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Solid Earth
Discussions

Interactive comment on "Deciphering the metamorphic evolution of the Pulo do Lobo metasedimentary belt (SW Iberian Variscides)" *by* Irene Pérez-Cáceres et al.

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Reply to the interactive comment of referee#1 (Cecilio Quesada) on "Deciphering the metamorphic evolution of the Pulo do Lobo metasedimentary belt (SW Iberian Variscides)" by Irene Pérez-Cáceres et al. (Manuscript number se-2019-143).

We acknowledge the interactive comment made by Cecilio Quesada as referee. His suggestions have contributed to clarify some issues of the manuscript, which are now included in the revised version. This review is focused on disputable interpretations of the regional geology rather than on the main topic of our manuscript. All of these regional issues are answered in the following paragraphs, though we have reorganized

and grouped them in order to avoid unnecessary repetitions. The line numbers quoted correspond to the revised version of the manuscript with tracked changes (uploaded as supplementary file to this response).

1. Geological setting. A more inclusive geological setting has been made by adding sentences and new references to authors with interpretations complementary or alternative to ours (lines 110-111, 128-129, 140-142).

2. Division in units of the SPZ. Regarding nomenclature, we prefer to use the term "Pulo do Lobo" in a merely descriptive way. Thus, the term belt was used in the submitted version of our manuscript; nevertheless, and in order to avoid any confusion (as claimed by the reviewer), we have renamed now the two major units of the region as: "Pulo do Lobo domain" and "SPZ domain" (lines 160-162). The subdivision of these two major domains is as follows, according to geological mapping both in Spain and Portugal: a) The Pulo do Lobo domain includes, from bottom to top, the following stratigraphic formations: i) the Pulo do Lobo Fm; ii) the Ribeira de Limas Fm; and iii) the Santa Iría Fm, which unconformably overlies the other two formations. The relatively minor mafic rocks are embedded in the Pulo do Lobo Fm. b) The SPZ domain includes, from bottom to top: i) the Phyllite-Quartzite (PQ) Group; ii) the Volcano-Sedimentary Complex (CVS); and iii) the Culm or Flysch Group. The southern ZSP is dominated by the Flysch Group, except at the southernmost corner where underlying formations equivalent to the PQ and CVS crop out. We realize that the Santa Iría Fm (Pulo do Lobo domain) and the Flysch Group of the SPZ might be considered as a single tectonosedimentary unit with younger ages southwards. However, in order to comprehensively describe the tectonostratigraphic evolution of each domain (particularly the Pulo do Lobo domain; section 2.1 of the manuscript), the division shown above seems preferable.

3. Age of the Santa Iría Fm. There are two sources of evidence for the age of the Santa Iría Fm. On the one hand, palynological data (Pereira et al., 2018) suggest a Late Famennian age. On the other hand, detrital zircon populations (Braid et al., 2011;

Pérez-Cáceres et al., 2017) point to an early Carboniferous age. The latter age seems preferable due to the common palynomorph reworking shown in some papers (Lopes et al., 2014). Alternatively, partial rejuvenation of the zircon U/Pb system during low-grade metamorphism has been claimed to discard the sedimentary early Carboniferous age, though the detrital zircon populations are robust and highly concordant (particularly SHRIMP data). Anyway, the exact age of the Santa Iría Fm is neither definitely conclusive (see Pereira et al., 2018, comment and reply) nor crucial for the tectonic evolution of the region.

4. Incomplete sampling? The Pulo do Lobo, Ribeira de Limas and Santa Iría formations crop out from west to east (from Portugal to Spain) all along the Pulo do Lobo domain, without significant differences along strike. Hence, sampling latitude is irrelevant. We have sampled two transects which include the three formations of the Pulo do Lobo domain (they have been specified as requested; lines 234-239). Thus, we consider unfounded claiming that our sampling was incomplete. Furthermore, some of our samples (PLB-91 and 93) were collected from the same area where the presence of "lawsonite pseudomorphs" was quoted by Rubio Pascual et al. (2013). Concerning the "lousy precision" of our sampling sites (Fig. 1b), we already added UTM coordinates as supplementary information to the first version of the manuscript. Regarding the metamafic rocks, our study was intentionally focused on the metapelites because they better recorded the successive episodes of deformation and, with the new techniques used, the PT conditions of the low-grade metamorphism can also be unveiled with relative accuracy. Future studies focused on the metabasites will be welcome, though keeping in mind that the age of these rocks is early Carboniferous (here again, zircon populations are robust and highly concordant, particularly SHRIMP data), which, in turn, precludes getting information on the early (Devonian) metamorphism of the Pulo do Lobo domain.

5. Sample preparation and interpretation of XRF data. The preparation of oriented aggregates of both whole-rock and <2 μm fractions strictly followed a well stablished

international procedure to minimize detrital mica content. Obviously, direct discrimination at small grain sizes is a hard task. In our case, both sample fractions yielded similar results, thus suggesting (detrital) mica re-equilibration during M1 metamorphism. Concerning the mechanical rotation of pre-existing minerals, our textural observations and chemical data (Figs. 2 and 3) support the preservation of variably rotated M1 micas during D2, as already discussed in our first manuscript (section 5.1).

6. Lawsonite? The presence of lawsonite in the Pulo do Lobo domain is only based on the external rhomboidal shape of an aggregate of epidote crystals interpreted as a lawsonite pseudomorph (Rubio Pascual et al., 2013). However, lawsonite can be easily mistaken for other minerals, such as clinozoisite. Indeed, the phengites analyzed by these authors "were not particularly indicative of HP recrystallization". Clearly, the lawsonite pseudomorph is an extremely weak evidence for HP metamorphism, which cannot defy our much more complete metamorphic study. Anyway, the claim for a first lawsonite-bearing mineral assemblage was already cited in our first manuscript (section 5.4).

7. Biotite? According to the peak temperatures obtained in our study, biotite could be present in the Pulo do Lobo Fm. Actually, Rubio Pascual et al. (2013) reported two chemical analyses corresponding to biotite. However, we did not identify biotite in any of our samples, possibly because this mineral is restricted to some –and scarce– particular lithologies. This issue has been included in the discussion (lines 567-570).

8. Sedimentary mélange or tectonic mélange? Our study (see also Pérez-Cáceres et al., 2015) suggests that the so-called Peramora mélange is a sedimentary mélange dominated by mafic olistholites, which were later affected by thrusting, thus resulting also in a tectonic mélange (reference to Apalategui et al., 1983 has been deleted here, as requested; line 214). Despite the reviewer's criticism, this twofold characterization of the Peramora outcrop has no contradiction. At other outcrops, the metamafic rocks seem to be intrusive in the Pulo do Lobo Fm. We realize, however, that the description of the Peramora rocks was a bit confusing and have rewritten it (lines 210-211).

9. Deformations recorded by the Santa Iría Fm. First of all, it is important to point out that we agree with the reviewer on two issues: i) three penetrative deformations affected the Pulo do Lobo and Ribeira de Limas Fms of the Pulo do Lobo domain; and ii) Santa Iría Fm unconformably overlies the Pulo do Lobo and Ribeira de Limas Fms. However, the reviewer believes that the Santa Iría Fm is only affected by the third deformation, while we state that it is affected by the last two of them (Fig. 2c). Regarding this issue, the reviewer's argument seems a bit confusing, being apparently based on: i) "it exists a general agreement"(?); and ii) the ages of deformed and undeformed facies of the Gil Márquez pluton (we deal with the Gil Márquez pluton in the following point of our answer). By contrast, our statement that the Santa Iría Fm is affected by two of the three penetrative deformations in the Pulo do Lobo domain is supported by a detailed structural analysis, which includes: cleavage identification, deformational microstructures, local vergences and indicators of stratigraphic polarity all across the Pulo do Lobo domain; the resulting macrostructure is displayed in Fig. 1 (see also Pérez-Cáceres et al., 2015).

10. Timing of deformations and associated metamorphism in the Pulo do Lobo domain. Regarding timing of deformations, the reviewer bases his argument on the ages and deformations recorded by the Gil Márquez pluton. According to him, the lack of deformation in the older mafic facies (354 Ma) implies that the two first penetrative deformations in the Pulo do Lobo domain are older than 354 Ma and therefore they did not affect the Santa Iría Fm. However, the mafic rocks of the Gil Márquez pluton constitute a highly competent body, which is a poor marker for superposed deformations, as demonstrated by the fact that a younger felsic facies of this pluton (345 Ma) is foliated while the older one is isotropic. By contrast, our statements about the Santa Iría Fm are: i) its age is early Carboniferous according to discussion in point 3; and ii) it is affected by two penetrative deformations, as demonstrated by a detailed and comprehensive structural analysis (see point 9). Thus, only the first penetrative deformation of the Pulo do Lobo domain is Devonian (Late Devonian) in age, while the two subsequent deformations are Carboniferous (as also noted previously by Silva et

al., 1990; line 211). Accordingly, the same timing applies to the syn-kinematic metamorphism associated with the first and second penetrative deformations of the Pulo do Lobo domain.

Regarding the third deformation (D3; upright folding), we already described a spaced and disjunctive crenulation cleavage S3 (lines 189-191, 202), which did not entail phyllosilicate growth (lines 399-400). This has been stressed in section 5.1 (lines 510-511), and no further implications are attained about D3.

11. The Gil Márquez pluton as evidence of active subduction. The calc-alkaline geochemistry of the Gil Márquez rocks is taken by the reviewer as evidence of active subduction at early Carboniferous time. The reviewer views this as a support to the subduction-related accretionary prism interpretation of the Pulo do Lobo domain. We believe, however, that these geochemical features are overrated when used to make inferences of active subduction at early Carboniferous time. Actually, the volume of the Gil Márquez rocks is very scarce to attest a magmatic arc, and, more importantly, the calc-alkaline geochemistry may be obtained from the residual mantle contaminated by the Devonian subduction, which at the time of Gil Márquez intrusion was no longer active. Indeed, there is regional evidence that collision started at Late Devonian time (e.g. Ponce et al., 2012 and references therein).

12. Writing corrections have been introduced in the revised version of the manuscript (lines 103, 136, 143, 234, 562).

To sum up and leaving aside the particular questions addressed above, the main concern of the reviewer is about the identification of the Pulo do Lobo lower formations (Pulo do Lobo and Ribeira de Limas Fms) with a subduction-related accretionary prism, an interpretation that we defy in our paper. If not used in a vague way (a usage that we do not endorse), an accretionary prism is a tectonic unit made up of a package of imbrications, having at least one of the two following key features: i) HP metamorphism indicative of subduction; ii) tectonic slices of mafic rocks and ocean floor sediments scrapped off from oceanic crust. None of these features is present in the lower formations of the Pulo do Lobo domain, according to the structural, radiometric and metamorphic data reported in our paper. Accordingly, we claim that: i) the structure is dominated by folding, despite local imbrications (see Fig. 1.c.2); ii) the mafic rocks embedded in the Pulo do Lobo Fm are dated at early Carboniferous age, thus being imbricated with Middle-Upper Devonian sediments and not representing slices of oceanic crust; and iii) the metamorphic gradient of these rocks is of low-pressure, as demonstrated by our detailed metamorphic study. Therefore, we maintain our conclusion that the Pulo do Lobo lower formations constitute a tectonic unit located very near the subduccion/collision OMZ/SPZ boundary, but without the most typical features of a subduction-related accretionary prism.

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