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Oxidation Kinetics of Iron Sulfide with *in-situ* Iron L-edge Scanning Transmission X-ray Microscopy

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Iron sulfide (FeS_{1-x}) minerals form readily in anoxic sediments across marine, freshwater, and terrestrial environments. Their oxidation generates reactive oxygen species (ROS) that can degrade organic matter, alter metal speciation, influence nutrient availability, and stress microbial communities. Yet how these reactions progress spatially and chemically at the sub-micrometer scale under aqueous conditions remain poorly understood. We used *in-situ* scanning transmission X-ray microscopy (STXM) at the Fe L-edge to capture the spectral and spatial evolution of synthetic FeS_{1-x} during aqueous oxidation. A buffered solution (1 mM KCl; 2 mM TRIS, pH 8.00) was flowed at 1 µL/min through a Hummingbird liquid cell over an FeS_{1-x} aggregate while image stacks were acquired hourly. Non-negative matrix factorization reduced each stack into spatially distinct spectral components. Iron oxidation states were quantified by two independent methods: linear combination fitting (LCF) using internal endmembers — unreacted FeS_{1-x} and Fe(III) oxyhydroxide from the final scan — and a modified integral white-line intensity ratio method yielding $Fe^{3+}/\Sigma Fe$ directly from the $L_{2,3}$-edge. Initially, aggregates consisted entirely of Fe(II) sulfide. Over the experiment they underwent progressive oxidation to mixed-valent Fe(II)/Fe(III) compositions, and after ~7.6 hours a spatially distinct Fe oxyhydroxide precipitated outside the original aggregate boundaries. The white-line method applied to the Fe oxyhydroxide precipitate yielded $Fe^{3+}/\Sigma Fe = 0.86 \pm 0.06$, indicating residual Fe(II). First-order kinetic fitting yielded $k = 0.14\ hr^{-1}$ ($t_{1/2} = 5.1$ hr) from LCF and $k = 0.11\ hr^{-1}$ ($t_{1/2} = 6.3$ hr) from the white-line method on the aggregate. Area analysis showed the aggregate footprint decreased ~12% while the Fe(III) background expanded ~60%, implicating oxidation of dissolved Fe^{2+} from solution. These results apply wherever dissolved oxygen reaches FeS_{1-x} in sediments. For example, the prairie pothole region (PPR), where wetlands underlain by pyrite-bearing glacial till host redox-active FeS_{1-x} minerals. Ex-situ STXM of sediments from wetlands P7 and P8 at the Cottonwood Lake Study Area, North Dakota, confirmed co-occurrence of reduced Fe phases and chemically heterogeneous organic carbon. ROS generated during FeS_{1-x} oxidation may transform associated organic carbon, increasing bioavailability and potentially amplifying greenhouse gas emissions. Future work will extend this in-situ approach to natural PPR sediments.