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Photoelectrons from Semiconducting Minerals: A Long-overlooked Energy Source for Non-phototrophic Microorganisms in Oligotrophic Ancient Environments

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The observed ^{34}S-depletions in Early Archean marine pyrite suggest a significant role for sulfate-reducing microorganisms (SRMs) in the formation of pyrite. However, the net primary productivity (NPP) before the advent of oxygenic photosynthesis appears too insufficient to support the carbon metabolism required by SRMs for widespread sulfate reduction and subsequent pyrite deposition in Archean seas. Semiconducting minerals, prevalent on Earth's surface, can efficiently convert light into electrons through photocatalysis. In this study, we propose the hypothesis that non-phototrophic sulfate-reducing microorganisms could utilize photoelectrons from semiconducting minerals as an energy source, enabling their survival in ancient, substrate-limited environments. To investigate this, we conducted batch experiments, microbial photoelectrochemical analyses, and transcriptomic and metabolomic studies to understand how SRMs acquire photoelectrons from extracellular sphalerite nanoparticles, and the impact on their internal metabolism and aggregation with minerals. Our results demonstrate that the uptake of photoelectrons from sphalerite promotes the intracellular electron transfer activity, sulfur metabolism, and ATP production of a model SRM, thereby extending the survival of cells in oligotrophic environments. This photoelectron-promoted dissimilatory sulfate reduction cannot be observed when organic substrates are abundant, suggesting a possible shift in primary electron donors for SRMs through geological time.