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REPLY
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Key Points:
- This contribution is a reply on a comment submitted by A. Argnani
- The alternate interpretation of the wide-angle seismic model is discussed
- The Alfeo Fault system is proposed to be the current location of STEP fault

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Reply to Comment by A. Argnani on "Geometry of the Deep Calabrian Subduction From Wide-Angle Seismic Data and 3-D Gravity Modeling"

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Abstract Andrea Argnani in his comment on Dellong et al. (2020, https://doi.org/10.1029/2019gc008586) (Geometry of the deep Calabrian subduction (Central Mediterranean Sea) from wide-angle seismic data and 3-D gravity modeling) proposes an alternate interpretation of the wide-angle seismic velocity models presented by Dellong et al. (2018, https://doi.org/10.1002/2017JB015312) and Dellong et al. (2020) and proposes a correction of the literature citations in these paper. In this reply, we discuss in detail all points raised by Andrea Argnani.

1. Introduction

First of all, we would like to thank Andrea Argnani for the interest he has shown in our work. Andrea Argnani in his comment on Dellong et al. (2020) (Geometry of the deep Calabrian subduction (Central Mediterranean Sea) from wide-angle seismic data and 3-D gravity modeling) proposes an alternate interpretation of the final velocity models presented by Dellong et al. (2018) and Dellong et al. (2020). Additionally, he claims that a part of the literature was not reported properly. While we basically agree with some of the interpretations presented in his comment (activity of the northern Malta Escarpment, presence of subducting crust at the base of the Calabrian crustal block), we fundamentally disagree with him on the presence and the activity of the lithospheric tear fault in the Ionian Sea south of Mt. Etna. We will respond to his points in the order that he raised them.

2. Active Tectonics and Tear Faults at the Malta Escarpment

2.1. Tectonic Activity of the Malta Escarpment

The activity of the Malta Escarpment (ME) has been discussed previously (Dellong et al., 2018; Gallais et al., 2013; Gutscher et al., 2016, 2017; Polonia et al., 2016). We agree with Argnani that the ME is a currently active structure in its northern portion (North of Siracusa) showing primarily normal faulting (extension to transtension). However, the central and southern part of the ME (south of Siracusa) does not exhibit significant crustal earthquakes nor seismic images of active faulting. This aspect of Argnani's comment seems much more directed toward earlier work (Dellong et al., 2018), which clearly explains why the Alfeo Fault System is preferred as the current-day location of the STEP (Subduction Transform Edge Propagator). Dellong et al. (2018) specify that the Malta escarpment affects the crust but represents probably an inherited structure from the Early Mesozoic, and previous studies show that activity is mostly normal (Torelli et al., 1998). The observation of strongly thinned continental crust at the foot of the escarpment cannot be explained without invoking a major phase of rifting and crustal thinning in the Mesozoic. But the tectonic history of the ME is not the main subject of the Dellong et al. (2020) article, and it is thus only briefly mentioned in the introduction and accordingly cites earlier work (Argnani & Bonazzi, 2005; Dellong et al., 2018). In reply to Comment Key Point 1, it is unclear which article Argnani is referring to when he states (Lines 27–28) "that at least in one case previous literature was not adequately cited," since he does not specifically mention the article that was allegedly "not adequately cited."

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3. Wide-Angle Seismic Data Alternate Interpretation

3.1. Deep and Asymmetrical Sedimentary Basin

Argnani questions the applicability of the rift basin interpretation, given a lack of expression in the surface morphology (Line 76). He also comments that other authors have extended this interpretation to the entire area between the Alfeo Fault and Ionian Fault and to be possibly related to serpentine diapirs (Polonia et al., 2017). To clarify this point, the "rifting" proposed in Dellong et al. (2018) affects only the upper plate, the Peloritan-Calabrian basement block, which structurally represents the continental backstop of the Ionian-Tyrrhenian subduction. We never discussed nor implied it could affect the oceanic basement further south between the Alfeo and Ionian Faults, although, indeed, the Western lobe of the accretionary wedge is down-dropped more than 1,000 m as a whole relative to the Eastern lobe and other publications propose this extension based on deep seismic data and geodetic models (Polonia et al., 2017; Ventura et al., 2014). Indeed, there is abundant evidence of NE-SW to E-W oriented extension in the straits of Messina area: from the pure normal faulting focal mechanism of the Messina 1908 M7.2 earthquake, to the extensional mechanisms of recent moderate magnitude earthquakes, to GPS data indicating up to 1 mm/year extension across the straits of Messina (Palano et al., 2012). And there is the observation of the 10–15 km deep basin of sediments above a thin (continental to transitional) crust discussed in earlier work (Dellong et al., 2018). However, as Argnani correctly points out, the surface morphology is not characteristic of a large-scale continental rift basin. The explanation likely lies in the unique tectonic setting that this particular "rift" at depth is overlain by 10–15 km of highly deformed, primarily folded (by compressional to transpressional deformation), accretionary wedge sediments. In a sense as soon as the space (at depth) is made available, it is immediately filled by the overwhelmingly large quantity of actively deforming accretionary wedge sediments, present all around, and ready to fill the gap. This unusual sedimentary-tectonic history will not produce a classic syn-rift depositional sequence.

3.2. Alternate Interpretation of the Calabrian Block

The study region exhibits a highly complex 3-D lithospheric structure, and as more profiles became available, the original interpretation of the DY-P3 profile evolved. We agree that the lower portion of the crustal block, initially interpreted as Calabrian continental crust along profile DY-P3, in fact represents oceanic crust of the downgoing Ionian Sea slab (Figure 1; Comment Key Point 2). We note in the text, "While along DY-P3 no slab was modeled, along the profile DY-P4, the slab is clearly imaged by the data from the land stations [...] The Moho depth along model distance 80–120 km on profile DY-P3 (31 km) corresponds to the depth of the oceanic Moho along DY-P4; however, the backstop-slab interface was not detected along DY-P3 (Figure 9 and Figure S6 in Dellong et al., 2020; electronic supplements)". This new interpretation is due to the better data quality of the well-coupled land stations than the sea bottom instruments. So we agree with some parts of the interpretation offered in this comment, which is different from Dellong et al. (2018), but less so with Dellong et al. (2020).

3.3. Oceanic Crustal Thickness, Gravity Models, and Figure 2 of the Comment

As to differences in crustal thickness between the oceanic crust imaged along DY-P4 and DY-P3, the top of the oceanic crust along the DY-P3 velocity model was never shown in Dellong et al. (2018) nor in Dellong et al. (2020), as it was not directly observed in the DY-P3 OBS data. If the author of the comment is referring to the oceanic crust location presented in the gravity models, it is worth mentioning that this specific "best fit" model was built to fit the free-air gravity anomaly and consequently does not reflect our latest interpretation of the area. The starting point of these models was the DY-P3 velocity model only, without the knowledge of the DY-P4 velocity model. The resulting interpreted oceanic slab depth coming from the gravity models was at around 30 km but with a high uncertainty. Later, the DY-P4 velocity model was produced, and the oceanic slab depth was found around 25 km more precisely. Finally, in Figure 2 of the comment, the author is using an arbitrary iso-velocity line as "top of Ionian slab." This iso-velocity line does not correspond to any layers from the model and does not correlate well with the DY-P4 velocity model (20 km depth instead of 25 km), which may explain the differences in crustal thickness observed by the author of the comment.

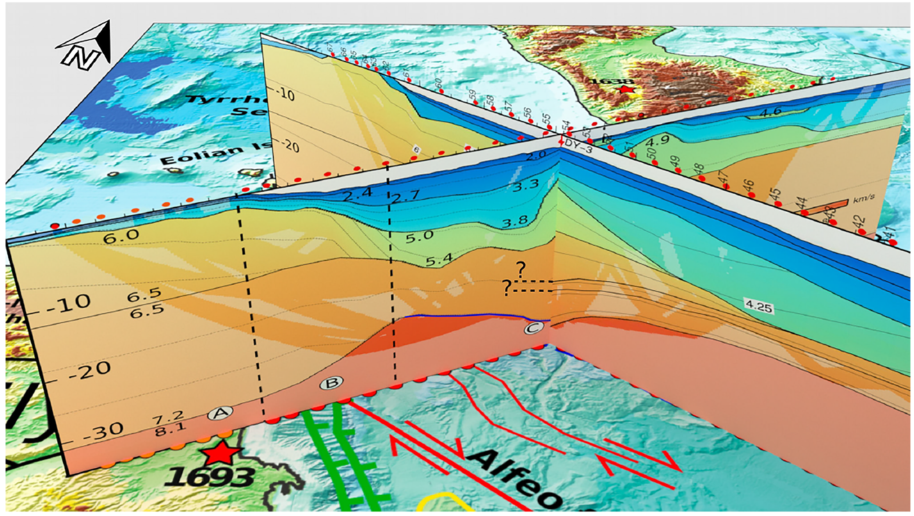

Figure 1. Three-dimensional view of the crossing point between DY-P3 and DY-P4 above the bathymetric map (Figures 1 and 2 of Dellong et al., 2020). The dotted line with question marks shows a possible extension of the upper and lower crustal oceanic layers along the DY-P3 profile given the depth and location of the oceanic crust along the DY-P4 profile (Figure V.13 of Dellong, 2018).

3.4. Differences With the Interpretation of DY-P3 Proposed by Argnani

The interpretation of the DY-P3 velocity model proposed by the author of the comment disagrees with the one proposed in the Dellong et al. (2020) on two major points: (1) the interpretation of the green layer of intermediate velocities that was interpreted as the upper-crustal layer of the Calabrian block and is interpreted as a sedimentary layer by the author of the comment and (2) the Continent-Ocean Boundary (COB) location along the DY-P3 profile and the western edge of the oceanic slab along this same profile.

(1) In both articles (Dellong et al., 2018, 2020) this hypothesis was investigated, but a satisfactory answer with solid proof could not be achieved that this layer was an upper-crustal layer. We still prefer our final interpretation for at least two main reasons:

1. Along the southern profile DY-P1, the intermediate velocity layer (4.5–4.8 km/s) is of sedimentary origin, as demonstrated by the CROP reflection seismic data section, along which a well-stratified layer is imaged in this depth. Unfortunately, no such high-resolution MCS data exist for the northern profile DY-P3; however, seismic velocities are substantially higher than along DY-P1 (4.9–5.1 km/s), indicating a nonsedimentary origin of this layer here.
2. Second, arrivals on the OBS from this layer differ between arrivals from the overlying layer, indicating more resemblance to the arrivals at the WSW of the profile. The lateral change takes place along a narrow region but is gradual, and no abrupt contact was determined.

(2) It is worth noting that many of the regions where the author of the comment proposed a different interpretation from ours are in the deepest portions or at the ends of our velocity model, where ray coverage is sparse or absent and thus poorly constrained by the wide-angle seismic data. Thus, with the Dionysus velocity models presented in this study, the location of the COB along the DY-P1 cannot be precisely determined. With this interpretation it makes sense that the thinned continental crust in the middle of the DY-P3 profile could belong to the ME as discussed in the Dellong et al. (2018) because of the overall structure of the ME is similar between DY-P1 and DY-P3.

4. "There May Be No Lithospheric Tear Fault in the Ionian Sea and South of Mount Etna"

4.1. Comment Key Point 3, Line 109, and the Conclusion Lines 129–130

We strongly disagree with this, the crux of Argnani's comment. We stand by the interpretation given in the body of earlier work (Dellong et al., 2018; Gallais et al., 2013; Gutscher et al., 2016, 2017) that from Siracusa southward the central and southern portions of the ME show no sign of modern activity. Argnani also agrees with this (Argnani, 2020; Argnani & Bonazzi, 2005). Also, according to Govers and Wortel (2005), propagation of a STEP fault in the upper crust typically involves alongside vertical-axis structural rotations. However, the adjacent Hyblean Plateau is paleomagnetically unrotated (Cifelli et al., 2004), which excludes the ME as a STEP fault. Despite other different interpretations existing on the exact location of the tear fault system (Barreca et al., 2019; Polonia et al., 2016), we do all agree that the STEP is located in the Ionian Sea and not in the Tyrrhenian region. The AFS located 50 km eastward (along profile DY-P1) matches all the expected characteristics of a crustal scale tear fault, specifically a 50 km-long elongated basin with a 500–800 m thickness of syn-tectonic Neogene sediments, bounded by transtensional faults as imaged by high-resolution seismic images and morpho-bathymetry of the seafloor (Gutscher et al., 2016, 2017). Moreover, these bounding faults show continuity with large-scale crustal heterogeneities imaged by deep seismic profiling (Cernobori et al., 1996; Dellong et al., 2018; Gallais et al., 2013; Nicolich et al., 2000; Polonia et al., 2011). A recent seismic imaging study, based on a network of industry profiles, confirms the perfect correlation between the geomorphological expression of the transtensional structures (elongate basin, linear strike-slip to normal faults) and their deep expression as active faults affecting the basement (Maesano et al., 2017). Here is a quote from their work regarding the identification of the Alfeo Fault system as the STEP fault: “Here we show the lateral continuity of the STEP fault system at depth for over 150 km length, and confirm its importance as a lithospheric structure” (Maesano et al., 2017). The latest work by this group (Maesano et al., 2020) reinforces the same conclusions: “We confirmed the role of the AFS as a lithospheric tear,” though they report on decoupling between shallow and deep fault segments, due to the effect of the accretionary wedge sediments. We have explained briefly here (in this paragraph) and in greater detail in earlier work (Dellong et al., 2018; Gallais et al., 2013; Gutscher et al., 2016, 2017) why the shallow and deeply rooted tectonic activity of the Alfeo Fault System qualifies it as the best candidate for the present-day lithospheric tear fault. It is clearly distinct from and located 30–80 km east of the Malta Escarpment over most of its length (except in the Catania-Mt. Etna region, where the two structures intersect).

Data Availability Statements

The ocean-bottom seismometer data used in this publication are accessible in standard Segy format upon request (at http://doi.org/10.17882/52435).

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