chelle-Michou C., Couzinié S.,
1119 Villaros A., Bellanger B.; Flow of partially molten crust controlling construction, growth and
1120 collapse of the Variscan orogenic belt: the geologic record of the French Massif Central. Bulletin de
1121 la Société Géologique de France 2020;; 191 (1): 25. doi: <https://doi.org/10.1051/bsgf/2020013>
- 1122 von Raumer JF, Bussy F, 2004. Mont-Blanc and Aiguilles-Rouges: Geology of their polymetamorphic
1123 basement (External massifs, France-Switzerland): *Mémoires de Géologie (Lausanne)* 42:1–203.
- 1124 Von Raumer J, Albrecht J, Bussy F, Lombardo B, Ménot R.-P, Schaltegger U. 1999. The Palaeozoic
1125 metamorphic evolution of the Alpine External Massifs. *Schweiz. Miner. Petrog Mitt.* 79: 5–22.
- 1126 Von Raumer JF, Stampfli GM, Bussy F. 2003. Gondwana-derived microcontinents, the constituents of
1127 the Variscan and Alpine collisional orogens. *Tectonophysics* 365:7–22.
- 1128 Von Raumer JF, Bussy F, Scaltegger U, Schulz B, Stampfli G.M. 2013. Pre-Mesozoic Alpine
1129 basements? Their place in the European Paleozoic framework. *GSA Bull.* 125:89–108.
- 1130 Von Raumer JF. Stampfli GM. Arenas R. Martínez SS. 2015. Ediacaran to Cambrian oceanic rocks of
1131 the Gondwana margin and their tectonic interpretation. *Int. J. Earth Sci.* 104:1107–1121.
- 1132 Villaros, A., Laurent, O., Couzinié, S., Moyen, J. F., & Mintrone, M. 2018. Plutons and domes: the
1133 consequences of anatexic magma extraction—example from the southeastern French Massif Central.
1134 International Journal of Earth Sciences, 107(8), 2819-2842.
- 1135 White RW, Powell R, Holland TJB, Worley BA. 2000. The effect of TiO₂ and Fe₂O₃ on metapelitic
1136 assemblages at greenschist and amphibolite facies conditions: mineral equilibria calculations in the
1137 system K₂O-FeO-MgO-Al₂O₃-SiO₂-H₂O-TiO₂-Fe₂O₃. *J Metamorph Geol* 18:497–511.
- 1138 White RW, Powell R, Holland TJB, Johnson TE, Green ECR. 2014. New mineral activity–composition
1139 relations for thermodynamic calculations in metapelitic systems. *J Metamorph Geol* 32:261–286.
- 1140

1141 **Figure Captions:**

1142

1143 Figure 1. A: Location of the External Crystalline Massif (ECMs) within the Variscan
1144 framework, modified after Franke et al. (2017). B: State-of-the art concept showing the possible
1145 shear zone pattern along the ECMs and Corsica-Sardigna, in relation with the dextral EVSZ
1146 (modified from Simonetti et al. 2020). The studied area, i.e. the Belledonne-Pelvoux massif, is
1147 not yet considered in this scheme.

1148

1149 Figure 2. A: Simplified Geological map of the ECMs. Dashed square shows the extent of Figure
1150 2B. B: Geological map of the Pelvoux Massif with sample location. Dashed area shows the
1151 location of Figure 3.

1152

1153 Figure 3. A: Structural map of the Pelvoux massif showing the heterogeneous Variscan strain
1154 pattern. Lower-hemisphere Wulf stereographic plots of poles of foliations and strikes
1155 of lineation.

1156

1157 Figure 4. A: NW-SE cross-section through the northern part of the Pelvoux massif. B: E-W
1158 cross-section through the western part of the Pelvoux massif. C: W-E cross-section through the
1159 central part of the Pelvoux Massif.

1160

1161 Figure 5. Field pictures of D_2 folding and shearing. A and B: F2 folding of migmatitic S_1 and
1162 development of N30°E trending S_2 foliation as axial surface or transposition layering. C and D:
1163 Folding and shearing along the C_2 and C'_2 trend (NS and NW-SE). The folded and sheared
1164 foliation is a S_1 , S_2 or C_2 planar surface. In photograph 5C, the gneissic protolith was folded
1165 when the anatetic melt was present, and the melt also migrated along D_2 shear zone that
1166 parallels the axial plane. In 5D, shearing parallel to the axial plane resulted in solid-state
1167 recrystallization. E: Diatexit with a high proportion of leucocratic neosome with metamafic
1168 layers showing D_2 folding and sinistral shearing along a N120°E trending C'_2 syn-melt shear
1169 zone. F: Schollen diatexit with meter scale metamafic enclaves stretched along N-S direction
1170 (C_2) and shearing by a NW-SE trending C'_2 infilled by melt. Location of outcrop photographs
1171 is given in Figure 2.

1172

1173 Figure 6: Field pictures of D_2 deformation synchronous with partial melting. A: Sigmoidal
1174 quartz-rich resistor within D_2 metatexite indicating sinistral shearing along C_2 directed

1175 migmatitic foliation. B: Oblate metamafic enclave observed in the XY-section within a
 1176 stromatic diatexite. C: Conjugate melt-bearing dextral and sinistral shear bands within
 1177 heterogeneous diatexite. Main foliation is subvertical and trends ca. N170°E. D: Schollen
 1178 diatexite migmatite developed from a hornblende-bearing volcano-sedimentary protolith. E:
 1179 Close-up on Figure 6D showing the dioritic to tonalitic composition of the leucocratic material
 1180 containing various proportions of hornblende, some pyroxenes are also observed. The pen
 1181 points to a garnet + hornblende rich schlieren. F: Metataxite migmatite showing two sets of late
 1182 cordierite-bearing leucosome, one set parallels the main foliation trends (~N15°E, i.e. C₂) and
 1183 the other one is oblique to the foliation, and oriented ~N135°E (C'₂).
 1184

1185 Figure 7: A: Schematic drawing showing the three main trends of the D₂ planar surface arranged
 1186 in a sinistral S₂-C₂-C'₂ like anastomosed transpressional system. This representative outcrop
 1187 comes from the Bans valley, southeastern Inner Pelvoux. Picture 7B shows the steeply dipping
 1188 S₂ cleavage observed within the Peyre-Arguet mafic granulite, retrogressed into amphibolite.
 1189 Very thin seams of leucosome are located parallel to the compositional layering, and S₂ or C₂
 1190 foliation. Picture 7C shows a strongly layered stromatic migmatite that has been reworked by
 1191 solid-state deformation during sinistral shearing along a C'₂ plane.
 1192

1193 Figure 8. Outcrop photographs and micro-photographs of the D₃ deformation. A: Folding and
 1194 transposition of the subvertical S₂ foliation by the flat laying S₃ foliation in the northern part of
 1195 the *Le Rochail* block. B: Folding and transposition of the relictual S₁ foliation by the flat laying
 1196 S₃ foliation in the northern part of the *Le Rochail* block. C: S₃-C₃ structures showing top-to-the-NW
 1197 kinematics from sample MCE382b. D: Zoom of the photo E with top-to-the-NW
 1198 kinematic indicators and schematic block diagram of the outcrop.
 1199

1200 Figure 9. Field pictures of D₃ deformation. A and B. Low-angle S₃ reworking a steep S₂
 1201 foliation. Both foliations are melt-bearing and a pegmatitic leucosome parallels C₃ shear bands.
 1202 The outcrop is located near the Gioberney mountain refuge. C. Melt-bearing flat-lying D₃ shear
 1203 zone cross-cutting the steep S₂ foliation. Outcrop photographs A, B C and D are located around
 1204 the Gioberney mountain refuge, in the La Meige Block. D. Vertical shortening of S₂ and
 1205 development of axial planar S₃. E. Mylonitic S₃ with top-to-the NW shearing at the base of the
 1206 Cortical Pelvoux, near Villard-Notre-Dame village. F. Moderately dipping migmatitic gneiss
 1207 (MCE 330) showing a solid-state protomylonitic foliation S₃ developed during D₃ shearing and
 1208 cooling.

1209

1210 Figure 10. Thin-sections photographs and BSE images showing structural and petrological
 1211 relationships of samples *MCE379* and *MCE382b*. A: Thin-section photograph of sample
 1212 *MCE379* structured by D₁ planar fabric. B: BSE image of a monazite included in K-feldspar. C
 1213 and D: BSE images of monazite grains in mica marking the S₁ foliation. E: Thin-section
 1214 photograph of sample *MCE382* structured by D₁ planar fabric and D₃ shear bands. F: BSE
 1215 image of a monazite included in K-feldspar. G and H: BSE images of monazite grains in biotite
 1216 marking the S₃ foliation. Mineral abbreviations from Kretz (1983).

1217

1218 Figure 11. Thin-sections photographs and BSE images showing structural and petrological
 1219 relationships of samples *MCE339v*, *MCE338* and *MCE328*. A: Thin-section photograph of
 1220 sample *MCE339v* structured by D₂ planar fabric. B: BSE image of a monazite oriented parallel
 1221 with the ancient S₁ foliation preserved in kyanite (white dotted line). C: BSE image of monazite
 1222 grains in mica marking the S₂ foliation. D: Thin-section photograph of sample *MCE338*
 1223 structured by D₁ planar fabric showing elongated garnet grains parallel to the S₁ foliation. E:
 1224 BSE image of a monazite included in quartz showing a sigmoidal shape. F: BSE image of a
 1225 monazite in micas marking the S₂ foliation. G: Thin-section photograph of sample *MCE328*
 1226 structured by D₁ planar fabric and D₃ shear bands. H: BSE image of a monazite elongated
 1227 parallel to the S₁ foliation included in quartz. I: BSE image of a monazite staurolite and quartz.

1228

1229 Figure 12. Monazite U-Pb concordia diagrams obtained by LA-ICPMS. A: *MCE379*; B:
 1230 *MCE382b*; C: *MCE339v*; D: *MCE338*; E: *MCE328*; F: *MCE314*. Error ellipses and
 1231 uncertainties in ages are $\pm 2\sigma$. Dotted ellipses are not considered for the age calculation.

1232

1233 Figure 13. Thermobarometric modelling of metapelitic sample *MCE339v* located in the Cortical
 1234 Pelvoux. A: Chemical profile of a garnet. B: T-XH₂O diagram calculated with a pressure of 0.7
 1235 GPa, the mineral assemblage of the sample indicates a H₂O content of 1.33 %wt. C:
 1236 Pseudosection calculated in the MnNCKFMASH system. D: Modelling of the Qcmp factor of
 1237 the mineral composition of biotite based on MgO, FeO, MnO, Al₂O₃ and SiO₂ contents (Table
 1238 S2). Bi, Biotite; Mu, muscovite; Crd, Cordierite; Kfs, K-feldspar; Pl, Plagioclase; Gt, Garnet;
 1239 and, Andalousite; ky, Kyanite; sill, Sillimanite; Opx, Orthopyroxene; q, Quartz; melt, silicate
 1240 liquid.

1241

1242 Figure 14. Thermobarometric modelling of metapelitic sample *MCE338* located in the Cortical
 1243 Pelvoux. A: Chemical profile of a garnet. B: T-XH₂O diagram calculated with a pressure of 0.5
 1244 GPa, the mineral assemblage of the sample indicates a H₂O content of 1.47 %wt. C:
 1245 Pseudosection calculated in the MnNCKFMASH system. Modelling of the Qcmp factor of the
 1246 mineral composition of (D) biotite based on MgO, FeO, MnO, Al₂O₃ and SiO₂ contents, (E)
 1247 muscovite based on Na₂O, K₂O, CaO, Al₂O₃, FeO, MgO and SiO₂ contents, and (F) plagioclase
 1248 based on K₂O, Na₂O, CaO, Al₂O₃ and SiO₂ contents (Table S2). Bi, Biotite; Mu, muscovite; Crd,
 1249 Cordierite; Kfs, K-feldspar; Pl, Plagioclase; Gt, Garnet; and, Andalousite; ky, Kyanite; sill,
 1250 Sillimanite; Opx, Orthopyroxene; q, Quartz; melt, silicate liquid.

1251

1252 Figure 15. Zircon U-Pb Tera Wasserburg diagrams obtained by LA-ICPMS. A: *MCE330*; B:
 1253 *MCE140b*; C: *MCE313b*; D: *MCE304v2*. Error ellipses and uncertainties in ages are $\pm 2\sigma$.
 1254 Dotted ellipses are not considered for the age calculation.

1255

1256 Figure 16. Geochronological and tectono-metamorphic interpretations for the Pelvoux massif.
 1257 (a) P-T-t path of sample *MCE338* inferred from the mineral assemblage and mineral
 1258 compositions and from textural features of monazite. (b) P-T-t path of sample *MCE339v*
 1259 inferred from the mineral assemblage and biotite composition and from textural features of
 1260 monazite. (c) P-T-t conditions from the Pelvoux massif. P-T-t paths of the Cortical Pelvoux are
 1261 from this study. P-T data from metabasites of the Inner Pelvoux are from Jacob et al. (2022)
 1262 and Grandjean et al. (1996). P-T conditions of Crd-migmatites are theoretical and age
 1263 corresponds to monazite age of sample *MCE314* from this study. (d) Geochronological results
 1264 constraining the ages of D₁, D₂ and D₃ from this study, (Fréville et al., 2018; Fréville, 2016).
 1265 (e) Inferred tectono-metamorphic evolutions of the Cortical and Inner Pelvoux.

1266

1267 Figure 17. Sketch showing the strain partitioning in the Belledonne-Pelvoux orogenic crust
 1268 suffering bulk NW-SE directed contraction (black arrows). The upper unmolten crustal level
 1269 recorded folding, while the partially molten lower domain recorded lateral flow and sinistral
 1270 transpression.

1271 Figure 18. Sketch map of the anastomosed network of dextral shear zones of the EVSZ with
 1272 local conjugate sinistral shear zones in the Pelvoux massif. Ante-alpine positions of the ECMs
 1273 (black arrow) are from Bellahsen et al. (2014), except the Argentera massif. Positions of the
 1274 Maures-Tanneron, Corsica and Sardinia massifs are from Edel et al. (2014, 2018). Blue arrow
 1275 represents the present orientation in reference to the north. AG: Aar-Gothard; Arg: Argentera;

1276 AR-MB: Aiguilles-Rouges - Mont-Blanc; Bell: Belledonne; BSZ: Barrabisa Shear Zone;
1277 EBSZ: Emosson-Bérarde Shear Zone; FMSZ: Ferrière-Mollière Shear Zone; GF: Grimaud
1278 Fault; MF: La Moure Fault; PAL: Posada-Asinara Shear Zone; Pelv: Pelvoux; PVSZ: Porto
1279 Vecchio Shear Zone.

1280

1281 Table 1. Summary of geographic location, rock types, and U-Pb geochronological results for
1282 samples analyzed in this study.

1283

1284 Table 2. Bulk-chemical composition in weight percent oxides for samples *MCE339v* and
1285 *MCE338*.

1286

1287 Table 3. Representative chemical compositions of minerals used for themobarometric
1288 calculation.

1289

1290 Table 4. Summary of tectonic and metamorphic events recorded in the Belledonne-Pelvoux
1291 area.

1292

1293 Supplementary material:

1294

1295 Figure S1. Zircon cathodoluminescence and monazite back-scattered electrons images from
1296 studied samples.

1297

1298 Table S1. U-Pb analyses for dated samples.

1299

1300 Table S2. Operating conditions for the LA-ICP-MS equipment for Montpellier.

1301

1302 Table S3. Operating conditions for the LA-ICP-MS equipment for BRGM.

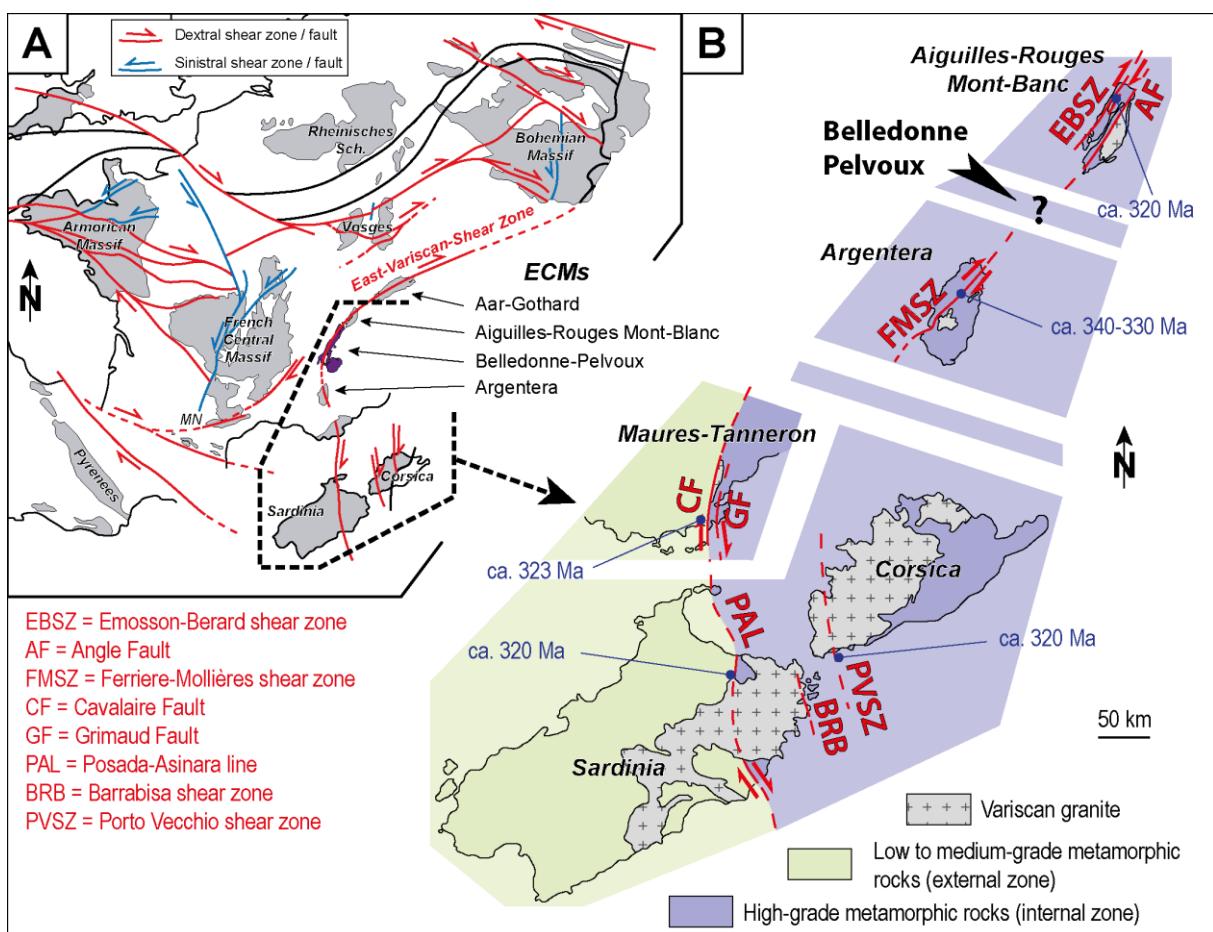
1303

1304 Table S4. Operating conditions for the LA-ICP-MS equipment for Rennes.

1305

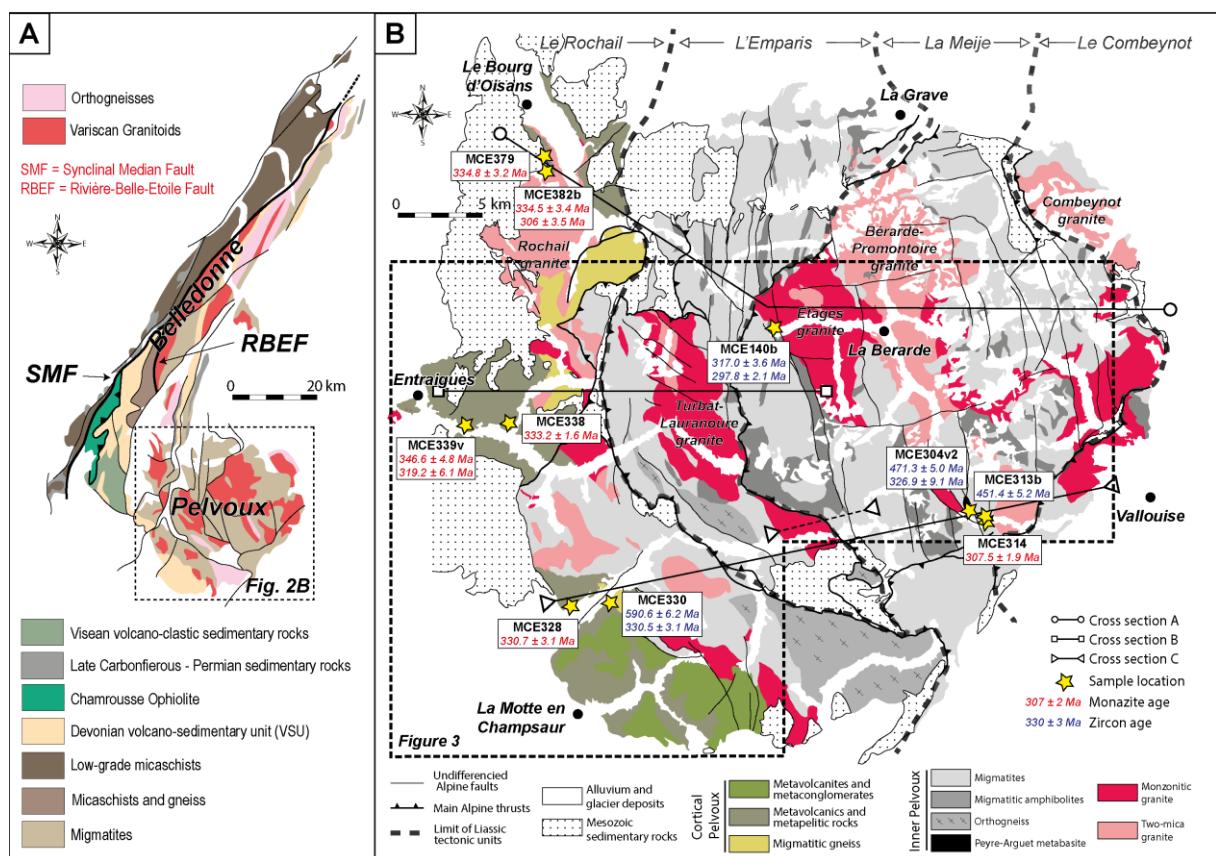
1306

1307 Figure 1



1313 Figure 2

1314



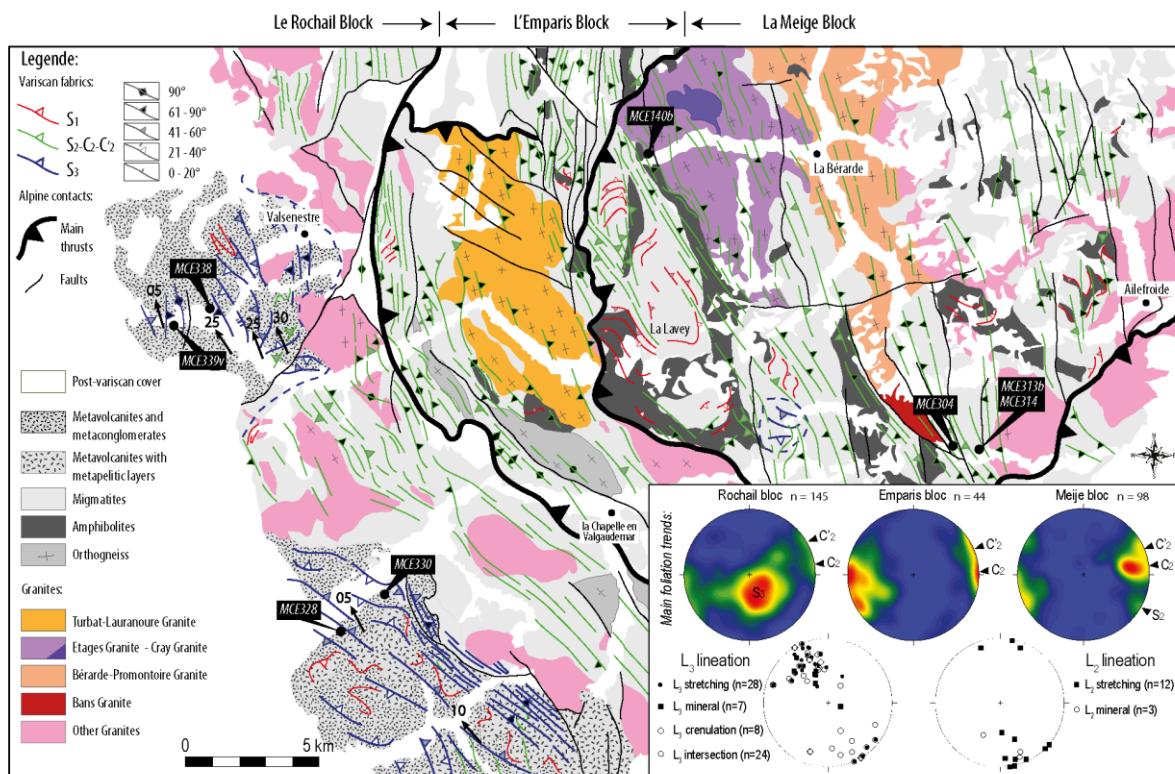
1315

1316

1317 Figure 3

1318

1319



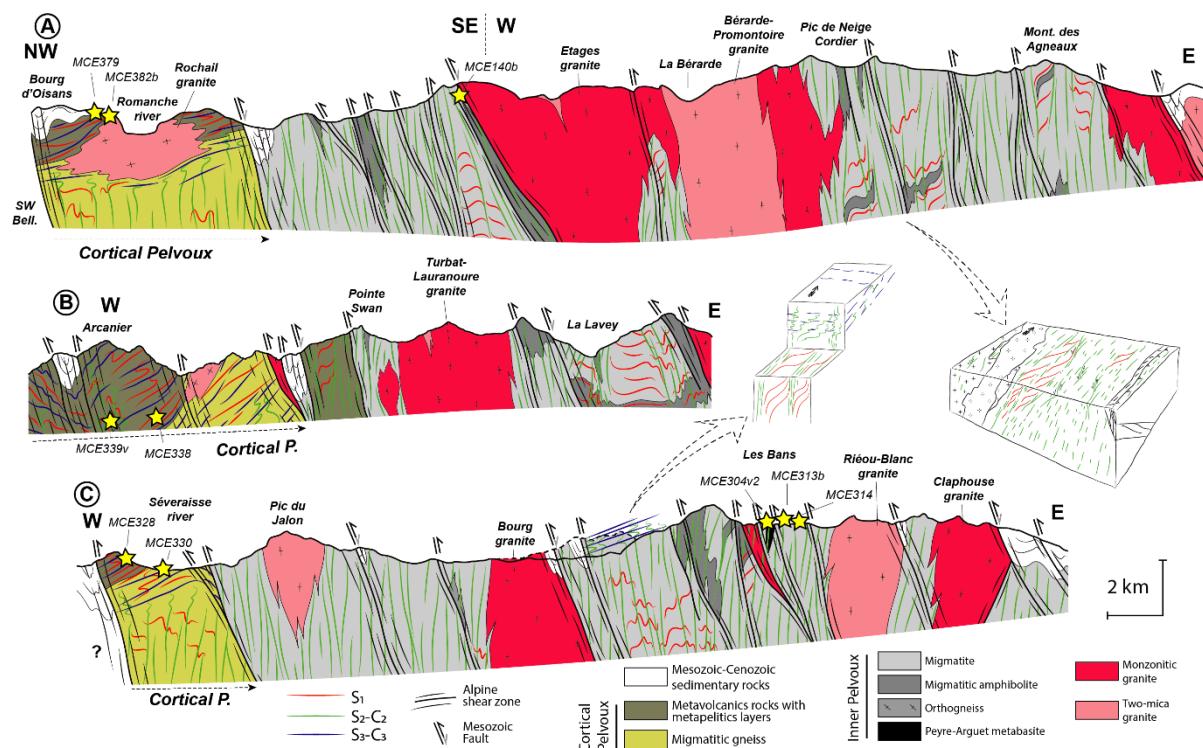
1320

1321

1322

1323 Figure 4

1324



1325

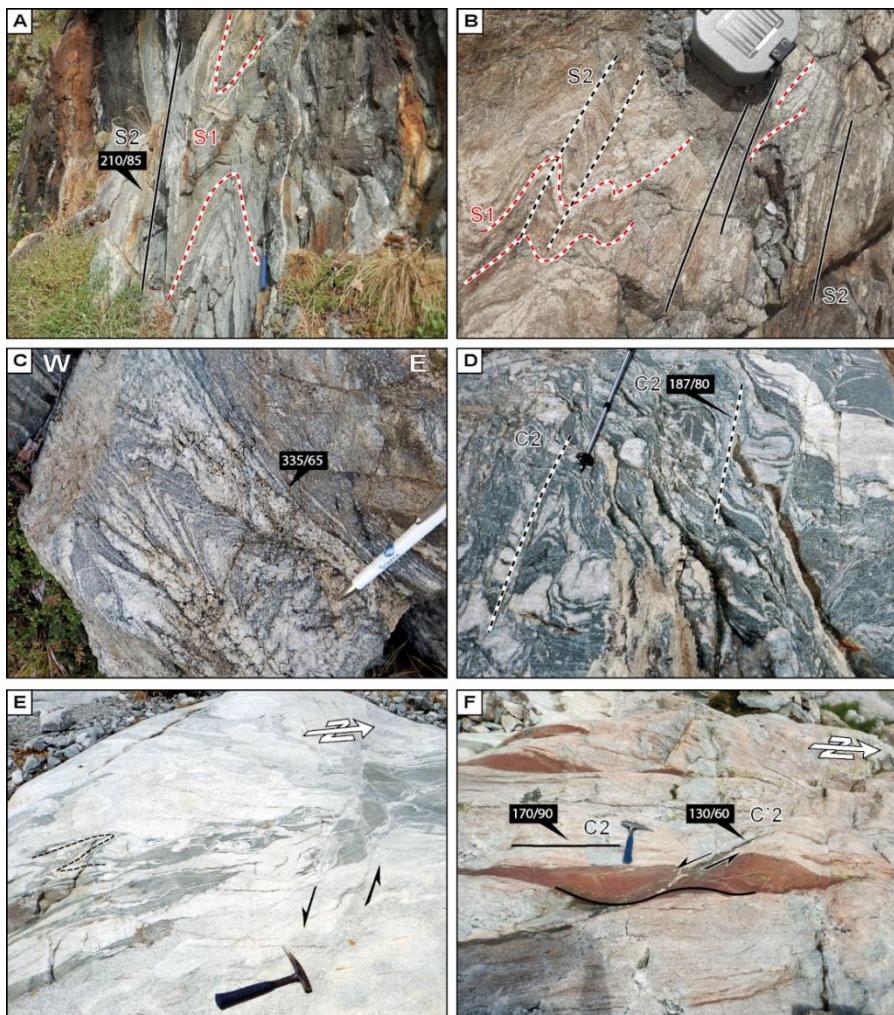
1326

1327

1328

1329 Figure 5

1330

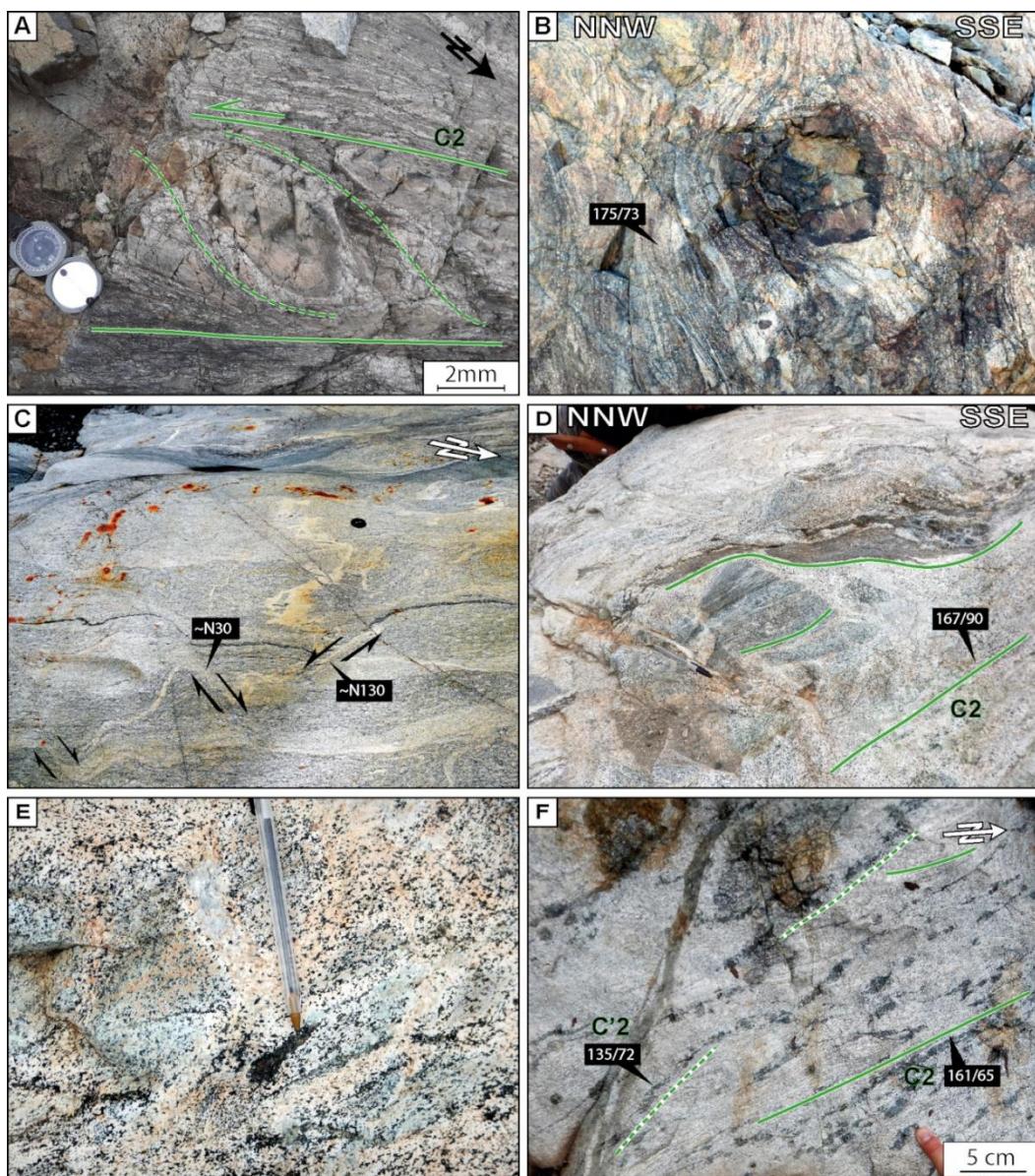


1331

1332

1333 Figure 6

1334



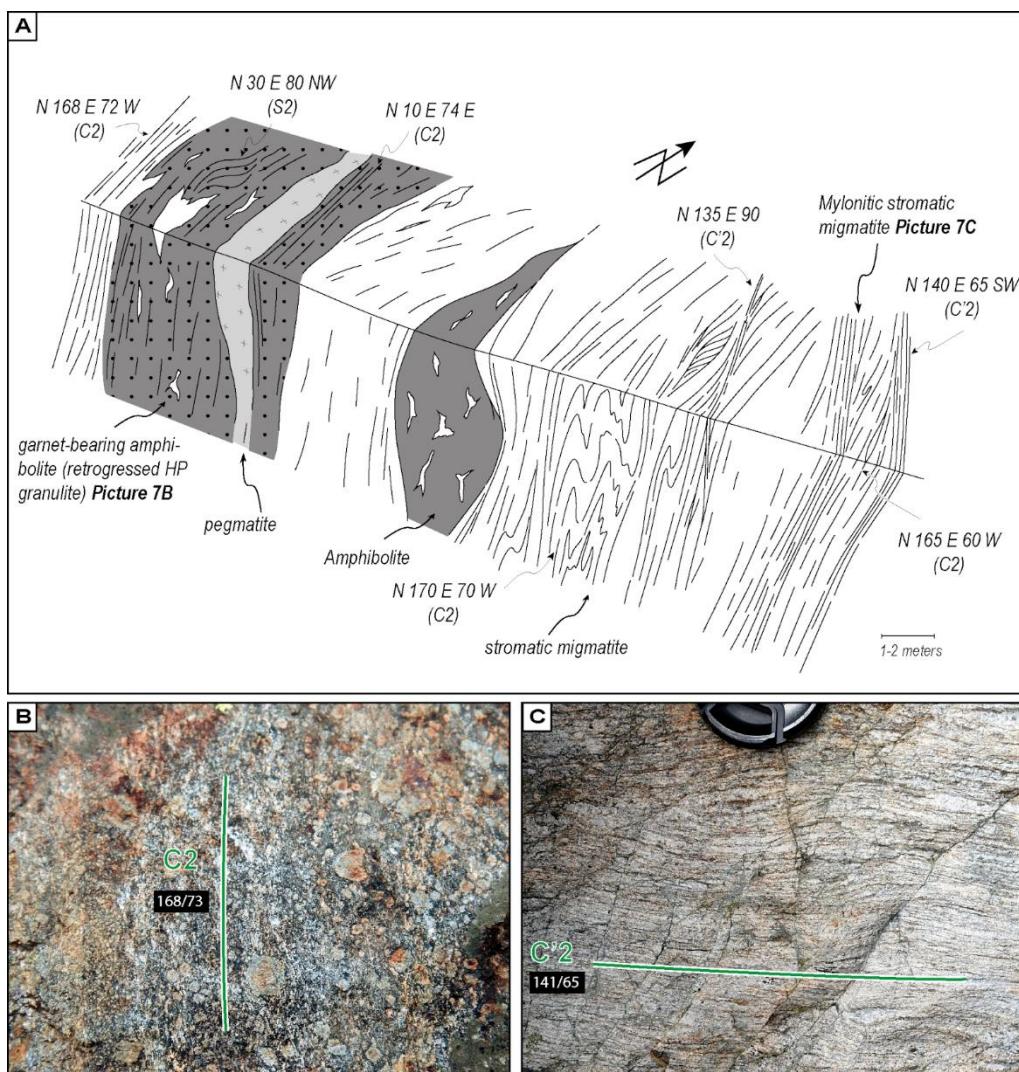
1335

1336

1337

1338 Figure 7

1339



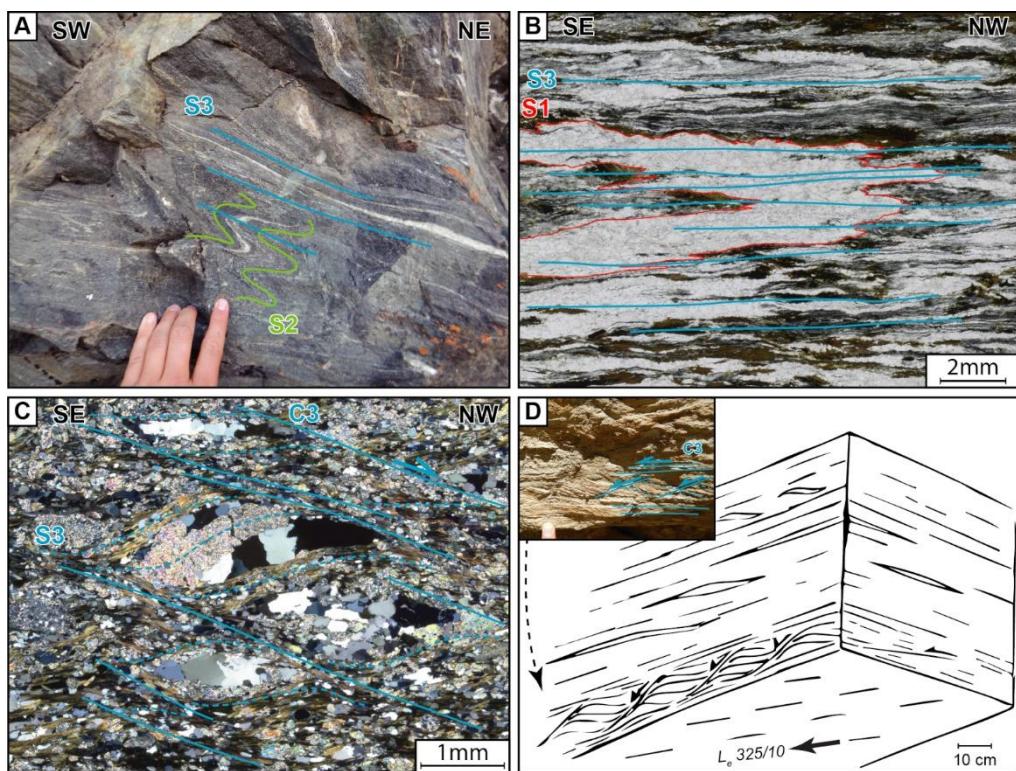
1340

1341

1342

1343 Figure 8

1344



1345

1346

1347

1348

1349 Figure 9

1350



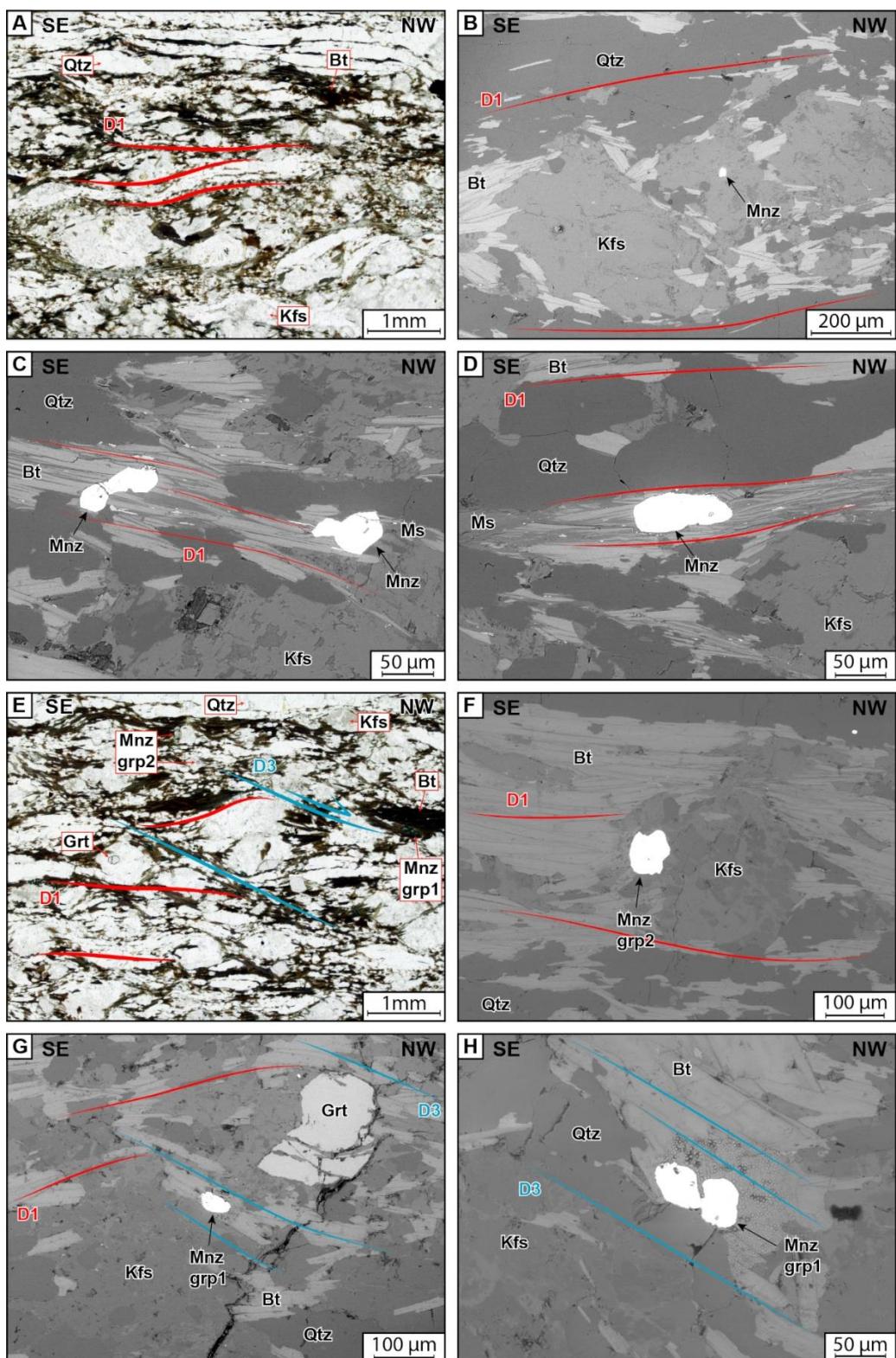
1351

1352

1353

1354 Figure 10

1355



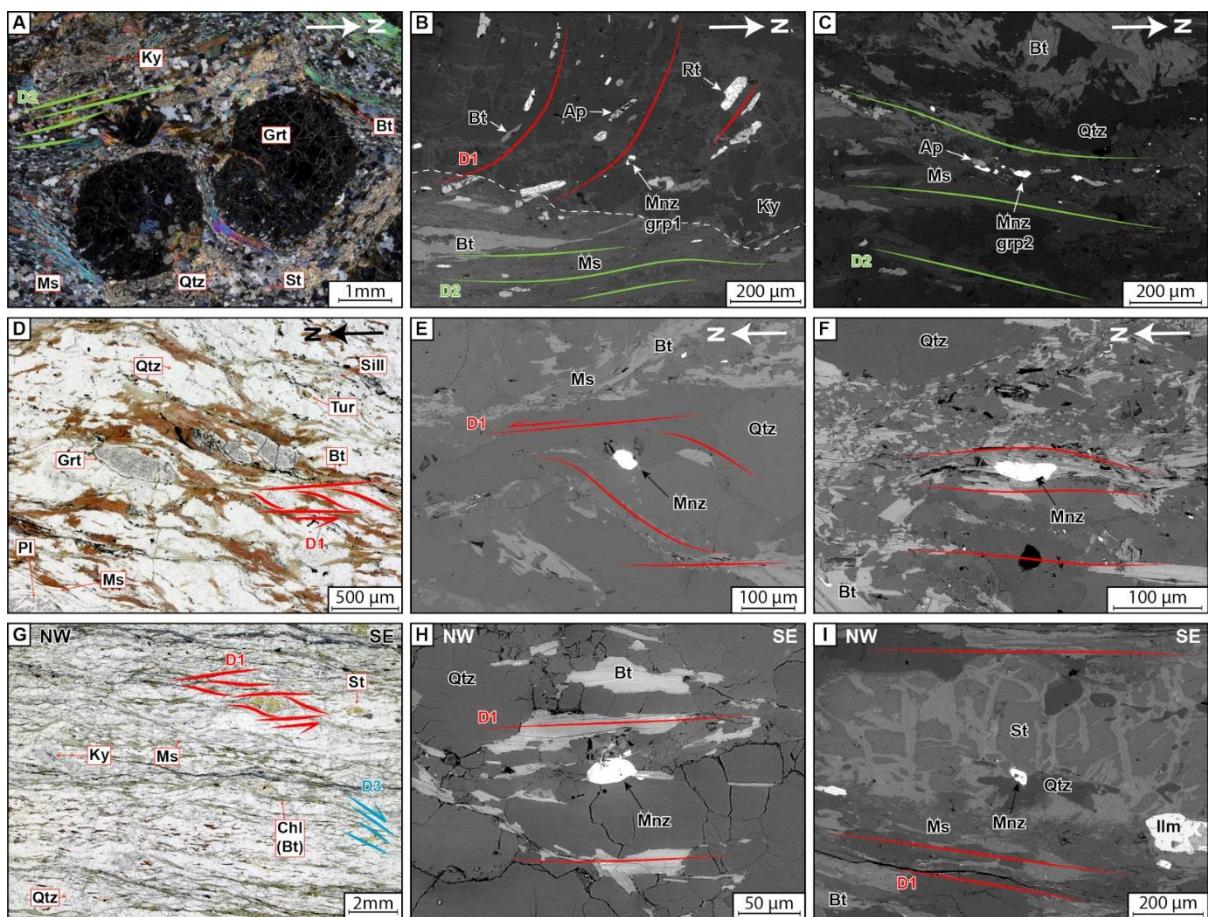
1356

1357

1358

1359 Figure 11

1360



1361

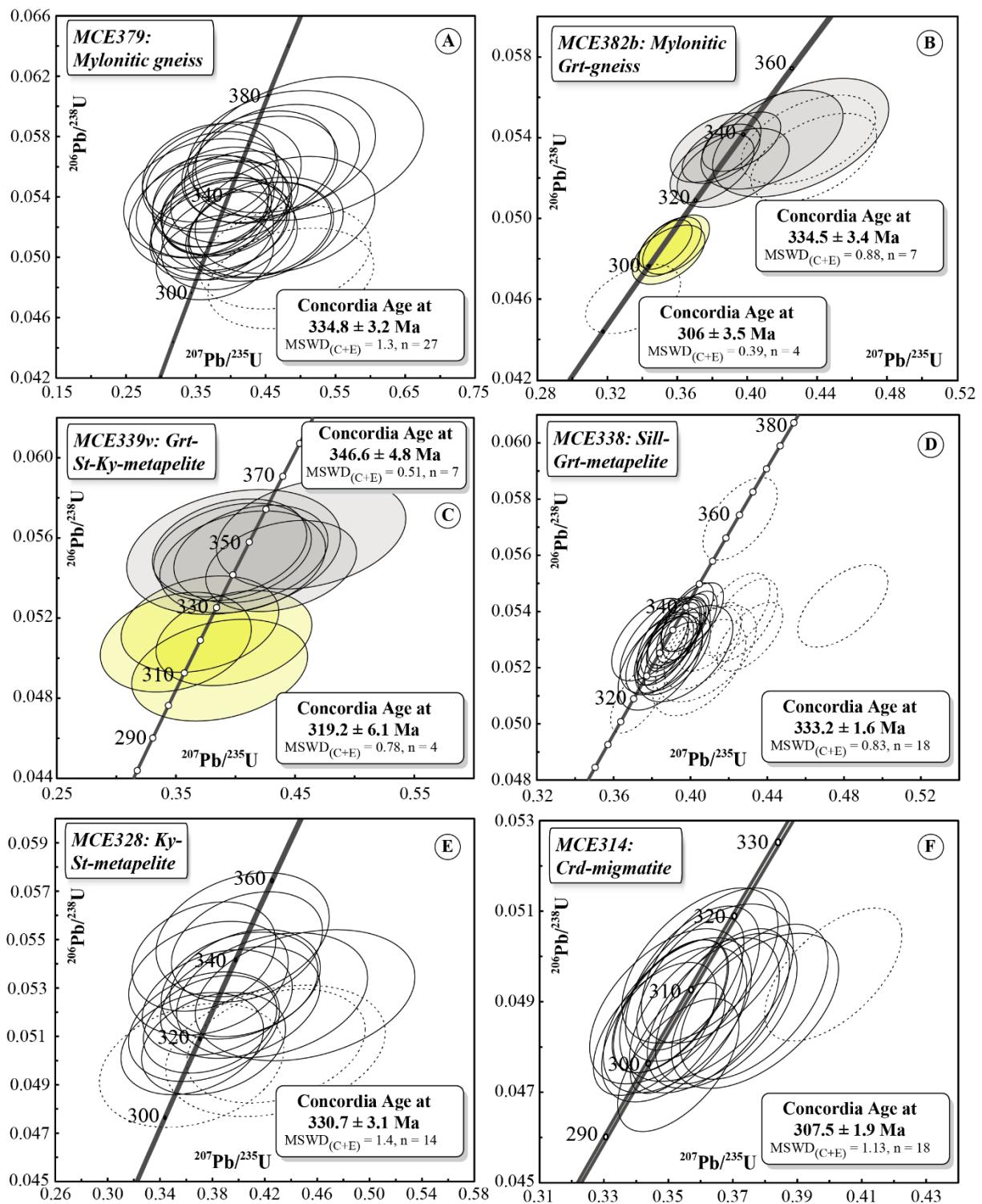
1362

1363

1364

1365 Figure 12

1366



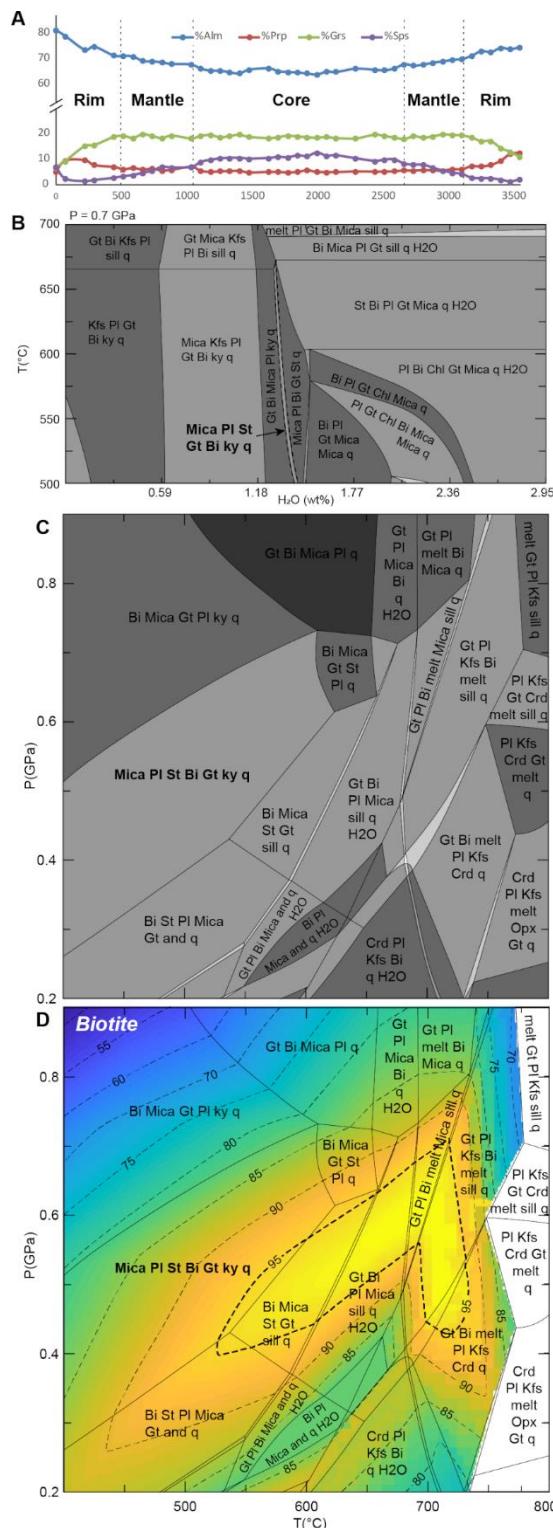
1367

1368

1369

1370 Figure 13

1371

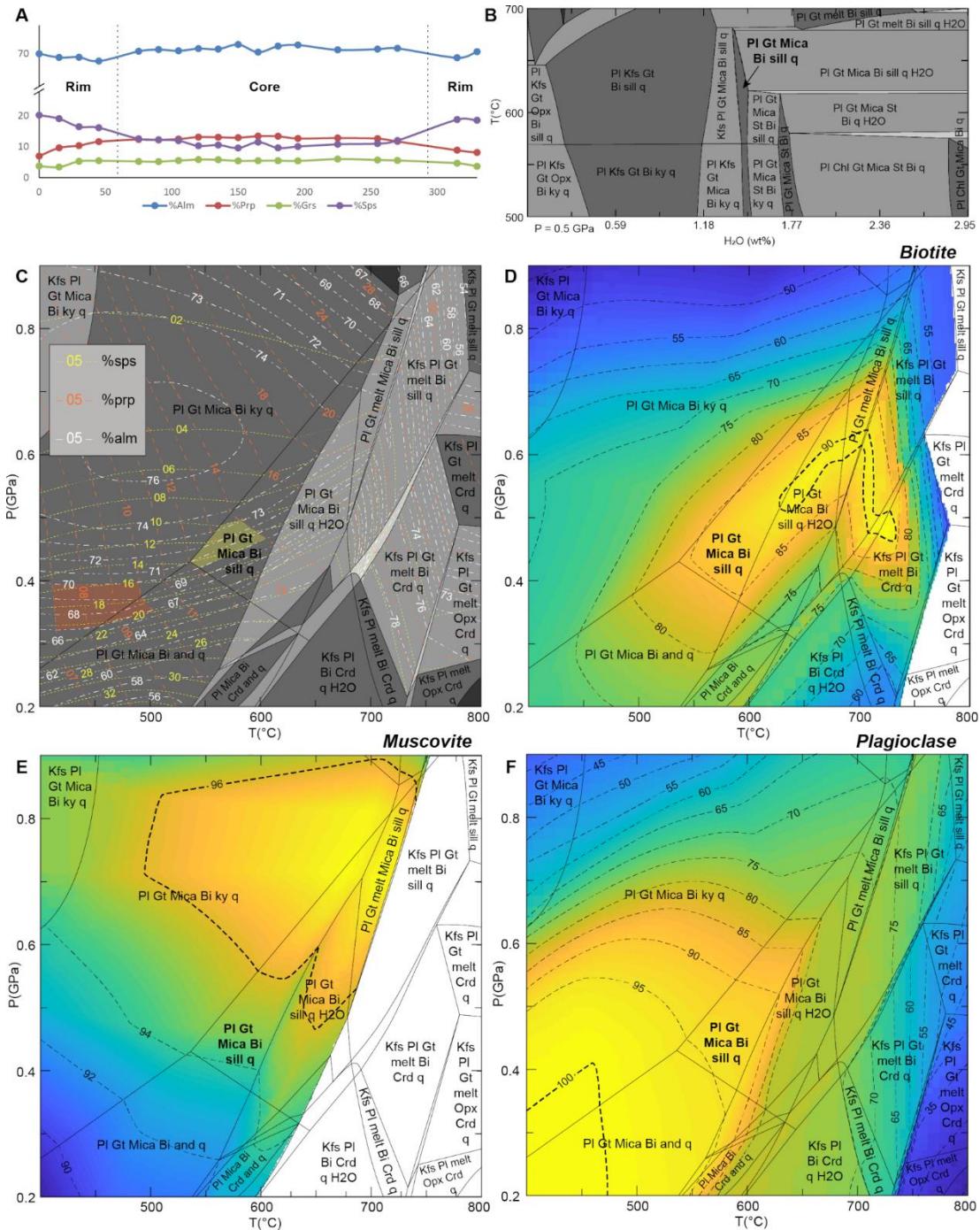


1372

1373

1374 Figure 14

1375



1376

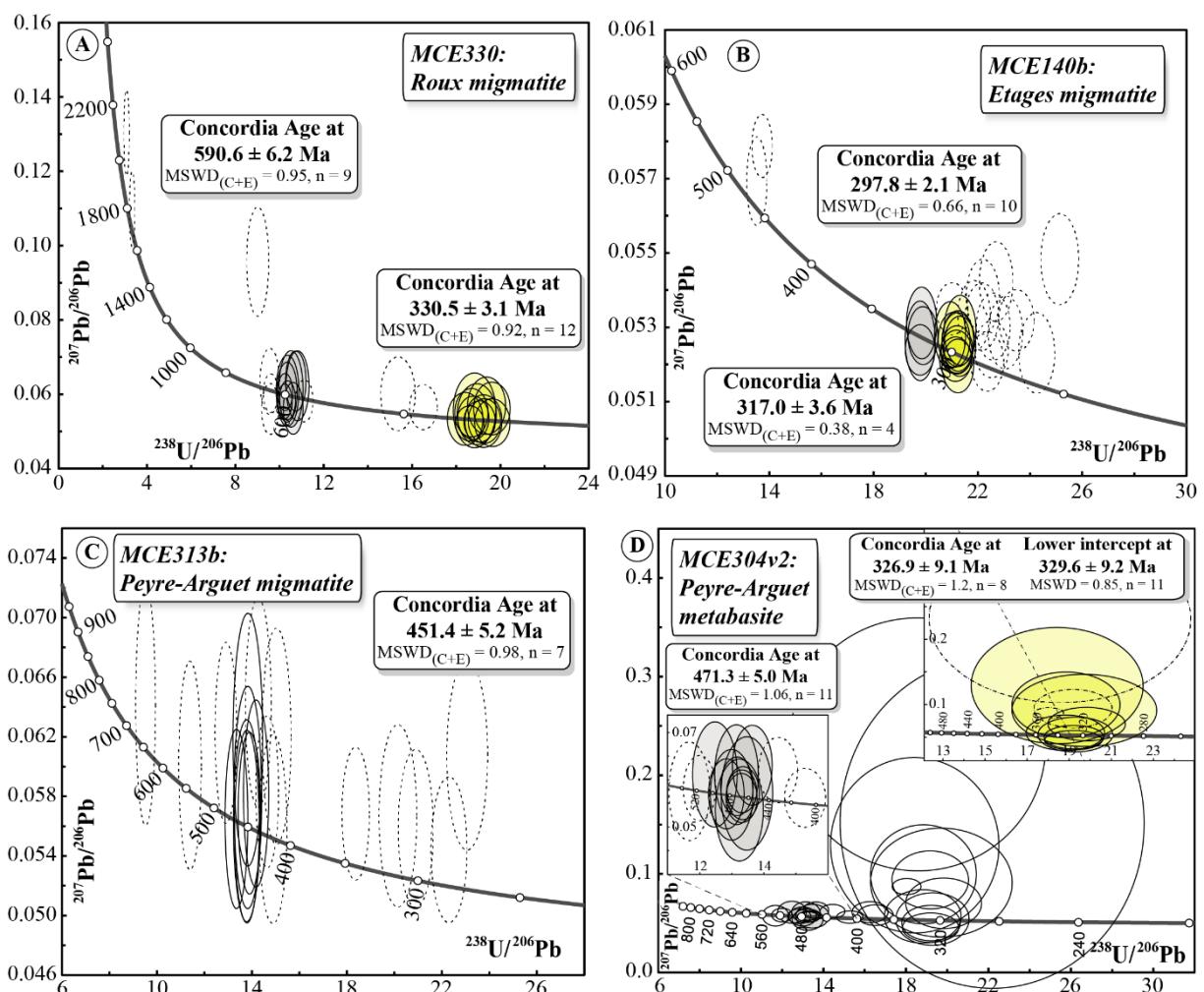
1377

1378

1379

1380 Figure 15

1381



1382

1383

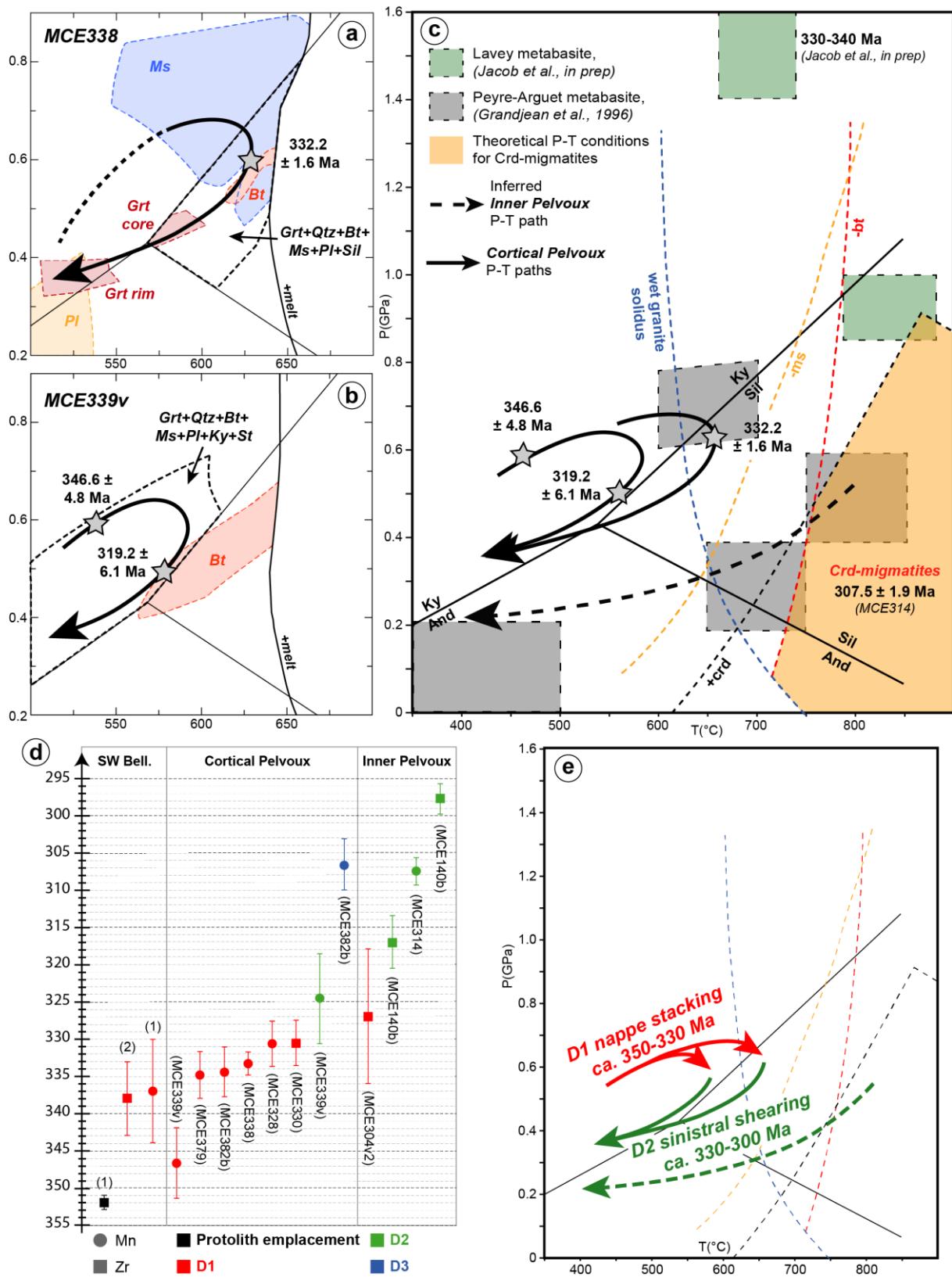
1384

1385

1386

1387 Figure 16

1388

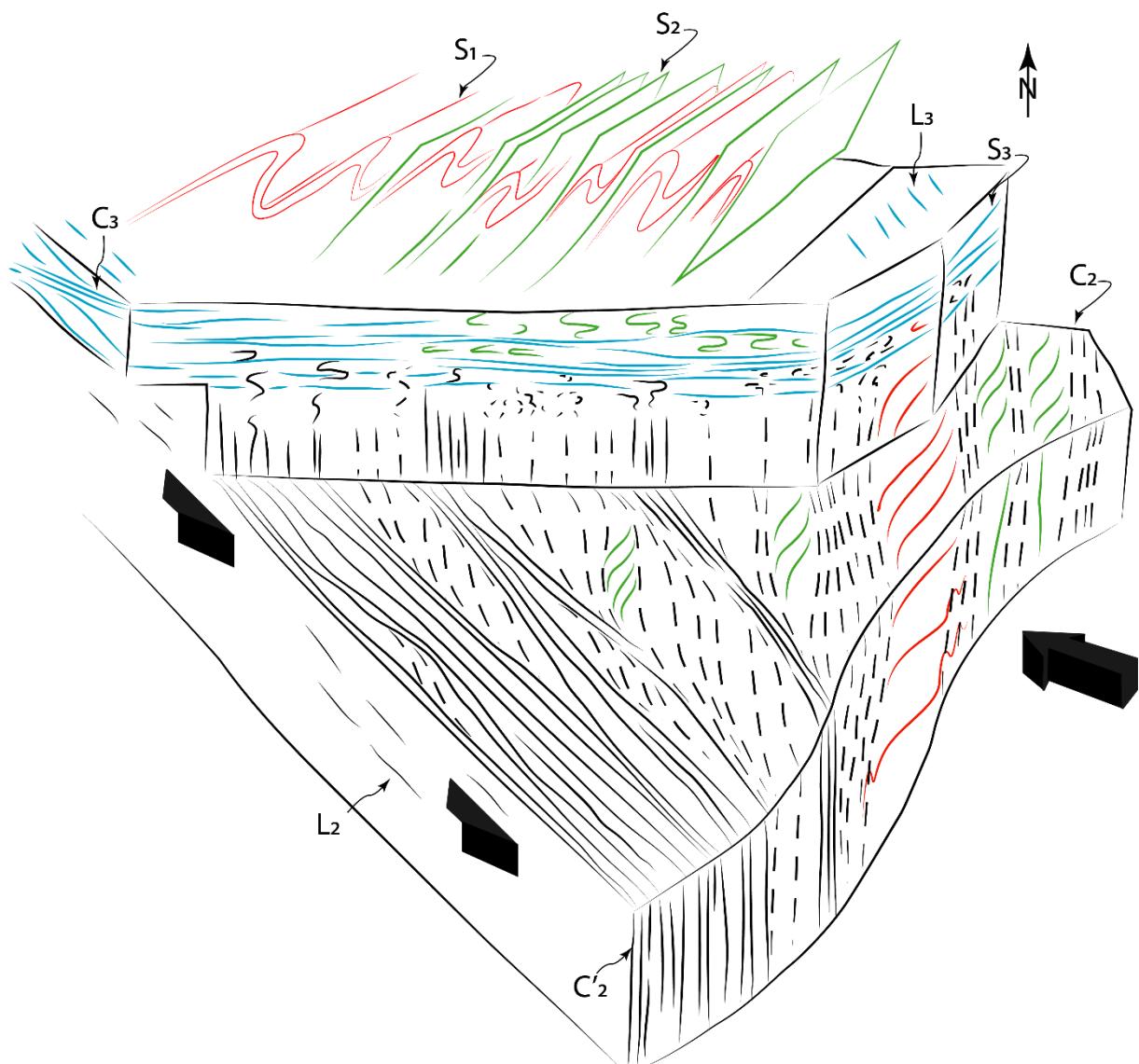


1389

1390

1392 Figure 17

1393



1394

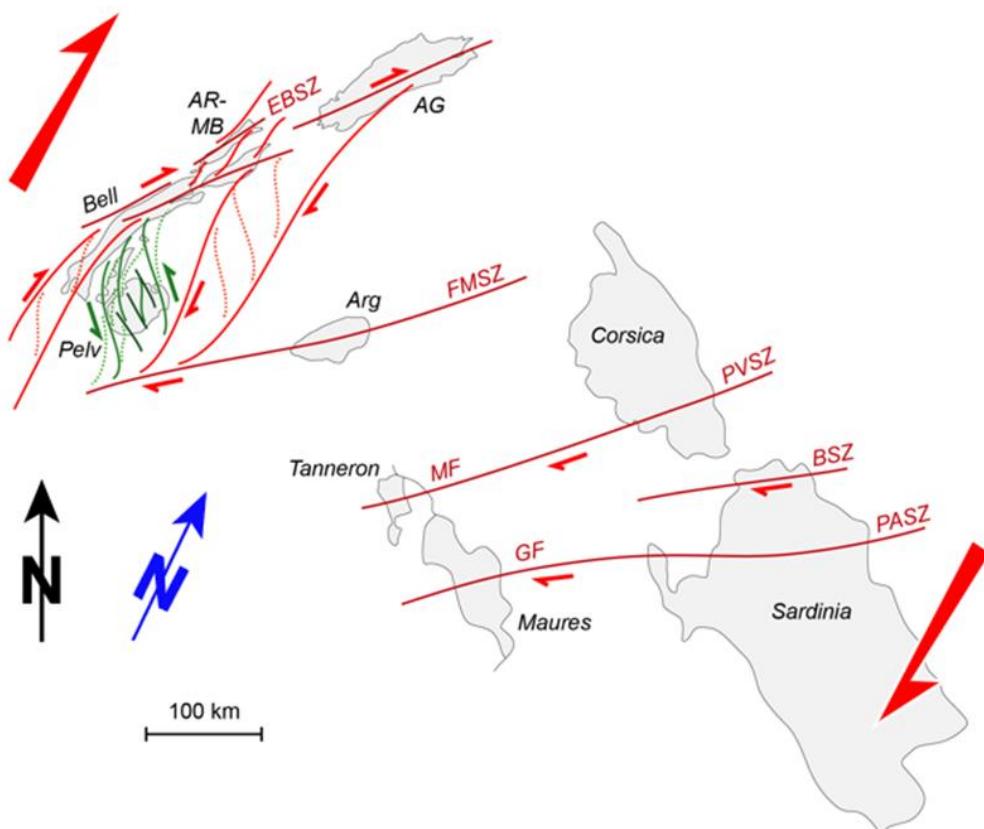
1395

1396

1397

1398 Figure 18

1399



1400

1401

1402

1403 Table 1

1404

Sample	Rock type	GPS location	Mineral dated	U-Th-Pb age ($\pm 2\sigma$)
Cortical Pelvoux				
MCE379	Mylonitic gneiss	N45°1'23.49" E06°2'33.70"	Monazite	334.8 \pm 3.2 Ma
MCE382b	Mylonitic Grt-gneiss	N45°1'2.61" E06°2'50.99"	Monazite	334.5 \pm 3.4 Ma
				306.0 \pm 3.5 Ma
MCE339v	Grt-St-Ky-metapelite	N44°52'52.00" E05°59'17.34"	Monazite	346.6 \pm 4.8 Ma
				319.2 \pm 6.1 Ma
MCE338	Sill-Grt-metapelite	N44°52'58.84" E06°0'49.10"	Monazite	333.2 \pm 1.6 Ma
MCE328	Ky-St-metapelite	N44°47'12.12" E06°4'1.62"	Monazite	330.7 \pm 3.1 Ma
MCE330	Roux migmatite	N44°47'29.86" E06°5'18.09"	Zircon	330.5 \pm 3.1 Ma
				590.6 \pm 6.2 Ma
Inner Pelvoux				
MCE314	Peyre-Arguet Crd-migmatite	N44°50'6.69" E06°22'2.42"	Monazite	307.5 \pm 1.9 Ma
MCE313b	Peyre-Arguet migmatite	N44°56'4.37" E06°12'55.58"	Zircon	451.4 \pm 5.2 Ma
MCE140b	Etages migmatite	N44°56'4.37" E06°12'55.58"	Zircon	297.8 \pm 2.1 Ma
				317.0 \pm 3.6 Ma
MCE304v2	Peyre-Arguet metabasite	N44°50'15.34" E06°21'22.25"	Zircon	326.9 \pm 9.1 Ma
				471.3 \pm 5.0 Ma

1405

1406

1407 Table 2

1408

<i>oxyde (wt%)</i>	SiO ₂	Al ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	Cr ₂ O ₃	NiO	LOI	total
<i>MCE339v</i>	67,30	16,00	5,95	2,26	1,01	2,09	3,18	0,75	0,07	0,16	0,01	0,00	2,15	100,93
<i>MCE338</i>	59,70	19,00	7,32	3,26	1,09	2,07	3,82	0,93	0,11	0,12	0,02	0,00	2,95	100,39

1409

1410

1411

1412 Table 3

1413

	Garnet				Biotite		Muscovite	Plagioclase
	MCE339v		MCE338		MCE339v	MCE338	MCE338	MCE338
	Core	Rim	Core	Rim				
<i>Oxydes (wt%)</i>								
SiO ₂	36,39	36,71	36,38	36,54	34,19	35,05	46,27	61,19
Al ₂ O ₃	20,34	20,44	20,48	20,16	19,23	18,45	36,41	23,14
TiO ₂	0,19	0,05	0,03	0,01	1,66	1,47	0,34	
FeO	29,56	33,90	31,96	30,09	20,16	20,48	1,33	
MgO	1,27	2,31	3,14	2,02	8,63	9,10	0,69	
MnO	4,57	0,86	4,78	8,13	0,05	0,05	0,02	
CaO	6,62	5,14	1,93	1,31	0,00	0,02	0,03	4,83
Na ₂ O					0,11	0,18	1,31	8,61
K ₂ O					8,51	8,99	9,62	0,11
Total	98,94	99,41	98,70	98,26	92,54	93,79	96,02	97,88
<i>Mol cations</i>								
Si	2,97	2,97	2,97	3,02	2,68	2,72	3,05	2,79
Al	1,96	1,96	1,98	1,96	1,78	1,69	2,83	1,24
Ti	0,01	0,00	0,00	0,00		0,09	0,02	
Fe ²⁺	2,02	2,30	2,14	2,05	1,32	1,33	0,07	
Fe ³⁺	0,00	0,00	0,05	0,03				
Mg	0,16	0,28	0,38	0,25	1,01	1,05	0,07	
Mn	0,32	0,06	0,33	0,61	0,00	0,00	0,00	
Ca	0,58	0,45	0,57	0,11	0,00	0,00	0,00	0,24
Na					0,02	0,03	0,17	0,62
K					0,85	0,89	0,81	0,01
X _{Fe}					0,57	0,56		
<i>End members</i>								
An							71,89	
Orth							27,34	
Prp	5,13	9,21	12,66	8,35			0,77	
Alm	65,26	74,09	70,77	68,69				
Grs	18,87	14,49	5,51	3,85				
Sps	10,45	1,96	10,97	19,07				

1414

1415

1416 Figure 4

1417

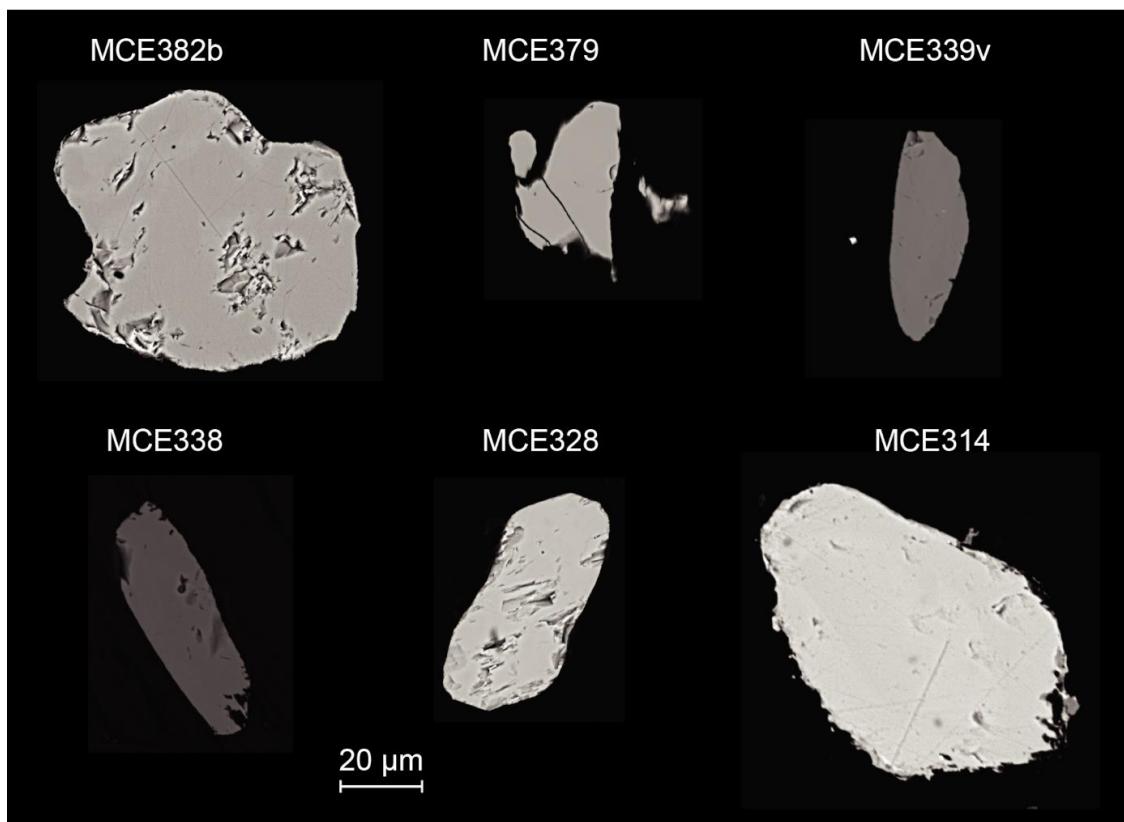
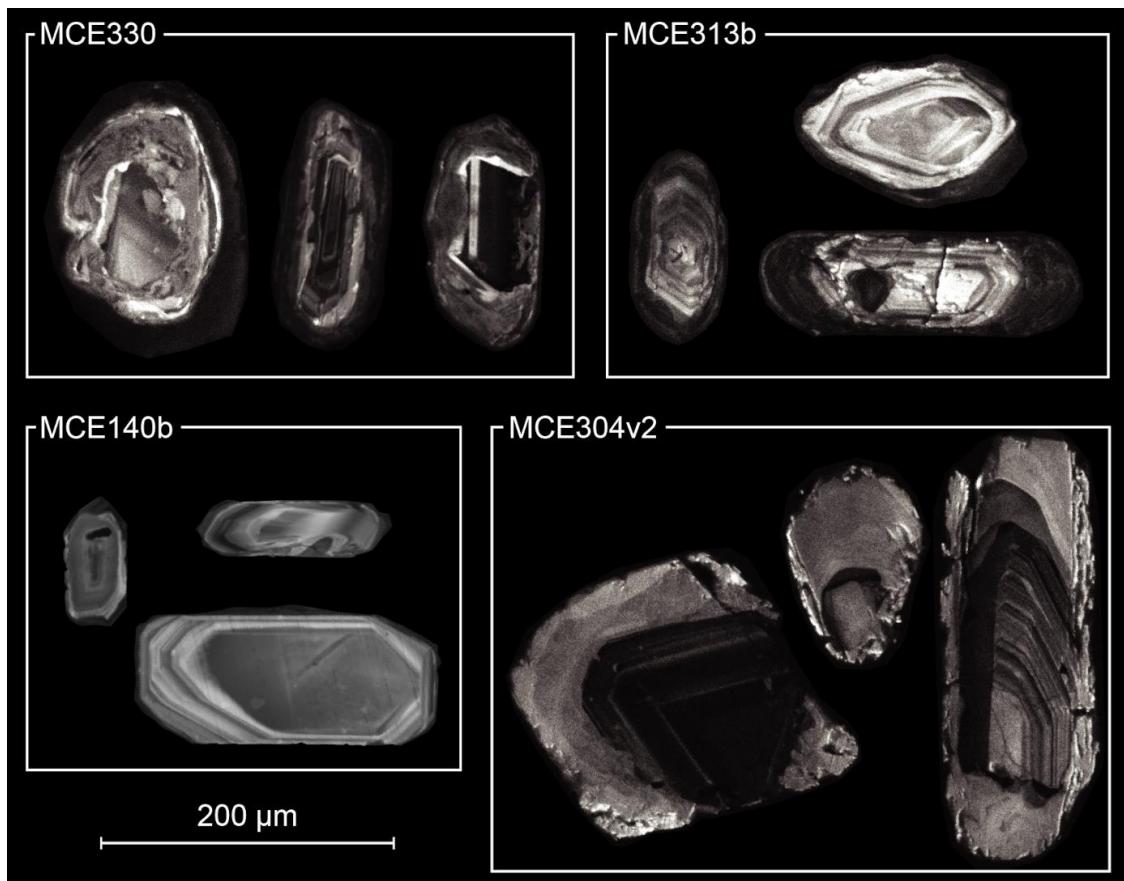
Event		Belledonne SW	Cortical Pelvoux	Inner Pelvoux
D3	Structure		Low angle S3 +/- mylonitic Horizontal axis F3 fold and a-Type F3 fold Top to NE shearing	Low angle S3 +/- mylonitic Horizontal axis F3 fold
	P-T		Retrograde amphibolite facies 0.45-0.35 GPa-450- 50 °C	High-T migmatite Cordierite bearing migmatite
	Age		ca. 306-298 Ma	ca. 306-298 Ma ?
D2	Structure	High angle S2 N030E Upright fold NE-SW axis NE-SW L2	High angle S2 N030E High angle C2 N-S High angle C'2 N150E Folded S2, Horizontal axis	High angle S2 N030E Upright fold NE-SW axis High angle C2 N-S High angle C'2 N150E NS to NE-SW L2
	P-T	Sill +melt	Low-T migmatite	Low-T migmatite
	Age	ca. 330-310 Ma <i>Freville et al. 2018</i>	ca. 330-298 Ma	ca. 330-298 Ma
D1	Structure	Low angle S1 Recumbent fold to the east E-W L1	Mark the lithological limits low angle S1-3	Mostly erased Relictual S1 in F2 fold hinge
	P-T	Amphibolite facies Grt-Bt +melt 0.6-0.8 GPa-600-630°C	Amphibolite facies ? +melt	No evidence
	Age	339 +/- 5 Ma	ca. 350-330 Ma	ca. 340-330 Ma ? (HP stage, <i>Jacob et al., in review</i>)

1418

1419

1420 Figure S1

1421



1422

1423

1424 Table S1

1425

	U (ppm)	Pb (ppm)	207Pb/206Pb	$\pm 1\sigma$	207Pb/235U	$\pm 1\sigma$	206Pb/238U	<i>Isotopic Ratios</i>
MCE330 (Roux migmatite)								
mce330-1	1093	101	0,0602	0,0024	0,8661	0,0329	0,104	
mce330-2	1258	58	0,0528	0,0027	0,3776	0,0185	0,051	
mce330-3	1614	140	0,0580	0,0021	0,7825	0,0276	0,097	
mce330-4	951	45	0,0536	0,0026	0,3939	0,0186	0,053	
mce330-5	868	74	0,0584	0,0024	0,7774	0,0306	0,096	
mce330-6	331	31	0,0560	0,0030	0,8072	0,0426	0,104	
mce330-7	139	40	0,1303	0,0053	5,8510	0,2323	0,325	
mce330-8	1142	99	0,0606	0,0023	0,8151	0,0296	0,093	
mce330-9	2004	95	0,0521	0,0021	0,3862	0,0154	0,053	
mce330-10	1007	80	0,0582	0,0025	0,7221	0,0307	0,089	
mce330-11	247	12	0,0556	0,0044	0,4076	0,0313	0,053	
mce330-12	1055	49	0,0527	0,0025	0,3811	0,0174	0,052	
mce330-13	506	42	0,0635	0,0036	0,8163	0,0449	0,093	
mce330-14	923	49	0,0565	0,0027	0,4721	0,0219	0,060	
mce330-15	649	173	0,1098	0,0046	4,5500	0,1852	0,300	
mce330-16	150	15	0,0957	0,0066	1,4641	0,0977	0,111	
mce330-17	765	36	0,0550	0,0029	0,4060	0,0208	0,053	
mce330-18	1226	55	0,0523	0,0028	0,3675	0,0195	0,050	
mce330-19	621	52	0,0562	0,0031	0,7296	0,0391	0,094	
mce330-20	1561	70	0,0562	0,0031	0,3948	0,0215	0,051	
mce330-21	321	26	0,0623	0,0041	0,7939	0,0514	0,092	
mce330-22	624	53	0,0606	0,0036	0,8077	0,0462	0,096	
mce330-23	1178	54	0,0528	0,0031	0,3783	0,0218	0,052	
mce330-24	1237	59	0,0534	0,0031	0,3998	0,0229	0,054	
mce330-25	651	30	0,0547	0,0036	0,3979	0,0256	0,052	
mce330-26	2605	119	0,0569	0,0034	0,4050	0,0236	0,051	
mce330-27	787	73	0,0635	0,0039	0,9153	0,0551	0,104	
mce330-28	338	29	0,0610	0,0042	0,8110	0,0545	0,098	
mce330-29	323	27	0,0615	0,0045	0,8054	0,0577	0,099	
mce330-30	396	23	0,0601	0,0044	0,5393	0,0381	0,065	
MCE304v2 (Peyre-Arguet metabasite)								
mce304V2-1	301	20,2	0,0586	0,0028	0,6144	0,0283	0,076	
mce304V2-2	32	1,4	0,0702	0,0111	0,4882	0,0751	0,050	
mce304V2-3	545	36,2	0,0562	0,0023	0,5822	0,0237	0,075	
mce304V2-4	164	11	0,0536	0,0047	0,5586	0,0477	0,079	
mce304V2-5	153	8,2	0,0581	0,0046	0,4854	0,0372	0,060	
mce304V2-6	27	1,3	0,0569	0,0115	0,4170	0,0826	0,053	

mce304V2-7	1349	89,6	0,0576	0,0021	0,5964	0,0210	0,075	
mce304V2-8	27	1,3	0,0939	0,0130	0,6750	0,0904	0,052	
mce304V2-9	199	13,6	0,0568	0,0042	0,6032	0,0435	0,077	
mce304V2-10	104	7	0,0611	0,0046	0,6409	0,0473	0,076	
mce304V2-11	189	12,3	0,0631	0,0038	0,6378	0,0369	0,073	
mce304V2-12	8	0,3	0,0911	0,0243	0,6372	0,1644	0,050	
mce304V2-13	166	11,5	0,0570	0,0033	0,6131	0,0344	0,078	
mce304V2-14	12	0,6	0,0996	0,0219	0,7286	0,1553	0,053	
mce304V2-15	81	6,1	0,0576	0,0046	0,6802	0,0527	0,085	
mce304V2-16	43	2	0,0502	0,0076	0,3599	0,0536	0,052	
mce304V2-17	72	3,3	0,0455	0,0063	0,3269	0,0446	0,052	
mce304V2-18	801	53,3	0,0572	0,0025	0,5908	0,0254	0,074	
mce304V2-19	483	35,8	0,0582	0,0031	0,6695	0,0344	0,083	
mce304V2-20	5	0,2	0,1517	0,0743	0,9431	0,4450	0,045	
mce304V2-21	1852	91,5	0,0872	0,0037	0,6665	0,0275	0,055	
mce304V2-22	6	0,3	0,1290	0,0398	0,9654	0,2859	0,054	
mce304V2-23	114	6,3	0,0612	0,0047	0,5190	0,0387	0,063	
mce304V2-24	142	10,2	0,0612	0,0049	0,6761	0,0526	0,080	
mce304V2-25	29	1,3	0,0542	0,0112	0,3874	0,0790	0,051	
mce304V2-26	677	41,8	0,0621	0,0031	0,5925	0,0289	0,069	
mce304V2-27	3	0,1	0,2312	0,0686	1,7179	0,4555	0,053	
mce304V2-28	102	6,8	0,0571	0,0052	0,5848	0,0522	0,074	
mce304V2-29	1480	86,5	0,0562	0,0028	0,5072	0,0245	0,065	
MCE140b (Etage migmatite)								
	5010616	25	469	0,0527	0,0051	0,3668	0,0053	0,050
	6010616	21	404	0,0531	0,0046	0,3690	0,0052	0,050
	7010616	189	4205	0,0523	0,0044	0,3407	0,0043	0,047
	8010616	84	1723	0,0524	0,0045	0,3651	0,0047	0,050
	9010616	195	4292	0,0524	0,0044	0,3408	0,0043	0,047
	10010616	71	1548	0,0528	0,0044	0,3658	0,0049	0,050
	11010616	129	2730	0,0522	0,0046	0,3401	0,0043	0,047
	12010616	54	1196	0,0525	0,0046	0,3397	0,0045	0,048
	16010616	106	2329	0,0527	0,0044	0,3420	0,0044	0,047
	17010616	69	1541	0,0526	0,0046	0,3417	0,0046	0,047
	18010616	109	2361	0,0535	0,0040	0,3510	0,0045	0,047
	19010616	80	1727	0,0524	0,0046	0,3208	0,0042	0,044
	20010616	90	1971	0,0520	0,0049	0,3374	0,0044	0,047
	21010616	71	938	0,0579	0,0029	0,5814	0,0076	0,072
	22010616	95	2083	0,0527	0,0045	0,3443	0,0045	0,047
	23010616	64	1460	0,0521	0,0049	0,3212	0,0043	0,044
	27010616	20	279	0,0569	0,0035	0,5804	0,0084	0,073
	28010616	90	2143	0,0532	0,0043	0,3123	0,0042	0,042
	29010616	55	1165	0,0528	0,0046	0,3477	0,0047	0,047
	30010616	55	1174	0,0529	0,0046	0,3423	0,0047	0,048
	31010616	78	1818	0,0530	0,0045	0,3236	0,0044	0,044

	32010616	43	1112	0,0548	0,0041	0,3007	0,0045	0,039
	33010616	89	2001	0,0533	0,0044	0,3363	0,0046	0,043
	34010616	129	2961	0,0533	0,0044	0,3316	0,0045	0,043
	38010616	53	1308	0,0523	0,0053	0,2974	0,0043	0,043
	39010616	216	5260	0,0529	0,0047	0,3161	0,0044	0,043
	40010616	78	1772	0,0538	0,0043	0,3344	0,0047	0,043
	41010616	87	1954	0,0542	0,0042	0,3294	0,0047	0,043
MCE313b (Peyre Arguet migmatite)								
mce313b-1	1645	79	0,0568	0,0020	0,4266	0,0147	0,054	
mce313b-2	353	23	0,0565	0,0027	0,5834	0,0268	0,074	
mce313b-4	411	26	0,0560	0,0029	0,5597	0,0278	0,072	
mce313b-5	1043	66	0,0569	0,0024	0,5642	0,0234	0,072	
mce313b-7	631	38	0,0583	0,0023	0,5489	0,0210	0,068	
mce313b-9	466	32	0,0623	0,0027	0,6653	0,0283	0,077	
mce313b-12	472	29	0,0643	0,0031	0,6211	0,0294	0,070	
mce313b-15	2404	96	0,0544	0,0022	0,3364	0,0132	0,044	
mce313b-17	327	21	0,0582	0,0028	0,5660	0,0264	0,070	
mce313b-18	2335	90	0,0608	0,0029	0,3633	0,0165	0,043	
mce313b-19	2106	90	0,0558	0,0024	0,3684	0,0153	0,041	
mce313b-21	499	30	0,0620	0,0033	0,5689	0,0289	0,066	
mce313b-22	436	28	0,0579	0,0033	0,5778	0,0320	0,072	
mce313b-23	815	49	0,0558	0,0028	0,5169	0,0254	0,067	
mce313b-24	566	37	0,0564	0,0030	0,5639	0,0293	0,072	
mce313b-26	292	19	0,0618	0,0038	0,6162	0,0364	0,072	
mce313b-28	1608	71	0,0567	0,0028	0,3880	0,0182	0,049	
mce313b-29	286	27	0,0641	0,0036	0,9290	0,0508	0,105	
mce313b-30	753	59	0,0601	0,0031	0,7272	0,0368	0,087	

1426

1427

1428

1429 Table S2

1430

1431 **Table S2: Operating conditions for the LA-ICP-MS equipment**

Laboratory & Sample Preparation	
Laboratory name	Géosciences Montpellier, UMR CNRS 5243, Montpellier, France
Sample type/mineral	Monazite
Sample preparation	Polished thin-section
Imaging	Hirox SH3000, BSE detector BRGM
Laser ablation system	
Make, Model & type	LambdaPhysiks, Compex 102, Excimer
Ablation cell	Geolas
Laser wavelength	193 nm
Pulse width	15 ns
Fluence	10 J/cm ⁻²
Repetition rate	2 Hz
Spot size	26 µm
Sampling mode / pattern	Single spot
Carrier gas	100% He mixed with Ar before entering the plasma
Background collection	15 seconds
Ablation duration	45 seconds
Wash-out delay	/
Cell carrier gas flow (He)	0.3 l/min
ICP-MS Instrument	
Make, Model & type	Element XR, SF-ICP-MS
Sample introduction	Via conventional tubing
RF power	1350W
Sampler, skimmer cones	Ni
Extraction lenses	/
Make-up gas flow (Ar)	0.6 l/min
Detection system	Electron multiplier
Data acquisition protocol	Time-resolved analysis
Scanning mode	Peak hopping, three points per peak
Detector mode	Pulse counting, except for ²⁰⁸ Pb and ²³² Th (analog mode), dead time correction applied.
Masses measured	²⁰⁴ (Hg + Pb), ²⁰⁶ Pb, ²⁰⁷ Pb, ²⁰⁸ Pb, ²³² Th, ²³⁸ U
Integration time per peak	10.24 ms for all masses, except ²⁰⁸ Pb and ²³² Th (5.12 ms) and ²⁰⁷ Pb (40.96 ms)
Sensitivity / Efficiency	3000 cps/ppm Pb (26µm, 4Hz)
Data Processing	
Gas blank	15 seconds on-peak
Calibration strategy	Manangotry monazite standard used as primary reference material.
Reference Material info	Manangotry (Poitrasson et al., 2000)
Data processing package used	GLITTER ® (van Achterbergh et al., 2001)
Quality control / Validation	/

1432

1433

1434

1435 Table S3

1436

Laboratory & Sample Preparation	
Laboratory name	Bureau de Recherche Géologique et Minière (BRGM), Orléans, France
Sample type/mineral	Zircon
Sample preparation	Polished thin-section
Imaging	Hirox SH3000, BSE detector BRGM
Laser ablation system	
Make, Model & type	CETAC Excite 193, Excimer
Ablation cell	Helex II
Laser wavelength	193 nm
Pulse width	15 ns
Fluence	6 J/cm ²
Repetition rate	3 Hz
Spot size	15 µm
Sampling mode / pattern	Single spot
Carrier gas	100% He mixed with Ar with ‘Squid system’ before entering the plasma
Background collection	20 seconds
Ablation duration	40 seconds
Wash-out delay	/
Cell carrier gas flow (He)	0.45 l/min
ICP-MS Instrument	
Make, Model & type	Thermo-scientific, X-serie II, Q-ICP-MS
Sample introduction	Via conventional tubing
RF power	1400W
Sampler, skimmer cones	Ni
Extraction lenses	/
Make-up gas flow (Ar)	1 l/min
Detection system	Electron multiplier
Data acquisition protocol	Time-resolved analysis
Masses measured	²⁰⁴ (Hg + Pb), ²⁰⁶ Pb, ²⁰⁷ Pb, ²⁰⁸ Pb, ²³² Th, ²³⁸ U
Integration time	50 ms for all masses
Data Processing	
Calibration strategy	Trebilcock monazite standard used as primary reference material.
Reference Material info	Trebilcock (272 ± 2 Ma, Tomascak et al. 1996)
Data processing package used	GLITTER ® (van Achterbergh et al., 2001)
Quality control / Validation	Madmon Monazite standard used has quality control (515 Ma, Schulz et al., 2007.)

1437

1438

1439

1440

1441 Table S4

1442

1443 **Table S4: Operating conditions for the LA-ICP-MS equipment**

Laboratory & Sample Preparation	
Laboratory name	GeOHeLiS Analytical Platform, OSUR, Univ Rennes 1, France
Sample type/mineral	Detrital zircon
Sample preparation	Epoxy mount
Imaging	MIRA3 TESCAN, Tescan CL detector (semi-parabolic mirror and light guide), BRGM
Laser ablation system	
Make, Model & type	ESI NWR193UC, Excimer
Ablation cell	ESI NWR TwoVol2
Laser wavelength	193 nm
Pulse width	< 5 ns
Fluence	8 J/cm ⁻²
Repetition rate	4 Hz
Spot size	25 µm
Sampling mode / pattern	Single spot
Carrier gas	100% He, Ar make-up gas and N ₂ (3 ml/mn) combined using in-house smoothing device
Background collection	20 seconds
Ablation duration	60 seconds
Wash-out delay	15 seconds
Cell carrier gas flow (He)	0.75 l/min
ICP-MS Instrument	
Make, Model & type	Agilent 7700x, Q-ICP-MS
Sample introduction	Via conventional tubing
RF power	1350W
Sampler, skimmer cones	Ni
Extraction lenses	X type
Make-up gas flow (Ar)	0.85 l/min
Detection system	Single collector secondary electron multiplier
Data acquisition protocol	Time-resolved analysis
Scanning mode	Peak hopping, one point per peak
Detector mode	Pulse counting, dead time correction applied, and analog mode when signal intensity > ~ 10 ⁶ cps
Masses measured	²⁰⁴ (Hg + Pb), ²⁰⁶ Pb, ²⁰⁷ Pb, ²⁰⁸ Pb, ²³² Th, ²³⁸ U
Integration time per peak	10-30 ms
Sensitivity / Efficiency	22000 cps/ppm Pb (50µm, 10Hz)
Data Processing	
Gas blank	20 seconds on-peak
Calibration strategy	GJ1 zircon standard used as primary reference material, Plešovice used as secondary reference material (quality control)
Reference Material info	GJ1 (Jackson et al., 2004) Plešovice (Slama et al., 2008)
Data processing package used	GLITTER ® (van Achterbergh et al., 2001)
Quality control / Validation	Plešovice: concordia age = 336.3 ± 3.3 Ma (N=6; MSWD=0.54)

1444

1445