Tectonic Context of the August 2021 South Sandwich Islands Earthquake Sequence: Plate Boundary Geometry and Kinematics at Active STEPs

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THE 2021 SOUTH SANDWICH EARTHQUAKE SEQUENCE

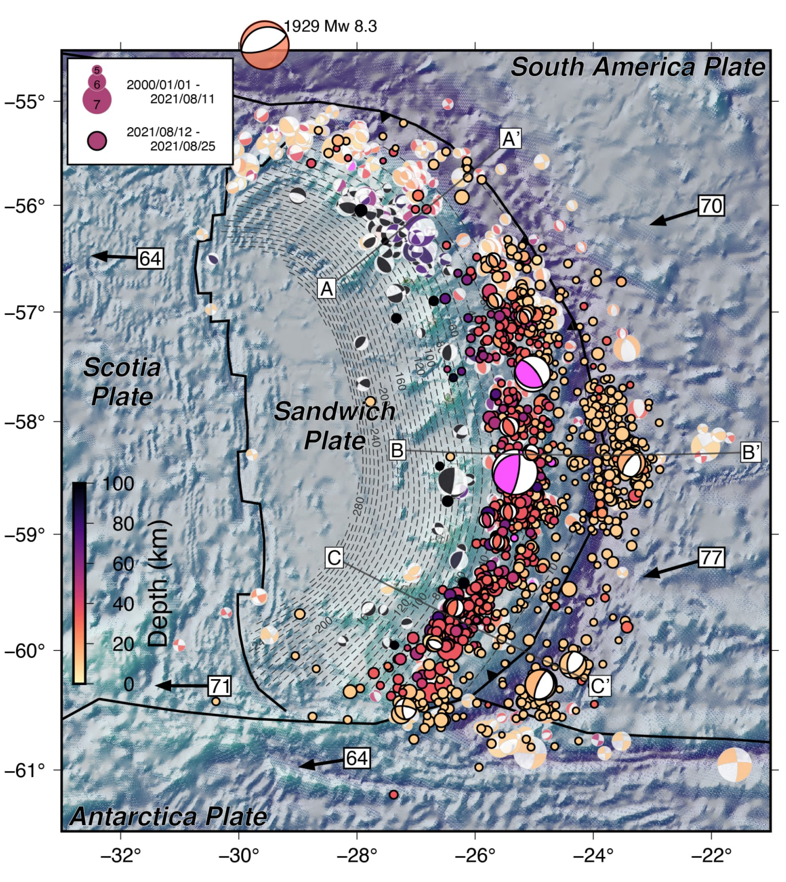

Figure 1. The Mw 7.5 and Mw 8.1 earthquakes occurred on the plate boundary between the subducting South America plate and the overriding South Sandwich (SS) plate (Jia et al., 2021; Figure 1). The complex earthquake sequence triggered aftershocks on the southern portion of the megathrust 56.5-60.5°S. The main event and most of the aftershocks occurred where the subducting South America plate is 35Myr old or younger (Seton et al., 2020). Some normal faulting events occurred in the South American plate outboard from the trench and may be associated with flexure or with co-seismic stretching of the slab (Herman and Govers, 2020).

Interestingly, the events also triggered Mw≤6.3 what appear to be right lateral earthquakes on the Antarctic-Sandwich transform plate boundary. Triggering across plate boundaries would be exceptional but not unique (Furlong et al., 2009). Notably, the SS trench terminates in the south at the triple junction with two transform plate boundaries, the Antarctic-Sandwich transform plate boundary, and the Antarctic South America transform plate boundary. No lithospheric foundering occurs at the triple junction, which is consequently not a Subduction-Transform-Edge-Propagator, or STEP (Govers and Wortel, 2005), and the Antarctic-Sandwich transform plate boundary is not a STEP Fault (Baes et al., 2011).

HISTORICAL SEISMICITY

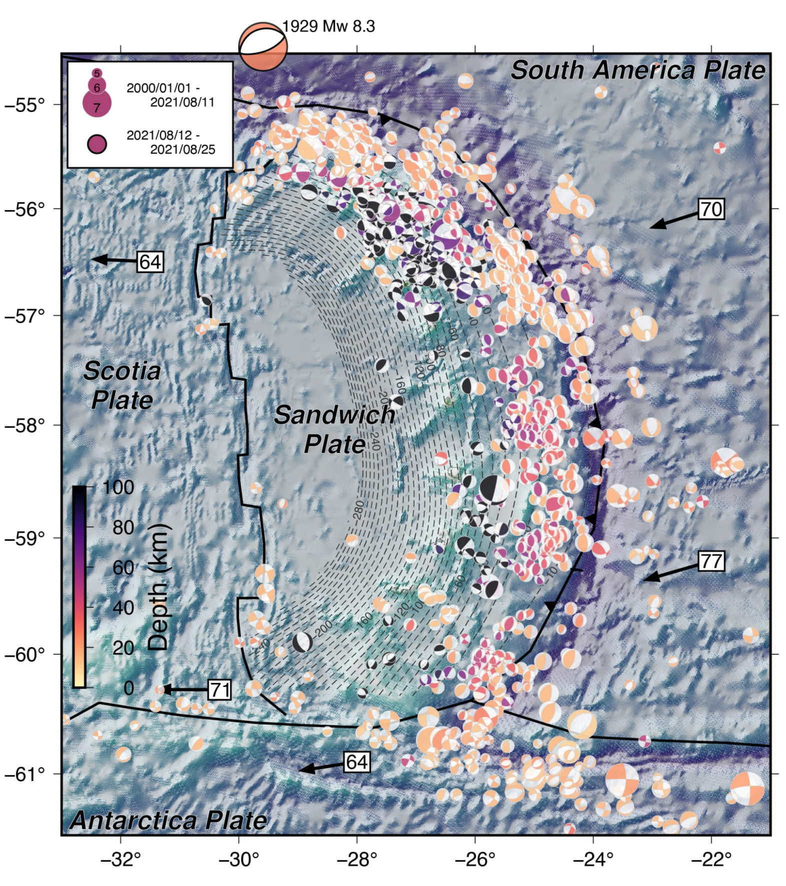

Figure 2. Pre-2021 seismicity from the gCMT catalog. The 1929 earthquake at 29.54°W 54.53°S is located well to the north of the STEP Fault plate boundary.

STEP PLATE BOUNDARY

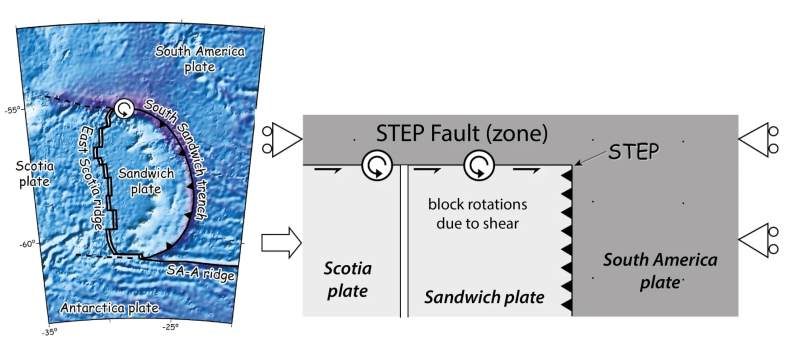

Figure 3. STEP/STEP Fault system proposed by Govers and Wortel (2005) for the northern plate boundary of the Sandwich plate. Active tearing of the lithospheric occurs at the STEP. This is not consistent with the kinematics documented by historical earthquakes.

The northern termination of the SS subduction was not seismically activated by the 2021 events. Here, a free slab edge was hypothesized by Govers and Wortel (2005) who follow the interpretation of Forsyth (1975) of hinge faulting here at the active STEP. The STEP Fault refers to the strike-slip plate boundary downstream from the STEP that become longer with time. Their interpretation is however problematic when we consider the P- and T-axes of shallow earthquakes along the South America-Scotia plate boundary west of ~26°W (Figure 4). Many of the P-axes are ~perpendicular to the plate boundary, which is more in line with an interpretation of a south dipping megathrust here. Leat et al (2004) come to the same conclusion based on magma chemistry (Figure 5).

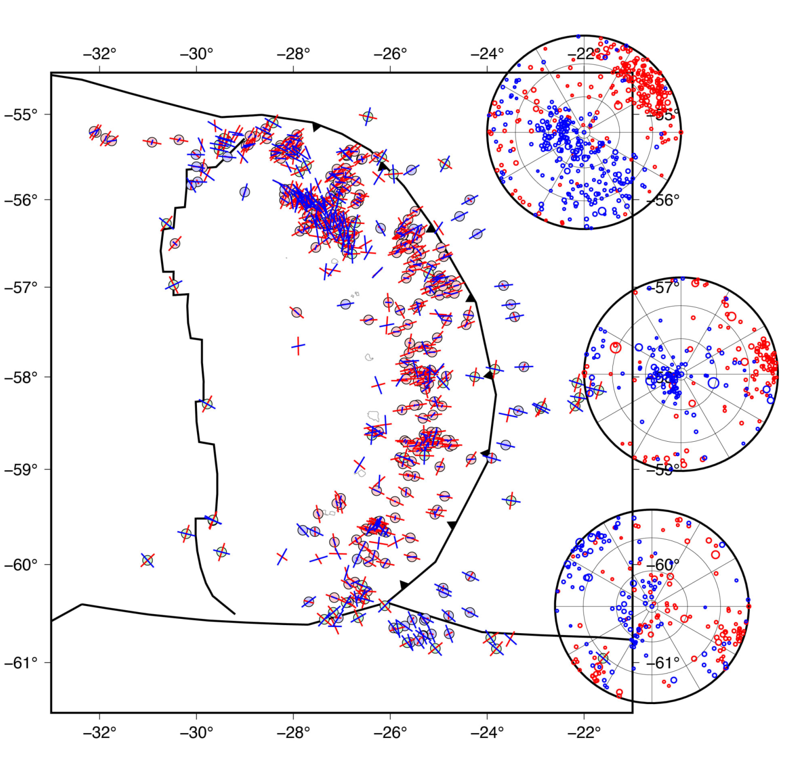

Figure 4. P (red) and T (blue) axes from the gCMT earthquake catalog. The pole diagrams show a rotation of east-west oriented P-axes in the central part of the subduction system, to northeast-southwest orientations further to the north.

LITHOSPHERIC TEARING AT A STEP

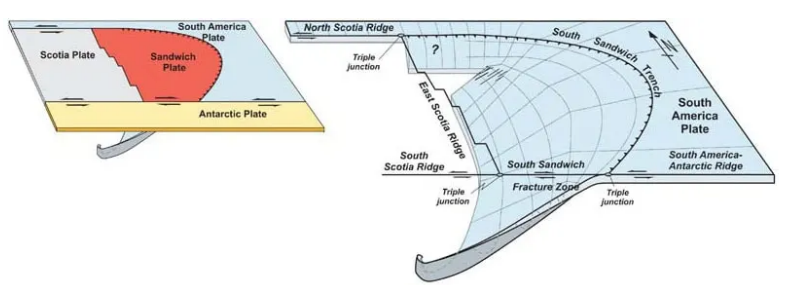

Figure 5. Regional slab structure as proposed on geochemical grounds by Leat et al (2004). The figure is from Giner-Robles et al. (2013). The focus of our study is on the development of the slablet perpendicular to the ~east-west oriented northern plate boundary of the Sandwich plate.

Another relevant observation near this part of the plate boundary is the mechanism of the 1929 earthquake, which was the largest earthquake that was ever recorded in the region. From their reevaluations of the original observations Okal and Hartnady (2009) infer that a Mw~8.3 normal faulting earthquake occurred on a steep fault plane that striked roughly east-west. They find a relocated epicenter at 29.54°W 54.53°S, i.e., well to the north of the plate boundary.

Similar observations and inferences were made at other STEP Faults, notably the Pliny-Strabo fault in the eastern Mediterranean (Bocchini et al., 2018), the Betic shear zone in west Mediterranean, and the El Pilar fault zone near Trinidad.

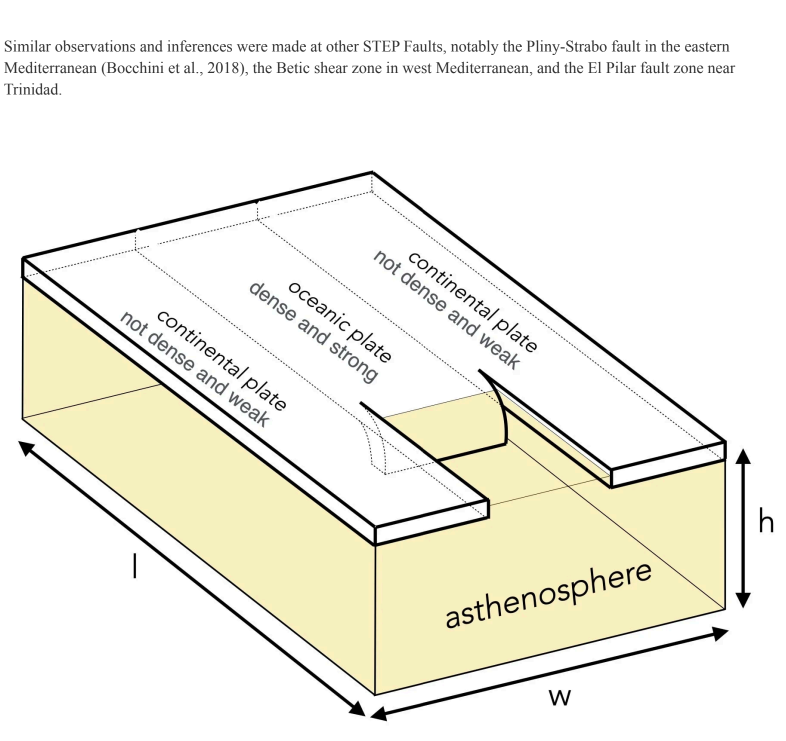

Figure 6. Setup of the analog experiment. Subduction initiation is facilitated by cutting the boundaries between the slab and the adjacent lithospheres. Further downstream the lithospheres are continuous however, and this is the part of the experiment where we can study the tearing process.

Here we present results of our new physical analog laboratory models that aim to elucidate what controls the geometry of the lithospheric STEP Fault zone. We focus on the ductile tearing in the process of STEP evolution, which is dynamically driven by the buoyancy of the subducting slab. In our experiments, the lithosphere as well as asthenosphere are viscoelastic media in a free subduction setup. A realistic stress-dependent rheology (developed by Broerse et al., 2019) plays a major role in localization of strain in tearing processes of lithosphere such as slab break-off. The model setup is shown in Figure 6.

ANALOG LAB EXPERIMENT

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1638718115/agu-fm2021/21-D6-A7-59-60-81-75-19-91-74-8D-BF-D2-D1-49-D3/Video/Step_11_side_view_x58weh.mp4

***Movie**. Side view of our analog model experiment of lateral tearing of the lithosphere in a STEP context. Tearing occurs at ~100km depth, resulting in lateral subduction of a slablet leading to a structure similar to Figure 5.*

The movie shows a side view of one of our model experiments. It shows that lithosphere tearing does not occur at the trench, but at depth after lateral parts of the slab have been underthrusted at the STEP Fault. The experimental results show significant extension in the surface plate perpendicular to the STEP Fault. The resulting geometry of the tear is remarkably similar to Figure 5.

When applied to the SS subduction, this would mean that South America lithosphere is subducted along the northern plate boundary between ~26°W and the Sandwich-Scotia ridge, and that the lateral slablet is disconnected from the main SS slab below ~130km depth. At shallower depths, the lateral slablet has a highly oblique velocity relative to the overriding plate consistent with right lateral focal mechanisms (~17% of the events, Giner-Robles et al., 2013). The 1929 Mw 8.3 event is consistent with normal faulting that we observe in the lab experiments.

CONCLUSIONS

Figure 5 illustrates the tectonic setting of the SS earthquake sequence, following from our lab experiments and in agreement with geochemical observations. The 2021 SS earthquake sequence may have jumped across plate boundaries at the triple junction in the south. The highly curved northern plate boundary is a STEP Fault following from lithospheric tearing at a depth of ~100km. This is a modification of the original STEP model of Govers and Wortel (2005) and likely exists in other STEP regions. The region's largest recorded event, the 1929 Mw 8.3 earthquake, may reflect horizontal extension perpendicular to the STEP fault.

DISCLOSURES

Taco Broerse was funded through the project "Location, nature, and evolution of the Caribbean-South America STEP plate boundary" (ISES 2014-UU-13) of the Netherlands Research Center for Integrated Solid Earth Science (ISES).

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ABSTRACT

Most of the seismic moment release of the complex earthquake sequence beneath the South Sandwich Islands occurred on the central part of the SS megathrust. Significant aftershock activity indicates that the central and southern megathrust was subsequently activated, i.e., where young South America lithosphere is subducted. Seismic activity thus seems to have been restricted by the lateral termination in the south of the SS Trench.

Relatively little energy release occurred on the northern part of the megathrust. It was hypothesized by Govers and Wortel (2005) that here the South America slab breaks away from the surface part of the plate at the active STEP. Geochemical observations and earthquake P-axes orientations do not seem to agree with the hypothesis and we investigate the cause.

We show results of new physical analog lab models that aim to elucidate what controls the geometry of the lithospheric STEP Fault. We study lithospheric tearing in the process of STEP evolution, which is dynamically driven by the buoyancy of the subducting slab. In our experiments, the lithosphere as well as asthenosphere are viscoelastic media in a free subduction setup. A stress-dependent rheology plays a major role in localization of strain in tearing processes of lithosphere such as slab break-off.

The results show that the highly curved northern plate boundary is a STEP Fault following from lithospheric tearing at a depth of ~100km. This is a modification of the original STEP model of Govers and Wortel (2005). This is consistent with available observations along the northern Sandwich plate boundary, and likely exists in other STEP regions. The region's largest recorded event, the 1929 Mw 8.3 earthquake, may reflect horizontal extension perpendicular to the STEP fault, which is also expected based on our experiments.

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