Tracking the Late Devonian high-P metamorphic belt in the Variscan Orogen: new constraints on the PT evolution of eclogites from the Cubito-Moura Unit (SW Iberian Massif)

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Abstract

The Cubito-Moura Unit is a high-P metamorphic succession that occurs in the southern part of the Ossa-Morena Complex (SW Iberian Massif). It includes a series of metasedimentary, metafelsic and metamafic rocks affected by a high-P, low to intermediate-T metamorphic event during Late Devonian times. Geochemistry of the metabasic rocks reveals that the generation of the protoliths occurred in a supra-subduction zone setting during Late Ediacaran to Early Ordovician times, either in a back-arc or fore-arc context. The eclogites contain atoll-like garnets, omphacite, amphibole, phengite (up to Si = 3.38 apfu), paragonite, rutile and quartz. Thermodynamic modelling in the MnNCKFMASTH system indicates a high-P metamorphic event at ~24 kbar and ~585ºC followed by a thermal peak at ~19 kbar and ~630ºC, and a subsequent exhumation to ~15 kbar. This P-T path indicates deep subduction at c. 370 Ma of this arc-related section. The lithostratigraphy and tectonothermal evolution of the Cubito-Moura Unit are equivalent to that of a number of units along the Iberian, Armorican and Bohemian massifs that can be correlated as a part of the same Basal Allochthonous Terrane. These units define a single Late Devonian high-P, low- to intermediate-T metamorphic belt developed during the first stages of the Variscan Orogeny.

Key-words: Eclogites; Thermodynamic modelling; SW Iberian Massif; Variscan Orogen; Variscan correlations

1. INTRODUCTION

Deep subduction of continental margins occurs in the initial stages of continental collision. This process leads to the formation of distinctive high/ultrahigh-P metamorphic belts, which are distributed along the suture zones of orogens and contain key information on the nature of the paleo-subduction zones. Therefore, the

identification of high-P metamorphic belts is essential to understand the tectonic evolution of orogens and plate margins (Dewey, 1975; Miyashiro, 1973). Along Western and Central Europe, large outcrops of the Variscan Orogen define theFrench Massif Central and Armorican, Bohemian and Iberian massifs (Fig. 1a). This orogenic belt formed during the Devonian and Carboniferous as a consequence of the diachronic collision between Gondwana and Laurussia which led to the assembly of Pangea (Arenas et al., 2014; Díez Fernández et al., 2016; Franke, 1989, 2000; Kroner and Romer, 2013; Martínez Catalán et al., 1997; Matte, 1991, 2001; Ribeiro et al., 2007; Simancas et al., 2005). In the Iberian Massif, there is a complete transverse cross-section of the Variscan Orogen, from the Gondwanan to the Laurussian forelands (Fig. 1b). It includes an Internal Variscan Zone comprising ophiolites and high-P units, which are preserved as tectonic klippen defining six allochthonous complexes (i.e. Cabo Ortegal, Órdenes, Malpica-Tui, Bragança, Morais and Ossa-Morena) featured by several suture zones exposures (Fig. 1b; Arenas et al., 2016a; Díez Fernández et al., 2016; Martínez Catalán et al., 2009).

In NW Iberian Massif, the allochthonous complexes comprise a thick stack of terranes (Fig. 1b). At the top of the nappe pile, a peri-Gondwanan continental-affinity terrane, so-called Upper Units, traces an Early Devonian high-P, high-T metamorphic belt (Ábalos et al., 2003; Fernández-Suárez et al., 2007; Fuenlabrada et al., 2010; Gil Ibarguchi et al., 1990; Mendía et al., 2001; Ordóñez Casado et al., 2001). It occurs above a group of Ophiolitic Units that define a complex Variscan suture zone (Arenas and Sánchez Martínez, 2015). At the base of the allochthonous complexes, there is another terrane of peri-Gondwanan affinity that experienced Late Devonian high-P, low- to intermediate-T metamorphism, the so-called Basal Units (Abati et al., 2010; Arenas et al., 1995; Díez Fernández et al., 2011; Gil Ibarguchi and Ortega Gironés, 1985; Martínez Catalán et al., 1996; Munhá et al., 1984; Rodríguez et al., 2003).

95   In the SW Iberian Massif, the Ossa-Morena Complex has been classically

96   interpreted as an autochthonous paleogeographic domain. However, during the last

97   decades tectonic units that developed high-P metamorphism in the Late Devonian

98   have been identified within this domain (Ábalos et al., 1991; Abati et al., 2018; Azor et

99   al., 1994; Fonseca et al., 1999; Leal, 2001; Mata and Munhá, 1986; Moita et al., 2005;

100   Pedro, 1996; Pereira et al., 2010; Rosas et al., 2008). This led to a proposal of

101   correlation along the Iberian Massif of the units affected by a Late Devonian high-P,

102   low- to intermediate-T metamorphic event, which would define a Basal Allochthonous

103   terrane all through Iberia (Arenas et al., 2016a; Díez Fernández and Arenas, 2015;

104   Díez Fernández et al., 2016).

105

106   In NW Iberia, the PT evolution of the Basal Units is rather well constrained

107   (Arenas et al., 1995; Gil Ibarguchi and Ortega Gironés, 1985; Gil Ibarguchi, 1995; Li

108   and Massone, 2016, 2017; Li et al., 2017; López Carmona et al., 2010, 2013, 2014;

109   Puelles et al., 2017; Rubio Pascual et al., 2002). Nevertheless, the metamorphic

110   evolution of the Late Devonian high-P, low- to intermediate-T Basal Units of SW Iberia,

111   including the Badajoz-Córdoba (BCU) and the Cubito-Moura (CMU) units (Fig. 1b), is

112   less well known. Arenas et al. (In press) have presented detailed thermodynamic

113   modelling of unusual Mg-rich chloritoid-bearing high-P metapelites from the BCU.

114   However, the most common high-P rocks in this tectonic unit are severely retrogressed

115   eclogites (Ábalos et al., 1991; Abati et al., 2018; López Sánchez-Vizcaíno, 2003; Mata

116   and Munhá, 1986; Pereira et al., 2010). In the CMU, the high-P rocks of the Évora

117   Massif and further south (Fig. 1b), are better preserved than those of the BCU, and

118   some qualitative constrains regarding their PTt evolution have been published (Moita et

119   al., 2005; Rosas et al., 2008). In this paper we update this information by means of

120   thermodynamic modelling.

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122 The contrasting metamorphic information available for the sequences grouped

123 into the Basal Allochthonous Units demand new research in order to achieve a

124 coherent view of the entire Late Devonian metamorphic belt. The aim of this work,

125 which includes whole-rock geochemistry and mineral chemistry of the Safira eclogites,

126 and thermodynamic modelling in the MnNCKFMASHT system, is to constrain the

127 nature of the protoliths and the PT evolution followed by these rocks of the CMU. In

128 addition, our findings are compared with the tectonothermal evolution of the high-P

129 units from NW and SW Iberia to test tectonic correlations, and to provide far-reaching

130 conclusions regarding the structure and dynamics of the associated subduction

131 channel system active during the Late Devonian.

132

133 **2. GEOLOGICAL SETTING**

134 **2.1 Basal Units: SW Iberian Massif**

135 In SW Iberian Massif, the Ossa-Morena Complex contains two Late Devonian

136 high-P, low- to intermediate-T units (Basal Units) with a NW-SE trend: the Badajoz-

137 Córdoba Unit (BCU) to the north (also known as Central Unit; Fig. 1b) and the Cubito-

138 Moura Unit (CMU) to the south (Fig. 1b).

139

140 2.1.1 Badajoz-Córdoba Unit

141 The BCU and CMU (Fig. 1b) have the same tectonostratigraphic position within

142 the allochthonous pile (Díez Fernández and Arenas, 2015). The BCU is divided into

143 two sequences (Azor et al., 1994). The Lower Sequence contains albite-bearing

144 paragneisses alternating with minor quartzites and marbles, with abundant alkaline and

145 calc-alkaline orthogneisses and metabasites. The Upper Sequence is composed by

146 micaschists, garnet-bearing micaschists and orthogneisses. Protolith ages of the felsic

147 gneisses and metabasites range from c. 577 to 480 Ma, and from c. 615 to 585 Ma,

148 respectively (Abati et al., 2018). The BCU was affected by high-P, low- to intermediate-

149   T metamorphism dated at c. 377 Ma (Abati et al., 2018), reaching peak-P conditions at

150   c. 20 kbar and 525ºC (Arenas et al., In press).

151

152   2.1.2 Cubito-Moura Unit

153   The CMU extends along two hundred kilometers from the Évora Massif to the

154   north of the Aracena Massif and is divided into two juxtaposed sequences according to

155   their lithostratigraphy (Díez Fernández and Arenas, 2015; Díez Fernández et al.,

156   2016). The Lower Sequence is found in the Évora Massif, and further south in the

157   Alvito-Viana do Alentejo sector (Fig. 1b). The Évora Massif is a large dome-like

158   structure located in the westernmost part of the Ossa-Morena Complex (Dias da Silva

159   et al., 2018; Pereira et al., 2009). It is composed of two domains: a high-grade domain

160   (footwall block) separated from an overlying low- to intermediate-grade domain

161   (hanging-wall block) by extensional shear zones (Dias da Silva et al., 2018; Pereira et

162   al., 2003, 2007, 2009) (Fig. 2). The high-grade metamorphic domain appears in the

163   core of late upright antiforms and comprises gneisses, migmatites and amphibolites

164   closely associated with gabbro-diorites and granitic rocks dated at c. 341-336 Ma

165   (Moita et al., 2015; Pereira et al., 2015). In the Montemor-o-Novo - Safira area, the low-

166   to-intermediate-grade metamorphic domain appears in the core of the late upright

167   synforms where the Lower Sequence of the Basal Units occurs, such as the Cabrela-

168   Carvalhal synform (Fig. 2), representing a later contractional structure (Chichorro,

169   2006; Díez Fernández et al., 2017; Pereira et al., 2007, 2009). The Lower Sequence

170   includes metasedimentary, metafelsic and, in less proportion, metamafic rocks variably

171   distributed in two members (Fig. 2). The lower member (Escoural Unit or Serie Negra

172   Group; Chichorro, 2006; Chichorro et al., 2008), comprises metapelites,

173   metagreywackes, paragneisses, micaschists, black metacherts and black quartzites,

174   with maximum depositional ages around 560-540 Ma (Late Ediacaran; Pereira et al.,

175   2008). These metasedimentary rocks are associated with amphibolites and abundant

176   felsic gneisses yielding a protolith age of c. 522-517 Ma (Early Cambrian; Chichorro et

al., 2008). The upper member (Monfurado Unit), comprises micaschists, meta-arkoses, marbles and interbedded metafelsic and metamafic rocks, assigned to the Early-Middle Cambrian (Chichorro, 2006; Pereira et al., 2007). Geochronological and geochemical features of the Late Ediacaran metasedimentary rocks (i.e. Escoural Unit) suggest a depositional environment in a basin related to the erosion of a Cadomian magmatic arc in the Gondwanan margin, with strong contribution from the West African Craton (Chichorro et al., 2008; Díez Fernández et al., 2017; Pereira et al., 2008). Later, siliciclastic and carbonate sediments and volcanic rocks (i.e. Monfurado Unit) deposited as a result of a Cambrian rifting process (Chichorro et al., 2008; Pereira et al., 2007).

In the Évora Massif, the Lower Sequence of the Basal Units is tectonically overlain by the Carvalhal Unit (Carvalhosa and Zbyszewski, 1994) (Fig. 2) representing an igneous (mafic-dominated) and sedimentary complex (Chichorro, 2006; Pereira et al., 2007), interpreted as a Middle Cambrian-Ordovician (?) ophiolitic unit (Díez Fernández et al., 2017).

2.2 Basal Units: NW Iberian Massif

The Basal Units in NW Iberian Massif (Galicia) are divided into two tectonically juxtaposed sequences according to their lithostratigraphy (Díez Fernández et al., 2010). The Lower Sequence is composed by siliciclastic metasediments of Late Ediacaran age (c. 560-540 Ma, U-Pb in detrital zircon; Díez Fernández et al., 2010). The Upper Sequence includes siliciclastic metasediments and marbles, with a Middle-Late Cambrian maximum depositional age (c. 512-480 Ma, U-Pb in detrital zircon; Díez Fernández et al., 2010, 2013). These sediments were intruded by Cambrian-Ordovician calc-alkaline granitoids and mafic dykes (c. 498-493 Ma; Abati et al. 2010; Andonaegui et al., 2017) and by a suite of peralkaline affinity (c. 482-470 Ma; Díez

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205 Fernández et al., 2012a; Montero et al., 2009). The Basal Units in NW Iberia are

206 considered the remnants of a Cadomian peri-Gondwanan back-arc located at the

207 eastern part of the West African Craton affected by a Cambrian rifting episode (Díez

208 Fernández et al., 2010; Fuenlabrada et al., 2012).

209

210 The PT conditions experienced during Late Devonian times (c. 377-372 Ma;

211 Abati et al., 2010; Beranoaguirre et al., 2019; Rodríguez et al., 2003) by the Basal

212 Units in NW Iberia correlate, in general, with their tectonostratigraphic division. In the

213 Lower Sequence, PT conditions increase progressively to the west, from the

214 blueschists to intermediate-T eclogite facies, as a likely consequence of different

215 original position of tectonic units in a W-dipping subducting slab (present coordinates,

216 Martínez-Catalán et al., 1996; Díez Fernández et al., 2012b). The Upper Sequence is

217 characterized by blueschist facies metamorphism at the base, while high-P

218 metamorphism has not been identified at the top of the sequence (López-Carmona et

219 al., 2010, 2013, 2014; Rodríguez et al., 2003). The colder metamorphic evolution of the

220 Upper Sequence has been attributed to the regional scale depression of isotherms

221 during the subduction channel dynamics (Díez Fernández et al., 2011).

222

223 **3. HIGH-P METAMORPHISM IN THE CMU: BACKGROUND**

224 In the CMU, Fonseca et al. (1993), Leal (2001), Moita (1997), Pedro (1996) and

225 Rosas (2003) reported blueschists and eclogites in the Évora Massif (i.e. Montemor-o-

226 Novo – Safira area), and further south (Alvito-Viana do Alentejo area). They are

227 interpreted to represent a Variscan high-P and low- to intermediate-T metamorphic

228 event at c. 371 Ma (Sm-Nd whole rock-garnet isochron; Moita et al., 2005). In spite of

229 the detailed descriptions of these high-P metamafic rocks, their PT conditions and

230 paths remain poorly constrained.

231

232   In the Montemor-o-Novo - Safira area, meter-scale lenses of eclogites mainly

233   composed of garnet, omphacite and white mica, locally with glaucophane, are found

234   surrounded by felsic gneisses and micaschists (Leal, 2001; Pedro, 1996). A major

235   feature of the Safira eclogites is the atoll-shaped garnets, which are not recognized in

236   the Alvito-Viana do Alentejo eclogites (Leal, 2001). Minimum-T of 520-620 ºC and

237   minimum-P of 10-13 kbar were estimated for the metamorphic peak of the Safira

238   eclogites using thermobarometry (Leal, 2001; Pedro, 1996).

239

240   In the Alvito-Viana do Alentejo area, variably retrogressed glaucophane-bearing

241   eclogites and blueschists occur as meter-scale lenses within metapelites, marbles and

242   gneisses (Moita, 1997; Leal, 2001). The eclogites are mainly composed of garnet,

243   omphacite, and glaucophane, and include white mica, quartz and rutile as accessories,

244   whereas blueschists consist mostly of garnet and glaucophane. PT conditions of 10 to

245   16 kbar and 450-650ºC for the metamorphic peak of the glaucophane-bearing eclogites

246   were estimated by Moita (1997) via classical thermobarometry. Also, pseudosection

247   modelling was performed by Leal (2001) in the NCFMASH system, which yielded 650-

248   700 ºC and 18 kbar for the metamorphic peak. On the other hand, Moita (1997)

249   inferred lower pressures of 10-12 kbar in the blueschists based on the classical stability

250   fields for blueschists proposed by different authors.

251

252   **4. METHODS**

253   **4.1 Mineral chemistry**

254   The mineral chemistry of two fresh samples of the Safira eclogites was

255   investigated to estimate their P-T conditions of metamorphism and decipher their

256   tectonothermal evolution. Elemental X-Ray maps of the two eclogite samples were

257   obtained with a JEOL Superprobe JXA-8900M from Universidad Complutense (Madrid,

258   Spain). The microprobe was operated at 300 nA beam current, 20 kV accelerating

259   voltage, 2 μm pixel size and 20 ms counting time, to acquire (by means of wavelength

dispersive spectrometry, WDS) X-Ray maps of Si (Kα), Ti (Kα), Al (Kα), Fe (Kα), Mn (Kα), Mg (Kα), Ca (Kα), Na (Kα) and K (Kα). The images were processed with DWImager software (Torres-Roldán and Garcia Casco, 2003, unpublished see Garcia-Casco, 2007). As shown in the figures, the X-Ray maps were masked for polish defects, voids and selected minerals in order to better show the textural-chemical features of the mineral of interest. Furthermore, manipulation of several histograms at a time allowed to create phase maps, and to obtain the abundance of the minerals. The elemental maps were quantified applying an internal mineral standard selected among the analyzed minerals in the scanned area after the acquisition of the X-Ray maps. The quantification follows the Bence and Albee (1968) scheme, and the α-factor table by Kato (2005). Each pixel in the quantified maps corresponds to a mineral analysis expressed as color-coded atoms per formula unit or atomic ratios. $Fe^{2+}= Fe_{Total}$ in the quantified maps. A grey-scale base-layer, calculated with the expression:

$$\sum counts * A_i$$

(where A is atomic number, and i is Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K and P) underlies the masked areas of the X-Ray maps. This layer contains the basic textural information of the scanned areas. Spot analyses were performed on the scanned areas and other significant areas of the thin sections. The operation conditions were 20 kV accelerating voltage and 20 nA beam current, and the PAP correction procedure was used (Pouchou and Pichoir, 1985). Structural formulas of minerals were normalized to 12, 11 and 2 oxygens for garnet, white mica and rutile, respectively. The structural formula of pyroxene was normalized to 6 oxygens following the procedure proposed by Morimoto (1988). The structural formula of amphiboles was normalized to 23 oxygens using the method of Schumacher (in Leake et al., 1997) and follows the classification scheme of Leake et al. (1997). The atomic concentration of elements per formula units is abbreviated apfu. Mg# is the abbreviation of the Mg number ($Mg/(Mg+Fe^{2+})$). Mineral abbreviations are after Whitney and Evans (2010). Projection after coexisting phases

287 and condensation along exchange vectors of the multidimensional chemical space has

288 been performed using CSpace software (Torres-Roldan et al., 2000) in order to

289 produce tetrahedral diagrams (ACFN deluxe diagram, Garcia-Casco et al., 2013,

290 based on the ACF diagram of Thompson, 1982) containing the full mineralogical

291 information of the samples. The compositions of analyzed garnet, clinopyroxene,

292 amphibole, white mica and plagioclase from the two samples of eclogite are listed in

293 Tables S1-S4 (Data Repository).

294

295 **4.2 Whole-rock geochemistry**

296 Whole-rock chemical analyses of 12 fresh samples of eclogite from the Montemor-o-

297 Novo - Safira and Alvito-Viana do Alentejo areas were performed at ActLabs

298 laboratories (Ontario, Canada). Lithium metaborate/tetraborate fusion was employed,

299 and samples were analyzed by Inductively Coupled Plasma analysis (ICP-OES and

300 ICP-MS). In major elements, the precision of the analysis is 0.01%, with MnO and TiO_2

301 reaching 0.001%. The precision of the trace elements is ranges from 0.002 to 30 ppm.

302 Major and trace elements, including REE, of the eclogite samples are listed in Table S5

303 (Data Repository) and represented in Fig. 11.

304

305 **5. RESULTS**

306 **5.1. Petrography and mineral chemistry**

307 The Safira eclogites occur as variably retrogressed lenses of variable size

308 surrounded by metasedimentary rocks and ortogneisses (Fig. 2). The lenses usually

309 contain a well-preserved central zone surrounded by a retrogressed rim (Leal, 2001).

310 The host metamorphic rocks show a post-eclogitic regional foliation

311 (amphibolite/greenschists facies) probably related to the exhumation of the high-P unit

312 (Chichorro, 2006; Pereira et al., 2007). Samples 116748 and 116747 of the Safira

313 eclogites were selected for detailed study. They show a well-preserved mineral

314 assemblage that allows deducing the metamorphic peak.

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315

5.1.1 Sample 116748

Sample 116748 is a very fine-grained isotropic eclogite. It consists of garnet (~26 vol.%), clinopyroxene (~40 vol.%) and amphibole (~21 vol.%), with phengite (~3 vol.%), paragonite (~0.25 vol.%), rutile (~2 vol.%), quartz (~1 vol.%), apatite (~0.5 vol.%), dolomite (~0.1 vol.%) and pyrite (~0.2 vol.%) as accessory phases (Fig. 3a, b).

Garnet commonly occurs as fine-grained idioblastic to subidioblastic atoll-like crystals (up to 0.4 mm in size), although non-atoll-like blasts are found locally (hereinafter referred to as 'complete' garnet). X-Ray maps show well differentiated garnet core and rim domains (Fig. 4). Garnet cores (hereinafter referred to as garnet I; ~15 vol.%) in both, atoll and 'complete' blasts, have a compositional zoning characterized by outward decreasing Ca and Mn, and increasing Mg (Figs. 4c-f, 5b). Garnet rims (hereinafter referred to as garnet II; ~11 vol.%) show patchy zoning, and have lower Ca and higher Mg contents compared to garnet I (Figs. 4c-f, 5b; Table S1). Fe increases from garnet I to II, locally displaying patchy distribution in both (Fig. 4f). Mn content in garnet II is similar to the concentration in garnet I cores (Fig. 4d). Within the 'complete' garnet crystal shown in Fig. 4c-f, an 'island' (in the sense of Fayard et al., 2010) with the same composition of garnet II occurs. This garnet crystal also shows a 'peninsula' linked to garnet II (Fig. 4a, c-f). In addition to rings surrounding garnet I and islands and peninsulas in 'complete' garnet blasts, garnet II also occurs as small grains usually within the atoll structures or connecting different atoll crystals (Fig. 4a, c-f). Fig. 3e shows the presence of microveins connecting garnet I and II that show almost identical image contrast to that of garnet II. Both, garnet I and II are of almandine-rich composition (garnet I: Alm_{51-57} Grs_{25-34} Prp_{12-19} Sps_1; garnet II: Alm_{52-53} Grs_{18-22} Prp_{21-23} Sps_{1-2}; Table S1; Fig. 5a) and include rutile and quartz, and locally omphacite is found within garnet I. . The mineral paragenesis found within the atoll

12

342 structure comprises mostly amphibole, phengite and quartz, although small crystals of

343 omphacite, rutile, and apatite also occur (Fig. 4a).

344

345   Clinopyroxene is the most abundant mineral in the matrix, although it also

346 appears as tiny crystals inside the atoll garnet rings. Locally it occurs associated with

347 garnet II islands within garnet I. It is classified as omphacite, with most omphacite

348 crystals showing weak zoning (Fig. 4g) with increasing jadeite contents from cores

349 (41.2 mol.%) to rims (53.4 mol.%) (Table S2; Fig. 5d,e). The X-Ray maps show

350 omphacite inside the atoll garnets with the same chemical composition as the rims of

351 matrix omphacite (Fig. 4g). Aegirine content in omphacite ranges from 0 mol.% to 9

352 mol.%.

353

354   Amphibole occurs in both, matrix and inside atoll garnet rings. It is green-

355 colored in plane polarized light (Fig. 3a) and of relatively uniform barroisite composition

356 (Si = 6.84-7.29 apfu; Al(C) = 1.25-1.44 apfu; Na(B) = 0.89-1.33 apfu; Na+K(A) = 0.34-

357 0.48; Mg# = 0.71-0.76; Fig. 5h; Table S3), although some crystals show a weak zoning

358 with rims richer in Ca, Fe and Al contents, and poorer in Na and Si contents.

359

360   Phengite appears in the matrix and encompassed by atoll garnet rings. When in

361 the matrix, it shows a xenoblastic habit, as opposed to well-developed crystal faces

362 when inside atoll garnet rings, except for the faces in contact with garnet, which follow

363 the shape of garnet (Fig. 4a). Matrix phengite does not show inclusions, whereas

364 phengite within atoll garnet includes rutile, quartz, apatite, garnet I and garnet II (Fig.

365 4a). Phengite exhibits no zoning and there is no compositional difference between the

366 two textural types. Si content is high and ranges between 3.25 and 3.31 apfu (Table

367 S4; Fig. 5g). Paragonite occurs exclusively in the matrix as idioblastic to subidioblastic

368 grains that may contain garnet I and II inclusions. Na and K contents range from 0.66

369 to 0.87 apfu and from 0.04 to 0.09 apfu, respectively (Table S4).

13

370

371   Rutile crystals occur in the matrix with tens of micrometers to ~0.2 mm in size.

372   Rutile grains a few micrometers in size are found also within the atoll garnet rings.

373   Besides, it also appears as inclusion in both, garnet I and II. Quartz is present in the

374   matrix as fine grains and inside the atoll garnet with up to 0.1 mm in size. Fine-grained

375   dolomite is considered retrograde, for it appears in the matrix usually close to late

376   amphibole or associated with late amphibole in fractures within omphacite.

377

378   Textural and chemical relations allow defining a first mineral assemblage

379   consisting of garnet I, omphacite cores, rutile, quartz and phengite that was followed by

380   the metamorphic peak mineral assemblage composed by garnet II, omphacite rims,

381   quartz, rutile and phengite. Finally, paragonite, barroisite and dolomite formed during

382   retrogression.

383

384   **5.1.2 Sample 116747**

385   Sample 116747 is a very fine-grained isotropic eclogite. Compared to sample

386   116748 it has lower volumes of garnet (~18 vol.%), clinopyroxene (~28 vol.%),

387   phengite (~0.2 vol.%), rutile (~1.5 vol.%) and quartz (<1 vol.%), and higher volumes of

388   amphibole (~45 vol.%), paragonite (~1.5 vol.%) and plagioclase (~1.5 vol.%) (Fig.

389   3c,d).

390

391   Garnet occurs as fine idioblastic to subidioblastic atoll-like crystals with

392   maximum crystal sizes of 0.3 mm. As in sample 116748, two well differentiated

393   domains are recognized using X-Ray maps (Fig. 4b,h-j). Garnet atoll structure has a

394   greater development in this sample compared to sample 116748, with a lower volume

395   of garnet I (~9 vol.%, Fig. 4b). Yet, zoning is recognized (Fig. 5c), with Ca content

396   decreasing towards the outermost part of garnet I while Mg content increases (Fig. 4h).

397   Due to the larger development of atoll structures, it is more difficult to identify a zoning

pattern in Mn content, although some crystals show slight depletion towards the outermost part of garnet I (Fig. 4i). Fe does not show zoning in garnet I (Fig. 4j). On the other hand, garnet II occurs as rings surrounding garnet I or as xenoblastic crystals in the matrix (Fig. 4b). Garnet II is not zoned, and it has lower Ca and higher Mg and Mn contents than garnet I (Fig. 4h,i). Fe is slightly higher in garnet II (Fig. 4j). As in sample 116748, garnet show microveins connecting garnet I with garnet II, but with a greater development (Fig. 3f). The mineral paragenesis developed within the atoll structure is composed of amphibole, omphacite, phengite and fine crystals of rutile, garnet II, and apatite (Fig. 4b). Both garnet I and II are of almandine-rich composition (garnet I: Alm_{51-61} Grs_{22-40} Prp_{6-11} Sps_{1-2}; garnet II: Alm_{60-61} Grs_{19-22} Prp_{17-19} Sps_{2-3}; Table S1; Fig. 5a).

Clinopyroxene in the matrix and inside atoll garnet (Fig. 4k) is of omphacite composition (Table S2; Fig. 5d). Grains in the matrix show cores poorer in jadeite (37.3 mol.%) than in the rims (55.2 mol.%) (Fig. 5f; Table S2), while omphacite inside atoll garnet shows no zoning and is similar in composition to matrix omphacite rims (Fig. 4k). The aegirine content ranges between 1.5 and 13.3 mol.%.

Amphibole grains appear zoned in sample 116747. In the matrix and inside atoll garnet rings, bluish amphibole (Fig. 3c) classified as glaucophane (Si = 7.25-7.69 apfu; Na(B) = 1.51-1.77 apfu; Mg# = 0.64-0.75; Table S3; Fig. 5j) is predominant. In the matrix, glaucophane cores evolve to barroisite towards rims of grains, with higher Al, Fe, Ca and K, and lower Si, Mg and Na content (Si = 6.95-7.37 apfu; Al(C) = 1.36-1.66 apfu; Na(B) = 0.76-1.48 apfu; Na+K(A) = 0.29-0.47; Mg# = 0.60-0.67; Table S3; Fig. 5h). Locally, amphibole rims exhibit still higher Al, Ca and K and lower Si, Mg and Na contents and classify as magnesiokatophorite (Si = 6.50-6.88 apfu; Na(B) = 0.81-1.02 apfu; Na+K(A) = 0.51-0.67; Mg# = 0.56-0.66; Table S3; Fig. 5i). Magnesiokatophorite also overgrowths omphacite and is associated with late plagioclase.

426   Phengite is scarce and mainly occurs within atoll garnet rings, usually with well-

427 developed faces, although very fine grains (tens of micrometers in size) with irregular

428 faces occur in the matrix (Fig. 4b). Both types of phengite do not show inclusions and

429 compositional differences, with Si content ranging between 3.27 and 3.38 apfu (Table

430 S4, Fig. 5g). Paragonite occurs in the matrix as large subidioblastic crystals (up to 0.45

431 mm in length) with Na content ranging between 0.68 and 0.94 apfu (Table S4).

432 Plagioclase is of albite composition (Ab = 98.2-98.9 mol.%; Table S4) and replaces

433 omphacite and is associated with magnesiokatophorite.. Rutile occurs in the matrix

434 (~0.1 mm in size) and within atoll garnet (very fine crystals).

435

436   According to textural relationships and mineral composition, garnet I, omphacite

437 cores, glaucophane, rutile and phengite formed a first paragenesis that was followed by

438 the metamorphic peak paragenesis composed by garnet II, omphacite rims,

439 glaucophane, quartz, rutile and phengite. During retrogression, barroisite and

440 paragonite formed first shortly before albite and magnesiokatophorite. The mineral

441 assemblage development for this sample is presented in Fig. 6 and the corresponding

442 ACFN diagrams of Fig. 7. In the latter, the composition of the sample and coexisting

443 minerals are shown, while the tie-lines connecting mineral analyses represent

444 equilibrium during the different stages of metamorphism.

445

446 **5.2. Isochemical phase diagrams**

447   Isochemical phase diagrams were calculated for samples 116748 and 116747

448 in the MnNCKFMASTH system using the software Theriak-Domino (De Capitani and

449 Brown, 1987; De Capitani and Petrakakis, 2010). The internally consistent database

450 5.5 of Holland and Powell (1998; updated November 2003) was used (database

451 "tcdb55c2d" and input "THERIN" are provided in the supplementary material). Activity-

452 composition models were considered for clinopyroxene (Green et al., 2007), garnet,

453 biotite, ilmenite, spinel (White et al., 2007), amphibole (Diener et al., 2007),

orthopyroxene (White et al., 2002, 2007; also in Baldwin et al., 2005), white mica (Coggon and Holland, 2002), feldspar (Baldwin et al., 2005), epidote, talc and chlorite (Holland and Powell, 1998). Pure phases used in the calculation include quartz/coesite, rutile, lawsonite and titanite (Holland and Powell, 1998). Calculations were performed assuming H_2O in excess. The compositions used for the calculation are reported in Table 1. Calculations were made in a P-T window from 5 to 30 kbar and 500 to 650 ºC. Both samples yielded almost identical results. Below, we offer the thermodynamic modelling of sample 116747, while results for sample 116748 are provided in the supplementary material (Fig. S1).

5.2.1 Sample 116747

Results for this sample are shown in Fig. 8. The peak assemblage (Grt+Omp+Gln+Ph+Qz+Rt) is stable from 570 to 650 ºC and from 16 to 27 kbar. Si-in-phengite isopleths constrains pressure to 18-20 kbar (Si = 3.27-3.38 apfu; Fig. 8b). The distribution of garnet isopleths (Fig. 8c-e) reproduces the observed decrease in grossular content (0.22 to 0.30) and the increase in pyrope (0.11 to 0.15) and almandine contents (0.58 to 0.61) in pre-peak garnet I, constraining initial PT conditions to c. 570 ºC and c. 19 kbar. The prograde evolution, constrained by zoning of garnet I, trends towards a maximum pressure of ~24 kbar constrained by the almost isobaric isopleths of almandine (X_{Alm} = 0.61) while grossular and pyrope isopleths (X_{Prp} = 0.15; X_{Grs} = 0.22) constrain the temperature of pressure peak to 580 ºC, corresponding to outermost part of garnet I. This estimation is consistent with the increase in Al observed in omphacite (Fig. 8f).

For stage 2 of mineral assemblage development (Figs. 6 and 7), the intersection of Si-in-phengite (within the atoll structures, Si_{max} = 3.38 apfu) with grossular (0.19-0.22), pyrope (0.17-0.19) and almandine (0.60-0.61) isopleths for garnet II yield 615-640ºC and 18-20 kbar (Fig. 8 and 9). Some garnet analysis with

482   lower grossular, and higher pyrope and almandine contents do not intersect the

483   maximum Si content in phengite in the stability field of the peak mineral assemblage

484   (stage 2). This may be due to analytic errors, uncertainties in the standard state

485   properties of end-members and solution models and/or problems with the effective bulk

486   composition (e.g. fractionation during the growth of garnet and clinopyroxene).

487   Phengite from the matrix and within the atoll structure shows the same chemical

488   composition, indicating re-equilibration during this stage. Moreover, omphacite within

489   atoll structures and rims of matrix omphacite show the same composition, and

490   isopleths of Al content in clinopyroxene show that it was formed at the highest

491   temperature reached (Fig. 8f). Hence, we conclude that stage 2 developed upon

492   decompression and heating after stage 1 (Fig. 9). Finally, stage 3 paragonite grew

493   during decompression (Figs. 8 and 9), when albite, barroisite and magnesiokatophorite

494   formed at the expense of omphacite. This mineral paragenesis points to a pressure

495   below 15 kbar, although the temperature cannot be constrained. However, volume

496   isopleths for garnet (19%), omphacite (28%), amphibole (45%) and plagioclase (2%)

497   intersect at 14-15 kbar in the range of 625-640ºC (Fig. 10a-d), which is considered a

498   rough estimation of the temperature of arrest of reaction progress in the sample. A

499   similar evolution is inferred for sample 116748 (Fig. S1).

500

501   **5.3. Whole-rock geochemistry**

502   Major and trace element composition of eclogites from the CMU allow rock

503   classification and determination of the tectonic setting of formation of their protoliths.

504   Four of the samples were collected in the Montemor-o-Novo - Safira area, and eight in

505   the Alvito-Viana do Alentejo area. Eclogite samples exhibit a limited variation in their

506   major elements and they have a relatively low Mg#, in the range of 0.26 to 0.48 (Table

507   S5). Immobile elements have been used for classification in order to minimize the

508   effect of possible element mobility during alteration and/or metamorphism (Pearce,

509   2014). In terms of Zr/Ti-Nb/Y diagram (Pearce, 1996), all of the high-P rocks fall in the

basalt field, although two samples are in the limit of basalt and andesite + basaltic andesite fields, and all of them display subalkaline nature (Nb/Y = 0.02 to 0.51, Zr/Ti = 0.008 to 0.017; Table S5, Fig. 11a).

The tectonic setting of the protoliths was determined following the procedure proposed by Pearce (2014). Fig. 11b shows N-MORB normalized (Sun and McDonough, 1989) immobile-element patterns of analyzed samples. Due to their similar behavior, pairs of elements Nb-Ta, Hf-Zr and Ho-Y are plotted as averages instead of individually (Pearce, 2014). Samples display an almost flat pattern subparallel to N-MORB, with a marked negative Nb+Ta anomaly suggesting that they probably formed in a supra-subduction zone setting (Pearce, 2008, 2014). In the Th/Yb versus Nb/Yb diagram of Pearce (2008), most samples show high Th/Nb ratios (Fig. 11c) which are typical of basaltic rocks from supra-subduction zones (Pearce, 2014). Th/Yb and Nb/Yb values of 0.02 to 0.47 and 0.21 to 6.40 (Table S5), respectively, for the studied samples span from the limit of the MORB-OIB array to higher Th/Yb ratios towards the oceanic island arc field, with two samples plotting within this field (Fig. 11c). The relations between V and Ti also point to a supra- subduction zone setting (Fig. 11d). All samples show low V/Ti and plot in the MORB and slab-distal back-arc basin basalts and fore-arc basalts field (Fig. 11d; V/Ti = 0.02 to 0.04, Table S5). In sum, the geochemical features of the CMU high-P metamafic rocks indicate a supra-subduction zone setting for their genesis, most likely in a back-arc or forearc basin. This assumption fits well with the existence of a magmatic arc-system in the periphery of Gondwana during the Late Ediacaran to Early Ordovician times, but this hypothesis needs to be confirmed by isotopic dating. This new interpretation contrasts with a previously proposed anorogenic setting where basaltic magmas intruded continental crust (Leal, 2001).

6. DISCUSSION

6.1 Atoll garnet formation

Atoll garnet structures developed close to the metamorphic peak (stage 2, Figs. 6 and 7). Several authors (e.g., Cao et al., 2018; Fayard et al., 2010; Hyppolito et al., 2016) proposed that the most likely context for the development of atoll texture is the formation of micro-cracks which serve as pathways for fluid infiltration within garnet. Alternatively, coalescence and multiple nucleation of garnet crystals have been proposed (e.g., Spiess et al., 2001). The existence of microveins in garnet crystals of the Safira eclogites (Fig. 3e,f) supports a fluid infiltration process as responsible of the atoll garnet formation. In this scenario, compositional peninsulas and islands formed due to the replacement of garnet I by garnet II in 'complete' garnets. Fayard et al. (2010) have proposed that peninsulas may have played the role of principal channels for fluid infiltration. As an atoll structure evolves, the consumption of garnet I cores release elements which were incorporated into garnet II rings, peninsulas and islands, as well as in other phases contained in the atolls (and the matrix) such as clinopyroxene or amphibole. Higher Mn content of garnet II compared to Mn content in the outermost part of garnet I is evidence for the release of this element upon garnet I dissolution and incorporation into garnet II (Fayard et al., 2010). However, the process involved a large-scale multicomponent reaction in a more complex effective bulk composition, for replacement of garnet I cores included the formation of garnet II (rings around garnet I and fine-grained matrix crystals), glaucophane, phengite, rutile and omphacite.

6.2 Metamorphic evolution

Fig. 9a,b shows the PT evolution proposed for the studied eclogite samples of the Cubito-Moura Unit. Both trajectories show a first prograde segment that implies simultaneous burial and heating from initial conditions recorded at ~19-21 kbar at 550-570 ºC to ~24-25 kbar (~85-90 km depth), at ~585 ºC. The associated thermal gradient yields ~7 ºC/km, typical of cold subduction zones. After reaching peak pressure, the

20

566   rocks (unit) detached from the subducting slab and started exhumation in the

567   subduction channel. The process involved heating, as a likely consequence of arrest of

568   subduction due to stacking of incoming units. The metamorphic peak attained during

569   exhumation reached ~630 ºC (at ~19 kbar), and was followed by subsequent near-

570   isothermal decompression down to ~15 kbar (c. 50 km depth), suggesting late tectonic-

571   assisted (likely extension) exhumation of the unit.

572

573   **6.3 Tracking the Late Devonian metamorphic belt across the Iberian Massif and**

574   **other Variscan correlatives**

575   The recent correlation of the Late Devonian metamorphic belt across the Iberian

576   Massif proposed by Díez Fernández and Arenas (2015) has been discussed by

577   Simancas et al. (2016). In NW Iberian Massif, the intermediate-T eclogite facies rocks

578   from the Lower Sequence of the Malpica-Tui Unit record a burial path up to peak

579   pressure of c. 23 kbar at 540-620 ºC followed by an almost isothermal decompression

580   (Li and Massone, 2016, 2017; Li et al., 2017; paths 6, 7 and 8 in Fig. 12). The

581   comparison with the Safira eclogites from the Lower Sequence of the CMU shows very

582   similar metamorphic evolution (paths 9 and 10 in Fig. 12). The prograde zonation of

583   garnet in the CMU eclogites yield burial to c. 24-25 kbar at 580-600 ºC, similar to that

584   of the Malpica-Tui Unit (Fig. 12), though exhumation of the Safira eclogites was

585   accompanied by heating up to peak 620-630 ºC at c. 19-20 kbar, previous to strong

586   decompression.

587

588   The PT conditions reported for the blueschists and glaucophane-bearing

589   eclogites are still poorly constrained in the Alvito-Viana do Alentejo area (CMU),

590   although high-P metamorphism has been dated at c. 370 Ma (Moita et al., 2005). In the

591   Upper Sequence of the BCU, PT conditions of c. 20 kbar and 550 ºC were recently

592   reported for the Late Devonian metamorphic peak of high-P metapelites (path 16, Fig.

593   12, Arenas et al., In press). On the other hand, in the Upper Sequence of the Malpica-

594   Tui Complex, the Ceán Unit reached PT conditions of c. 19-22 kbar and 460-520 ºC

595   during the Late Devonian metamorphic event (López-Carmona et al., 2010, 2013,

596   2014) (Fig. 12 and 13). Arenas et al. (In press) proposed that the BCU and Ceán units

597   share the same PT evolution related to subduction of the Basal Units. At present, more

598   exhaustive work in the Alvito-Viana do Alentejo high-P, low- to intermediate-T rocks

599   should be accomplished in the future to better constrain their PT evolution in order to

600   confirm correlations with similar rocks of the NW Iberian Massif. However, similarities

601   between the lithostratigraphy of the Basal Units from NW and SW Iberia, structural

602   position in the allochthonous pile, tectonothermal evolution and high-P metamorphic

603   ages seems to fairly support the correlation of both terranes in the Iberian Massif.

604

605   In a larger regional context, the Late Devonian high-P-, low- to intermediate-T

606   metamorphic belt can be followed along the Variscan massifs in Europe (Fig. 1a),

607   where it is overlain by ophiolitic units which, in turn, rest under an Early Devonian high-

608   P, high-T belt (Arenas et al., In press; Ballèvre et al., 2014; Kroner and Romer, 2013;

609   Martínez Catalán et al., 2020). This distribution of Variscan allochthonous units is found

610   in the Bohemian, Armorican and Iberian massifs, where the tectonic units show

611   similarities in the structural position, lithostratigraphy, age of the protoliths and

612   tectonothermal evolution.

613

614   In the northern border of the Bohemian Massif, a discontinuous E-W-trending

615   high-P, low-T belt contains glaucophane-bearing metabasites and micaschists that

616   reached PT peak conditions of 11-20 kbar and 350-550 ºC (Fayard and Kachlík, 2013).

617   A correlation between the high-P metamorphic belts of the Bohemian and NW Iberian

618   massifs has been recently proposed by Martínez Catalán et al. (2020). In the

619   Armorican Massif, the Basal Allochthonous Units are well preserved in the

620   Champtoceaux and Essarts Complexes, where they include eclogite-facies metapelites

621   with peak conditions ranging from 15-20 kbar at 550 ºC to 20-25 kbar at 650 ºC,

followed by near-isothermal decompression (Ballèvre and Marchand, 1991). This high-P metamorphic event was dated at c. 356-362 Ma (U-Pb data on zircon and Sm-Nd isochron; Bosse et al., 2000; Maurel et al., 2003). Structurally above, in the Ile-de-Groix and Bois-de-Cené units, blueschists-facies metabasites and micaschists (Ballèvre et al., 2003; Bosse et al., 2002; El Korh et al., 2009) reached peak PT conditions of 16-18 kbar and 450-500 ºC (Bosse et al., 2002). In these tectonic units, high-P metamorphism is dated at c. 360-370 Ma (Rb-Sr and $^{40}Ar/^{39}Ar$ methods). The structural position, lithostratigraphy and tectonothermal evolution of the Basal Allochthonous Units in the Armorican Massif is quite similar to those of the Iberian Massif, which led to the corresponding correlations proposed by Ballèvre et al. (2014) for the European Variscan belt.

6.4 Protoliths and geodynamic inferences

Based on the new geochemical results, the protoliths of the eclogites in the CMU were probably generated in a supra-subduction zone setting, likely related to a Cadomian magmatic arc system in the Gondwana margin. The Cadomian magmatic arc was located in the margin of the West African Craton, as indicated by provenance analysis of the Ediacaran sedimentary rocks from SW Iberia and NW Iberia equivalents (Chichorro et al., 2008; Díez Fernández et al., 2010, 2017; Fuenlabrada et al., 2012; Pereira et al., 2008). Felsic and mafic magmas intruded the Ediacaran to Middle Cambrian sedimentary sequences probably deposited in a back-arc or forearc basin. It occurred during the Cambrian in the CMU (Chichorro et al., 2008), and in the Cambrian-Ordovician in the BCU and NW Iberia (Abati et al., 2018; Díez Fernández et al., 2012). These differences in age are attributed to slightly different lateral positions of the Basal Units along the margin of Gondwana combined with diachronic magmatic events (Díez Fernández et al., 2017; Fuenlabrada et al., 2020).

649   The earliest interactions between Gondwana and Laurussia continental margins

650   started in the Early Devonian and culminated with the assembly of Pangea (Arenas et

651   al., 2014; Díez Fernández et al., 2016; Franke, 1989, 2000; Kroner and Romer, 2013;

652   Matte, 1991, 2001; Martínez Catalán et al., 1997; Simancas et al., 2005; Ribeiro et al.,

653   2007). In this study, we adopt a geodynamic model in which an intra-Gondwana

654   subduction zone dipping towards Laurussia formed in relation to a lithospheric neck in

655   the peri-Gondwana margin at c. 400-410 Ma (Díez Fernández et al., 2016). This

656   subduction system led to the formation of a first Early Devonian high-P, high-T

657   metamorphic belt, presently preserved in the Upper Allochthonous Units (Fernández-

658   Suárez et al.; 2007; Mendía et al., 2001). Subsequent opening of Middle Devonian

659   ephemeral oceanic basins, due to strike-slip tectonics (pull-apart type; Arenas et al.,

660   2014) or due to extension in the upper plate (suprasubduction type; Díez Fernández et

661   al., 2020), was followed by the simultaneous subduction of the whole Basal Units

662   during Late Devonian times (c. 377-370 Ma, Abati et al., 2010, 2018; Beranoaguirre et

663   al., 2019; Moita et al., 2005). Considering the PT gradient of the Lower Sequence in

664   NW Iberia (paths 1 to 8; Fig. 12; Arenas et al., 1995, 1997; Martínez Catalán et al.,

665   1996), the Safira eclogites from the CMU show a slightly higher P and T at the baric

666   peak conditions (paths 9 and 10, Fig. 12), suggesting a deeper position within the

667   subducting slab. The proposed model for the exhumation of the Basal Allochthonous

668   Units in NW Iberia was accompanied by the development of ductile thrusts that overlain

669   the deepest domains from the Lower Sequence (i.e. Agualada and Espasante units;

670   paths 11 and 12; Fig. 12) over the Upper Sequence, and subsequent development of

671   recumbent folds (Martínez Catalán et al., 1996; Díez Fernández et al., 2011).

672

673   **7. CONCLUSIONS**

674   In the SW Iberian Massif, the Cubito-Moura Unit (CMU) represents a high-P,

675   low- to intermediate-T metamorphic belt. Thermodynamic modelling of intermediate-T

676   eclogites from the Lower Sequence of the CMU in the MnNCKFMASHT system

677 indicates a prograde PT evolution up to ~24 kbar and 585 ºC, followed by

678 decompression accompanied by moderate heating (~19 kbar, 630 ºC), and a

679 subsequent isothermal decompression to 15 kbar. This evolution suggests deeper

680 subduction of the CMU during the Late Devonian (c. 370 Ma) than previously thought.

681 The CMU shares similar lithostratigraphic sequences and tectonothermal evolution with

682 the Badajoz-Córdoba Unit (BCU), and the Basal Allochthonous Units of NW Iberian

683 Massif. We propose that they represent equivalent allochthonous terranes with a

684 common tectonothermal history since Late Ediacaran to Carboniferous times. The

685 Basal Allochthonous Units in NW and SW Iberian Massif are considered the remnants

686 of an arc-derived section built on the thinned margin of Gondwana during Late

687 Ediacaran-Cambrian times, later subducted during the first stages of the assembly of

688 Pangea. Along the Armorican, Bohemian and Iberian massifs,allochthonous terranes

689 with similar lithostratigraphy and Variscan tectonothermal evolution conform a single

690 Late Devonian high-P, low- to intermediate-T metamorphic belt developed during the

691 amalgamation of Pangea that can be followed along the Variscan Orogen in Europe for

692 thousands of kilometers.

693

703

704

FIGURE CAPTION

Fig. 1. a) Zonation of the Variscan Orogen in Europe (Díez Fernández and Arenas, 2015). b) Geological map of the Iberian Massif. In NW Iberia, the Internal Variscan Zone is represented in the allochthonous complexes of Cabo Ortegal (COC), Órdenes (OC), Malpica-Tui (MTC), Bragança (BC) and Morais (MC), whereas in SW Iberia is represented by the Ossa-Morena Complex (OMC). AF, Azuaga Fault; BAO, Beja-Acebuches Ophiolite; CA, Carvalhal Amphibolites; CF, Canaleja Fault; CMU, Cubito-Moura Unit; CO, Calzadilla Ophiolite; BCU, Badajoz-Córdoba Unit; ET, Espina Thrust; HF, Hornachos Fault; IOMZO, Internal Ossa-Morena Zone Ophiolites; LLF, Llanos Fault; MLF, Malpica-Lamego Fault; OF, Onza Fault; OVD, Obejo-Valsequillo Domain; PG-CVD, Puente Génave-Castelo de Vide Detachment; PRF, Palas de Rei Fault; PTF, Porto-Tomar Fault; RF, Riás Fault; VF, Viveiro Fault. After Díez Fernández and Arenas (2015) and Arenas et al. (2016b).

Fig. 2. a) Geological map of the southern part of the Évora Massif and b) composite cross-section (Díez Fernández et al., 2017). See Fig. 1b for location. c) Tectonostratigraphic column of the Lower Sequence of the Basal Units in the Évora Massif. d) Tectonostratigraphic column of the Carvalhal ophiolite (Díez Fernández et al., 2017). The star indicates the location of the Safira eclogites sampled and studied in this work.

Fig. 3. Microphotographs of the studied eclogites. a) and b) Plane-polarized light (a) and cross-polarized light (b) of eclogite sample 116748. c) and d) Plane-polarized light (c) and cross-polarized light (d) of eclogite sample 116747. e) and f) BSE images showing microveins in sample 116748 (e) and 116747 (f).

733

734   Fig. 4. a) and b) Phase maps constructed after manipulation of X-ray maps showing

735   the distribution of mineral phases in samples 116748 and 116747, respectively. c)

736   X-Ray map showing Ca content (apfu) in garnet (sample 116748). d) X-Ray map

737   showing Mn content (apfu) in garnet (sample 116748). e) X-Ray map of Mg

738   content (apfu) in garnet (sample 116748). f) X-Ray map of Fe content (apfu) in

739   garnet (sample 116748). g) X-Ray map showing Na/(Na+Ca) ratio (counts) in

740   clinopyroxene (sample 116748). The selected area corresponds to a different area

741   to those of c-f. h) X-Ray map showing Ca content (apfu) in garnet (sample

742   116747). i) X-Ray map showing Mn content (apfu) in garnet (sample 116747). j) X-

743   Ray map showing Fe content (apfu) in garnet (sample 116747). k) X-Ray map

744   showing Na/(Na+Ca) ratio (counts) in clinopyroxene (sample 116747). The

745   selected area corresponds to a different area to those of h-j.

746

747   Fig. 5. a) Triangular diagram showing the chemical composition of garnet (Coleman et

748   al., 1965). b) and c) Chemical profile of garnet in samples 116748 (b) and 116747

749   (c). d) Composition of omphacite with indication of the end-members. e) and f)

750   Chemical profile of clinopyroxene in samples 116748 (e) and 116747 (f). g)

751   Composition of phengite with indication of the end-members. h), i) and j)

752   Composition of amphiboles plotted in the classification scheme of Leake et al.

753   (1997).

754

755   Fig. 6. Summary of the observed mineral parageneses in sample 116747 in the

756   framework of metamorphic stages.

757

758   Fig. 7. ACFN phase diagrams for samples 116747 projected from phases quartz, rutile

759   and H_2O fluid and along the exchange vectors $MnFe_{-1}$, $MgFe_{-1}$, and KNa_{-1} (Fe =

760   Fe^{2+}_{total}). Red squares correspond to the composition of the end-members of solid

27

761   solutions of interest. Colored circles represent the measured mineral composition.

762   Diamond corresponds to the bulk composition. a), b) and c) diagrams for

763   metamorphic stages 1, 2 and 3 in sample 116747, respectively.

764

765   Fig. 8. Results of thermodynamic modelling of sample 116747. a) Isochemical phase

766   diagram. The thermodynamic variance increases from lighter to darker color. The

767   main assemblage transitions are marked by colored thick lines. b) Isoplehts of Si

768   content in phengite. c) Isopleths of grossular content in garnet. d) Isoplehts of

769   pyrope content in garnet. e) Isopleths of almandine content in garnet. f) Isopleths

770   of Al in clinopyroxene. In b)-f), the color scale indicates concentration. Mineral

771   abbreviations are after Whitney and Evans (2010).

772

773   Fig. 9. PT paths proposed for the eclogite samples 116747 (a) and 116748 (b) based

774   on the thermodynamic modelling. In orange, isopleths of volume of garnet (vol. %).

775

776   Fig. 10. Isochemical phase diagrams showing isopleths of volume (%) of a) garnet, b)

777   clinopyroxene, c) amphibole and d) plagioclase.

778

779   Fig. 11. Immobile-element geochemical diagrams of eclogites from the Lower and

780   Upper Sequences (Cubito-Moura Unit). a) Zr/Ti-Nb/Y diagram for the classification

781   of protoliths (Pearce, 1996). b) Incompatible immobile element patterns normalized

782   to N-MORB (Sun and McDonough, 1989). c) Diagram based on the Th-Nb proxy to

783   discriminate mid-ocean ridge and suprasubduction basalts (Pearce, 2014). d)

784   Discrimination diagram based on the V-Ti proxy to distinguish subduction-zone

785   basalts (Pearce, 2014, based on Shervais, 1982).

786

787   Fig. 12. PT diagram showing the PT trajectories proposed for the Basal Units of the

788   Iberian Massif. Location of the rocks is showed in Fig. 13. 1) Basal Forcarei Unit

789 (Órdenes Complex, Martínez Catalán et al., 1996). 2) Middle Forcarei Unit

790 (Órdenes Complex, Martínez Catalán et al., 1996). 3) Upper Forcarei Unit

791 (Órdenes Complex, Martínez Catalán et al., 1996). 4) Lalín Unit (Órdenes

792 Complex, Martínez Catalán et al., 1996). 5) Santiago Unit (Órdenes Complex,

793 Arenas et al., 1995). 6) 7) and 8) Malpica-Tui Unit (Malpica-Tui Complex, Li and

794 Massone, 2016, 2017; Li et al., 2017). 9) CMU (Ossa-Morena Complex, sample

795 116748, this work). 10) CMU (Ossa-Morena Complex, sample 116747, this work).

796 11) Agualada Unit (Órdenes Complex, Arenas et al., 1997). 12) Espasante Unit

797 (Cabo Ortegal Complex, Arenas, 1991). 13), 14) and 15) Ceán Unit (Malpica-Tui

798 Complex, López-Carmona et al., 2010, 2013, 2014). 16) BCU (Ossa-Morena

799 Complex, Arenas et al., In press). In purple the PT path inferred for the mantle

800 wedge located above the accretionary complex (Martínez Catalán et al., 1996).

801

802 Fig. 13. Geological map of the Iberian Massif showing the distribution of high-P rocks

803 from the Basal Units referenced in Fig. 12.

804

805

806 **TABLE CAPTION**

807 Table 1. Chemical analysis of the studied Safira eclogites (wt.%). The input values for

808 the calculation of the isochemical phase diagrams are also shown (atomic molar

809 proportions).

810

811 **SUPPLEMENTARY MATERIAL**

812

813 Figure S1. Results of thermodynamic modelling of sample 116748. a) Isochemical

814 phase diagram. The thermodynamic variance increases from lighter to darker

815 color. The main assemblage transitions are marked by colored thick lines. b)

816 Isoplehts of Si content in phengite. c) Isopleths of grossular content in garnet. d)

817   Isoplehts of pyrope content in garnet. e) Isopleths of almandine content in garnet.

818   f) Isopleths of $Al_{(M1m)}$ in clinopyroxene. In b)-f), the color scale indicates

819   concentration. Mineral abbreviations are after Whitney and Evans (2010).

820

821 Table S1. Representative chemical analysis of garnet. Analysis marked with an

822   asterisk correspond to the chemical profiles.

823

824 Table S2. Representative chemical analysis of clinopyroxene. Analysis marked with an

825   asterisk correspond to the chemical profiles.

826

827 Table S3. Representative chemical analysis of amphibole.

828

829 Table S4. Representative chemical analysis of white micas and plagioclase.

830

831 Table S5. Whole rock analysis of major (wt%) and trace elements (ppm) from the high-

832   P rocks samples of the Safira and Alvito-Viana do Alentejo areas (CMU).

833

834 tcdb55c2d. Database used in this work.

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836 THERIN. Input used in this work.

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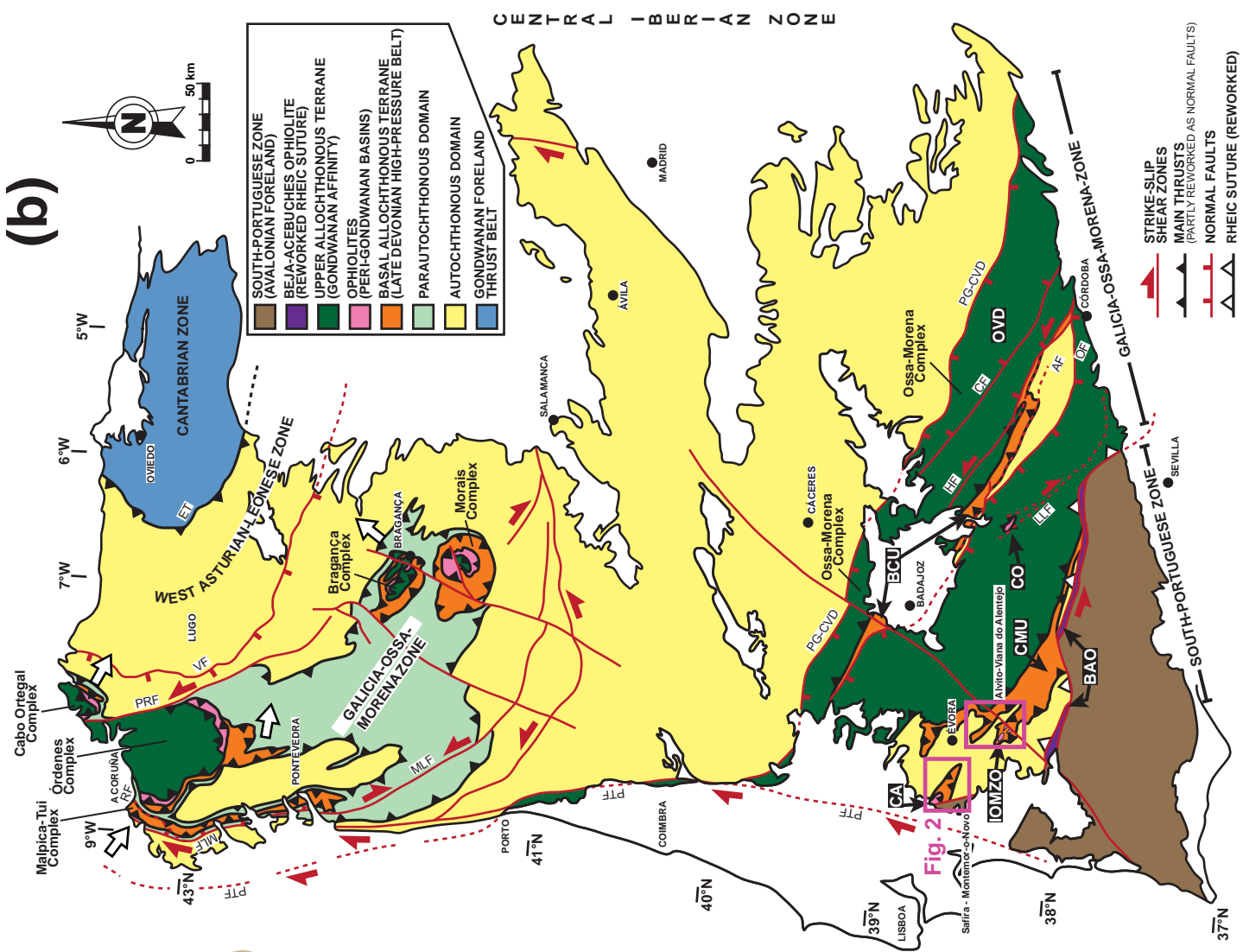1335   Journal of Metamorphic Geology 19, 269-290.

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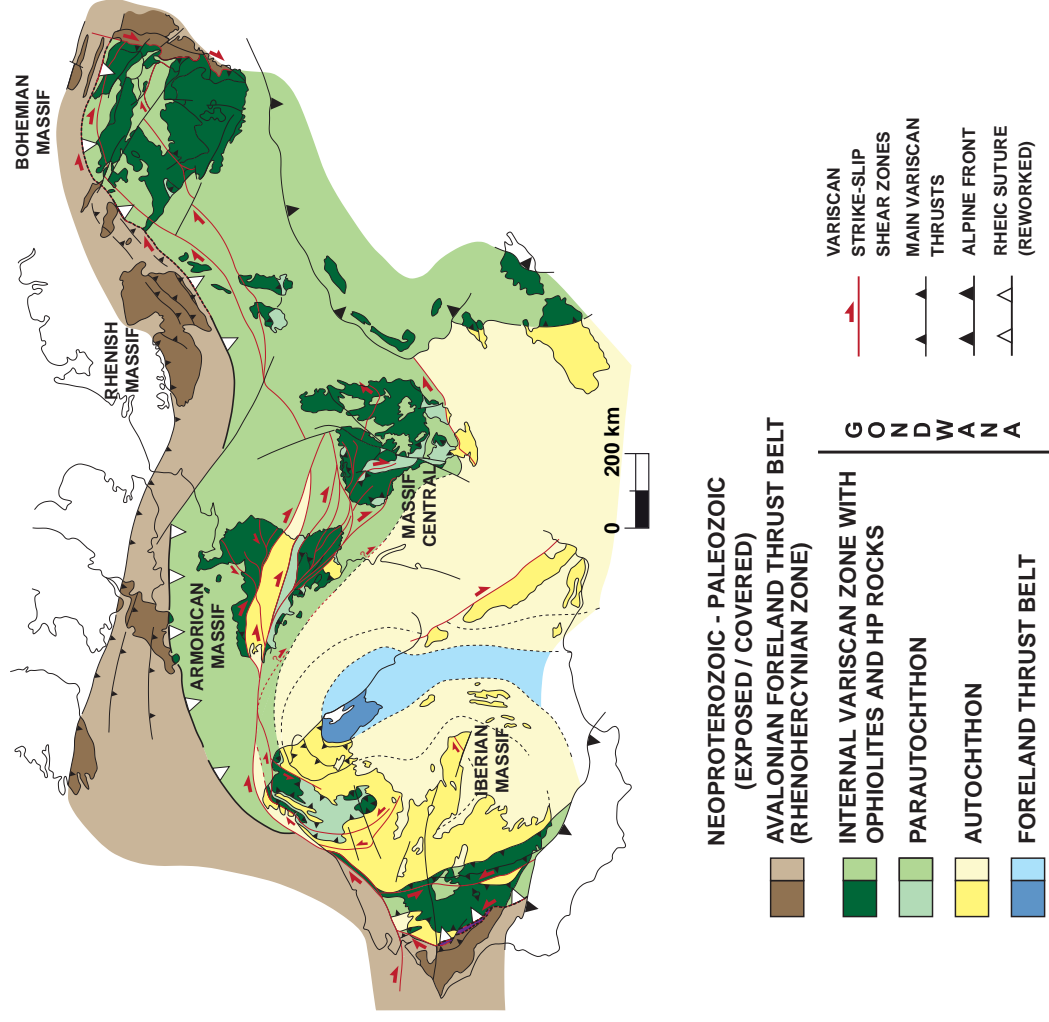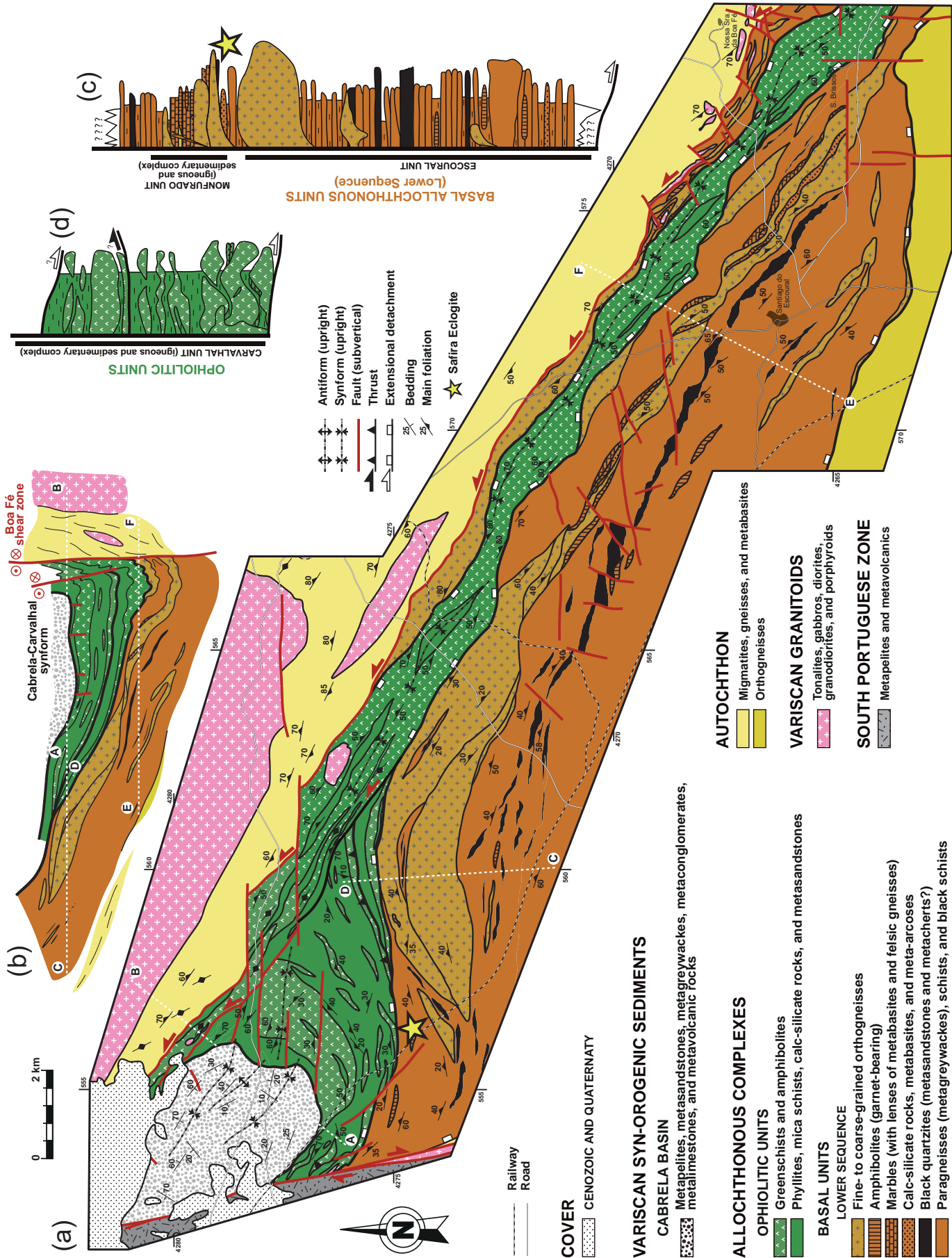1339   London, Special Publications 42, 313-345.

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(a)

BOHEMIAN MASSIF

RHENISH MASSIF

ARMORICAN MASSIF

MASSIF CENTRAL

IBERIAN MASSIF

NEOPROTEROZOIC - PALEOZOIC (EXPOSED / COVERED)

AVALONIAN FORELAND THRUST BELT (RHENOHERCYNIAN ZONE)

INTERNAL VARISCAN ZONE WITH OPHIOLITES AND HP ROCKS

PARAUTOCHTHON

AUTOCHTHON

FORELAND THRUST BELT

G O N D W A N A
Z O N E

0   200 km

VARISCAN STRIKE-SLIP SHEAR ZONES

MAIN VARISCAN THRUSTS

ALPINE FRONT

RHEIC SUTURE (REWORKED)

(b)

CANTABRIAN ZONE

WEST ASTURIAN-LEONESE ZONE

Cabo Ortegal Complex

Órdenes Complex

Malpica-Tui Complex

Bragança Complex

Morais Complex

GALICIA-OSSA-MORENAZONE

C E N T R A L - I B E R I A N   Z O N E

Ossa-Morena Complex

Ossa-Morena Complex

GALICIA-OSSA-MORENA-ZONE

SOUTH-PORTUGUESE ZONE

OVD

OMZO

CMU

BAO

CA

Fig. 2

MADRID

ÁVILA

SALAMANCA

CÁCERES

BADAJOZ

CÓRDOBA

SEVILLA

ÉVORA

OVIEDO

LUGO

A CORUÑA

PONTEVEDRA

PORTO

COIMBRA

LISBOA

Salfira - Montemor-o-Novo

Alvito-Viana do Alentejo

PRF

VF

MLF

MTF

RF

PTF

PTF

PTF

ET

ECU

PG-CVD

PG-CVD

HF

OF

AF

LLF

CO

BRAGANÇA

43°N

41°N

40°N

39°N

38°N

37°N

9°W   7°W   6°W   5°W

N

0   50 km

SOUTH-PORTUGUESE ZONE (AVALONIAN FORELAND)

BEJA-ACEBUCHES OPHIOLITE (REWORKED RHEIC SUTURE)

UPPER ALLOCHTHONOUS TERRANE (GONDWANAN AFFINITY)

OPHIOLITES (PERI-GONDWANAN BASINS)

BASAL ALLOCHTHONOUS TERRANE (LATE DEVONIAN HIGH-PRESSURE BELT)

PARAUTOCHTHONOUS DOMAIN

AUTOCHTHONOUS DOMAIN

GONDWANAN FORELAND THRUST BELT

STRIKE-SLIP SHEAR ZONES

MAIN THRUSTS (PARTLY REWORKED AS NORMAL FAULTS)

NORMAL FAULTS

RHEIC SUTURE (REWORKED)

(a)

(b)

(c)

(d)

Boa Fé shear zone

Cabrela-Carvalhal synform

Cabrela Basin

Santiago do Escoural

Nossa Sra da Boa Fé

S. Brissos

BASAL ALLOCHTHONOUS UNITS

MONFURADO UNIT (igneous and sedimentary complex)

ESCOURAL UNIT (Lower Sequence)

OPHIOLITIC UNITS

CARVALHAL UNIT (igneous and sedimentary complex)

Safira Eclogite

Antiform (upright)
Synform (upright)
Fault (subvertical)
Thrust
Extensional detachment
Bedding
Main foliation

COVER

CENOZOIC AND QUATERNARY

Railway
Road

VARISCAN SYN-OROGENIC SEDIMENTS

CABRELA BASIN

Metapelites, metasandstones, metagreywackes, metaconglomerates, metalimestones, and metavolcanic rocks

ALLOCHTHONOUS COMPLEXES

OPHIOLITIC UNITS

Greenschists and amphibolites

Phyllites, mica schists, calc-silicate rocks, and metasandstones

BASAL UNITS

LOWER SEQUENCE

Fine- to coarse-grained orthogneisses

Amphibolites (garnet-bearing)

Marbles (with lenses of metabasites and felsic gneisses)

Calc-silicate rocks, metabasites, and meta-arcoses

Black quartzites (metasandstones and metacherts?)

Paragneisses (metagreywackes), schists, and black schists

AUTOCHTHON

Migmatites, gneisses, and metabasites

Orthogneisses

VARISCAN GRANITOIDS

Tonalites, gabbros, diorites, granodiorites, and porphyroids
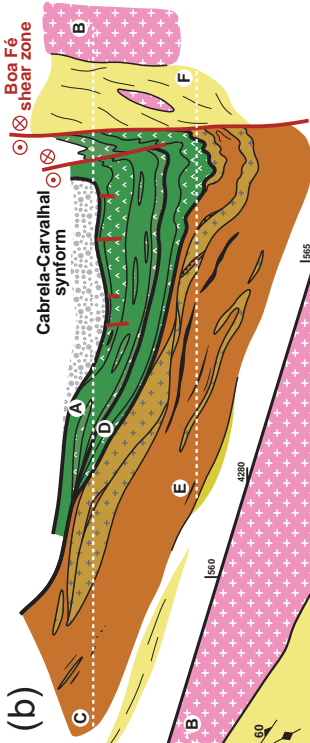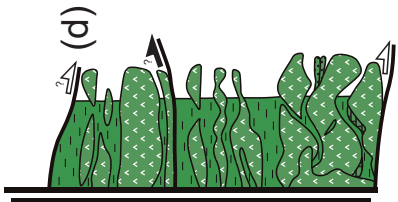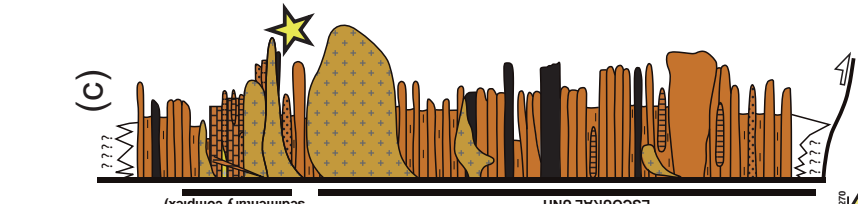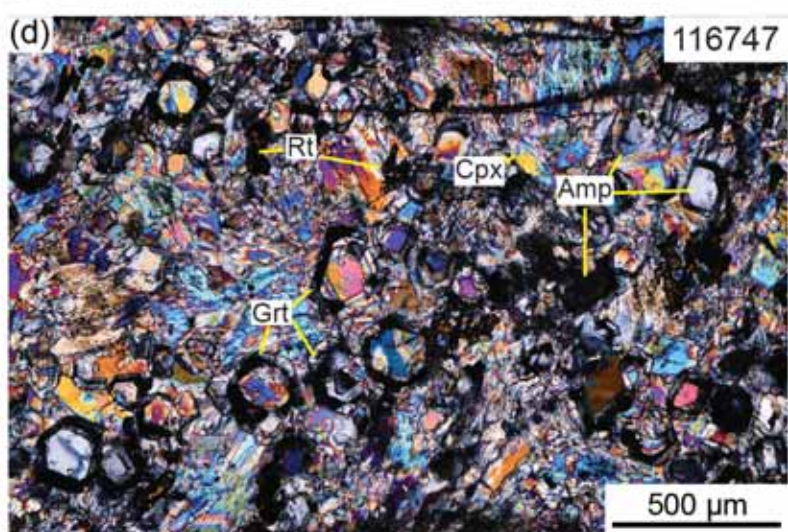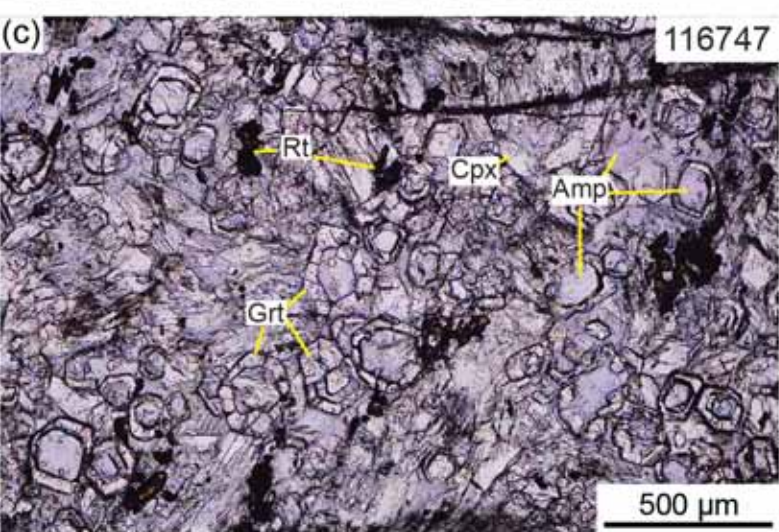
SOUTH PORTUGUESE ZONE

Metapelites and metavolcanics

(a) 116748 — Grt, Cpx, Rt, Amp — 500 µm

(b) 116748 — Grt, Cpx, Rt, Amp — 500 µm

(c) 116747 — Rt, Cpx, Amp, Grt — 500 µm

(d) 116747 — Rt, Cpx, Amp, Grt — 500 µm

(e) 116748 — Grt II, Grt I, Micro-veins — 50 µm

(f) 116747 — Grt I, Grt II — 50 µm

(a) 116748 — Omphacite (41%), Rutile (2%), Garnet II (11%), Garnet I (14%), Phengite (3%), Paragonite (0.25%), Dolomite (0.1%), Quartz (1%), Apatite (0.6%), Pyrite (0.2%), Amphibole (21%) — 1 mm

(b) 116747 — Omphacite (28%), Rutile (1%), Garnet II (8%), Garnet I (11%), Phengite (0.2%), Paragonite (1.2%), Pyrite (0.15%), Plagioclase (2%), Amphibole (45%) — 1 mm

(c) 116748 — Peninsula, Amp, Ph, Island, Cpx — Ca (apfu) in Grt, 0.3 – 1.3

(d) 116748 — Ph, Cpx, Amp — Mn (apfu) in Grt, 0 – 0.06

(e) 116748 — Ph, Cpx, Amp — Mg (apfu) in Grt, 0.2 – 1

(f) 116748 — Ph, Cpx, Amp — Fe (apfu) in Grt, 1 – 2.2

(g) 116748 — Atoll, Grt — Na/(Na+Ca) in Cpx, 0.2 – 0.4

(h) 116747 — Amp, Pg, Cpx, Ph — Ca (apfu) in Grt, 0.3 – 1.1

(i) 116747 — Amp, Pg, Cpx, Ph — Mn (apfu) in Grt, 0 – 0.07

(j) 116747 — Amp, Pg, Cpx, Ph — Fe (apfu) in Grt, 0.8 – 2

(k) 116747 — Pg, Ph, Grt atoll, Amp — Na/(Na+Ca) in Cpx, 0.2 – 0.5

Garnet fracturation & infiltration of fluids

116747	Stage 1	Stage 2 (peak)	Stage 3
Garnet	X_{Grs}=0.30 X_{Prp}=0.11 Grt I X_{Grs}=0.22 X_{Prp}=0.15	X_{Prp}=0.17-0.19 X_{Alm}=0.60-0.61 Grt II X_{Grs}=0.19-0.22	
Clinopyroxene	X_{Jd}=0.37 Omp included in Grt I & Core compositions	Inside atoll & Rim composition X_{Jd}=0.55	
Ca-Na Amphibole		Glaucophane in matrix & inside atoll	Barroisite Magnesiokatophorite
Phengite	Si = ? Xenoblastic in matrix	Si = 3.27 - 3.38 apfu Inside atoll	
Paragonite			
Quartz			
Rutile			
Plagioclase			
Apatite			
Pyrite			

(a)

(b)

(c)

Projection points

Exchange vectors:
MnFe$_{-1}$
MgFe$_{-1}$
KNa$_{-1}$

Phases:
+Qz
+Rt

(a) 116747

Grt Omp Ph Gln Coe Rt
+Coe
+Qz

Grt Omp Ph Gln Lws Coe Rt

Grt Omp Ph Gln Lws Qz Rt

Grt Omp Ph Gln Lws Rt

Grt Omp Ph Gln Qz Rt

Grt Omp Bt Gln Lws Rt
+Chl

Grt Omp Chl Bt Gln Lws Rt

+Bt

Grt Omp Chl Ph Gln Lws Rt

+Lws

Grt Omp Ph Gln Rt

Grt Omp Chl Ph Gln Zo Rt

Grt Omp Chl Ph Pg Gln Rt

Grt Omp Chl Ph Pg Gln Zo Rt

+Zo

Grt Omp Chl Pg Gln Zo Rt

Grt Omp Ph Pg Gln Rt

Grt Omp Ph Pg Bt Gln Rt

+Pg

Grt Omp Ph Pg Gln Qz Rt

Grt Omp Pg Bt Gln Rt

Grt Omp Chl Pg Bt Gln Zo Spn

Grt Omp Chl Pg Gln Zo Spn

Grt Omp Pg Bt Gln Gru Zo Rt

Grt Omp Pg Bt Brs Gru Qz Rt

Pl Grt Omp Bt Brs Qz Rt

Pl Grt Omp Bt Gru Rt

+Pl

Pl Grt Bt Gru Spn Rt

Pl Ilm Grt Bt Gru Spn Rt

Pl Ilm Grt Di Bt Gru Rt

Pl Ilm Grt Di Bt Gru Rt
+Cpx

+Rt

Pl Grt Chl Bt Tr Gru Spn

Pl Ilm Grt Bt Gru Spn

Pl Ilm Grt Chl Bt Tr Gru Spn

+Ilm

Pl Ilm Grt Chl Bt Tr Gru

Pl Ilm Grt Bt Gru

Pl Ilm Grt Bt Gru

(b) 116747 — Si_{Ph} (3.89 / 3.21)

3.70, 3.65, 3.60, 3.55, 3.50, 3.45, 3.40, 3.35, 3.30, 3.25, 3.24, 3.23, 3.22, 3.21

(c) 116747 — x_{Grs} (0.44 / 0.12)

0.14, 0.15, 0.16, 0.17, 0.18, 0.19, 0.20, 0.21, 0.22, 0.23, 0.24, 0.25, 0.26, 0.27, 0.28, 0.30, 0.31, 0.32, 0.34, 0.36, 0.38, 0.39, 0.40, 0.41, 0.29, 0.25, 0.33

(d) 116747 — x_{Prp} (0.23 / 0.03)

0.04, 0.05, 0.06, 0.07, 0.08, 0.10, 0.11, 0.12, 0.13, 0.14, 0.15, 0.16, 0.17, 0.18, 0.19, 0.20, 0.21

(e) 116747 — x_{Alm} (0.69 / 0.33)

0.52, 0.53, 0.55, 0.56, 0.57, 0.58, 0.59, 0.60, 0.61, 0.62, 0.63, 0.64

(f) 116747 — Al_{Cpx} (0.54 / 0.33)

0.47, 0.48, 0.49, 0.50, 0.51, 0.52, 0.53, 0.54

(a) 116747

Grt Omp Ph Gln Lws Rt

Grt I (rim)

Grt Omp Ph Gln Qz Rt

Grt I (core)

26

Grt Omp Ph Gln Rt

Grt II + Ph

25

24

23

22

vol.% (Grt)

(b) 116748

16
15
17
18
19
20
21
22
23

24
25

Grt Omp Ph Gl Lws Qz Rt

Grt I (rim)

31

Grt Omp Ph Gl Qz Rt

25

Grt I (core)

30

30

25

29

4   5

5   6   7   8

vol.% (Grt)

Legend: Safira area (orange diamond), Alvito-Viana do Alentejo area (blue diamond)

(a) Zr/Ti vs Nb/Y classification diagram. Fields: Alkali rhyolite, Phonolite, Rhyolite + dacite, Trachyte, Trachy andesite, Tephri-phonolite, Andesite + basaltic andesite, Alkali basalt, Foidite, Basalt. Lower axis: subalkaline, alkaline, ultra-alkaline.

(b) Rock/N-MORB spider diagram: Th, Ta Nb, La, Ce, Pr, Nd, Hf Zr, Sm, Ti, Gd, Tb, Dy, Ho Y, Er, Tm, Yb.

(c) Th/Yb vs Nb/Yb diagram. Fields: Continental Arcs, Oceanic Arcs, MORB-OIB Array. Points: OIB, E-MORB, N-MORB.

(d) V (ppm) vs Ti (ppm)/1000 diagram. Fields: Boninites, IAT (and slab-proximal BABB and FAB), MORB (and slab-distal BABB and FAB).

Legend:

- SOUTH-PORTUGUESE ZONE (AVALONIAN FORELAND)
- BEJA-ACEBUCHES OPHIOLITE (REWORKED RHEIC SUTURE)
- UPPER ALLOCHTHONOUS TERRANE (GONDWANAN AFFINITY)
- OPHIOLITES (PERI-GONDWANAN BASINS)
- BASAL ALLOCHTHONOUS TERRANE (LATE DEVONIAN HIGH-PRESSURE BELT)
- PARAUTOCHTHONOUS DOMAIN
- AUTOCHTHONOUS DOMAIN
- GONDWANAN FORELAND THRUST BELT

- STRIKE-SLIP SHEAR ZONES
- MAIN THRUSTS (PARTLY REWORKED AS NORMAL FAULTS)
- NORMAL FAULTS
- RHEIC SUTURE (REWORKED)
- EMPLACEMENT DIRECTION FOR THE HP/L-IT BELT

Map labels:

CANTABRIAN ZONE, WEST ASTURIAN-LEONESE ZONE, GALICIA-OSSA-MORENA ZONE, CENTRAL IBERIAN ZONE, SOUTH-PORTUGUESE ZONE, GALICIA-OSSA-MORENA-ZONE

Cities: OVIEDO, A CORUÑA, LUGO, BRAGANÇA, PONTEVEDRA, PORTO, COIMBRA, SALAMANCA, ÁVILA, MADRID, CÁCERES, LISBOA, BADAJOZ, ÉVORA, CÓRDOBA, SEVILLA

Other labels: PRF, VF, ET, MLF, PTF, PG-CVD, CU, HF, OVD, CF, AF, OF, LLF, CMU, CO, BAO, CA, IOMZO

Coordinates: 7°W, 6°W, 5°W, 9°W, 43°N, 41°N, 40°N, 39°N, 38°N, 37°N

Scale: 0 — 50 km

Fig. S1. Thermodynamic modeling of sample 116748

Table 1

Sample	wt.%			MnNCKFMASHT		
	116747	116748	Input	116747	116748
SiO_2	49.75	48.53	Si	53.55	52.69
TiO_2	1.98	2.12	Ti	1.6	1.73
Al_2O_3	14.63	15.30	Al	18.56	19.58
FeO	11.50	10.00	Fe	10.35	9.08
MnO	0.22	0.18	Mn	0.2	0.17
MgO	7.03	7.14	Mg	11.28	11.56
CaO	7.31	9.02	Ca	8.43	10.49
Na_2O	4.98	3.85	Na	10.39	8.1
K_2O	0.16	0.65	K	0.22	0.9
Total	100.20	100.4	H_2O	In excess	In excess

Table S1. Representative chemical analysis of garnet.

Sample	116748	116748	116748	116748	116748	116748	116747	116747	116747	116747	116747	116747
Mineral	Grt I	Grt I	Grt I	Grt I	Grt II	Grt II	Grt I	Grt I	Grt I	Grt II	Grt II	Grt II*
Location	Core	Core	Outermost part	Outermost part	Rim	Rim	Core	Core	Outermost part	Rim	Rim	Rim
Number	42	97	3	15	90	96	184	185	49b	122	189	125p
SiO_2	38.87	38.54	38.72	39.04	39.18	37.67	37.62	37.43	38.58	38.07	38.03	38.22
TiO_2	0.13	0.15	0.11	0.02	0.02	0.00	0.09	0.05	0.03	0.04	0.03	0.03
Al_2O_3	22.19	22.43	22.47	22.80	23.16	23.16	22.91	22.61	22.68	22.69	22.71	21.40
FeO_{Total}	23.75	23.19	25.44	24.43	23.85	24.21	26.14	26.22	26.92	26.60	26.19	27.49
MnO	0.36	0.48	0.42	0.40	0.44	0.40	0.23	0.14	0.73	1.08	0.70	1.19
MgO	4.00	3.47	4.36	4.85	6.64	5.52	2.70	2.97	3.82	4.71	4.09	4.20
CaO	10.74	12.14	8.83	9.65	7.86	8.59	10.66	10.24	7.65	6.73	7.62	7.03
Total	100.05	100.41	100.34	101.20	101.15	99.55	100.44	99.71	100.50	99.97	99.46	99.65
Si	3.01	2.98	3.00	2.99	2.98	2.93	2.94	2.95	3.00	2.97	2.98	3.01
Ti	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Al	2.03	2.05	2.05	2.06	2.07	2.12	2.11	2.10	2.08	2.09	2.10	1.99
Fe^{3+}	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	1.54	1.50	1.65	1.56	1.51	1.53	1.71	1.72	1.75	1.74	1.72	1.81
Mn	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.01	0.05	0.07	0.05	0.08
Mg	0.46	0.40	0.50	0.55	0.75	0.64	0.32	0.35	0.44	0.55	0.48	0.49
Ca	0.89	1.01	0.73	0.79	0.64	0.72	0.89	0.86	0.64	0.56	0.64	0.59
X_{Prp}	0.16	0.14	0.17	0.19	0.26	0.22	0.11	0.12	0.15	0.19	0.17	0.17
X_{Alm}	0.53	0.51	0.57	0.53	0.52	0.53	0.58	0.59	0.61	0.59	0.60	0.61
X_{Sps}	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.02	0.03
X_{Grs}	0.31	0.34	0.25	0.27	0.22	0.23	0.30	0.29	0.22	0.19	0.22	0.20

Table S2. Representative chemical analysis of clinopyroxene.

Sample	116748	116748	116748	116748	116748	116748	116747	116747	116747	116747	116747	116747
Mineral	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx
Location	Core	Core	Core	Rim	Rim	Rim	Core	Core	Core	Rim	Rim	Rim
Number	150p*	152p*	111	53	145p*	148p*	142	182p*	205	173p*	151	192p*
SiO_2	56.12	56.34	55.08	56.50	56.11	56.25	55.87	56.03	55.28	56.42	55.06	56.53
TiO_2	0.07	0.01	0.09	0.08	0.05	0.10	0.03	0.03	0.06	0.07	0.19	0.06
Al_2O_3	10.30	10.05	11.13	12.75	11.79	13.31	11.68	11.04	11.16	12.89	13.35	12.66
FeO	4.04	4.22	4.25	2.75	3.47	3.59	3.86	3.72	4.43	3.60	3.88	2.96
MgO	8.99	8.97	8.78	8.29	7.85	6.47	8.37	8.05	7.84	7.17	7.23	7.40
CaO	14.93	14.24	13.06	12.26	13.04	10.63	12.63	13.45	12.68	11.83	11.09	11.32
Na_2O	6.36	6.20	6.94	7.50	7.09	8.07	7.50	6.58	7.17	7.86	8.38	7.27
Total	100.83	100.14	99.33	100.12	99.45	98.61	99.93	98.95	98.62	99.93	99.31	98.38
Si	1.99	2.00	1.97	1.99	2.00	2.01	1.98	2.01	1.99	1.99	1.96	2.01
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Al	0.43	0.42	0.47	0.53	0.49	0.56	0.49	0.47	0.47	0.54	0.56	0.53
Fe^{3+}	0.04	0.00	0.09	0.01	0.00	0.00	0.09	0.00	0.05	0.02	0.00	0.00
Fe^{2+}	0.08	0.13	0.04	0.07	0.10	0.11	0.03	0.11	0.08	0.09	0.12	0.09
Mg	0.47	0.48	0.47	0.43	0.42	0.34	0.44	0.43	0.42	0.38	0.38	0.39
Ca	0.57	0.54	0.50	0.46	0.50	0.41	0.48	0.52	0.49	0.45	0.42	0.43
Na	0.44	0.43	0.48	0.51	0.49	0.56	0.52	0.46	0.50	0.54	0.58	0.50
Jd	39.77	42.78	41.15	50.43	49.03	45.18	44.16	46.36	45.29	52.52	48.93	52.38

Table S3. Representative chemical analysis of amphibole.

Sample	116748	116748	116748	116748	116748	116748	116747	116747	116747	116747	116747	116747
Mineral	Brs	Brs	Brs	Brs	Brs	Brs	Gln	Gln	Gln	Brs	Mkt	Brs
Number	39	49	103	109	113	114	163	176	201	121	145	207
SiO_2	48.90	49.23	51.12	50.89	48.63	49.19	52.67	54.47	52.36	52.12	45.26	49.13
TiO_2	0.34	0.30	0.22	0.20	0.45	0.38	0.16	0.14	0.15	0.16	0.27	0.69
Al_2O_3	14.51	13.89	13.57	13.55	14.30	14.38	13.88	13.30	13.43	13.74	15.69	13.89
FeO	9.56	9.51	9.10	8.98	9.41	9.70	8.70	9.19	10.61	9.93	12.56	11.78
MgO	11.63	12.35	12.05	11.95	12.08	11.93	10.20	10.23	9.81	10.24	9.85	10.23
CaO	6.80	5.82	4.05	4.54	6.69	6.16	2.21	1.46	2.20	3.19	7.06	5.73
Na_2O	4.69	5.12	6.06	6.06	4.72	5.34	7.20	7.40	6.77	6.44	4.83	5.37
K_2O	0.28	0.26	0.19	0.26	0.29	0.26	0.14	0.08	0.10	0.11	0.29	0.17
Total	96.87	96.66	96.55	96.51	96.86	97.52	95.38	96.34	95.63	96.18	96.13	97.20
Si	6.95	6.98	7.19	7.19	6.91	6.95	7.47	7.61	7.44	7.37	6.62	7.02
Ti	0.04	0.03	0.02	0.02	0.05	0.04	0.02	0.01	0.02	0.02	0.03	0.07
Al	2.43	2.32	2.25	2.25	2.40	2.39	2.32	2.19	2.25	2.29	2.71	2.34
Fe^{3+}	0.11	0.26	0.25	0.15	0.18	0.16	0.00	0.07	0.19	0.09	0.19	0.11
Fe^{2+}	1.01	0.80	0.76	0.87	0.90	0.94	1.03	0.99	1.04	1.07	1.30	1.27
Mg	2.46	2.61	2.53	2.52	2.56	2.51	2.15	2.13	2.08	2.16	2.15	2.18
Ca	1.04	0.88	0.61	0.69	1.02	0.93	0.34	0.22	0.34	0.48	1.11	0.88
Na	1.29	1.41	1.65	1.66	1.30	1.46	1.98	2.00	1.87	1.77	1.37	1.49
K	0.05	0.05	0.03	0.05	0.05	0.05	0.02	0.01	0.02	0.02	0.05	0.03
$^{VI}Al(C)$	1.39	1.30	1.44	1.44	1.31	1.34	1.79	1.80	1.68	1.66	1.33	1.36
Na(B)	0.94	1.05	1.33	1.27	0.94	1.03	1.66	1.76	1.62	1.50	0.83	1.09
Mg#	0.71	0.75	0.75	0.73	0.73	0.72	0.68	0.68	0.66	0.67	0.61	0.63

Table S4. Representative chemical analysis of white mica and plagioclase.

Sample	116748	116748	116748	116748	116748	116747	116747	116747	116747	116747	116747	116747
Mineral	Ph	Ph	Ph	Pg	Pg	Ph	Ph	Ph	Pg	Pg	Pl	Pl
Number	59	68	86	60	64	131	168	193	134	181	119	213
SiO_2	49.46	49.87	48.51	45.71	47.14	49.99	49.26	48.44	46.07	45.46	67.35	66.72
TiO_2	0.40	0.66	0.57	0.17	0.16	0.47	0.48	0.59	0.15	0.08	0.00	0.00
Al_2O_3	29.11	29.17	30.03	41.33	40.46	27.63	28.21	29.43	40.60	40.73	20.36	20.14
FeO	1.69	1.73	1.53	0.57	0.51	2.01	1.85	1.84	0.44	0.42	0.27	0.23
MgO	3.30	3.35	3.15	0.22	0.21	3.47	3.57	3.14	0.12	0.13	0.05	0.00
CaO	0.00	0.00	0.00	0.26	0.16	0.00	0.00	0.06	0.12	0.14	0.36	0.26
Na_2O	0.94	1.02	0.98	6.89	6.78	0.74	0.74	1.07	7.60	7.46	11.97	12.01
K_2O	9.31	9.01	9.24	0.83	1.07	8.86	8.65	8.62	0.64	0.52	0.02	0.00
Total	94.56	95.06	94.42	96.13	96.55	93.39	93.03	93.54	95.93	95.10	100.48	99.50
Si	3.31	3.31	3.25	2.90	2.98	3.38	3.34	3.27	2.93	2.92	2.94	2.94
Ti	0.02	0.03	0.03	0.01	0.01	0.02	0.02	0.03	0.01	0.00	0.00	0.00
Al	2.30	2.28	2.37	3.10	3.01	2.20	2.25	2.34	3.05	3.08	1.05	1.05
Fe	0.09	0.10	0.09	0.03	0.03	0.11	0.11	0.10	0.02	0.02	0.01	0.01
Mg	0.33	0.33	0.31	0.02	0.02	0.35	0.36	0.32	0.01	0.01	0.00	0.00
Ca	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01
Na	0.12	0.13	0.13	0.85	0.83	0.10	0.10	0.14	0.94	0.93	1.01	1.03
K	0.79	0.76	0.79	0.07	0.09	0.76	0.75	0.74	0.05	0.04	0.00	0.00
An											1.65	1.16
Ab											98.23	98.84
Kfs											0.12	0.00

Table S5. Whole rock analysis of major (wt%) and trace elements (ppm) from the high-P rocks samples of the Safira and Alvito-Viana do Alentejo areas (CMU).

Sample	116742	116743	116747	116748	116751	116752	116753	116754	116755	116756	116757	116758
Location		Safira area						Alvito-Viana do Alentejo area				
SiO_2	50.38	51.28	49.75	48.53	49.20	52.78	49.66	52.67	50.57	51.58	49.26	49.45
TiO_2	1.76	2.95	1.98	2.12	2.39	2.60	3.03	2.19	1.72	1.77	2.45	2.36
Al_2O_3	13.61	13.59	14.63	15.30	14.31	13.50	12.67	13.07	13.85	13.87	14.13	14.31
Fe_2O_3	1.85	1.37	1.05	2.13	4.20	1.53	1.73	1.47	3.96	4.89	4.99	4.78
FeO	9.30	13.60	11.50	10.00	9.40	11.40	13.10	11.80	8.20	6.90	8.40	8.80
MnO	0.12	0.25	0.22	0.18	0.29	0.28	0.28	0.25	0.19	0.16	0.24	0.22
MgO	8.74	4.75	7.03	7.14	5.78	4.17	5.27	4.68	6.24	6.26	5.51	5.81
CaO	6.67	7.09	7.31	9.02	7.05	7.00	7.56	8.24	8.40	8.38	7.64	7.36
Na_2O	3.41	4.38	4.98	3.85	4.40	4.89	3.94	3.94	2.59	2.69	4.11	4.40
K_2O	0.90	0.08	0.16	0.65	0.35	0.15	0.04	0.08	0.15	0.22	0.05	0.09
P_2O_5	0.23	0.30	0.20	0.23	0.27	0.37	0.40	0.25	0.14	0.14	0.28	0.31
LOI	2.19	-0.77	0.14	0.11	1.63	-0.33	0.13	-0.33	2.27	1.97	1.30	1.10
Total	100.20	100.40	100.20	100.40	100.30	99.61	99.27	99.63	99.20	99.60	99.30	99.97
Na_2O+K_2O	4.31	4.46	5.14	4.50	4.75	5.04	3.98	4.02	2.74	2.91	4.16	4.49
Mg#	0.48	0.26	0.38	0.42	0.38	0.27	0.29	0.28	0.43	0.48	0.40	0.40
V	414	388	261	258	367	340	420	334	338	343	372	350
Y	55.7	59	33.5	21.5	39	53	60.5	44.9	36.2	36.6	40.3	40.1
Zr	107	232	105	132	123	272	253	144	100	102	116	117
Nb	1.1	4.1	2.6	11	2.4	7.2	6.4	3.5	1.7	1.7	2.4	2.4
La	5.09	11.5	6.27	11	6.19	16.6	12.4	7.25	5.46	5.24	6.19	6.19
Ce	11.5	29.9	14.7	25.8	16.7	39	33.2	19.7	14.1	13.7	16.6	16.7
Pr	2.08	4.33	2.11	3.51	2.61	5.83	5.02	3.06	2.2	2.12	2.7	2.61
Nd	12.2	22.1	10.8	15.7	13.8	27.2	25.1	16	11.4	11.8	13.4	13.7
Sm	4.62	6.93	3.94	4.29	4.59	7.54	7.69	5.47	4.06	4.07	4.81	5.05
Gd	7.38	9.07	5.52	4.76	6.31	9.58	9.67	7.14	5.55	5.47	6.43	6.51
Tb	1.44	1.62	0.96	0.76	1.11	1.67	1.72	1.24	1.01	1	1.09	1.14
Dy	9.55	10.3	6.07	4.38	7.11	9.98	11	7.95	6.35	6.3	6.96	7.02
Ho	2	2.08	1.17	0.79	1.43	1.89	2.18	1.6	1.26	1.29	1.39	1.45
Er	5.57	6	3.29	2.12	4.18	5.4	6.16	4.65	3.63	3.78	4.01	4.14
Tm	0.812	0.894	0.486	0.286	0.587	0.787	0.909	0.672	0.541	0.538	0.59	0.582
Yb	5.31	5.83	3.12	1.72	3.89	5.05	5.95	4.3	3.52	3.52	3.98	3.8
Hf	2.7	5.1	2.4	2.9	3	5.4	5.7	3.4	2.7	2.6	3	2.8
Ta	0.07	0.31	0.19	0.85	0.14	0.5	0.51	0.22	0.09	0.09	0.16	0.16
Th	0.09	1.04	0.38	0.81	0.27	1.21	0.69	0.63	0.56	0.56	0.27	0.28
Nb/Y	0.020	0.069	0.078	0.512	0.062	0.136	0.106	0.078	0.047	0.046	0.060	0.060
Zr/Ti	0.010	0.013	0.009	0.010	0.009	0.017	0.014	0.011	0.010	0.010	0.008	0.008
Nb/Yb	0.207	0.703	0.833	6.395	0.617	1.426	1.076	0.814	0.483	0.483	0.603	0.632
Th/Yb	0.017	0.178	0.122	0.471	0.069	0.240	0.116	0.147	0.159	0.159	0.068	0.074
Ti/1000	10.749	17.685	11.858	12.685	14.328	15.575	18.147	13.117	10.305	10.581	14.706	14.124
V/Ti	0.039	0.022	0.022	0.020	0.026	0.022	0.023	0.025	0.033	0.032	0.025	0.025