The 2021 South Sandwich Islands Earthquake Sequence

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 (SSI) plate (Mo et al., 2021; Figure 1). The complex earthquake sequence triggered significant tsunami. Aftershocks occurred on the southern portion of the megathrust 56.5-60.5°S. The main event and most of the aftershocks occurred near the subducting South American plate is 35Myr old or younger (Selam et al., 2023). Some normal faulting events occurred in the South American plate offshore from the trench, and may be associated with basement or with co-seismic stretching of the slab (Hieber and Govers, 2005).

Figure 2. Pre-2021 seismicity from the gCMT catalog. The 1998 earthquake at 28.54°W 54.53°S is located well to the north of the STEP Fault plate boundary.

The northern termination of the SS subduction was not seismicly activated by the 2021 events. Here, a free slab edge has been hypothesized by Govers and Wortel (2005) who follow the interpretation of Forsyth (1979) of hinge folding here at the active STEP. The STEP Fault reffers to the strike-slip plate boundary downstream from the STEP that becomes 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 (Figure 3). The P- and T-axes of the P axes are perpendicular to the plate boundary, which is more in line with an interpretation of a south dipping megathrust here (Levi et al. 2004) come to the same conclusion based on magmas chemistry (Figure 6).

Interestingly, the events also triggered Mw 3 magnitude events on the Antarctic-Odendahl transform plate boundary. Triggering across plate boundaries would be exceptional but not unique (Furlow et al., 2009). Notably, the 55 trench terminations in the south at the triple junction with two transform plate boundaries, the Antarctic-Odendahl transform plate boundary, and the Antarctic South America transform plate boundary. No lithostructural bounding occurs at the triple junction, which is consequently not a Subduction-Transform-Edge Propagation, or STEP (Govers and Wortel, 2005), and the Antarctic-Sandwich transform plate boundary is not a STEP Fault (Baer et al., 2011).

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

The 1998 earthquake at 28.54°W 54.53°S was a large, shallow earthquake located well to the north of the STEP Fault plate boundary. The 1998 earthquake at 28.54°W 54.53°S was a large, shallow earthquake located well to the north of the STEP Fault plate boundary.

Two relevant observation near this part of the plate boundary is the mechanism of the 1999 earthquake, which was the largest earthquake that was ever recorded in the region. From their reevaluations of the original observations Olais and Hartnady (2009) infer that a Mw~8.3 normal faulting earthquake occurred on a step fault plane that struck nearly east-west. They find a relocated epicenter at 29.04°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 Pitny-Straub fault in the eastern Mediterranean (Bouchon et al., 2018), the Betic subzone in west Mediterranean, and the BI-Palat fault zone near Trinidad.

Figure 4. P and T (Thick) axes from the gCMT earthquake catalog. The plate diagrams show a rotation of east-west oriented P axes in the central part of the subduction system, to northwest-southeast orientations further to the north.

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 tectonic in the process of STP evolution, which is dynamically driven by the buoyancy of the subducting slab. In our experiments, the lithosphere as well as the basement is used in a free boundary condition. Here, we use the same conclusion based on magmas chemistry (Figure 6).

Analog Laboratory Experiments of STEP Tearing

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

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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 underthrust 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 slab is disconnected from the main SS slab below 10km depth. At shallower depths, the lateral slab has a highly obligate velocity relative to the overriding plate consistent with right-lateral motion by 1/2 of the HEL mechanism (~1/2 of the events). Giner-Robles et al. (2013). The 1929 MW 8.3 earthquake 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 geoschemical 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.

References


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

Figure 7. Stepwise initiation of a slab tear in a STEP Fault experiment. The slab is cut at 2 cm intervals and the slab is maintained at 250°C (green) and 10°C (red) during experiments. The slab is cut at 2 cm intervals and the slab is maintained at 250°C (green) and 10°C (red) during experiments.

Figure 8. Stepwise initiation of a slab tear in a STEP Fault experiment. The slab is cut at 2 cm intervals and the slab is maintained at 250°C (green) and 10°C (red) during experiments. The slab is cut at 2 cm intervals and the slab is maintained at 250°C (green) and 10°C (red) during experiments.