Biogeochemical Controls on the Corrosion of Depleted Uranium Alloy in Subsurface Soils

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Military activities have left a legacy of depleted uranium (DU) penetrator waste in the near-surface terrestrial environment. To understand the fate of this DU alloy, the mechanisms and controlling factors of corrosion need to be determined. In this study, field-moist and waterlogged microcosms were used to investigate the effect of redox conditions and soil water content on the corrosion and fate of DU in subsurface soil, and the impact of corroding DU on the soil microbial population. The mechanism of corrosion and the corrosion products formed were highly dependent on the water status of the soil. Under field-moist conditions, DU corroded at a rate of $0.49 \pm 0.06 \text{ g cm}^{-2} \text{ y}^{-1}$ and the main U input to surrounding soil was large metaschoepite $[(\text{UO}_2)_8\text{O}_2(\text{OH})_{12} \cdot (\text{H}_2\text{O})_{10}]$ particles. However, under waterlogged conditions the rate of corrosion was significantly slower at $0.01\text{--}0.02 \text{ g cm}^{-2} \text{ y}^{-1}$ and occurred with the release of dissolved species to the surrounding environment. Corrosion ceases under reducing conditions, thus redox conditions are important in determining the persistence of penetrators in the environment. Corroding DU alters the redox conditions in the surrounding environment and both mechanisms of corrosion impact the microbial community.

Introduction

Depleted uranium (DU) penetrators were used extensively during the 1991 Gulf War, the 1999 Kosovo/Serbia conflicts, and the 2003 Iraq conflict (1). The 1991 Gulf War deposited

approximately 321 tonnes of DU in the terrestrial environment (1), mainly consisting of whole penetrators and large fragments, since 70–90% of aircraft projectiles miss their targets (2). The depth that penetrators become embedded within the soil depends on the angle of impact and physical properties, with reported penetration depths of >2 m in denser clay soils (3) and 6–7 m in soft soils (4).

Moisture content, O₂ supply, pH, temperature, and microbial community influence soil corrosivity (5). Investigations into DU corrosion rates and products formed in soils have included in situ and laboratory studies. At two sites in an arid surface soil in the Mojave Desert, USA, U migration from corroding penetrators produced distinct layers (6, 7). The surface soil contained yellow-orange schoepite, whereas at 2–4 cm depth, yellow metaschoepite was observed, and below 4 cm, U was present as secondary U-silicate species (6, 7). At Kirkcudbright, UK, DU coupons were buried to 0.3 m depth in an organic, silty-clay soil and sampled over 4.4 years. Black and yellow corrosion products, characterized as uranium dioxide and schoepite, respectively, were observed on the DU coupons and in surrounding soil at the first sampling time (102 days), and corrosion rates over 4.4 years were $0.8\text{--}1.1 \text{ g cm}^{-2} \text{ y}^{-1}$ (8). In the laboratory, DU corrosion has been studied in two soils (sandy-loam and silty-loam) at 20 °C, with simulated rainfall (16 mm week^{-1}). Black and yellow corrosion products formed, and there was negligible difference in corrosion rates for the two soils ($0.19 \pm 0.03 \text{ g cm}^{-2} \text{ y}^{-1}$) (9).

The diffusion rates of O₂ in soils range from 10^{-2} to $10^{-6} \text{ cm}^2 \text{ s}^{-1}$ for dry and water-saturated soils, respectively (10). Limited O₂ diffusion into waterlogged soils results in anaerobic conditions in which microorganisms utilize alternative terminal electron acceptors (TEAs) for organic matter oxidation. The relative energy yields govern TEA utilization, giving rise to the “redox cascade” of O₂, NO₃[−], Mn(IV), Fe(III), SO₄^{2−}, and CO₂ reduction. Corroding uranium is a strong reducing agent; this property together with hydrogen released during DU corrosion (11) may reduce TEA concentrations (12).

Investigations into DU corrosion have not explicitly considered the effect of soil water content and redox processes on corrosion, leaving a level of uncertainty when predicting the fate of DU penetrators in the wide-ranging environments found in test-fire and war zones. Microcosm experiments have therefore been carried out to investigate the corrosion of DU penetrator materials in field-moist and progressively anoxic waterlogged soils, to test the hypothesis that the rate of DU corrosion and the nature of corrosion products formed are dependent on the water content and local redox processes.

Experimental Section

Sampling and Characterization. A soil (silty-loam) from North Wyke Research Station, Devon (Lat: 50.777451°N Long: 3.920402°W GB; 26.01.05) was sampled (10–40 cm depth), sieved (2 mm), stored (15 °C), and used within 6 months. Drain channel water collected at the same site was stored (4 °C) and used within 1 week. The full characterization protocols for soil and water subsamples have been described previously (12).

Microcosm Experiments. Experiments were designed to investigate DU corrosion under realistic subsurface soil environments. The variations in water and O₂ content generated three distinct subsurface environments, denoted as “field-moist”, “open waterlogged”, and “closed waterlogged”. DU from a penetrator (Dstl, Porton Down, UK) was cut into triangular “coupons” (triangular face of ca. 1.5×1.5

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× 1.0 cm, thickness 0.5 cm; mass 5–10 g) by AWE (Aldermaston, UK). DU coupons were cleaned to remove cutting oil and surface contaminants (12). Microcosms consisting of 50 mL glass serum bottles and 15 g of soil were prepared on the same day. Waterlogged and field-moist conditions were simulated by adding 15 and 1 mL of drainage water, respectively. For the open systems (open waterlogged and field-moist), 15 microcosms containing a DU coupon were prepared, together with an equivalent number of controls without DU. A nylon mesh was tied around the neck of the open bottles to allow gas exchange. The microcosms were weighed monthly and water loss was compensated for by adding high purity water (MQ water, ≥ 18.2 M Ω cm $^{-1}$). For the closed waterlogged system, 30 microcosms containing a DU coupon were prepared, together with an equivalent number of controls. The microcosms were sealed with butyl stoppers and aluminum seals. A syringe needle was inserted through the stopper to prevent pressure build-up (none observed). All microcosms were incubated in the dark at 10 °C.

At each time-point of interest over 510 days, microcosms were opened for analysis (“sacrificed”) and characterized in triplicate, along with three controls. To preserve redox conditions, sacrifices and further manipulations were carried out within an anaerobic chamber (95% N $_2$, 5% H $_2$). The closed systems were swirled for 15 min (200 rpm) to homogenize the sample and then sacrificed. For the open systems, the microcosms were weighed and adjusted to contain 15 mL of water by addition of deoxygenated MQ water, sealed, homogenized, and sacrificed. The addition of deoxygenated MQ water to the field-moist microcosms allowed the extraction of diluted pore-water. The entire contents of the microcosms were then filtered successively through nylon mesh (65 μ m) and a disposable syringe filter (0.45 μ m, mixed cellulose ester), and collected in polypropylene vials. The DU coupons, solution, and sediment were then prepared for further analysis as described below. All errors stated are one standard deviation of three replicate microcosms.

DU Coupon Analysis. The DU coupons were rinsed with MQ water to remove soil, air-dried, and stored in a desiccator (<1 month). For a visual record, coupons were photographed under a light microscope fitted with a digital camera. The corrosion products were removed as described previously (12) and reweighed to determine mass loss (%).

Geochemical Methods and Modeling. Apart from the adaptations stated here, all geochemical methods (pH, Eh, O $_2$ determination, redox indicator analysis; determination of colloidal and dissolved U in water) and modeling have been previously described (12). Acid-extractable Fe(II) was extracted from soils with 0.5 M HCl for 30 min (13) and determined spectrophotometrically (562 nm) using the ferrozine method (14). Accurately weighed subsamples of dried soil from the waterlogged microcosms on day 510 were refluxed with concentrated nitric acid for 8 h and analyzed for total U by inductively coupled plasma optical emission spectrometry (0.1 mg L $^{-1}$ detection limit).

DU Distribution and Particle Analysis. Soil from day 337 of each series of microcosms was screened using phosphor imaging analysis. Representative dried soil (1 g) was thinly spread onto a grid plate and a phosphor screen was placed directly above it for 8 h. The image was used to identify areas of enhanced radioactivity, which were isolated and analyzed by environmental scanning electron microscopy energy-dispersive X-ray (ESEM-EDAX). The field-moist soil contained sufficient quantities of crystalline U mineral particles for analysis by X-ray diffraction (XRD).

Microbiological Methods. Field-moist and closed waterlogged samples and their controls were selected for microbial analysis to identify changes in the microbial community as a result of long-term (435 days) DU con-

tamination. Ribosomal intergenic spacer analysis (RISA) was used to identify microbial community change. Further investigation by DNA sequencing of 16S rRNA gene clone libraries and phylogenetic analysis was also carried out. The methods used in this study have been described in detail previously (12).

Results and Discussion

Soil and Water Characterization. The soil had a moisture content of 22% (m/m), a particle size distribution of 54% sand, 41% silt, and 5% clay, organic carbon by mass of $12.0 \pm 0.1\%$, CEC of 21.2 ± 0.4 meq/100 g, and an initial inorganic carbon content of 80 ± 1 mg kg $^{-1}$. Iron oxides comprised 6.0% (m/m) of the soil. The pH of the water prior to mixing with soil was 7.4, inorganic carbon content was 73 ± 2 mg L $^{-1}$, and anion concentrations (mg L $^{-1}$) were chloride 130 ± 2 , nitrate 120 ± 2 , and sulfate 10 ± 1 .

Impact of DU on Redox Processes in Field-Moist Soil. In the field-moist microcosms pH (5.2–5.8) and Eh (500–600 mV) stayed constant over the 510 day experimental period. Changes in redox indicator (NO $_3^-$, Fe(II), SO $_4^{2-}$) concentrations over time are shown in Figure 1. In the control microcosms, redox indicators were not reduced over the experimental period, suggesting oxic conditions were maintained. This is consistent with the visible, air-filled macropores in the soil structure. However, in the DU-amended experiments, depletion of NO $_3^-$ was observed from day 242 (510 ± 70 mg L $^{-1}$) to day 510 (17 ± 5 mg L $^{-1}$), with concurrent in-growth of Fe(II) into soils. Sulfate in the DU-amended and control microcosms remained fairly constant throughout the experiment, indicating that SO $_4^{2-}$ reduction did not occur. This suggests that the presence of DU directly impacts soil redox processes, leading to reduction of TEAs.

Impact of DU on Redox Processes in Waterlogged Soil. Suboxic conditions developed in the open waterlogged microcosms and controls over time due to low diffusion rates of oxygen through waterlogged soil (10). Dissolved oxygen decreased from 84% initially to 35% by day 133. Eh decreased slightly from 610 to 570 mV and pH slightly increased over the duration of the experiment, from pH 5.0 to 5.2 in the controls, and from pH 4.9 to 5.5 in the DU-amended experiments. Nitrate reduction, indicated by the decrease in NO $_3^-$ concentration, was observed in both the DU-amended experiments and controls after 69 days (Figure 1) although NO $_3^-$ was more depleted in the DU-amended microcosms. Iron(III) reduction was not observed and SO $_4^{2-}$ concentrations increased in both systems.

The closed waterlogged microcosms and controls became progressively anoxic, with Eh decreasing from 610 to –170 mV by day 510. Dissolved oxygen was depleted from 85% initially to 5% by day 34, and pH increased over the 510 days from 4.9 to 6.5. Differences in redox indicator concentrations were observed over time between control and DU-amended microcosms. Onset of NO $_3^-$ reduction was observed on day 34, and was complete by day 242 and 337 in the DU-amended microcosms and controls, respectively. In-growth of Fe(II) into soils was observed by days 242 and 337 for the DU-amended microcosms and controls, respectively. Sulfate initially increased in both the DU-amended and control microcosms. After this initial increase, SO $_4^{2-}$ reduction was observed concurrently with Fe(III) reduction in the DU-amended and control microcosms between days 242 and 337, respectively. Thus, in both the waterlogged systems, the presence of DU increased the rate of progression through the redox cascade. An increased rate has also been observed in DU-amended estuarine sediment microcosms (12).

Corrosion of DU under Field-Moist Conditions. Representative DU coupons from the field-moist microcosms are shown in Figure 2 after 242 and 337 days incubation. DU coupons had visually corroded by day 242, via localized pitting

FIGURE 1. DU-amended (x) and control (o) redox indicator time series data for the subsurface field-moist (A,D,G), open waterlogged (B,E,H), and closed waterlogged (C,F,I) microcosms. Nitrate (A–C), acid extractable Fe(II) (D–F), and sulfate (G–I) concentrations are shown over time. Error bars ± 1 s.d. ($n = 3$).

FIGURE 2. Black and white photographs showing DU coupons retrieved from the field-moist microcosm (A) after 242 days with a highlighted area (<) of pitting corrosion and a heavily corroded coupon (B) retrieved after 337 days. Also shown are DU coupons retrieved from the closed (C) and open waterlogged (D) microcosms after 337 days with highlighted areas (filled arrows) of pitting corrosion.

and cracking of the metal surface and by day 337 the coupons were covered with protruding, predominately yellow corrosion products. Corrosion of DU, as indicated by % mass loss (Figure 3A), was not significant until day 242 ($0.75 \pm 0.20\%$; $p = 0.0012$), indicating a latent period prior to the onset of corrosion. After day 242, corrosion progressed linearly ($r^2 = 0.99$) with a mass loss of 21% by day 510. The latent period could reflect the presence of a protective oxide layer. For pure U, this protective oxide layer will thicken and eventually crack at 75 nm, accelerating corrosion (11). Depletion of NO_3^- and in-growth of Fe(II) occurred with the onset of DU corrosion. Corroding U is a strong reducing agent and generates H_2 (11), thus these redox indicators may

be reduced biotically, through stimulation of H_2 -reducing species, or abiotically (12). These induced changes in the redox processes did not influence the DU corrosion rate, which progressed linearly ($R^2 = 0.99$).

Corrosion of DU under Progressively Reducing Waterlogged Conditions. Representative DU coupons retrieved from the open and closed waterlogged microcosms on day 337 both showed shallow pitting (Figure 2). DU corrosion, indicated by % mass loss (Figure 3), was not significant for the open ($p = 0.59$) and closed ($p = 0.43$) waterlogged microcosms until days 133 and 69, respectively, which corresponded with NO_3^- -reducing conditions. Once NO_3^- reduction was complete (by days 337 and 242 for the open and closed waterlogged systems, respectively), % mass loss was similar ($p = 0.84$) at $0.36 \pm 0.02\%$ and $0.37 \pm 0.08\%$, respectively. Concomitant DU corrosion and NO_3^- depletion suggests the two processes are related. In fact, NO_3^- reduction intermediates are reported to oxidize UO_2 to more mobile U(VI) species (15). For the remaining experimental period, no significant corrosion was observed in the open ($p = 0.10$) and closed ($p = 0.99$) waterlogged microcosms. Therefore, corrosion in the waterlogged systems occurred during NO_3^- reduction and ceased during Fe(III) and SO_4^{2-} reduction. Similar redox controls on DU corrosion have been observed in estuarine sediments, with corrosion ceasing during SO_4^{2-} -reducing conditions (12). In both studies the Eh/pH conditions were consistent with uraninite (UO_2) formation and subsequent passivation of the metal surface (16). This demonstrates that soil/sediment and water character do not appear to influence DU corrosion under anoxic conditions.

Rate of DU Corrosion as a Function of Redox Environment. The corrosion rates ($\text{g cm}^{-2} \text{y}^{-1}$) were calculated as described previously (12), but excluding the latent periods to increase accuracy and comparability. The time periods of corrosion used for calculations were: field-moist, days 242–510; open waterlogged, days 69–337; closed waterlogged, days 33–133. Experimental uncertainties on replicate microcosms for both time points were used to estimate total uncertainties. When calculating coupon surface area, the slightly curved side of the coupon was assumed to be straight, introducing a $\pm 2\%$ uncertainty.

FIGURE 3. Time series for DU corrosion in the field-moist (A,D), open waterlogged (B,E), and closed waterlogged (C,F) microcosms. A–C show mass loss (%) of DU metal from the DU coupon (◇) and D–F show changes in uranium concentration in the <0.45 μm (+) and <10 kDa (□) fractions. Error bars ± 1 s.d. (n = 3).

Corrosion was fastest in the field-moist microcosms ($0.49 \pm 0.06 \text{ g cm}^{-2} \text{ y}^{-1}$), intermediate between reported rates in soils exposed to 16 mm week⁻¹ of simulated rainwater ($0.19 \pm 0.03 \text{ g cm}^{-2} \text{ y}^{-1}$) (9) and the in situ rate at Kirkcudbright, UK ($0.8\text{--}1.1 \text{ g cm}^{-2} \text{ y}^{-1}$) (8). Corrosion rates in the open and closed waterlogged systems were 0.0092 ± 0.0005 and $0.020 \pm 0.005 \text{ g cm}^{-2} \text{ y}^{-1}$, respectively. This corrosion occurred only under NO₃⁻-reducing conditions and was at least an order of magnitude slower than that in field-moist soils. Corrosion rates in the waterlogged soils were also lower than observed in waterlogged marine sediments ($0.056 \pm 0.006 \text{ g cm}^{-2} \text{ y}^{-1}$) (12) under suboxic conditions, highlighting the importance of chloride concentrations in DU corrosion (17, 18).

Total corrosion time for a 120 mm “Charm 3” penetrator was estimated using corrosion rate ($\text{g cm}^{-2} \text{ y}^{-1}$), approximate mass (4500 g), and mean surface area during corrosion (i.e., 150 cm²) (12). Under field-moist soil conditions, the total corrosion time would be 55–69 years. Under waterlogged soils, with NO₃⁻-reducing conditions, total corrosion times in open and closed systems would be 3100–3400 and 1200–1900 years, respectively.

Corrosion Products and their Solubility. DU coupons from the field-moist microcosms had loosely bound corrosion products. Phosphor imaging of the surrounding soil indicated a heterogeneous distribution of U with scattered intense radioactive hotspots. These correlated with bright yellow corrosion products that were partially covered in soil. XRD analysis suggested the presence of metaschoepite or a similar phase, as previously reported (7). A representative ESEM image and EDAX spectrum of the selected particles are shown in Figure 4A–B. The image shows desiccation cracks, indicative of a partially dehydrated metaschoepite phase (7). The spectrum shows major U and O peaks and minor peaks from common matrix elements (Si, Fe, Mg, Al). In field-moist microcosms, dissolved U concentration correlated linearly with % mass loss ($r^2 = 0.96$) (Figure 3). By day 510, only 0.03% ($16 \pm 1 \text{ mg L}^{-1}$) of the corroded U was in solution, following a 15 min water extraction, which reinforces the dominance and low solubility of the particulate corrosion products observed. Colloidal U oxides were not important in this system, since the U concentrations in the <0.45 μm and <10 kDa fractions were not significantly different ($p = 0.10$). However, large particulate DU-oxides were observed and these would be naturally weathered in the environment.

DU coupons retrieved from the waterlogged soils had shallow pitting corrosion with no visible surface bound corrosion products. Phosphor imaging of the waterlogged

FIGURE 4. ESEM images (A,C) and EDAX spectra (B,D) of a corroded DU particle retrieved from field-moist microcosm (A,B) and a soil particle from a closed waterlogged microcosm (C,D).

systems indicated a dispersed, homogeneous distribution of U. A representative ESEM image and EDAX spectrum of selected soil particles are shown in Figure 4C,D. The spectrum shows minor U peaks and signals from Si, Fe, and Al. These results indicate that DU is present in the soil as sorbed species, rather than discrete corrosion products. Uranium concentrations in the <0.45 μm and <10 kDa fractions were not significantly different in the open ($p = 0.13$) and closed waterlogged ($p = 0.11$) microcosms, indicating that colloidal U oxides were not important (Figure 3). By day 337, 0.36% and 0.37% of the DU had corroded in the open and closed waterlogged microcosms, respectively. This corresponded with a dissolved U concentration in the open waterlogged system of $0.12 \pm 0.01 \text{ mg L}^{-1}$ (<0.01% of the corroded DU), with pH 5.7, Eh 600 mV, and NO₃⁻-reducing conditions. In the closed waterlogged systems, the dissolved U concentration was $1.02 \pm 0.47 \text{ mg L}^{-1}$ (<0.1% of the corroded DU), with pH 6.4, Eh -65 mV, and Fe(III)- and SO₄²⁻-reducing conditions. Using the initial inorganic carbon concentrations, the geochemical model Hydra/Medusa (Puigdomenech, Royal Institute of Technology, Stockholm) suggests U will

FIGURE 5. Phylogenetic affiliations of clones in field-moist (A,B) and the closed waterlogged (C,D) soils on day 435. Alpha, Beta, Delta, and Gamma represent proteobacterial divisions.

predominantly be in low solubility forms in both systems. In the open system, low solubility UO_2CO_3 would dominate, with some soluble species such as $\text{UO}_2(\text{CO}_3)_2^{2-}$ present. In contrast, reduced UO_2 species would dominate in the closed system, with minor amounts of soluble species such as $\text{UO}_2(\text{CO}_3)_2^{2-}$. Uranium soil extraction and water analyses show that by day 510, all corroded DU was associated with the soil ($100 \pm 4\%$) rather than the DU coupon and $<0.1\%$ U was in the solution phase. This provides further evidence that under waterlogged conditions, corrosion occurs by oxidation of DU metal to dissolved uranyl species, with subsequent dispersion into the environment. This corrosion mechanism has been proposed previously for DU in marine sediments (12), suggesting that water status is a major controlling factor.

Microbial Community Profile. The microbial community analysis using RISA of the field-moist and closed waterlogged soils on day 435 indicated DU had impacted the microbial community (Supporting Information (SI), Figure 1). Detailed phylogenetic analysis was conducted by PCR amplification, cloning and sequencing of fragments (approximately 1 kb) of the 16S rRNA genes within the bacterial community (SI Tables 1–4). The phylogenetic results obtained from DNA profiling are shown in Figure 5.

In the control field-moist soil, the clone library (55 clones analyzed, 15 RFLP types) was made up of a large number of novel, uncharacterized microorganisms, dominated by species of the Gammaproteobacteria genus *Rhodanobacter* (representing 38% and 44% of the 16S rRNA genes detected in the clone library, respectively). However, in the clone library from the field-moist DU-amended microcosm (55 clones analyzed, 20 RFLP types) the Gammaproteobacterial group was greatly reduced (consisting of 4% of the clones affiliated to *Rhodanobacter* species) while Gram-positive Bacilli, many of which can denitrify, dominated the clone library (48% of clones). The Bacilli phylogenetic class thrive in soil exposed to U_3O_8 (19) and at heavily contaminated U sites (20, 21). DU oxides (U_3O_8) have previously been shown to alter microbial community structures and reduce diversity (19), although reduced diversity was not shown in this system. The dominant organism detected in the DU impacted microbial community was closely related to *Sporosarcina Soli strain 180* (98% match over 925 bases), characterized as Bacilli phylogenetic class, aerobic, and NO_3^- -reducing microorganisms.

In both the control and DU-amended waterlogged soils (Figure 5) the clone libraries were again dominated by a large number of novel uncharacterized microorganisms. In the DU-amended microcosm a loss in microbial diversity was suggested (24 compared to 31 RFLP types from 57 clones analyzed from each soil); with the phylogenetic classes Alphaproteobacteria, Clostridia, Dehalococcoidete, Nitrospiro, and Sphingobacteria not detected in the presence of DU. They were replaced by other organisms, including Gammaproteobacteria (12% of clone library), comprising mostly an organism related to *Aquicella siphonis*, previously isolated from water samples in central Portugal (22).

The different end-members identified in both the field-moist and waterlogged soils may arise from adaptation to the chemical environment associated with the DU, resistance to toxic soluble uranium and/or particulate corrosion products, or even direct use of the DU itself as an electron donor (23). In the system studied here the presence of metaschoepite corrosion product caused a marked shift in the microbial community composition, whereas the presence of dissolved U caused a marked decrease in microbial community diversity. A similar effect was reported in a waterlogged marine sediment system containing dissolved U (12).

DU Corrosion as a Function of Soil Conditions. This study shows that mechanisms of DU corrosion and the products formed in subsurface soils are controlled by redox processes and soil water content. In field-moist soil, the metaschoepite corrosion product observed is in agreement with other laboratory and in situ studies (6–9). Under these conditions, DU corrodes at the fastest rate of $0.49 \pm 0.06 \text{ g cm}^{-2} \text{ y}^{-1}$, again broadly in agreement with literature data (8, 9), and is linear over time.

In waterlogged soils the mechanism of U release is the same as in waterlogged marine sediments (12), showing that water status and redox processes control UO_2 oxidation from the penetrator surface to mobile U(VI) species, and passivation of the metal surface as conditions become anoxic. DU corrosion has only been observed under NO_3^- -reducing conditions in waterlogged soil and the corrosion rate correlated with the rate of NO_3^- reduction. Comparison of these rates ($0.01\text{--}0.02 \text{ g cm}^{-2} \text{ y}^{-1}$) with those in marine sediment ($0.056 \pm 0.006 \text{ g cm}^{-2} \text{ y}^{-1}$) (12) highlights that the corrosion mechanism is controlled by water status and redox processes but the corrosion rate is influenced by the chloride concentration.

DU corrosion increased the rate of TEA utilization under all conditions investigated in this study and in a marine sediment (12). However, corroding DU impacts the microbial community in different ways under field-moist and waterlogged conditions, presumably due to the different corrosion products formed. The formation of predominantly metaschoepite corrosion products results in a shift in community structure, while the formation of predominantly soluble/ionic U species decreases diversity.

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Supporting Information Available

RISA profiles and tables containing the clone library DNA sequencing results. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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