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Geomorphic markers tell a different story about fault slip rates in Tierra del Fuego, Patagonia

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Sandoval and De Pascale[1] report the results of a tectonic study of the Magallanes Fault System in Tierra del Fuego, at the southern end of the American continent. This fault zone accommodates the relative movement between the South America and Scotia plates. The study of Sandoval and De Pascale[1] assigns slip rates to different fault segments on the basis of direct geomorphologic analysis and available regional dating. The Magallanes Fault System is situated in a remote zone and has been poorly studied up to date. Therefore, new data are received with interest as they may considerably increase our understanding of regional and local tectonics. In particular, as slip-rate constraints on the Magallanes Fault System have strong implications in global geodynamics, regional tectonics and seismic hazard, their investigation must be particularly rigorous. In tectonic geomorphology, this means using suitable geomorphic markers recording deformation and producing for them a robust dating. In this comment, we challenge the work carried out by Sandoval & De Pascale[1] and we explain our concerns over the robustness of the dating and the suitability of the geomorphic markers that have been used.

Our team has been working for several years in Tierra del Fuego on similar topics, as attested by the paper of Roy et al.[2], whose publication preceded that of Sandoval and De Pascale[1]. It appears that the authors did not consider this previous work and its findings. We studied the Magallanes Fault System geometry and estimated Quaternary slip rates, with field observations carried out at all sites described by Sandoval and De Pascale[1]. Drawing on our extensive experience, we would like to warn against some of the authors' statements and conclusions. In particular, we aim to explain how: (1) unsuitable markers have been used to determine offsets along the fault; (2) Late-Quaternary slip rates for different fault segments have been proposed with considerable precision but they are not based on any direct dating.

1. The choice of offset markers to determine fault slip rates is contentious and the inferences are controlled by the way the observations are presented. We refer in particular to the two fault segments studied in Chile. The first segment is said to control the geometry of a river channel in a region where the Magallanes Fault has no obvious surface expression within Quaternary deposits over several tens of kilometers. The channel is described by Sandoval and De Pascale[1] as laterally offset by the fault by 80 ± 5 m to 95 ± 5 m (Fig. 1). In their figure, the portion of river shown is limited to a narrow window close to the presumed fault zone. In this view, the sharp river bend looks consistent with a left-lateral slip. However, a larger perspective clearly shows that this river channel is extremely meandrous. Such an irregular geometry makes it impossible to determine whether channel bends are associated with deformation or simply result from the natural evolution of the river[3,4]. For example, the meander just upstream of the one examined by the authors shows an apparent right-lateral slip of comparable magnitude. Moreover, another river of similar size flowing a few hundred meters to the west does not show any channel geometry consistent with a left-lateral offset while crossing the proposed fault. Due to its irregular geometry, the chosen marker is not suitable for slip rate estimation; therefore, it is advised not to draw conclusions based on the data as presented. Also, we advise against focusing only on some details using cropped images, as it makes it difficult for the reader to consider the wider morphological context.

The second fault segment examined by Sandoval and De Pascale[1] runs along the Azopardo valley, between Fagnano Lake and Magallanes Strait. Three sites are described (one in the main paper and two in the Supplemental Material); deformed markers are measured at two of them (Fig. 2). At site A, a small scarp is visible on the right bank of Azopardo River. The proposed sinistral offset, inferred from the comparison of two topographic profiles parallel to the fault, is actually in large part resulting from the obliquity of the river with respect to the

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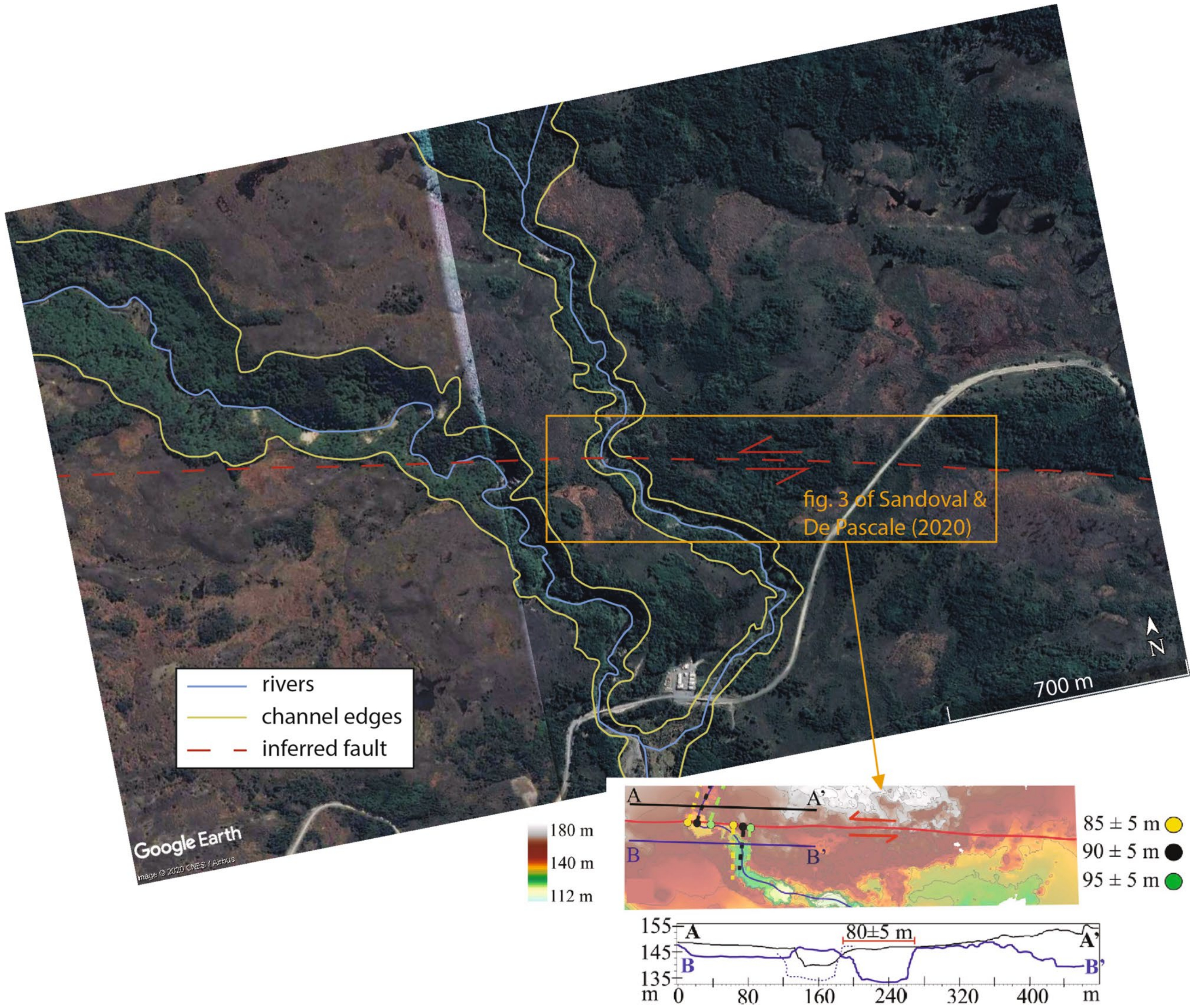

Figure 1. Map of the river channels across the proposed Magallanes Fault, which includes the location shown in Fig. 3 of the paper by Sandoval and De Pascale[1] (orange box). At this scale, it is possible to appreciate the meandrous character of the river channel investigated by Sandoval and De Pascale[1], the presence of another undeformed river channel along the inferred fault trace continuation, and the limits of the original view, failing to show the complete settings due to the small extension. Their observations—interpreted DEM and "left-lateral offset" estimation across the river meander—are added for clarity at the bottom of the figure. Map data: Google, CNES/Airbus. Software used: Google Earth Pro and Adobe Illustrator CS6.

azimuth of profiles. Indeed, while the risers close to the river appear out of phase, the small topographic heights located some tens of meters to the East on either side of the fault perfectly match. In this zone, the contour line highlighted in red extends almost straight across the fault, though the authors assigned to it the largest offset (23 ± 3 m). At site B, several morphologies (river risers, hillslopes) cross the fault and none of them are deformed. The authors identify and precisely measure offset contour lines, locally perturbed by the presence of a gully parallel to the inferred fault. However, on the original DEM (Fig. 2B, top panel), the straightness of contour lines projected from one side to the other side of the gully is evident. Therefore, the deflections marked by the authors cannot be reasonably inferred. At site C, no offset is found, which fully justifies the appellation of "inferred fault" in this valley.

2. Dating of offset markers is constrained without using any absolute age measurement. Sandoval and De Pascale[1] propose that the till deposits they observe in Chile have an age comprised between 10.2 and 12.5 ka. The minimum age (10.2 ka) refers to an old paper of 1932[5], that obviously could not have provided such a precise dating. The maximum age (12.5 ka) is a rough estimation proposed by Waldmann et al.[6] by extrapolating the sedimentation rate in the Fagnano Lake over several thousand years. However, the chronology of deglaciation in the region has been largely revised since this publication. New ages as old as 17 ka obtained near the Darwin Cordillera suggest an extremely rapid retreat of the Inutil Bay lobe from Last Glacial Maxi-

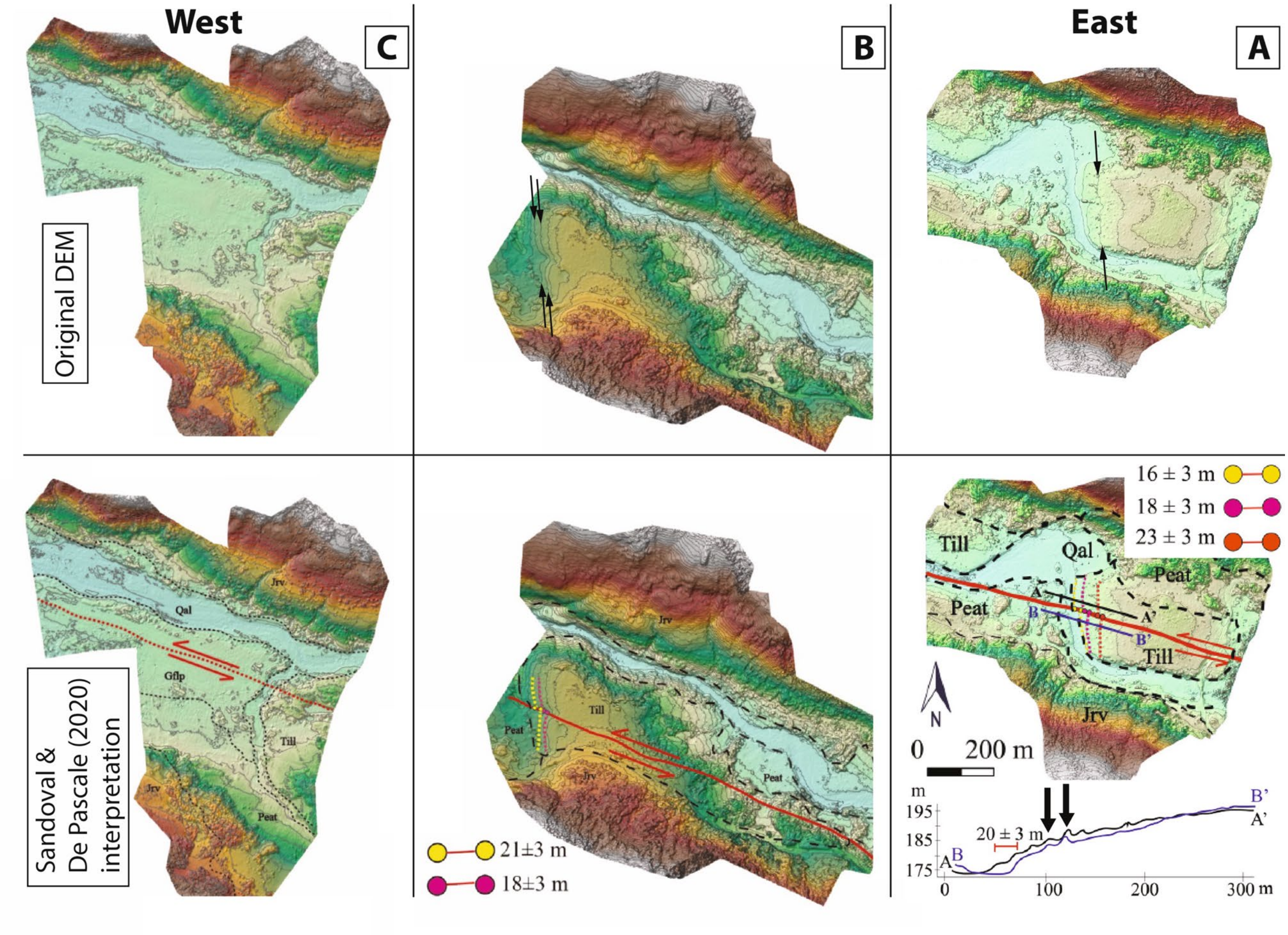

Figure 2. Original and interpreted high-resolution DEM from Sandoval and De Pascale[1] at three sites of the proposed fault segment along the Azopardo valley, with lateral offset estimations. Looking at the original DEM, it is evident that several contour lines and geomorphic markers cross the inferred fault without any lateral deflection. Some of the deflections marked by Sandoval and De Pascale[1], such as the red contour line at site A or the yellow and pink contour lines at site B cannot be reasonably inferred from the original DEM, as instead proposed by the authors. Original contour lines are indicated by black arrows.

mum positions to within a few kilometers of the present ice extent[7–9], which suggests that tills on the western shore of Fagnano Lake are much older than proposed.

In Argentina, Sandoval and De Pascale[1] propose that the age of the Lainez River channel and adjacent hillslope offset is between 13.4 and 17.8 ka. They argue that the maximum age (17.8 ka) corresponds to the beginning of the deglaciation after the Last Glacial Maximum in the Magellan Straits and Inutil Bay areas, 200 km northward[10]. The great distance makes it difficult to correlate those data to Fagnano ice lobe recessional phases. In addition, the age found by McCulloch et al.[10] for this stage is 25.2–23.1 ka, in contrast with that cited by Sandoval and De Pascale[1]. The minimum age (13.4 ka) refers to the study of Coronato et al.[11], which is often mentioned by the authors. Actually, this paper does not address deglaciation chronology and should not be referred to for that purpose. The appropriate citation is Coronato et al.[12]. As stressed in that work, the 13.4 ka age based on radiocarbon dating of basal peat bog does not provide the minimum absolute age of ice recession in the area, because the huge dead ice chunks may have delayed the formation of peat for many thousands of years. In agreement with this statement, Roy et al.[2] directly dated by in situ ^{10}Be the fossilization of glaciofluvial valleys in this area and the beginning of the tectonic surface deformation record at 18 ± 2 ka.

Finally, a slip rate of at least 1 mm/year is attributed to the Deseado Fault, but no measure offset nor geochronological data is provided to substantiate it. This rate is then added to the strike-slip rate across the Magallanes Fault system, but it is evident that with no robust evidence to back it, this result is highly questionable.

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References

1. Sandoval, F. B. & De Pascale, G. P. Slip rates along the narrow Magallanes Fault System, Tierra Del Fuego Region, Patagonia. *Sci. Rep.* **10**, 1–13. https://doi.org/10.1038/s41598-020-64750-6 (2020).

2. Roy, S. *et al.* Co-seismic deformation and post-glacial slip rate along the Magallanes-Fagnano fault, Tierra Del Fuego, Argentina. *Terra Nova* **32**, 1–10. https://doi.org/10.1111/ter.12430 (2020).
3. Yeats, R. S., Sieh, K. & Allen, C. R. The geology of earthquakes. *Seismol. Res. Lett.* **68**(5), 778–779. https://doi.org/10.1785/gssrl.68.5.778 (1997).
4. McCalpin, J. P. ed. *Paleoseismology*, vol. 95, 1–613 (Academic Press, 2009).
5. Caldenius, C. C. Z. Las Glaciaciones Cuaternarias en la Patagonia y Tierra del Fuego: Una investigación regional, estratigráfica y geocronológica. Una comparación con la escala geocronológica sueca. *Geogr. Ann. A* **14**, 1–164 (1932).
6. Waldmann, N., Ariztegui, D., Anselmetti, F. S., Coronato, A. & Austin, J. A. Jr. Geophysical evidence of multiple glacier advances in Lago Fagnano (54 S), southernmost Patagonia. *Quat. Sci. Rev.* **29**, 1188–1200. https://doi.org/10.1016/j.quascirev.2010.01.016 (2010).
7. Hall, B. L., Porter, C. T., Denton, G. H., Lowell, T. V. & Bromley, G. R. Extensive recession of Cordillera Darwin glaciers in southernmost South America during Heinrich stadial 1. *Quat. Sci. Rev.* **62**, 49–55 (2013).
8. Hall, B. L., Denton, G., Lowell, T., Bromley, G. R. M. & Putnam, A. E. Retreat of the Cordillera Darwin icefield during Termination I. *Cuadernos de Investigación Geográfica* **43**, 751–766. https://doi.org/10.18172/cig.3158 (2017).
9. Davies, B. J. *et al.* The evolution of the Patagonian Ice Sheet from 35 ka to the present day (PATICE). *Earth-Sci. Rev.* **204**, 103152. https://doi.org/10.1016/j.earscirev.2020.103152 (2020).
10. McCulloch, R. D., Fogwill, C. J., Sugden, D. E., Bentley, M. J. & Kubik, P. W. Chronology of the last glaciation in central Strait of Magellan and Bahía Inútil, southernmost South America. *Geogr. Ann. A* **87**, 289–312 (2005).
11. Coronato, A., Roig, C., Collado, L., & Roig, F. *Geomorphologic Emplacement and Vegetation Characteristics of Fuegian Peatlands, Southernmost Argentina, South America in Peatlands: Evolution and Records of Environmental and Climatic Changes* (eds Martini, I. P., Matinez Cortizas, A., & Chesworth, F.) 111–128 (Elsevier, 2006).
12. Coronato, A., Seppälä, M., Ponce, J. F. & Rabassa, J. Glacial geomorphology of the Pleistocene lake Fagnano ice lobe, Tierra del Fuego, southern South America. *Geomorphology* **112**, 67–81. https://doi.org/10.1016/j.geomorph.2009.05.005 (2009).

Author contributions

Analysis of original paper weaknesses: R.V., J.M., S.R.; Background literature review: R.V., J.M., S.R.; Writing of main manuscript text: R.V., J.M., S.R.; Preparation of figures: R.V.

Competing interests

The authors declare no competing interests.

Additional information

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