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Earth Surface Dynamics Discussions

Interactive comment on "Oxidation of sulphides and rapid weathering in recent landslides" *by* R. Emberson et al.

Anonymous Referee #2

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Emberson et al., Oxidation of sulphides and rapid weathering in recent landslides. Earth Surface Dynamics.

Determining how erosion and weathering are related to one another in tectonically-active mountains is important for understanding how mountain uplift influences geochemical cycling. Here Emberson et al. present geochemical data from surface waters in Taiwan. They focus on the chemistry of stream waters as well as waters that have flowed through landslide debris, deposited by extensive hillslope failures associated with Typhoon Morakot. The pyrite and carbonate bearing marine sedimentary rocks in the study area offer a mineralogical contrast to a complimentary study the group conducted in the Southern Alps of New Zealand, where the mineralogy of the bedrock differs. Emberson et al. conclude that sulfuric acid generated by pyrite oxidation drives the dissolution of carbonate rock within the fractured landslide mass and that, above a

threshold minimum of landsliding, that total dissolved solids, Ca, and sulfate increase with increasing catchment landslide volume. These results provide new, process-level insight on the generation of solutes in tectonically-active landscapes, and will be of broad interest and is an appropriate contribution to Earth Surface Dynamics. I believe the manuscript can be accepted for publication following revision to address questions regarding several aspects of the paper.

Main comments: This manuscript lacks a distinct Results section, nor is the statistical treatment of the data clearly described in the Methods section, such that the reader does not know how the various dataset are analyzed with respect to one another until the statistics are presented as part of the Discussion. A revised manuscript without an explicit Results section could work, but if so, additional description of the Methods are needed to better link the different sections of the paper and prepare the reader for the Discussion.

Line 318-319. It is worthwhile to present data that demonstrate that the magnitude of landsliding (and TDS) does not scale with topographic metrics such as slope or relief. The reason being is that erosion rates (and hence coupled weathering rates) scale with catchment topography. Hence it might be expected that, even in the absence of any landsliding, the range of TDS values could be explained by topographic variation of the watersheds. For the arguments presented in the paper, it is important to show this is not the case.

Line 406-414. It would be worthwhile to elaborate and make the logic very clear here, as this paragraph is laying out a conceptual framework, based on the observations, for understanding the role landslides play in the weathering budget of mountains. In particular, more explanation of the role of sediment retention time would be useful. The instantaneous weathering flux from the landslide debris should decay as a function of time, whereas the cumulative flux of weathering products from landslide debris will increase with time. Hence there should be more explanation to support the claim that long sediment residence times would have a limited effect on CO2 budgets-if this

indeed is the case, which seems unlikely. The return interval of landslide-triggering events should also play a role, as this ultimately sets the volume per time of landslide debris subjected to sulfuric acid weathering. A conceptual diagram showing the roles of residence time and return interval would be a useful approach to organize these thoughts in this paragraph. Additionally, there has been at least some work on 14C dating of alluvial deposits in southern Taiwan, presumably which record valley alluviation due to landsliding in some cases. Although these studies may not be in the same catchment as was investigated here, these studies could be drawn upon to estimate to a first order the length of time landslide derived sediment is likely to persist in the watershed.

Hsieh, Meng-Long, and Shyh-Jeng Chyi. "Late Quaternary mass-wasting records and formation of fan terraces in the Chen-yeo-lan and Lao-nung catchments, central-southern Taiwan." Quaternary Science Reviews 29.11 (2010): 1399-1418.

Hsieh, Meng-Long, and Peter LK Knuepfer. "Synchroneity and morphology of Holocene river terraces in the southern Western Foothills, Taiwan: A guide to interpreting and correlating erosional river terraces across growing anticlines." GSA Special Paper (2002): 55-74.

Lines 415-420. Here it would be useful to point the way forward in terms of what data are needed to determine the sign of the CO2 budget in a rapidly eroding mountain range. There are already elements of this in the paragraph, but a thorough explanation of what suite of measurements are needed would be a forward looking way to wrap up the manuscript. Additionally, with the understandably limited data that are available, is there at least a signal of what process is dominating the CO2 budget, sulfuric acid weathering of carbonate, carbonic acid weathering of silicates, or organic carbon burial? For example, back of the envelope calculations assuming regional-scale runoff values to infer fluxes for this study, and comparison with previous work on organic carbon export in Taiwan may be useful, even if imprecise. Even if a very first order budget cannot be calculated, due to lack of constraints in the values for the various parts of the

budget, indicating that this is the case is a useful thing to do, as it points to the need for a different strategy in approaching erosion-CO2 links in mountains.

On a similar note, the paper begins by asking a question regarding the general influence of landslides on weathering and roles lithology and climate may play (Line 42-44). In concluding the Discussion it would be worthwhile to return to the specific parts of that question and assess the state of knowledge, as informed by this work, and prior publications.

Line 427-429 (also line 241). There is a contradiction in this statement, in that the suggestion is that weathering is kinetically-limited, so long as the involved minerals are ‘abundantly exposed’. The ‘abundant exposure’ is suggestive of supply limited weathering, and one interpretation of figure 3 (excluding the smaller landslide volumes in Taiwan), is that the supply of material by landsliding is setting the concentrations of dissolved species and likely also the weathering flux. My suggestion is to be very explicit here regarding use of the terms kinetic and supply limited weathering. Pyrite oxidation depends on kinetics (as do all reactions), but when the numbers of minerals involved in such reactions are increased, likely by orders of magnitude due to fracturing of the rock mass during landslide runout, then the supply of minerals plays a very large role in setting the concentrations of various dissolved species measured in the water.

Other comments: Line 14. Insert ‘landslide’ before seepage

Line 18 and elsewhere. Two significant digits on the R2 values is probably sufficient.

Line 34. Several additional citations are warranted here, including Gabet and Mudd (2009), Ferrier and Kirchner (2008) and West, (2012). Also, Dixon and von Blanckenburg do discuss the role of landsliding.

Line 38 and elsewhere. Many citations do not follow a uniform format, with author initials appearing in some cases. Some editing the entries in the reference management software/database that was used here is needed.

Line 46. ‘local’ is ambiguous, perhaps replace with ‘landslide’

Line 56. ‘importantly’ can be omitted in this case and elsewhere in the manuscript. Alternatively, switch the order of ‘importantly’ and ‘propagate’

Line 79-81. Perhaps break this into two sentences or put parentheses around: either directly from rainfall. . ...crest of landslides.

Line 90-91. This statement ought to have a citation to support it.

Line 98. While I have not been to the field site, observations elsewhere in Taiwan would suggest, based on the continuity of vegetation coverage, that a soil (or mobile regolith) mantle, while not necessarily laterally continuous, must cover a large fraction of the bedrock on hillslopes.

Line 105. Perhaps change ‘in view of this’ to ‘in light of this’

Line 115. The term ‘channel fill’ has an ambiguous meaning in this sentence. Does it have the same meaning as ‘alluvium’? Some clarification is needed.

Line 165. ‘landslides’ should be singular

Line 169. Perhaps edit ‘as prescribed by’ to ‘as described in’

Line 173. A G-cubed paper by Gen Li and colleagues also provides an important example of the effects of amalgamating landslide areas. Li, Gen, et al. "Seismic mountain building: Landslides associated with the 2008 Wenchuan earthquake in the context of a generalized model for earthquake volume balance." Geochemistry, Geophysics, Geosystems 15.4 (2014): 833-844.

Line 197. Edit so that ‘sit at’ is removed

Line 201. The statement that TDS values are high with respect to global concentrations needs a citation.

Line 220-221. Whether deeper landslides will expose proportionally more calcite to

weathering relative to shallow landslides will depend on the depth of the calcite weathering front. Whereas much calcite is likely lost from the soil, the soils are likely thin (<1 m?) and a small proportion of the total landslide thickness. Given the lithology there may well be considerable calcite in the near-surface environment in the study sites. Hence the lack of a correlation between TDS and landslide size may not be altogether unexpected.

Line 223. If reduced hydraulic conductivity at the base of landslide debris, relative to debris that is stratigraphically higher, has been documented this statement needs a citation. Otherwise some clarification is needed.

Line 224. Replace the slashes with ‘per’.

Line 236. To link this with the statistics above, replace ‘size’ with ‘area or volume’

Line 241. Avoid starting a sentence with ‘This’. Instead explicitly indicate something to the effect of: ‘Generating landslide debris from unweathered bedrock removes the supply limit. . .’

Line 242. Replace ‘and surrounds’ with some explicit definition of what is meant by surrounds. The other sites in southern Taiwan that were sampled?

Line 253. Omit importantly. Unless there is evidence the groundwater is ‘circulating’, simply refer to it as ‘deep groundwater’

Line 271. Replace ‘tops’ with ‘exceeds’

Line 302. Rainfall is not dependent on area, but runoff is. Clarify as needed.

Line 316. ‘..and these may be a source of variability. . .’ It is unclear what ‘these’ refers to in this sentence and this sentence doesn’t really follow from the previous one or set up the following one well. Some editing is needed here.

Line 321. ‘importantly’ can be omitted.

Line 329. First two words have unclear meaning.

Line 334. Replace ‘in keeping’ with consistent

Line 336. Problems with these references. e.g., should be Lyons et al.

Line 348. A ‘likely’ should be inserted between ‘exhumation’ and ‘not’. There are no data on the distribution of sulfide minerals within the rock, so you can only hypothesize that this variability also controls the variability in seepage concentrations at individual landslides.

Line 357-358. Suggest editing to: ‘. . .and the associated generation of sulfuric acid.’

Line 360. Different than what? Please complete this thought.

Line 361. Is there a better term than ‘minority’ minerals - reactive, highly soluble, labile? Choose one and use it consistently throughout. For example, there are likely many phases present in low abundance that do not contribute to non-equilibrium weathering.

Line 368. Some sort of punctuation to separate the sample numbers and the values of the measurements would be helpful.

Line 376. The statement regarding weathering by carbonic acid dominating in other parts of the landscape should be qualified. It is likely the case, but data are not discussed that support this. Can the data from the rivers be used to support this inference?

Line 378. It is not clear what ‘restricted’ means in this context. Please clarify.

Line 381. There is a comma that can be omitted.

Line 403. Elaborate on ‘. . .a more central role,. . .’ It will be useful to be explicit regarding what the central role refers to.

Line 406. Suggest replacing the ‘As’ with ‘when’

Line 426. Again, unclear if the waters in the landslide debris indeed circulate.

Line 430. Omit ‘in the first instance’ or replace with another term, such as foremost.

Line 434. Replace ‘units’ with ‘rocks’ and replace ‘This’ with a more explicit description of the process.

Line 436. Meaning of ‘subsumed’ is unclear in this context. Some editing is needed.

Line 339. Omit ‘first’ or replace with another term than does not imply a temporal relationship.

Line 454. ‘mineralogical’ instead of ‘lithological’?

Line 457. Gabet 2007, EPSL is a study that has examined the stochastic role of landslides in weathering.

Figure captions. ‘Total dissolved load (TDS)’ – the acronym should match the first letters of each word, e.g., total dissolved solids or TDL.

Figure 1. It would be useful to have an inset map showing Taiwan with a box showing the area of Figure 1a. This inset could go in the lower right corner of Fig. 1a.

Figure 2. There should be at least two labels on the y-axis in each panel to easily allow the reader to see the data range.

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