vEGU21-1545

3D tomographic imaging of the Cayman Trough lithosphere: challenges, ongoing work and first results

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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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Introduction and motivation

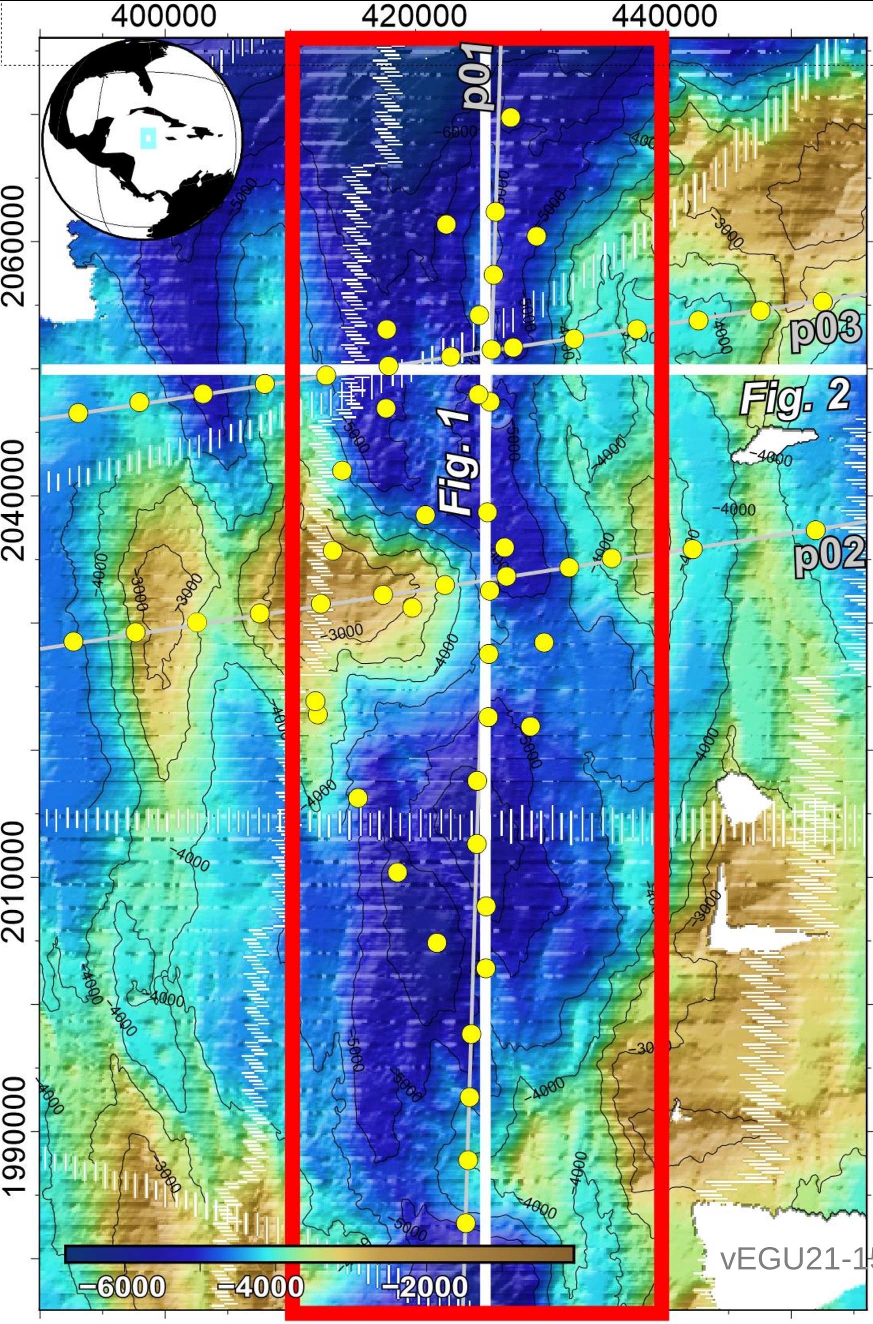
- About **25% of the Earth's mid-ocean ridges spread at ultraslow rates** of less than 20 mm/yr.

- **How the crust forms and ages at such spreading centres**, which traditional models predict to be magma-starved and cold, **remains poorly understood.**

- One of the most accessible ultra-slow spreading centres is the **Mid Cayman Spreading Centre (MCSC),** in the Caribbean Sea, with spreading rates of ~15-17 mm/yr.

- Understanding the sub-seabed geophysical structure of the MCSC is key to **understand** not only the lithologies and structures exposed at the seabed, but more fundamentally, how they are related at depth and what role hydrothermal fluid flow plays in **the geodynamics of ultraslow spreading.**

Data: The CAYSEIS seismic experiment



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•CAYSEIS project was proposed to survey the Cayman Trough area in order to obtain new data that constraints the nature of the crust, tectonic structures, lithologies outcropping and hydrothermal processes taking place in this area.

•CAYSEIS was a joint and multidisciplinary programme of German, British and US American scientists.

Figure: *Bathymetric map of the Cayman Trough (UTM zone 17N projection). The location of the WAS profiles and the OBH/S is shown (gray lines and yellow circles, respectively). The red rectangle shows the area tested in 3D (Figs. 1 and 2). CAYSEIS was a joint and multidisciplinary programme of German, British and US American scientists.*

CAYMAN project
A Marie Skłodowska Curie Individual Fellowship

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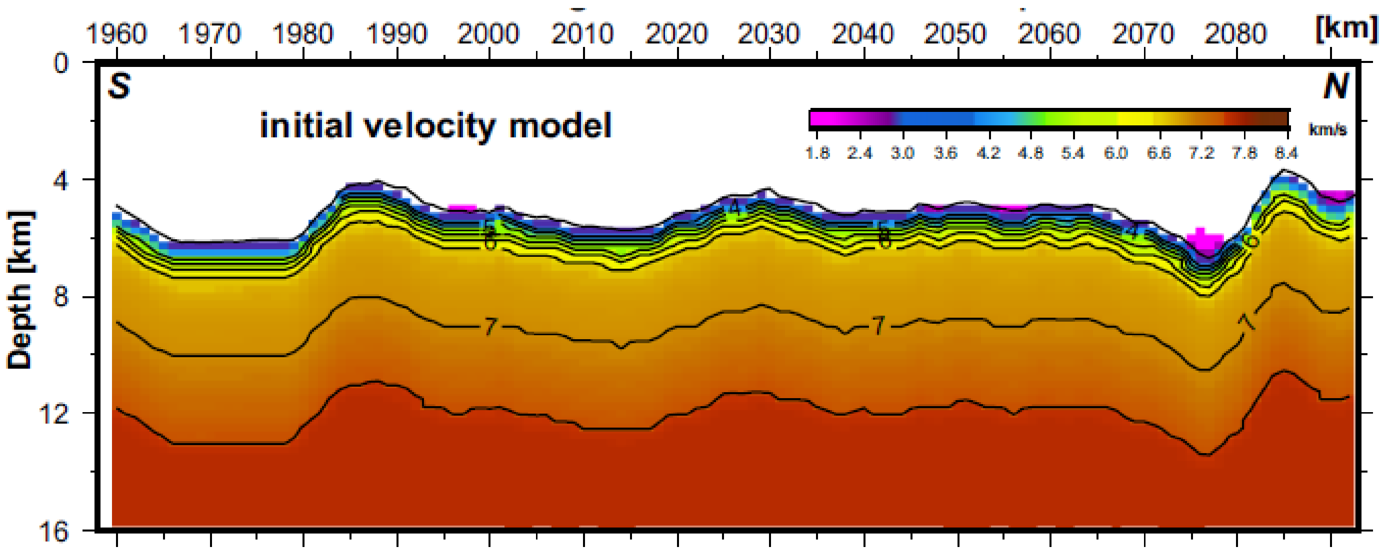
- In CAYMAN project, we are using the CAYSEIS dataset to **invert a 3D tomographic model of the Cayman Trough** lithosphere using the Tomo3D code (*Meléndez et al., 2019*).

- The results of this experiment will show the lithospheric structure along and across the MSCS, including the exhumed Ocean Core Complexes.

- The 3D lithospheric configuration of the region which is important to understand the crustal formation processes and the evolution of ultra-slow spreading settings.

Initial velocity model parameters

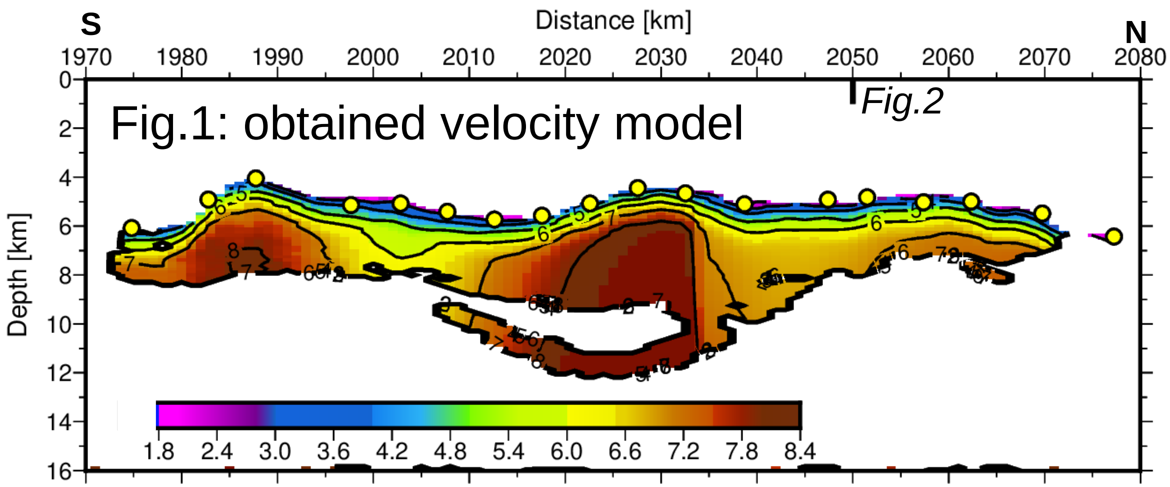


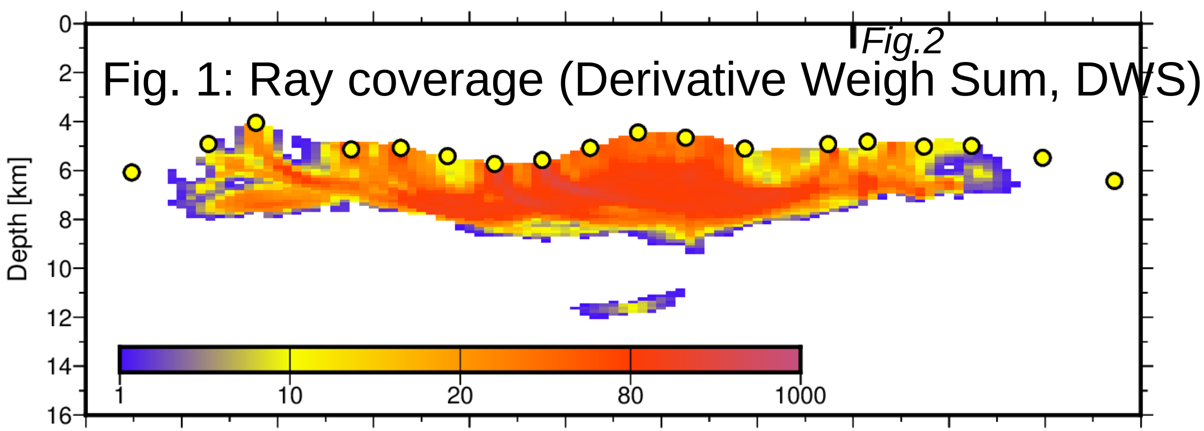
- Model spacing: 1x1 km in X and Y directions, 0.125 m in Z (depth)
- 1D velocity model for oceanic crust hanging from the seafloor (bathymetry grid)

3D inversion

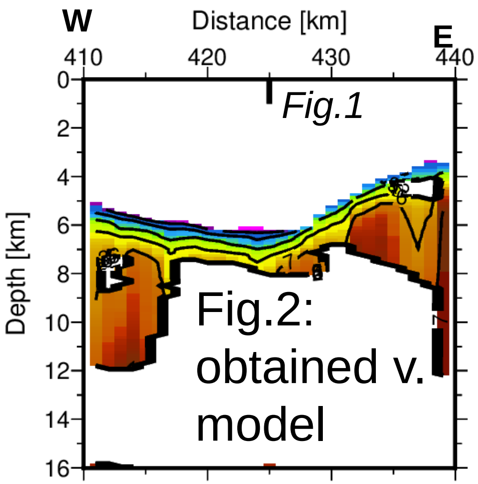
Velocity models

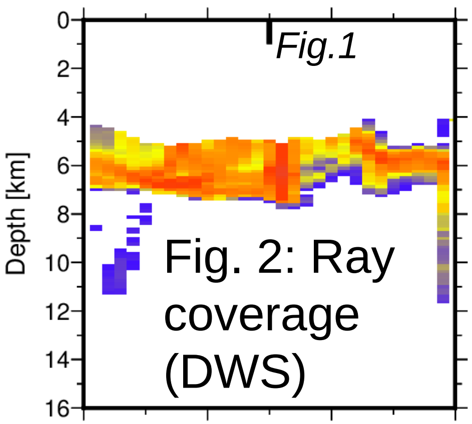
- **N-S direction**





- **W-E direction**





- **Comparison between p01 in 2D and 3D**

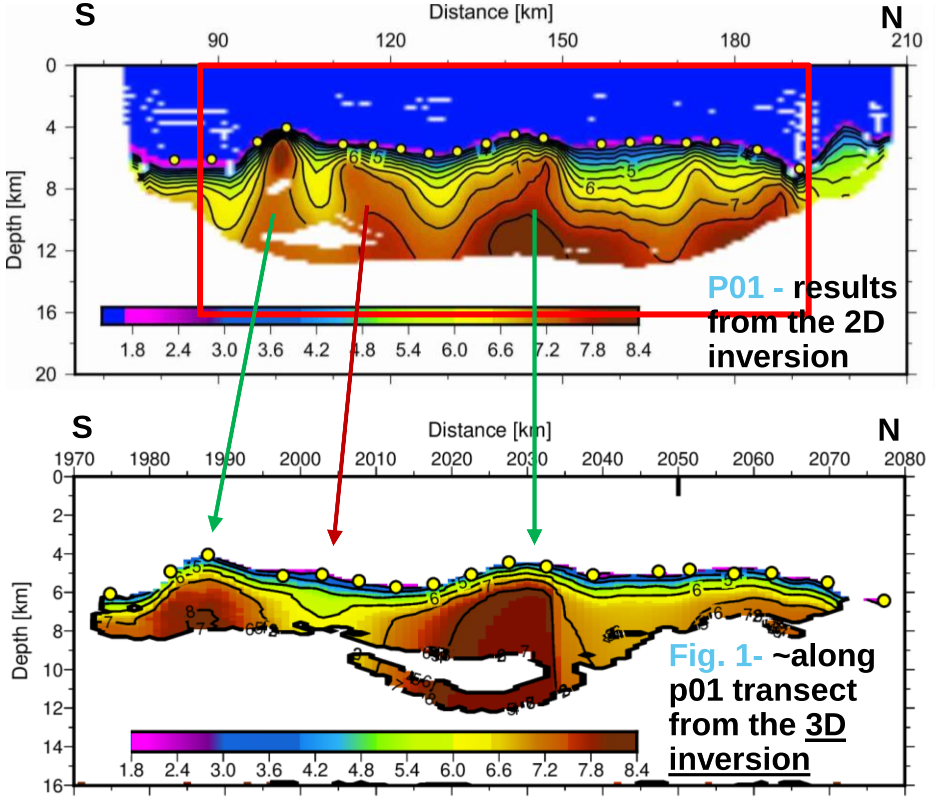


Figure: TOP) Results of the 2D velocity modelling along P01 using the tomo 3D code (Van Avendonk et al., 2017; Grevemeyer et al., 2019). BOTTOM) Results of the 3D inversion at X=425.000 (Fig. 1 in map). Green and red arrows indicates good and bad correlation of velocity anomalies between the two models.

•This is one of the first times that the Tomo3D code is used for 3D inversion of real datasets.

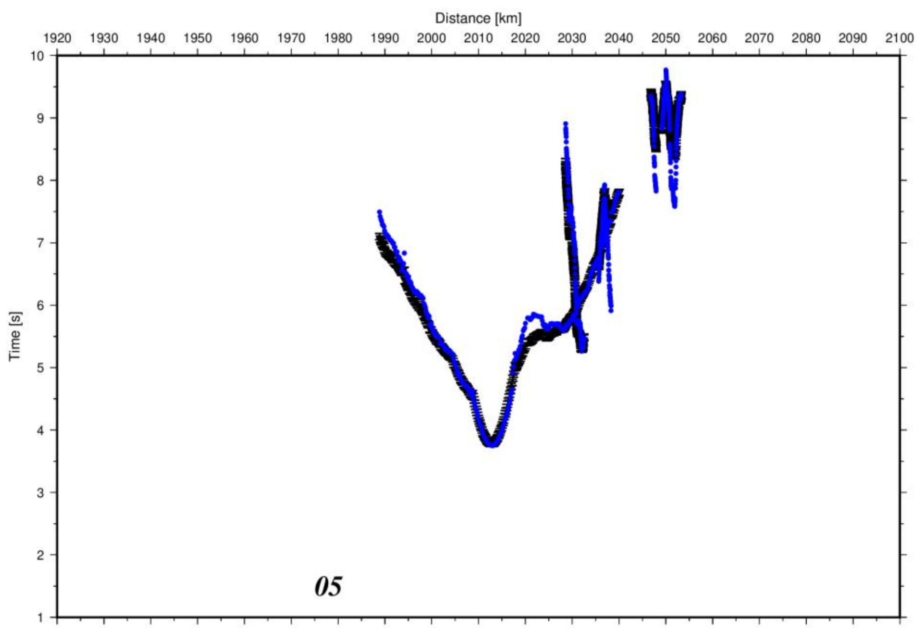
•To better understand the 3D inversion, we are comparing the results with the 2D tomographic inversion of profile p01.

•Assuming the 2D model as the real geometry, the crustal structure & velocity anomalies are only recovered partially in the 3D inversion.

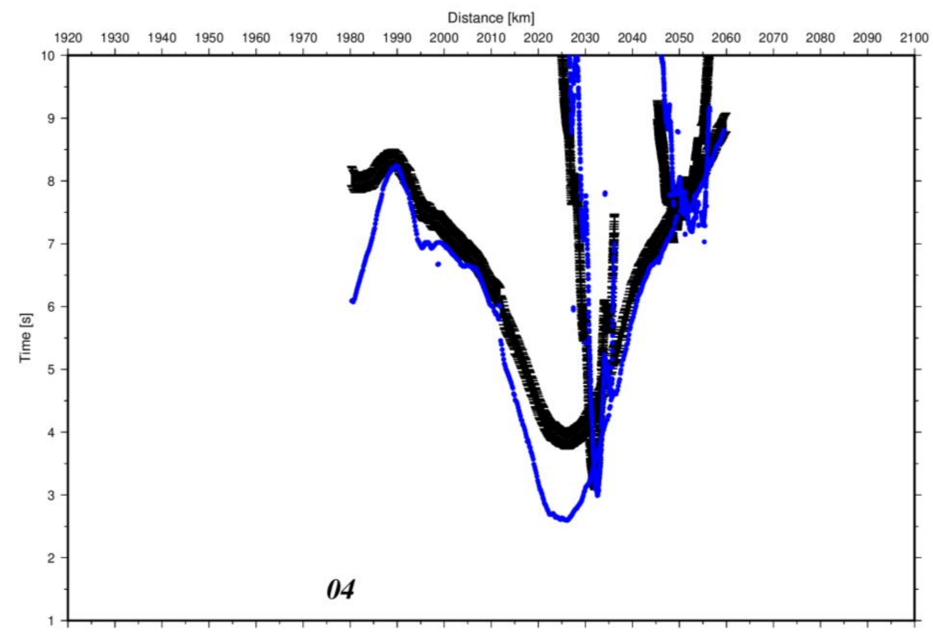
•We are testing the different parameters to obtain the more accurate and higher resolution model as possible.

3D inversion
Travel-time residuals

Calculated (in blue) **and picked** (in black) **travel times** for two stations:

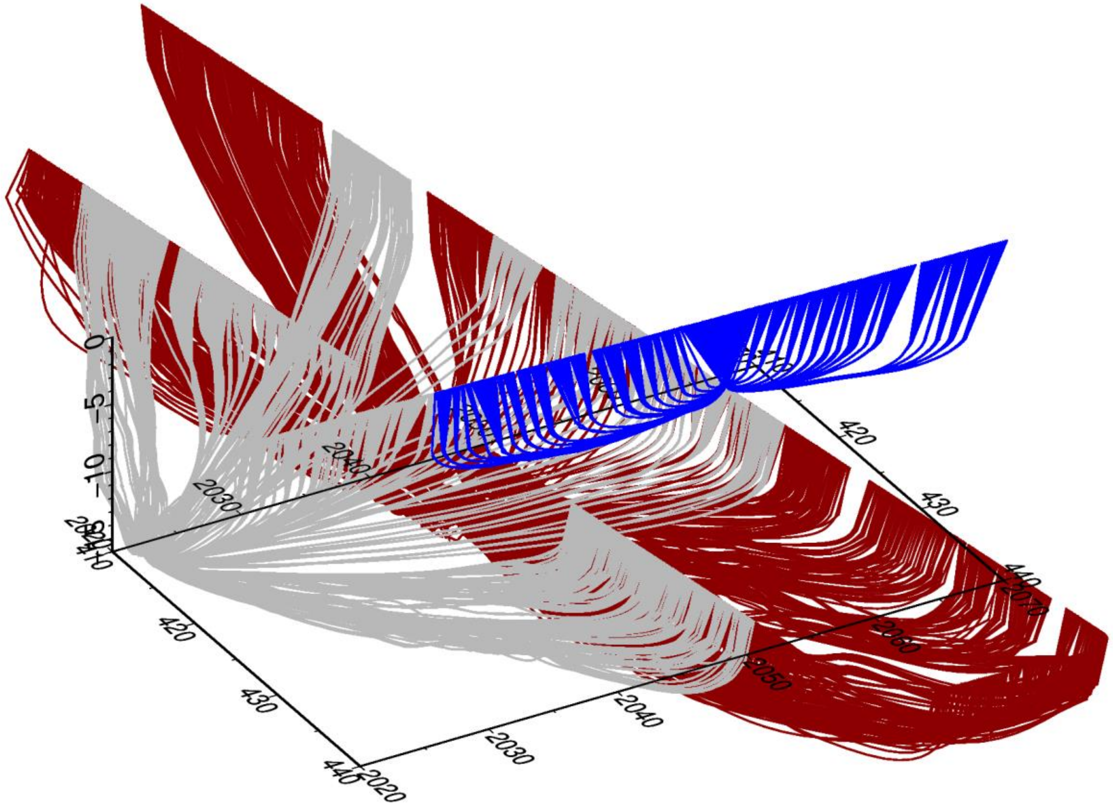


For the stations located on profile, the fit is relatively good.



However, there are still some issues with the stations located off line, probably located with a poor location of the instrument.

3D inversion
Ray paths and coverage



Example of the ray paths:

Three stations are shown:

- In blue, there are the ray paths of an station on p01. The rays only travel along the p01 direction.
- In dark red, there are the rays from an station on p03, imaging not only along p03 but also p02 and the area in between profiles.
- In grey, there are shown the ray paths of an offline OBS. These rays recorded the shots along profiles, and also travelled across the area in between.

First results and Future work

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- First results have been obtained running the 3D inversion using a subset of the data.
- These results image the crustal variation along and across the ridge axis (Figs. 1 and 2).
- Ongoing work is focused on the improvement of the resolution of the 3D model.

References: Grevemeyer, I. et al.: Maximum depth of brittle deformation at ultra-slow spreading ridges constrained by micro-seismicity. Geology, 47 (11), 1069–1073. (2019); Meléndez, A.: Anisotropic P-wave traveltime tomography implementing Thomsen's weak approximation in TOMO3D. Solid Earth. 10, 1857–1876 (2019); Van Avendonk, H.J.A. et al. Seismic structure and segmentation of the axial valley of the Mid-Cayman Spreading Center. G3 1–35 (2017).
Acknowledgements: L. Gómez de la Peña is funded by a Marie-Sklodowska Curie Individual Fellowship (H2020-MSCA-IF-2017 796013).

Thanks!

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