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Bedrock weathering contributes proton consumption in highly weathered subtropical critical zones

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Acid rain as one of the major environmental problems globally is thought to be responsible for acidifying soil and water, activating aluminum and other metals toxic to plants and fish, as well as depleting soil nutrients and inorganic carbon. However, the relative contributions of different acid-buffering processes to acid rain neutralization from top soil to underlying bedrock are largely unknown in the acidic critical zones usually coexisted with highly weathered conditions. Acidic and highly weathered critical zones in subtropical China were developed from Quaternary red clay underlain by sandstone bedrock and were selected as the studied area. Acid rain neutralization processes in the critical zones were explored by using deep drilling and sampling, field observation, simulation experiment of soil- and rock-acid rain interaction, and theoretical calculation of proton consumption rate. We found that rain water and regolith were acidic with pH values less than 5.5, whereas streamwater and groundwater were neutral to slightly alkaline. Regolith, with thickness varying from 3.5 m to 9 m, presented a weak capacity of proton consumption. Bedrock weathering of sandstone containing calcite, albite and microcline showed a strong capacity of proton consumption. Proton consumption by bedrock weathering was estimated to occur at a rate of 198 mol H^+ ha^{-1} yr^{-1} from 2020 to 2023. These results highlighted the importance of bedrock weathering to buffering acidification in the acidic and highly weathered critical zones.