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Comment on "Geometry of the deep Calabrian subduction (Central Mediterranean Sea) from wideangle seismic data and 3-D gravity modeling" by Dellong Et Al.

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Key Points:

- The paper of Dellong et al. does not report adequately the content of previous papers on the tectonic activity of the Malta Escarpment.

- In an alternative interpretation the Calabrian units thrusted the Ionian oceanic crust which is still attached to the Hyblean margin.

- Subduction could be just incipient immediatly south of the Messina Strait, and there may be no lithospheric tear faults south of Mt . Etna.

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Abstract

The recent paper by Dellong et al. does not report properly the literature on the the Malta Escarpment and its tectonic activity. Moreover, the published set of data allows an alternative interpretation of one of their refraction profiles which implies that only incipient subduction is present south of the Messina Strait, without need for well developed lithospheric tear faults south of Mt . Etna.

1 Motivation

Dellong et al. (DEL hereafter) present very interesting results obtained after a seismic refraction campain in the Ionian Sea. The data presented offer a more coherent view of the crustal structure of the Ionian basin. However, in spite of the quality of the data the overall interpretation and the discussion of the results are not always convincing. Moreover, at least in one case previous literature has not been adequately cited. This last point has motivated this comment, where additional issues concerning the interpretation of refraction data have also been addressed.

2 Active tectonics and Tear faults

In a short statement the authors reject the proposition made by Argnani & Bonazzi (2005) that the STEP fault could have followed the Malta Escarpment. They argue that their reasoning is supported by the absence of tectonic deformation along the central to southern Malta Escarpment since the Messinian, as pointed out by Gutscher et al. (2016) on the basis of reflection seismic profiles. However, this absence of deformation was noticed and taken into account by Argnani and Bonazzi (2005) who explicitly stated that the Malta Escarpment was active recently only in the segment north of Siracusa. This interpretation is based on reflection seismic data but is also supported by present seismicity (Musumeci et al., 2005) and by tsunami modelling of the 1693 earthquake (Argnani et al., 2012). Therefore, i) the fact that the Malta Escarpment shows no evidence of recent tectonic activity south of Siracusa has been already illustrated by Argnani and Bonazzi 2005; and, ii) this evidence is not sufficient to rule out the possible occurrence of a lithospheric tear fault along the northern Malta Escarpment, unlike what was stated by DEL.

Although DEL interpreted the Ionian Fault as a possible STEP fault, there is little evidence for it. For example, the tectonic structures attributed to this fault are difficult to trace and there is remarkable absence of surficial deformation (e.g., Gutscher et al., 2017, 2019) and focussed earthquake activity. Furthermore, there is no Moho step in the crustal velocity model of DEL across the location of the proposed lithospheric fault (DEL, Fig. 9, DY-P1, profile distance 220-250 km), although such a feature can be difficult to image by refraction methods.

3 Refraction data: Alternative interpretation

An additional issue stands up when comparing the interpreted refraction profiles, two of which were previously published in Dellong et al. (2018). Profiles DY-P3 and DY-P1, both SW-NE-trending, cross the Malta Escarpment at its northern end and south of Sicily, respectively. The NW-SE-trending DY-P4 is of particular interest as it connects the DY-P3 and DY-P1 profiles (Fig. 1).

Dellong et al. (2018) considers the possible role of the Ionian and Alfeo faults in achieving the present configuration of lithology suggested by the velocity model of DY-P3, concluding that the Alfeo fault is the preferred tear fault. The profile shows a 30 km-thick crust on the western (Hyblean) and eastern (Calabrian) sides separated by a thinner crust, which, according to the authors, represents a "deep and asymmetrical sedimentary basin". The refraction interpretation, in fact, is suggestive of a rift basin, though reflection seismic data clearly show that there is no basin in that region but rather deformed sediments of the accretionary wedge (e.g., Argnani & Bonazzi, 2005; Argnani et al., 2009, 2013). This "rift" misconception has lead to some confusion as some authors have extended this rift interpretation to the whole region comprised between the Alfeo and Ionian lithospheric faults (Polonia et al., 2017). This region is considered to be underlain by thinned crust produced by a recent transtension, also suggesting that rifting has promoted the onset of serpentinite diapirs (Polonia et al., 2017). According to this interpretation a crustal thinning from 35 to 20 km (beta factor 1.75) should have occured in this ca. 50 km-wide belt of transtension during the Pleistocene. For its size and amount of extension this inferred rift sector would be comparable to the North Sea Central Graben (e.g., Wood & Barton, 1983), but rifting in the Ionian lithosphere would be produced in a much shorter time interval. However, there is no trace of such recent rifting in the surface morphology, as shown by multi-beam bathymetry (Gutscher et al., 2017) and there is no evidence for crustal thinning in the velocity model for DY-P1.

Comparing the velocity models of DY-P3 and DY-P4 where they cross (DEL, Fig. 9), the lower portion in the eastern part of DY-P3 (Fig. 2, profile distance 70 to 170 km) correlates with the subducted Ionian oceanic crust in DY-P4 (DEL, Fig. 9). At the crossing the top of the oceanic slab corresponds roughly to the iso-velocty line 6.75 km/s of profile DY-P3 (see DEL Fig S6), which is therefore taken as the top of the slab along the eastern part of DY-P3 (Fig. 2). It is worth noting that the interpreted oceanic crust in DY-P3 (Fig. 2) is thicker than the typical crust imaged in DY-P4 (DEL, Fig. 9, profile distance, 0-200 km), but this is due to the fact that DY-P3 displays an apparent thickness because the profile intercepts DY-P4 where the crust is dipping. The arguments indicated above imply that the Calabrian continental crust is thinner than interpreted in DEL (less than 20 km instead of 30 km; Fig. 2) and thrusted onto the Ionian oceanic crust; this thinner continental "crust" is more appropriate given the tectonic setting, as Calabria is not a continental fragment but a stack of crustal nappes (Graessner et al., 2000; Bonardi et al., 2001) representing the inner part of the Calabrian accretionary wedge. This piece of evidence leads to an alternative interpretation of profile DY-P3, where the portion of thin crust is a remnant of the original Hyblean margin, still attached to the oceanic crust (Fig. 2). The overlying layers with lower velocity represent deformed accretionary wedge sediments, bounded to the east by the front of Calabrian basement stack. The basal unit of the accreted sediments (Fig. 2, green layer) is considered composed by heavily deformed sediments that can account for the slightly high velocity of 4.9-5.1 km/s (e.g., Brocher, 2008), although an intercalation of basement and sedimentary units is equally possible. Accordingly, the north-eastern part of the profile is interpreted as composed by an incipiently subducted Ionian crust overlain by the Calabrian accretionary wedge, which at its base comprises a stack of basement nappes. The basement stack acted as a backstop within the accretionary wedge and its western extent can be tentatively traced offshore southern Calabria using the basement tip on refraction profiles and the connection with the Peloritani basement outcrops (Fig. 1). The NNW trend of the basement western tip suggests a possible role in controlling the development of the Alfeo fault system. On the other hand, the thinned continental crust of the Hyblean margin appears flexed under the load of the accretionary wedge, and is possibly close to the verge of rupture, but not necessarily detached from the adjacent oceanic crust.

The preferred gravity model of DEL along profile DY-P3 (their Fig. 8) produces a crustal structure that is quite different with respect to that obtained from refraction, particularly on the Calabrian side (Fig. 2; compare DEL's Figs. 8 and 9), though these differences are not commented in DEL. A key point in the gravity interpretation is the abrupt western boundary of the oceanic crust against a lithospheric tear fault. It should be noted, however, that at the crossing with DY-P4 the top of the Ionian oceanic crust is not deeper that 25 km, and this contrasts with the gravity-modelled crustal profile.

Within this alternative interpretation the location (or even the existence) of the STEP fault(s) in the Ionian Sea is questioned. Efficient wave propagation along the slab waveguide occurs from intermediate-deep Calabrian slab earthquakes to the stations in Eastern Sicily, up to north of Mt. Etna (Mele, 1998; Monna & Dahm, 2009), suggesting that any decoupling of the Ionian lithosphere from the Sicilian continental margin is limited. Lithospheric tears may be mostly limited to the Tyrrhenian region where their occurrence is imaged by tomographic studies (e.g., Montuori et al., 2007) and where the gaps in the distribution of deep seismicity in the Calabrian slab can be explained without calling for the propagation of lithospheric tears southward, into the Ionian Sea (Argnani et al., 2016).

In the interpretation here proposed profile DY-P3 shows a continental margin down-flexed under the load of the accretionary wedge (Fig. 2). The extensional faults along the northern part of the Malta Escarpment (Argnani & Bonazzi, 2005) can be related to this down-flexing at the continental margin. The dextral strike-slip faults of the Alfeo system, on the other hand, could be wrench faults related to the accretionary dynamics, only affecting the accretionary wedge above the Ionian crust (Fig. 1), as illustrated by the sandbox modelling of Gutscher et al. (2019; their model experiment #2). Maesano et al (2020) show that the faults bounding the sedimentary basins aligned along the Alfeo fault system are decoupled by the deeper faults affecting the Ionian basement. These authors note that the arrangement of these deep faults is consistent with extension, and therefore the surface expression of strike-slip motion (Gutscher et al., 2017) likely reflect deformation within the accretionary wedge. Although these authors see a close link between deep faulting and shallow basins, this connection is not so straightforward, particularly as regards timing, and different interpretations are possible, considering the basement faults as inherited features. In any case, the estimated maximum throw of the Ionian basement on the single fault is about 2000 m; if these features are the expression of a lithospheric tear, this tear is likely to be only incipent.

To conclude, the refraction profiles presented by DEL are open to an alternative interpretation, and it may be that there is no well-developed lithospheric tear fault immediately south of Mt. Etna.

Acknowledgements

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References

Argnani, A. (2014). Comment on the article "Propagation of a lithospheric tear fault (STEP) through the western boundary of the Calabrian accretionary wedge offshore eastern Sicily (Southern Italy)" by Gallais et al., 2013 Tectonophysics. Tectonoph. 610, 195–199.

Argnani, A. & Bonazzi, C. (2005). Malta escarpment fault zone offshore eastern Sicily: plio-quaternary tectonic evolution based on new multi-channel seismic data. Tectonics. 24, TC4009. https://doi.org/10.1029/2004TC001656.

Argnani, A., Brancolini, G., Bonazzi, C., Rovere, M., Accaino, F., Zgur, F., & Lodolo, E. (2009). The results of the Taormina 2006 seismic survey: possible implications for active tectonics in the Messina Straits. Tectonoph. 476, 159–169.

Argnani, A., Armigliato, A., Pagnoni, G., Zaniboni, F., Tinti, S., & Bonazzi, C. (2012). Active tectonics along the submarine slope of south-eastern Sicily and the source of the 11 January 1693 earthquake and tsunami. Nat. Hazards Earth Syst. Sci. 12, 1311–1319.

Argnani, A., Mazzarini, F., Bonazzi, C., Bisson, M. & Isola, I. (2013). The deformation offshore of Mount Etna as imaged by multichannel seismic reflection profiles. J. Volcanol. Geotherm. Res. 251, 50–64

Argnani A., Cimini G.B., Frugoni F. Monna S. Montuori C. (2016). The role of continental margins in the final stages of arc formation: Constraints from teleseismic tomography of the Gibraltar and Calabrian Arc (Western Mediterranean). Tectonoph. 677–678, 135–152.

Bonardi, G., Cavazza W., Perrone V. & Rossi S. (2001). Calabria- Peloritani Terrane and Northern Ionian Sea. In G.B. Vai & P. Martini (Eds.), Anatomy of an orogen: the Apennines and adjacent Mediterranean Basins (pp. 287-306). Kluwer Academic Publishers, Dordrecht.

Brocher, T. (2008). Compressional and Shear-Wave Velocity versus Depth Relations for Common Rock Types in Northern California. Bull. Seis. Soc. Am., 98, 950–968.

Dellong, D., Klingelhoefer, F., Kopp, H., Graindorge, D., Margheriti, L., Moretti, M., et al. (2018). Crustal structure of the Ionian basin and eastern Sicily margin: Results froma wide-angle seismic survey. J. Geoph. Res.: Solid Earth, 123, 2090–2114.

Dellong, D., Klingelhoefer, F., Dannowski, A., Kopp, H., Murphy, S., Graindorge, D., et al. (2020). Geometry of the Deep Calabrian Subduction (Central Mediterranean Sea) From Wide-Angle Seismic Data and 3-D Gravity Modeling. Geochem., Geoph., Geosys., 21. https://doi. org/10.1029/2019GC008586.

Frepoli A., Selvaggi G., Chiarabba C., & Amato A. (1996). State of stress in the Southern Tyrrhenian subduction zone from Fault-plane solutions. Geoph. J. Int., 125, 879-891.

Graessner T., Schenk V., Broeker M. & Mezger K. (2000). Geochronological constraints on the timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Hercynian crustal cross-section of Calabria. J. Metam. Geol., 18, 409-421.

Gutscher, M.-A., Dominguez, S., Mercier de Lepinay, B., Pinheiro, L., Gallais, F., Babonneau, N., et al. (2016). Tectonic expression of an active slab tear from high-resolution seismic and bathymetric data offshore Sicily (Ionian Sea). Tectonics 35, 1. http://dx.doi. org/10.1002/2015TC003898.

Gutscher, M.-A., Kopp, H., Krastel, S., Bohrmann, G., Garlan, T., Zaragosi, S., et al. (2017). Active tectonics of the Calabrian subduction revealed by new multi-beam bathymetric data and high-resolution seismic profiles in the Ionian Sea (Central Mediterranean). Earth Plan. Sci. Lett., 461, 61–72.

Gutscher M.-A., Dellong D.,, Dominguez S., Malavieille J., Graindorge D., & Klingelhoefer F. (2019). Strike-Slip Faulting in the Calabrian Accretionary Wedge: Using Analog Modeling to Test the Kinematic Boundary Conditions of Geodynamic Models. In J.C. Duarte (Ed.), Transform Plate Boundaries and Fracture Zones (pp. 321-337). Elsevier.

Maesano, F.E., Tiberti, M.M. and Basili, R., 2020. Deformation and Fault Propagation at the Lateral Termination of a Subduction Zone: The Alfeo Fault System in the Calabrian Arc, Southern Italy. Front. Earth Sci. 8:107. doi: 10.3389/feart.2020.00107

Mele, G. (1998). High-frequency wave propagation from mantle earthquakes in the Tyrrhenian Sea: new constraints for the geometry of the South Tyrrhenian subduction zone. Geophys. Res. Lett. 25, 2877–2880.

Monna, S. & Dahm, T. (2009). Three-dimensional P wave attenuation and velocity upper mantle tomography of the southern Apennines–Calabrian Arc subduction zone. J. Geophys. Res. 114, B06304. http://dx.doi. org/10.1029/2008JB005677.

Montuori, C., Cimini, G.B., Favali, P. (2007). Teleseismic tomography of the southern Tyrrhenian subduction zone: new results from seafloor and land recordings. J. Geophys. Res. 112, B03311. http://dx.doi.org/10.1029/2005JB004114.

Musumeci, C., Patanè, D., Scarfì, L., & Gresta, S. (2005). Stress directions and shear-wave anisotropy: observations from local earthquakes in southeastern Sicily, Italy. Bull. Seismol. Soc. Am. 95 (4), 1359–1374.

Polonia, A., Torelli, L., Gasperini, L., Cocchi, L., Muccini, F., Bonatti, E., et al. (2017). Lower plate serpentinite diapirism in the Calabrian Arc subduction complex. Nature Comms. | 8: 2172 | DOI: 10.1038/s41467-017-02273-x

Wood, R. & Barton, P. (1983). Crustal thinning and subsidence in the North Sea. Nature, 302, 134-136.

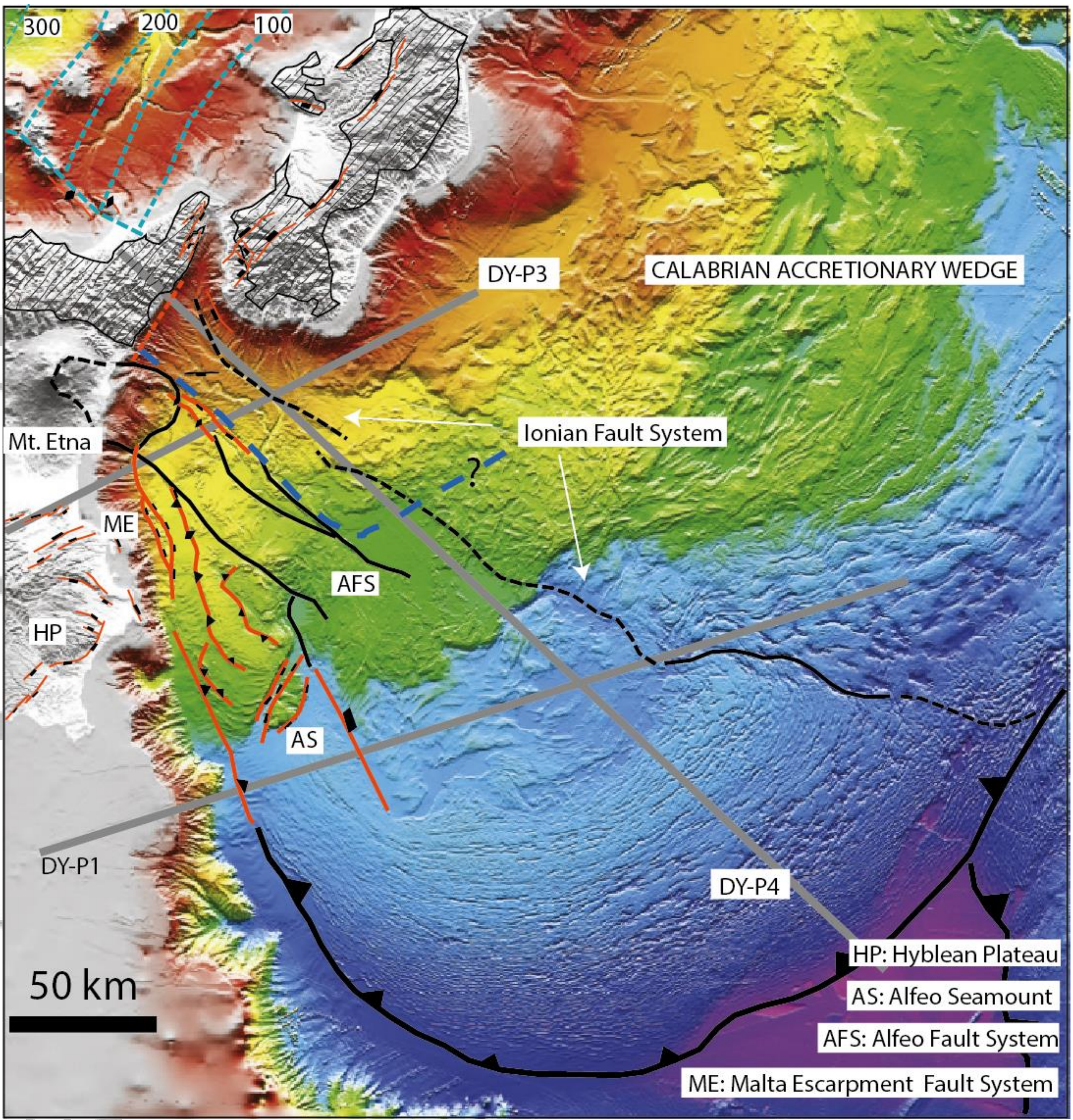

Figure 1. Simplified tectonic map of the western Ionian region, showing the main structural features (in red from Argnani, 2014, in black from Gutscher et al., 2017). The red dashed line in the Messina Strait indicates a flexure of the margin. Thick gray lines are refraction profiles in DEL. The dashed light blue lines in the Tyrrhenian region are the depth contours in km of the top of the subducted slab (from Frepoli et al., 1996). The outcrops of basement units in Peloritani and Calabria are indicated with oblique, subparallel, semi-continuous lines (after Graessner et al., 2000 and Bonardi et al., 2001) and the possible western offshore extent of the Calabrian basement is indicated with the thick dashed blue line. The structures are superimposed on the morpho-bathymetry of Gutscher et al. (2017).

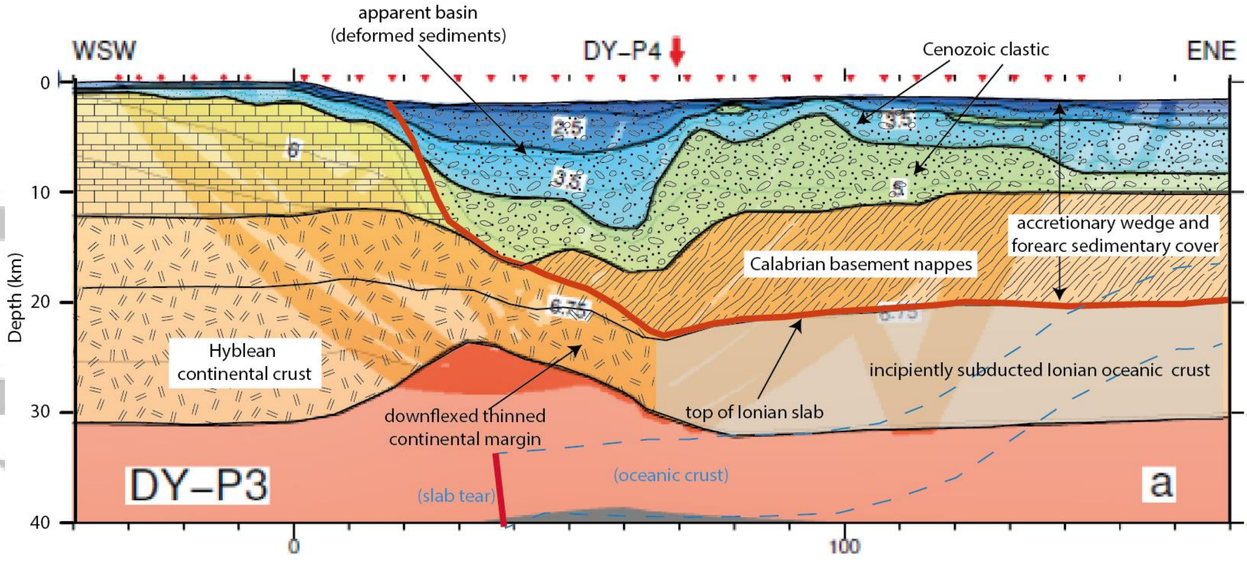

Figure 2. Refraction profile DY-P3 (after DEL) with superimposed the alternative interpretation discussed in the text, and related annotations. The position of the ocean-continent boundary is highly hypothetical and can vary from 35 to 65 km profile distance. The green layer is possibly composed by old and heavily deformed sediments. The position of the oceanic crust inferred by DEL from gravity modelling is also indicated with a blue dashed line, with the related tear fault (in red) at its western tip (annotated blue text within brackets).