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# Forum Comment

## Large-scale active slump of the southeastern flank of Pico Island, Azores

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We were interested to read the paper by Hildenbrand et al. (2012) outlining geodetic and geologic evidence for active movement of a giant slump in Pico Island, Azores. Such movement is potentially a concern to local communities, so the issues arising from the paper need addressing. We wish to correct two inaccuracies related to our work, which are relevant to the assessment. First, in Mitchell et al. (2012) we did not claim that the movement involved "vertical caldera collapse." Rather, we had explored whether or not that had occurred, in order to attempt to explain away the lack of benches in the offshore slope of the island that would normally be expected from the toes of active slumps. We judged that option unlikely. Second, although a debris field was interpreted from sidescan sonar data in Mitchell (2003), multibeam sonar data collected in 2003 failed to show such a feature; indeed, the general profile of the island here is more like the constructional flanks of ocean islands (Mitchell et al., 2002, 2008). A debris-flow–type movement (using terminology of Moore et al. [1989]), in contrast, commonly leaves a smoothly varying lower-gradient exponential slope profile (Mitchell et al., 2002). To reconcile the 2003 multibeam with the sidescan sonar data, we had suggested that earlier emplaced debris might have become covered by sediment to reduce its relief, while shallowly buried traces were still imaged by the low-frequency (6.5 kHz) sidescan sonar. The steep submarine slope of the island, we argued, was created recently from debris associated with lavas reaching the sea during the delta emplacement. The slope profile and morphology are consistent with an old slump-type landslide that has not recently runout in a rapid failure. Subaerial geology also suggests an old inactive slump (Madeira, 1998); none of the recent lava flows emitted from cones inside the slump or along the volcanic rift zone is cut by faults S1, S2, and S3 of Hildenbrand et al. (2012). Instead, these faults are buried by the flows.

The new data of Hildenbrand et al. do not obviously support a slump-type motion involving rigid bodies. Subsidence in the InSAR data does not change abruptly across the faults; e.g., it is similar on either side of the main slump scar shown by them. If movement occurred as rigid blocks above curved faults, subsidence should increase northward into the faults, not away from them as shown. A separate GPS campaign involving one of us (Madeira) also shows displacement of a monument within the landslide embayment, so we actually do not dispute that movement has been occurring. Though, in those data collected in four campaigns over 11 yr the movement is mainly a lateral translation, as normally expected of a slump, with only minor vertical movement.

In Mitchell et al. (2012), we reported marine geophysical data collected on the narrow abrasion shelf immediately seaward of this landslide. Those multibeam sonar, chirp, and boomer seismic data show no relief on faults except for one minor example. The relief was likely reset by coastal erosion during the last transgression, so this implies that there has been no resolvable movement over at least the past 7 k.y. since sea level stabilized. In particular, the multibeam data reveal the morphology of the exposed inner rock platform (where it lacks any sign of faulting) immediately adjacent to the faults labeled Main, S1, and S3 by Hildenbrand et al. One way to reconcile our observations with ongoing slump movement would be if movement had begun only very recently. Assuming that 1 m of fault relief is resolvable in the offshore geophysical data, 5–12 mm/yr movement would be possible over a period of 83–200 yr if continuous. Alternatively, movement is not localized on the faults at all, but rather forms a general subsidence, as mentioned above. Given the lack of information on the subterranean structure of the lava deltas, the option of subsidence related to compaction of the lava delta here should not be ruled out at this stage of investigation.

For the many collapses of volcanic islands that have occurred in the geological past, unfortunately, researchers are largely able only to suggest mechanisms based on circumstantial evidence because the conditions at the time of failure are poorly known. The wide range of suggested causes of failure (Keating and McGuire, 2000) largely reflects this lack of knowledge. South Pico is one of only a few sites of active movement in volcanic islands, so it is important to glean as much from it as we can. We strongly urge the installation of a micro-seismic network and array of continuously recording GPS instruments, which have been useful elsewhere in detecting volcano slump movements linked to intense rainfall (Cervelli et al., 2002). Such measurements have the potential to resolve this local issue, provide data of wider utility to understanding the threats to volcanic islands from failure, and help to reassure the local population.

### REFERENCES CITED

Cervelli, P., Segall, P., Johnson, K., Lisowski, M., and Miklius, A., 2002, Sudden aseismic fault slip on the south flank of Kilauea volcano: Nature, v. 415, p. 1014–1018, doi:10.1038/4151014a.

Hildenbrand, A., Marques, F.O., Catalão, J., Catita, C.M.S., and Costa, A.C.G., 2012, Large-scale active slump of the southeastern flank of Pico Island, Azores: Geology, v. 40, p. 939–942, doi:10.1130/G33303.1.

Keating, B.H., and McGuire, W.J., 2000, Island edifice failure and associated tsunami hazards: Pure and Applied Geophysics, v. 157, p. 899–955, doi:10.1007/s000240050011.

Madeira, J., 1998, Estudos de neotectónica nas ilhas do Faial, Pico e S. Jorge: Uma contribuição para o conhecimento geodinâmico da junção tripla dos Açores [Ph.D. thesis]: Lisbon, Portugal, Lisbon University, 481 p.

Mitchell, N.C., 2003, Susceptibility of mid-ocean ridge volcanic islands and seamounts to large-scale landsliding: Journal of Geophysical Research, v. 108, doi:10.1029/2002JB001997.

Mitchell, N.C., Masson, D.G., Watts, A.B., Gee, M.J.R., and Urgeles, R., 2002, The morphology of the flanks of volcanic ocean islands: A comparative study of the Canary and Hawaiian hotspot islands: Journal of Volcanology and Geothermal Research, v. 115, p. 83–107, doi:10.1016/S0377-0273(01)00310-9.

Mitchell, N.C., Beier, C., Rosin, P., Quartau, R., and Tempera, F., 2008, Lava penetrating water: Submarine lava flows around the coasts of Pico Island, Azores: Geochemistry Geophysics Geosystems, v. 9, Q03024, doi:03010.01029/02007GC001725.

Mitchell, N.C., Quartau, R., and Madeira, J., 2012, Assessing landslide movements in volcanic islands using near-shore marine geophysical data: South Pico island, Azores: Bulletin of Volcanology, v. 74, p. 483–496, doi:10.1007/s00445-011-0541-5.

Moore, J.G., Clague, D.A., Holcomb, R.T., Lipman, P.W., Normark, W.R., and Torresan, M.E., 1989, Prodigious submarine landslides on the Hawaiian Ridge: Journal of Geophysical Research, v. 94, p. 17465–17484, doi:10.1029/JB094iB12p17465.

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