Goldschmidt 2023 Abstract
https://doi.org/10.7185/gold2023.13843

The transition zone between permafrost and seasonally frozen ground: Invigorated biogeochemical dynamics in response to climate warming

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Climatic warming is accelerating the hydrological cycle in the Earth's cold regions. The concomitant changes in soil biogeochemistry and (surface and subsurface) water quality have major implications for associated watershed functions and ecosystem services [1]. This influence is typically characterized by highly invigorated, climate-sensitive biogeochemical dynamics in the transition zone between the permafrost and seasonally frozen ground, for both alpine and holarctic watersheds [2]. Here, we show that the rising surface temperatures in the Qinghai-Tibet Plateau and in China's northern mollisol regions have caused the conversion of historically continuous permafrost into the current patchy permafrost or seasonally frozen ground [3]. Furthermore, the significant changes in the concentrations of water total dissolved solids and trace elements, water types and nutrient status (among others) in these two regions are indicative of an enhanced biogeochemical hotspot of the transition zone between permafrost and seasonally frozen ground. In particular, leaching of soil organic matter and nutrients leads to increased concentrations of dissolved organic carbon, nitrate, and sulfate in surface water and groundwater that, in turn, amplify redox transformation therein. The biogeochemical activity in the transition zone increases greenhouse gas emissions in downstream receiving surface water bodies and deteriorates regional groundwater quality, especially that in shallow aquifers. We hypothesize that a major amplifier of the biogeochemical dynamics in the transition zone is climate warming-driven intensification of freeze-thaw cycles in the winter and shoulder seasons (viz., late fall and early spring). Freeze-thaw cycles may therefore have far-reaching impacts on the water and food securities for communities living in the cold regions.

[1] Pi *et al.* (2021) *ARER* **46**, 111-134. [2] Pan *et al.* (2022) *STOTEN* **834**, 155227. [3] Hu *et al.* (2023) *WRR*, e2022WR032426.