Answers to reviewer RC1 Christophe Larroque

We thank reviewer Christophe Larroque for the very helpful review and comments that in our opinion improve the manuscript.

We place the comments of RC1 in black and our answers and changes to the manuscript in green letters.

Comments on the paper « Basin inversion: Reactivated rift structures in the Ligurian Sea revealed by OBS » by M. Thorwart et al., submitted to Solid Earth.

General comments

The paper by Thowart et al. presents the seismotectonic interpretation of the data acquired in the Ligurian basin during 8 months in 2017-2018 by the 24 OBS of the Alparray experiment. This is the first data set of such importance acquired in this basin, with atypical oceanic crust or very thinned continental crust, located between the front of the southern subalpine chains and the Corso-Sardinia continental block. This area is known since a long time as an active intraplate setting with a very low deformation rate.

The experiment allows to detect 39 microearthquakes. This work focus on two clusters in the center of the basin, the first one with 13 events and the second with 3 events but only 4 focal mechanisms could be determined among the 13 events of the cluster 1. These 4 focal mechanisms, consistent with each other, are interpreted by the authors as evidence of the Ligurian basin inversion.

There is little new data but in this marine and low seismicity context any new data is welcome to be discussed and should be considered positively. The active inversion of the Ligurian basin has already been evidenced based on other structural and seismic datasets (Larroque et al., 2011; Sage et al., 2011; Larroque et al., 2016) and from this perspective this work confirms what is proposed. However, it seems to me that there are several important problems of substance and form in this article which require a serious reworking of the presentation of the data and their interpretation in the context of the work already carried out in this area. I recommend major revision.

I make few remarks and suggestions in the following.

- On the substance, the major problem concerns the exploitation of the seismic signal from very low magnitude earthquakes (1.5 to 2.5) recorded at stations located more than 150 km away (Fig1) to build the focal mechanisms. This essential part of the work must be strengthened to be credible. Firstly, as these are new mechanisms it is necessary to provide for each of them a clear diagram with the polarities and nodal planes (currently, only the diagram of the strongest earthquake is shown : c, fig4). Secondly, taking into account the large distances with some of the stations and the smallness of the magnitudes, the seismograms must be shown in order to attest the quality of the polarities read on this signal.

We updated figure 3c and provide a diagram for each event for which the focal mechanisms could be calculated. We included an Appendices as a new section in the manuscript and show there additional information on the 4 events with focal mechanism solution. This includes the seismograms, first motion plots and amplitude ratios of Sv/P.

- The context of the deformation in the Ligurian basin must be presented in its entirety. Particularly, the high rate of seismicity on the northern margin in relation to the center of the basin and its southern margin must be emphasized as it is an essential point in the discussion of the inversion process. From this point of view, mention of the work of Béthoux et al (2008) is essential. Also from a structural point of view, it should be mentioned that active north dipping reverse faults have been identified on the northern margin (Larroque et al., 2011; Sage et al., 2011). These faults allow the accommodation of most of the basin inversion since 5 Ma, as evidenced by the cumulative deformation which shows a margin uplift of more than 1000 m with respect to the basin. These 2 points are important because they show that the basin inversion started at least 5 Ma ago in the northern part while the absence of cumulated deformation and low seismicity in the central and southern part (this paper and Larroque et al., 2016) attest to a weaker and/or much more recent deformation.

We included the works about the basin inversion of Larroque et al. (2011) and Sage et al. (2011) in the introduction section and explained better previous knowledge on the past and recent deformation of the Ligurian basin in section 2. And we modified section 4.1 according to the suggestions: "*The main portion of the basin inversion in the Ligurian Basin is accommodated at the northern margin where a high rate of seismicity is observed compared to the basin centre and the Corsican margin (Béthoux et al., 2008). Active northward dipping reverse faults have been mapped that are evidence for a 5 Ma cumulative deformation with a margin uplift of more than 1 km (Larroque et al., 2011, Sage et al., 2011). The centre of the Ligurian Basin and the Corsican margin are characterised by low seismicity and diffuse distribution of rupture areas of small size spread over a wide area, which indicates the absence of cumulated deformation and points to a weaker or more recent deformation (Larroque et al., 2016).*".

- The input of new data is really low for such a paper in a major scientific journal. May be the authors could try to get more informations from the continuous seismic recordings of the OBS by using template matching method ? Even if the signals are not usable to determine focal mechanics, it would be interesting to know if a larger number of low magnitude events can be detected.

We used the template matching method using a cluster event as template and observed 2 events near station A423A and displayed their occurrence in figure 3a with black bars (2 events in September). In this work we focus on the two cluster, thus we did not look for more low magnitude events near other stations. But this is indeed a good suggestion to go back to the entire dataset. We added the method in section 3.1 by changing the sentence: "*Two low magnitude events were only observed at station A423A* ***using the template matching method (e.g. Shearer, 1994)*** *and were not further analysed (Fig. 3a, black bars).*"

- You need to take better account of existing work when it relates to your interpretations. For instance, the proposal by Dannowski et al (2020) on the nature of the crust in the Ligurian Basin is very interesting but at the moment it is not a consensual result. So highlight other interprétations such as Contrucci et al. (2001), Rollet et al. (2002), Gailler et al. (2009).

We included the works of Contrucci et al. (2001) and Rollet et al. (2002) in the discussion section 4.1: "*Additionally, no spreading axis was mapped in* ***previous*** *seismic studies* ***that interpreted the nature of the basin centre as atypical oceanic crust (Contrucci et al., 2001; Rollet et al., 2002). Analysis of*** *the LOBSTER seismic refraction profile p02 (Dannowski et al., 2020) proposes that rifting failed before seafloor spreading was initiated.*". We did not include the work of Gailler et al. (2009) in this discussion since it is far away from the cluster.

- The use of the results of the Pérez-Guissinyé and Reston model does not seem to me very adapted to the case of the Ligurian rifting. This model has been proposed by its authors to describe a possible evolution of Atlantic-type rifted margins in the case of cratonic and old orogen models. It is therefore difficult to consider that this model is generalizable to all types of non-volcanic rifting. The Ligurian basin is a back-arc basin, the crust was strongly affected by the alpine orogeny. The initial rheological conditions are therefore strongly different from what is considered in the Pérez-Guissinyé and Reston model. This comparison should therefore be discussed and justified.

We stay with the comparison as a possible explanation for the observed events in the uppermost mantle. The differences between both margins in initial conditions and evolution do not exclude similar changes in rheology due to rifting. We emphasize that there are differences between both types of rifted margins by extending the discussion: "*The initial conditions and the evolution of the Atlantic-type rifting of old orogens differs from the Ligurian Sea as back-arc basin where rifting took place during the alpine orogeny. Both margins show similarities and differences: common features are highly attenuated continental crust in the ocean-continent transition to a wide and thick basin starting rifting in subaerial conditions; the major difference is that in the Gulf of Lion the continent-ocean transition is probably made of exhumed lower continental crust, while the in the Atlantic the upper crust rests directly on top of mantle (Jolivet et al., 2015).*".

Specific comments

- Revise the title because most of the inversion is active on the northern margin that is not discussed. For the moment, only a recent and low compression is carried out in the center of the basin.

We change the title to point out that the study is about the basin cenre: Basin inversion: "*Reactivated rift structures in the **central** Ligurian Sea revealed by OBS*".

line 27 : usually, moderate activity is less than magnitude 6 and strong activity start with Mw 6.5 thus the 1887 Ligurian eq (Mw > 6.5 Larroque et al., 2012, Manchuel et al., 2017) attests that the sismicity on the Ligurian margin is mainly moderate but with possible strong earthquakes (this is of concern for hazard assement).

We included the possibility for strong earthqueakes and added the reference: "*… indicating a moderate seismic activity **with occasionally strong earthquakes** (Béthoux, 1992; Courboulex et al., 2007; Béthoux et al., 2008; Larroque et al., 2012, 2016; **Manchuel et al., 2017**).*".

Line 51 : the geodynamic setting WAS controlled by the Africa/Euraisa convergence, now it is not so clear (see Nocquet and Calais, 2004, Serpelloni et al., 2007, ….).

Changed and references added

Line 54 : « Lamotte » is Frizon de Lamotte.

Changed

Line 70 : specify the rotation pole near Genoa and give the range of the counter-clockwise rotation from 23° (Speranza) to 45° (Gattacceca et al., 2007).

References added and changed to: "*The Corsica-Sardinia block underwent a counter-clockwise (CCW) rotation (Alvarez et al., 1973; Rehault et al., 1984; Speranza et al., 2002; Maffione et al., 2008) of ~23° (Speranza et al., 2002) to 45° (Gattacceca et al., 2007) or 53° (Le Breton et al., 2017) with an Euler rotational pole near Genoa, onshore or in the Gulf of Genoa (Fig. 2).*".

Line 159 : can you explain « faulty recording » ?

We changed "*faulty recording*" to "*a low velocity contrast between subsurface and water and might hint to a low shear modulus of the subsurface. Together with the high instrument weight, these effects could not be taken into account to determine amplitude ratios of P- and S-waves for the OBS*".

We did not take into account that even shear waves with a small amplitude would result in a large amplitude recorded at the OBS because the S-wave arrives at a free surface at the seafloor (doubling the amplitude), while the P-wave takes the seafloor as an interface with probably a low velocity contrast (little change in amplitude). Additionally the shear modulus of the subsurface might be small and the mass of the OBS is large, resulting in a high S-wave amplitude. These effects should be taken into account for amplitude ratios.

Line 34 and 190-196 : I disagree with this presentation of the spatial geodetic data. Nocquet and Calais (2004) showed that the convergence of Africa relative to stable Europe is 40% less than the prediction of the Nuvel-1 model (De Metz et al., 1994). Serpelloni et al. (2007) and Nocquet (2012) argue that 90% of the convergence is accomodated along the Maghrebides chain and Algeria margin but ~10% of the motion could be accommodated northward with a possible NW motion of the Corsica–Sardinia bloc of 0.5 mm/yr maximum. Masson et al. (2019) confirmed a NW motion of Corsica in the range of 0.4 mm/yr.

We added the new GPS work and adjusted the text as suggested in section 4.1: "~~*The Ligurian Basin and the Corsica-Sardinia block are seen as rigidly attached to stable Europe (Nocquet, 2012).*~~*An analysis of two decades of dense GPS data presents a ~0.4 mm/y motion of Corsica representing a NNW-SSE shortening that is compatible with the tectonic and seismicity observations at the Ligurian margin (Masson et al., 2019). It was proposed that this shortening is a result from the CCW rotation of the Adriatic microplate rather than from motion of an independent rigid Corsica-Sardinia block (Nocquet and Calais, 2004).*".

Line 194 : In my opinion reference to these long-term plate models (van Hinsbergen, Le Breton) are not relevant to discuss current movements because they have no resolution for the present-day.

Removed

Line 201 : the dip of the ~vertical plane (d, Fig5) is NW not SE ? In any case, in order to discuss the dip, one must have information on the uncertainties of epicenter location and depth because the difference are very tenuous.

We added the horizontal uncertainties to the table. Changed to NW.

Line 215-219 : you should mention the more recent and more precise work carried out on the rotation of the Corsica-Sardinia block by Gattacceca et al (2007). The rotation reconstructed from the paleomagnetic analyses of lavas is 45° counter-clockwise which leads to a much greater extension in the basin than from the 23° proposed by Speranza et al. (2002). At least both values should be mentioned.

Changed to the total amount of rotation that varies depending on the different studies. We use now 23° to 53° and cite works of Speranza et al. (2002), Gattacceca et al. (2007) and Le Breton et al. (2017).

Line 248-253 : the discussion about heat flow and the role of the sedimentary cover should take into account the results of Béthoux et al. (2008).

Reference to Béthoux et al. (2008) added.

Figure 2 : this figure is to be improved by showing the Ligurian thrust to the north, the normal faults of the Tyrrhenian Sea and the thrust to the north of Algeria….

We added the NTBZ taken from Hinsbergen et al. (2014). We added the reference to the list. We removed "*Balearic Sea*". We do not add the suggested zones of inversion. We cited a number of studies that show and describe the zones of inversion in the western Mediterranean. The zones of inversion are wide and of different ages and we want to keep the map as simple and understandable as possible showing the main geological features and location of the basins we describe and discuss. Showing all the faults would need a zoom into the two basins.

Caption figure 5 : (d) « crystalline basement » = top of crystalline crust ; number on (e) = Vp ?

Changed to "*top of crystalline basement*"; the numbers are P-wave velocities as given above in the colour bar.

Technical corrections

Check the references, e.g. Maggi et al. ???

Changed

Gattacceca, J., Deino, A., Rizzo, R, Jones, D.S., Henry, B., Beaudoin, B., Valeboin, F., 2007. Miocene rotation of Sardinia : new paleomagnetic and geochronological constraints and geodynamic implications. Earth Planet. Sci. Lett., 258, 359–377.

Included in the reference list

Larroque, C., Mercier de Lépinay, B., Migeon, S., 2011. Morphotectonic and fault–earthquake relationships along the northern Ligurian margin (western Mediterranean) based on high resolution multibeam bathymetry and multichannel seismicreflection profiles. Mar. Geophys. Res. 32 (1–2), 163–179, http://dx.doi.org/10.1007/s11001-010-9108-7.

Included in the reference list

Manchuel, K., Traversa, P., Baumont, D., Cara, M., Nayman, E. and Durouchoux, C., 2017. The French seismic CATalogue (FCAT-17). Bull. Earthquake Eng., 8, 16. 2227–2251, doi: 10.1007/s10518-017-0236-1.

Included in the reference list

Masson, C., Mazzotti, S., Vernant, P., 2019. Precision of continuous GPS velocities 20 from statistical analysis of synthetic time series. Solid Earth, 10, 329–342, https://doi.org/10.5194/se-10-329-2019.

We included instead: Masson, C., Mazzotti, S., Vernant, P., and Doerflinger, E.: Extracting small deformation beyond individual station precision from dense Global Navigation Satellite System (GNSS) networks in France and western Europe, Solid Earth, 10, 1905–1920, https://doi.org/10.5194/se-10-1905-2019, 2019.

Sage, F., Beslier, M.O., Thinon, I., Larroque, C., Dessa, J.X., Migeon, S., Angelier, J., Guennoc, P., Schreiber, D., Michaud, F., Stéphan, J.F., Sonnette, L., 2011. Structure and evolution of a passive margin in a compressive environment : example of the southwestern Alps-Ligurian basin junction during the Cenozoic. Mar. Pet. Geol., 28, 1263–1282, doi:10.1016/j.marpetgeo.2011.03.012.

Included in the reference list

Serpelloni, E., Vannucci, G., Pondrelli, S., Argnani, A., Casula, G., Anzidei, M., Baldi, P., Gasperini, P., 2007. Kinematics of the Western Africa-Eurasia plate boundary from focal mechanisms and GPS data. Geophys. J. Int., 169(3), 1180-1200, http://dx.doi.org/10.1111/j.1365246X.2007.03367.x.

Included in the reference list