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Solid Earth
Discussions

Interactive comment on "Kinematics of subduction in the Ibero-Armorican arc constrained by 3D microstructural analysis of garnet and pseudomorphed lawsonite porphyroblasts from Ile de Groix (Variscan belt)" *by* Domingo Aerden et al.

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This reply is also submitted as an attached pdf in which the text is better formatted

RESPONSE TO BOTH REFEREES

We sincerely thank both referees for their time and helpful recommendations. Because of our inexperience with the editorial procedure of Solid Earth including an open discussion period, we wrongly assumed that our responses to referees had to be accompanied by a fully revised manuscript, on which we have been working during the last 2 months and is now almost finished. However, we recently learned that we have to submit our replies first, and then wait for the editor to decide regarding possible submission of a revised paper.

RESPONSE TO REFEREE-1

We are pleased with the Referee's positive evaluation of our research and recognizes its implications, not only for the Variscan orogen, but also for the deeper question of whether structural complexity is due to 'progressive deformation' or by a superposition of different tectonic events. He rightly point out that our microstructural approach is still debated amongst structural geologists but regards that as scientifically stimulating.

A number of minor issues annotated in the original manuscript by referee-1 have all been fixed. Regarding the scientific content, the referee recommends that we provide a better description of the relationships between the (micro)structural evolution of the studied samples and the metamorphic evolution. We have added some extra information on this referring to previously established P-T paths (Ballèvre 2003, Schulz et al. 2001). We cannot say much more, though, than that garnets and lawsonite grew on the prograde path related to Late-Devonian oceanic subduction, followed by continental subduction and collision in the Carboniferous recorded in the Pouldu schists.

We have reorganized our paper giving it the following structure:

1. Introduction

2. Geological setting and previous work

3. Inclusion-trail data from thin sections

3.1. Preferred orientations of inclusion trails and genetic implications

3.2. Inclusion-trail curvature sense and implications for subduction polarity

3.3. Average FIA trends measured from radial thin-section sets

3.4. Mainland samples: Pouldu schists, Tréogat formation and Central Armorican Domain

4. Inclusion-trail data from X-ray tomography

4.1. Data acquisition and processing method

4.2. Sample G11

4.3. Sample G12

4.4. Sample G14

4.5. Sample G3

4.6. Sample G20

5. Tectonic interpretation

6. Discussion

6.1. Inclusion trail data vs. structural sequences in the field

6.2. Formation mechanism of sheath folds

6.3. Inclusion trail data vs. shear-bands

6.4. Comparison with inclusion-trail data from NW-Iberia

7. Conclusions

Referee-1 considers some of our interpretations insufficiently supported by data and points at specific parts of the original text copied below. We think the problem was that our ideas were too briefly and unclearly expressed. We have therefore expanded the text that needed clarification.

Line 353 - original text: "These foliations could have alternated with subhorizontal ones related to intermitted gravitational collapse stages, but the predominantly moderate to steep plunges of FIAs in the samples studied with X-ray tomography suggests these events were in any case weak."

Lines 393-396 However, considering that HP metamorphism of Ile de Groix rocks is Late-Devonian (360-370Ma; Bosse et al., 2005) and that the Variscan orogeny continued until at least 300Ma, vertical shortening can also be considered in the context of a gravitationally spreading thrust wedge with plate convergence and subduction continued below the wedge (cf. Bell & Johnson, 1992 - their Figs 16 and 17).

New text related to the above topics:

(section 3.1. - last paragraph) Additional support for a 'non-rotational' origin of the inclusion trails of Groix Island is provided by internal truncations within garnets of samples G7 and G14 (Fig. 4). These exhibit similar subvertical and subhorizontal preferred orientations as reported in other metamorphic belts (e.g. Bell et al., 1992; Hayward, 1992; Aerden, 1994, 1998, 2004; Mares, 1998; Bell & Sapkota, 2012; Sayab, 2005; Shah et al., 2009; Aerden and Ruiz Fuentes, 2020), where it is interpreted to witness alternating compression and (synorogenic) gravitational collapse. We are unaware of any alternative explanation for this data.

(Section 5, Tectonic interpretation") The average dip of all 106 inclusion-trail planes measured in 6 samples with X-ray tomography is 57° (σ=21°) and the average plunge of all 32 measured FIAs is 43° (σ=15°). These relatively high dip and plunge angles imply only a minor role of the intermitted gravitational phases that are suggested by subhorizontal truncations within garnets of samples G14 and G7 (Fig. 4). These events did not significantly rotate pre-existing steeply dipping fabrics as that would have resulted in a preponderance of subhorizontal FIAs caused by the intersection of subhorizontal and subvertical foliations (e.g. Bell et al., 1995). The penetrative subhorizontal crenulation cleavage in the matrix of G3, G7, G11, G12, and G14 is not continuous with the above mentioned subhorizontal truncations and therefore must have formed later. Based on what is known about the control of crenulation cleavage development on porphyroblast nucleation and growth (e.g. Bell & Hayward, 1991), we interpret that incipient development stages of the subhorizontal transposition foliation at Groix triggered the growth of lawsonite crystals and the latest stages of garnet growth in samples G11 (Fig. X2), which both preserve the previous subvertical WNW-ESE striking foliation. Porphyroblast growth would have ceased as soon as the newly forming cleavage intensified against porphyroblast margins, followed by continued intensification, folding and transposition in the matrix. In the eastern half of the island, the subhorizontal crenulation fully transposed older fabrics and is responsible for the overall flat-lying position of the macroscopic composite cleavage. In lower-grade western Groix the same cleavage appears to be more weakly developed as the main foliation there dips moderately to steeply NE or SW due to upright folding. These contrasting structural styles are clearly reflected in the orientation data of Cogné et al. (1966) which are compiled in extra Figure X3a. Structural relationship between the high-grade and lower-grade domains are further clarified by sketches of Cogné et al. (1966) and Boudier & Nicolas (1976) of an outcrop at Vallon du Lavoir (central south coast; Fig. 2a) showing a decametre-scale upright anticline overprinted by a horizontal crenulation cleavage with associated refolding suggesting a component of vertical shortening (Extra Fig. X3c and X3d). Indeed, Shelley & Bossière (1999) already deduced vertical shortening from quartz fabrics and conjugate shear bands indicating opposite shear senses. The sketch of Cogné et al.'s (1966) includes a zone where the horizontal cleavage appears overprinted itself by a steeply SE dipping foliation. Samples G18, G19 and G20 were collected at an outcrop in Port Lay (central north coast; Fig. 2a) where the main cleavage dips 55° NE without traces of a subhorizontal crenulation cleavage. This foliation strike parallel to the younger of 2 sets of inclusion trails present in sample G20 (Fig. 8c) suggesting a genetic relationship. Therefore, the main foliation at this outcrop is interpreted to predate the subhorizontal transposition cleavage in eastern Ile de Groix. The above micro- and macro-structural relationships, summarized in the conceptual sketch of Fig. X3b, are consistent with a gravitationally spreading thrust nappe. We envisage an emplacement mechanism similar as modelled experimentally by Bucher

(1956) or Merle (1989), and as proposed earlier for Variscan nappes in the Montagne Noire (Aerden, 1998; Aerden & Malavieille, 1999). The steeply dipping E-W striking foliation in the Pouldu schists and associated inclusion trails (see section 3.5.) record continued N-S plate convergence during the Carboniferous causing shortening in the footwall of the Ile de Groix ophiolitic nappe. This deformation may have produced the late chevron-style folds with E-W trending axes recognized on the island (Fig. X3a).

RESPONSE TO REFEREE-2

We are pleased that the second referee also values our research positively and appreciate his recommendations for improving our manuscript with (i) a more complete description of methods, (ii) a clearer separation of data vs. interpretation, and (iii) extra discussion regarding the relationships with previous structural data such as quartz cpo. and metamorphism. Below we reply to each of these concerns:

Concern-1. Methodology confusing, dispersed or even not explained. Lack of information regarding acquisition and processing of X-ray scans. FIA technique has to be explained and/or better illustrated. We have added a detailed descriptions of the method for determining FIAs using thin sections (section 3.4. of the new revised manuscript) and a whole new subsection (7.1.) describing the acquisition and processing procedures of the X-ray tomography.

Concern-2. Too much mixture of results and interpretation We have thoroughly reorganized our paper to improve the separation of data and interpretation. The new paper structures is:

1. Introduction

2. Geological setting and previous work

3. Inclusion-trail data from thin sections

3.1. Preferred orientations of inclusion trails and genetic implications

3.2. Inclusion-trail curvature sense and implications for subduction polarity

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Concern-3. Little discussion of previous structural data and link with metamorphism We have significantly expanded our discussion of structural data including: orientation data for folds and lineations, conventional shear-sense criteria (quartz c-axes and shear bands). We have also added discussion of the different structural styles of eastern and western Ile de Groix. The significance of sheath folds was already discussed. Two extra Figure have been made to illustrate this extra discussion. The first compiles and interprets data of Cogné et al. (1966). The other illustrates the geometry of shear bands in sample G11 and their relationship with inclusion trails in garnet and lawsonite pseudomorphs. This Figure is used in new discussion of the interpretation of shear-bands by Philippon et al. (2009). (Figures are attached to this reply).

Like Referee-1 also asked for more discussion of (micro)structure-metamorphism relationships. As we did not perform any detailed petrological or geochronological analyses of garnets, our discussion of this aspect remains limited. We only affirm that the studied garnets and their inclusion trails formed during prograde high-pressure metamorphism typical of subduction zones, and that Lawsonite grew with the latest stages of garnet growth. We have added some lines referring to the different metamorphic paths of Ballèvre (2003) who interprets a single metamorphic cycle versus Schulz (2001) who proposed 2 cycles.

Concern-4. Some thin sections are still missing.

We have now studied the thin sections we were waiting for from the Pouldu schists. The data obtained from those sections are a valuable addition and are presented in new section 3.4. and in an extra Figure (Fig. X1 - attached). Their tectonic significance is discussed in section 5.

We have also analysed an extra sample with X-ray tomography (G20). The new data are presented in a new stereogram added to Fig. 8 (attached). It significantly reinforces our interpretation of 3 sets of inclusion trails with regionally consistent strikes.

Please also note the supplement to this comment:
https://se.copernicus.org/preprints/se-2020-175/se-2020-175-AC1-supplement.pdf

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2020-175, 2020.

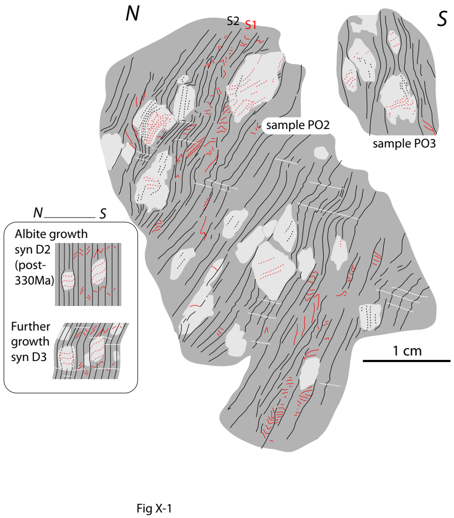

Fig. 1. New Figure showing and interpreting microstructrues in the Pouldu schists

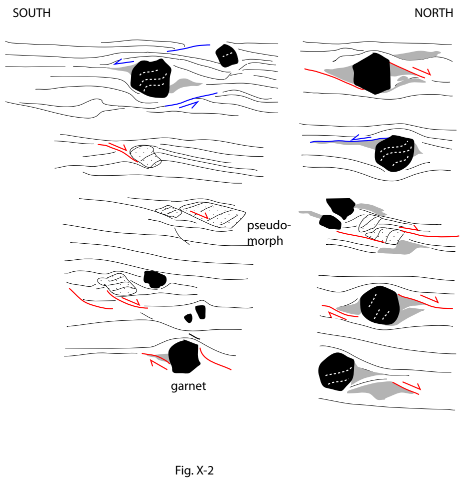

Fig. 2. New Figure showing conventional shear-sense criteria in G11

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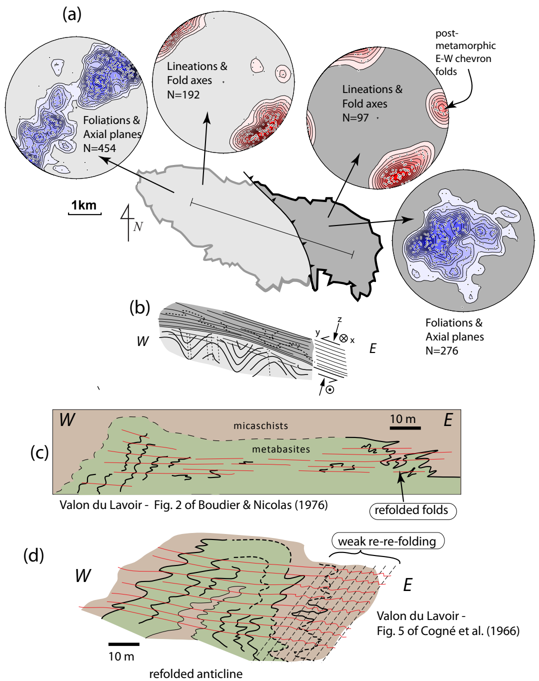

EXTRA FIGURE X3

Fig. 3. New Figure showing data from Cogné et al (1966) and Boudier & NIcolas (1976) and interpreting their data in terms of gravitational spreading

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