A scenic view of a city with a snow-capped mountain in the background and a cable car in the foreground. The sky is blue with some light clouds. The city below is densely packed with buildings and trees. A cable car is visible on the left side of the image, suspended from cables. The mountain in the background is prominent and has a significant snow cover.

In Situ Chemical Reduction (ISCR): The Role of Reactive Mineral Intermediate Phases (RMIs) and Sulfidation

**Paul G. Tratnyek, Professor
OHSU-PSU School of Public Health
Oregon Health & Science University
<http://www.ebs.ieh.ohsu.edu/tratnyek/>**

ISCR—In Situ Chemical Reduction

<http://www.springer.com/series/8449/>, Vol. 7, 2014, v7

Chlorinated Solvent Source Zone Remediation
 Series: *SERDP ESTCP Environmental Remediation Technology, Vol. 7
 Kueper, B.H., Stroo, H.F., Vogel, C.M., Ward, C.H. (Eds.)
 2014
 Price from **\$149.00**
 Available Formats: eBook | Hardcover | More Information

Processes, Assessment and Remediation of Contaminated Sediments
 Series: *SERDP ESTCP Environmental Remediation Technology, Vol. 6
 Reible, Danny D. (Ed.)
 2014
 Price from **\$69.99**
 Available Formats: eBook | Hardcover | Softcover | More Information

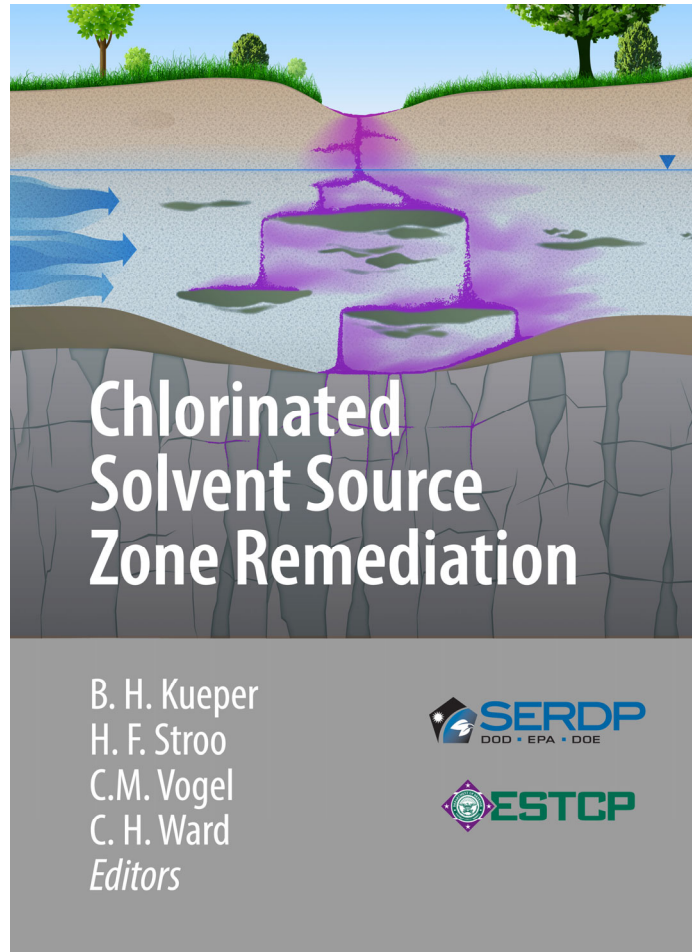
Bioaugmentation for Groundwater Remediation
 Series: *SERDP ESTCP Environmental Remediation Technology, Vol. 5
 Stroo, Hans F., Leeson, Andrea, Ward, C. Herb (Eds.)
 2013
 Price from **\$84.99**
 Available Formats: eBook | Hardcover | Softcover | More Information

Delivery and Mixing in the Subsurface
 Processes and Design Principles for In Situ Remediation
 Series: *SERDP ESTCP Environmental Remediation Technology, Vol. 4
 Kitanidis, Peter K., McCarty, Perry L. (Eds.)
 2012
 Price from **\$84.99**
 Available Formats: eBook | Hardcover | Softcover | More Information

In Situ Chemical Oxidation for Groundwater Remediation
 Series: *SERDP ESTCP Environmental Remediation Technology, Vol. 3
 Siegrist, Robert L., Crimi, Michelle, Simpkin, Thomas J. (Eds.)
 2011
 Price from **\$84.99**
 Available Formats: eBook | Hardcover | Softcover | More Information

In Situ Remediation of Chlorinated Solvent Plumes
 Series: *SERDP ESTCP Environmental Remediation Technology
 Stroo, Hans F., Ward, C. Herb (Eds.)
 2010
 Price from **\$84.99**
 Available Formats: eBook | Hardcover | Softcover | More Information

In Situ Bioremediation of Perchlorate in Groundwater
 Series: *SERDP ESTCP Environmental Remediation Technology
 Stroo, Hans F., Ward, C. Herb (Eds.)
 2009
 Price from **\$79.99**
 Available Formats: eBook | Hardcover | Softcover | More Information



IN SITU CHEMICAL REDUCTION FOR SOURCE REMEDIATION Paul G. Tratnyek, Richard L. Johnson, Gregory V. Lowry, and Richard A. Brown

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In situ chemical reduction (ISCR) has been given a variety of definitions since the term first started appearing in the late 1990s:

1. **Dolfing, van Eekert, Seech, Vogan, Mueller, 2006** (5th ChlorCon); **2008**, Soil Sed. Contam. 17(1): 63-74.
 - Combined C and Fe for synergistic effect
 - Context for Daramend® and EHC®
 - Trademarked by Adventus, no longer by FMC (now PeroxyChem)
2. **Brown et al., 2006** (5th ChlorCon); **2008** (6th ChlorCon); **2010** (SERDP Book, v5).
 - Evolving definitions some emphasizing analogy to ISCO
3. **Tratnyek 2010** (7th ChlorCon); **2014** (SERDP Book v7)
 - Precise, but inclusive
 - Non proprietary
 - Consensus

Wikipedia

In situ chemical reduction

From Wikipedia, the free encyclopedia

In situ chemical reduction (ISCR) is a new type of *environmental remediation* technique used for soil and/or groundwater remediation to reduce the concentrations of targeted environmental contaminants to acceptable levels. It is the mirror process of *In Situ Chemical Oxidation (ISCO)*. ISCR is usually applied in the environment by injecting chemically reductive additives in liquid form into the contaminated area or placing a solid medium of chemical reductants in the path of a contaminant plume.^[1] It can be used to remediate a variety of organic compounds, including some that are resistant to natural degradation.

The *in situ* in ISCR is just Latin for "in place", signifying that ISCR is a chemical reduction reaction that occurs at the site of the contamination. Like ISCO, it is able to decontaminate many compounds, and, in theory, ISCR could be more effective in ground water remediation than ISCO.

Chemical reduction is one half of a redox reaction, which results in the gain of electrons. One of the reactants in the reaction becomes oxidized, or loses electrons, while the other reactant becomes reduced, or gains electrons. In ISCR, reducing compounds, compounds that accept electrons given by other compounds in a reaction, are used to change the contaminants into harmless compounds.

Contents [hide]

- History
- Reductants
 - Zero valent metals (ZVM)
 - Iron minerals
 - Polysulfides
 - Dithionite
 - Bimetallic materials
 - Proprietary materials
- Reactions in ISCR
 - Reductive processes
 - Surface catalyzed reactions
 - Enhancement of reductive pathways
- Implementation
 - Semi-permeable reactive barrier
 - Direct injection of reductants
- Future of ISCR
- References
- External links

History [edit]

ISCR is a relatively new type of ground water remediation technology. The most work on this method of remediation has been done in the past 10–15 years, so there are still many gaps in the understanding of the chemistry behind this process. The development of ISCR started out when K.H. Sweeny conducted research with zero-valent copper and iron in the late 1970s. He was able to treat a number of different chlorinated substances such as DDT, endrin, chloroform, and hexachlorocyclopentadiene to name a few. His work has been the basis of ISCR today.^[2]

In the 1990s, Gilham, Tratnyek, Kriegman, Zhang, and Balchelor all made significant contributions in testing different metals and oxides for the use of ISCR.^[3] Gilham and Tratnyek in particular applied the reductive chemistry to groundwater treatment with the emplacement of ZVI barriers. Although it has been shown that other metals like aluminum and magnesium can produce the same effect in the laboratory, ground water treatment most generally focuses on the use of iron.^[4] Other major contributions in the field includes Zhang, who researched naphosale iron, and Balchelor, who researched zero-valent iron clay (ZVI Clay). This past decade, more aspects of ISCR have been researched and new methods of implementation, such as ZVI clay and emulsified ZVI (EZVI), have been created.

Scientists have also found that certain iron minerals, like green rust, magnetite, and pyrite, also have reductive capabilities although they contain ferrous iron rather than ZVI.^[5]

EnviroWiki

Chemical Reduction (In Situ - ISCR)

In situ chemical reduction (ISCR) refers to the *in situ* groundwater remediation approaches that principally involve contaminant treatment by chemical reduction. ISCR can occur via natural biogeochemical processes, catalyzed by *in situ* microbial activity, or by adding chemical reductants. Here, we introduce the basic principals and comment on the use of ISCR in remediation activities including outlining the common ISCR technologies available with links to more information.

Related Article(s):

- Chemical Oxidation (In Situ - ISCO)
- Biodegradation - Reductive Processes
- Remediation Technologies
- Monitored Natural Attenuation (MNA)

CONTRIBUTOR(S): Dr. Paul Tratnyek and Dr. Dimin Fan

Key Resource(s):

- Chemical Oxidation and Reduction for Chlorinated Solvent Remediation^[1]

Introduction

In situ chemical reduction (ISCR) has been given a variety of definitions since the term first started appearing in the late 1990s.^{[2][3][4][5][18]} In general, and for the purposes of this article, ISCR refers to the category of *in situ* groundwater remediation technologies where treatment occurs primarily by chemical reduction of contaminants. The emphasis of ISCR is on abiotic degradation processes, but contaminant reduction by biogenic minerals is included if the role of microbial activity in the contaminant reduction is indirect. The reducing conditions necessary for ISCR can arise from natural attenuation via "intrinsic" biogeochemical processes, or be generated by stimulation of *in situ* microbial activity (i.e. enhanced anaerobic bioremediation), or be created by addition of chemical reductants.

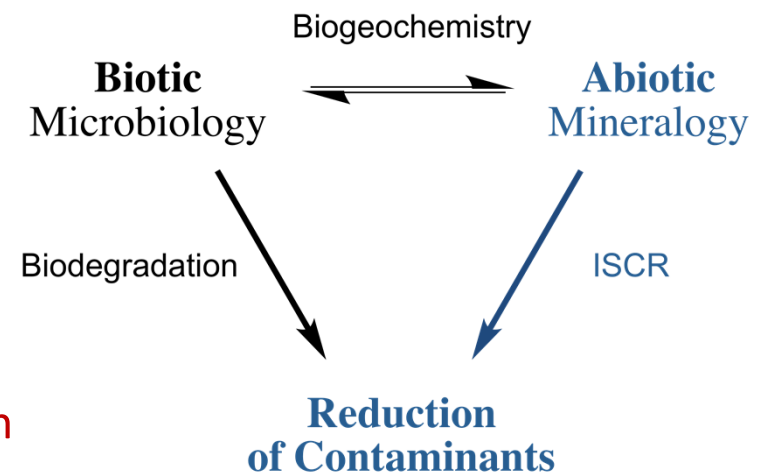
Contents [hide]

- Introduction
- Principles
- State of the Practice
- Common Approaches
- References
- See Also

ISCR—Definitions

Tratnyek, Johnson, Lowry, Brown (2014) SERDP Book Series, v7

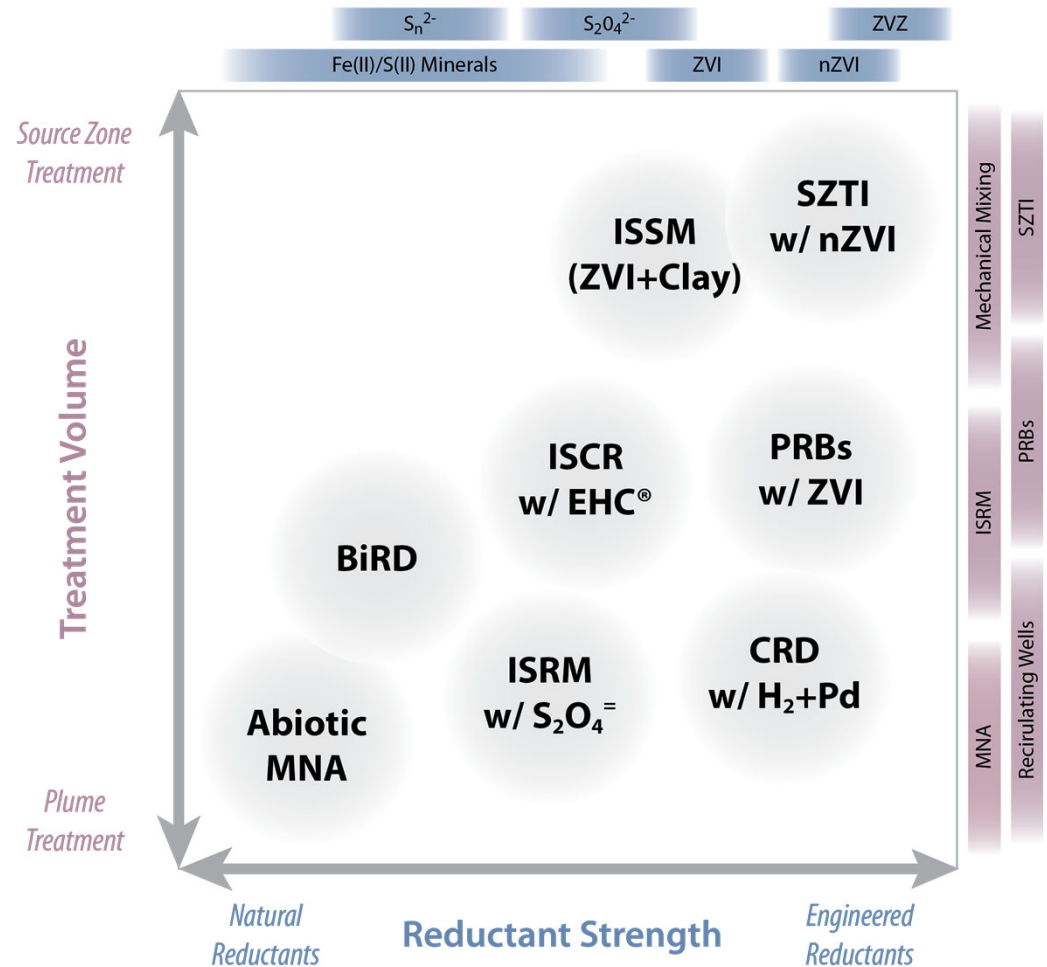
- In general, ISCR refers to the **category of in situ groundwater remediation technologies where treatment occurs primarily by chemical reduction of contaminants.**
 - Partially analogous to ISCO
- The emphasis of ISCR is on **abiotic processes**, but contaminant reduction by biogenic reducing minerals is included if the **role of microbial activity in the contaminant reduction is indirect.**
 - Implies a continuum from abiotic to biotic
- The reducing conditions necessary for ISCR can arise from **natural “intrinsic” biogeochemical processes**, or be generated by **stimulation of in situ microbial activity**, or be “engineered” by **addition of strong chemical reductants.**



ISCR—Technologies

Tratnyek, Johnson, Lowry, Brown (2014) SERDP Book Series, v7

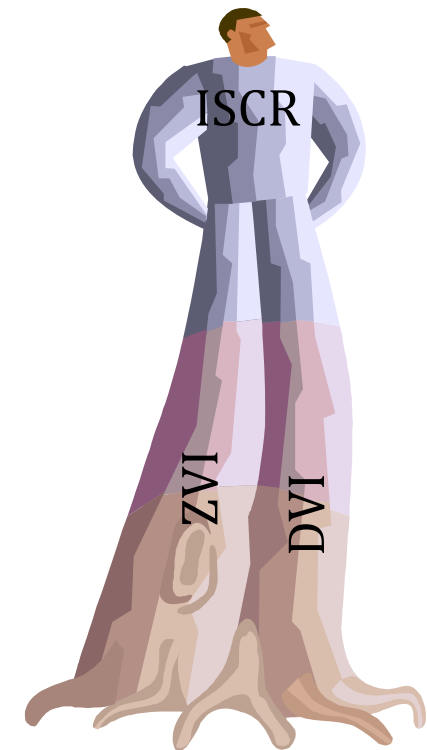
- **SZTI** (w/ nZVI):
Source zone targeted injection
- **ISSM** (w/ ZVI + Clay):
In situ soil mixing
- **ISCR^(®)** (w/ Daramend^(®) or EHC^(®)):
In situ chemical reduction
- **PRBs** (w/ ZVI):
Permeable reactive barriers
- **ISRM** (w/ dithionite):
In situ redox manipulation
- **CRD** (w/ H₂ + Pd):
Catalytic reductive dechlorination
- **ISBGT/BiRD** (w/ C and S):
Biogeochemical reductive dechlorination
- **Abiotic MNA**:
Monitored natural attenuation



The reductants that contribute to ISCR can be divided into two “branches”:

1. Relatively mild “**intrinsic**” reductants: natural minerals that contain **Fe^{II}** (DVI), **S^{-II}**, and/or **S^{-I}**, and natural organic matter (**NOM**).
2. Relatively strong “**engineered**” reductants: **dithionite** ($S_2O_4^{2-}$), zerovalent iron (**ZVI**) or other zerovalent metals (**ZVMs**).

Most of what applies to (1) may also be involved in (2).



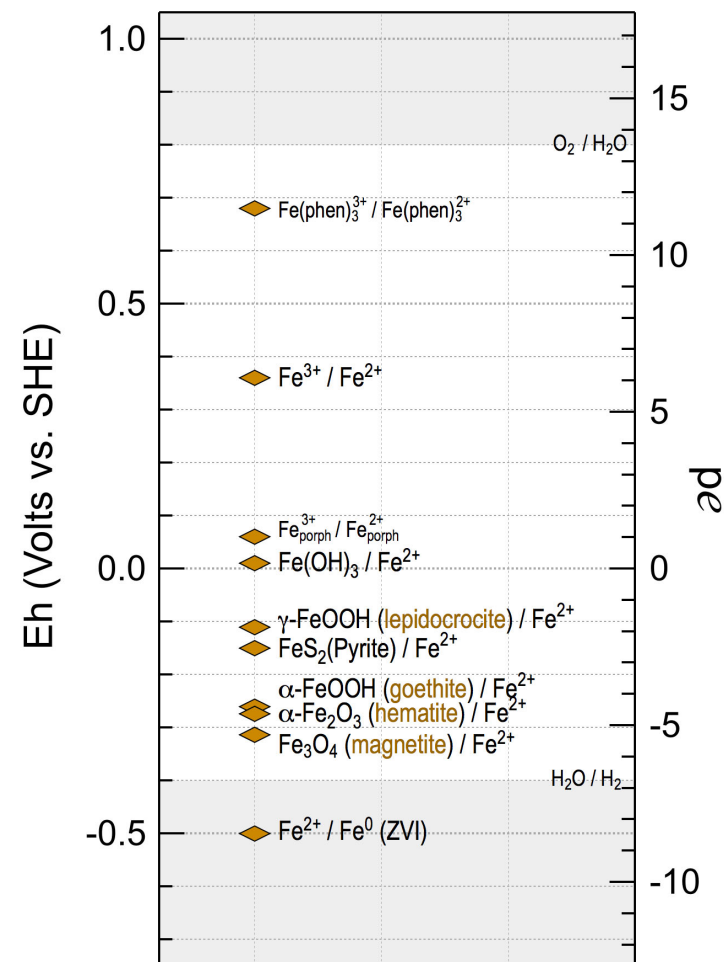
Various PPTs by
Dick Brown (ca. 2010)

ISCR—Reductants (Intrinsic)

Tratnyek, Johnson, Lowry, Brown (2014) SERDP Book Series, v7

The three types of “intrinsic” (naturally occurring), abiotic reductants that have been studied most thoroughly are:

1. Minerals (or their amorphous analogs) that derive reducing properties from **Fe^{II}** (DVI). These include **magnetite, green rust, ferruginous clays, iron oxides with adsorbed Fe^{II}**, and possibly minerals commonly associated with basalt.
2. Minerals deriving their reducing properties from **S^{-II} (or S^{-I})** as well as Fe^{II}. The most-studied such minerals are **mackinawite and pyrite**, but other Fe^{II} and S^{-II/-I} phases of possible significance include **greigite, marcasite, and amorphous FeS**.
3. Redox-active moieties associated with **natural organic matter**, which are mainly **quinones**, but could also include thiol groups and/or complexed iron.



ISCR—Reductants (Intrinsic)

Becvar, Evans, et al. (2008) AFCEE/ESTCP Workshop Report

- Biogeochemical Processes**

- Microbes (blue) respire
- TEAPs make $\text{Fe}^{\text{II}}/\text{S}^{-\text{II}/-\text{I}}$
- $\text{Fe}^{\text{II}}/\text{S}^{-\text{II}/-\text{I}}$ sorbs or precipitates (red)
- Mineral surfaces reduce TCE (yellow)

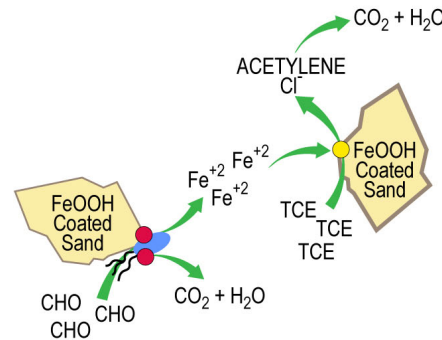
- Four Scenarios:**

- *Top row:* Fe^{II} sorbed onto $\text{Fe}^{\text{II/III}}$ oxides (Goethite, Magnetite)
- *Bottom row:* $\text{Fe}^{\text{II}}/\text{S}^{-\text{II}/-\text{I}}$ precipitate as Mackinawite or Green Rust

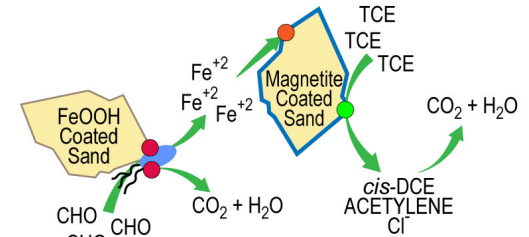
- Key Features:**

- Reductive elimination by (β or α) “abiotic” $2e^-$ pathway
- Makes acetylene etc., avoids “stall” intermediates (DCE, VC, CF)

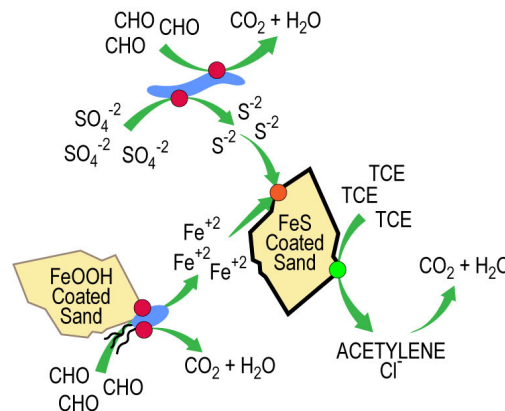
Ferrous Iron Chemisorption Mediated Transformation



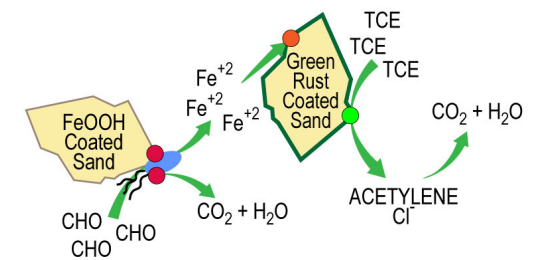
Magnetite Mediated Transformation



Iron Sulfide Mediated Transformation



Green Rust Mediated Transformation

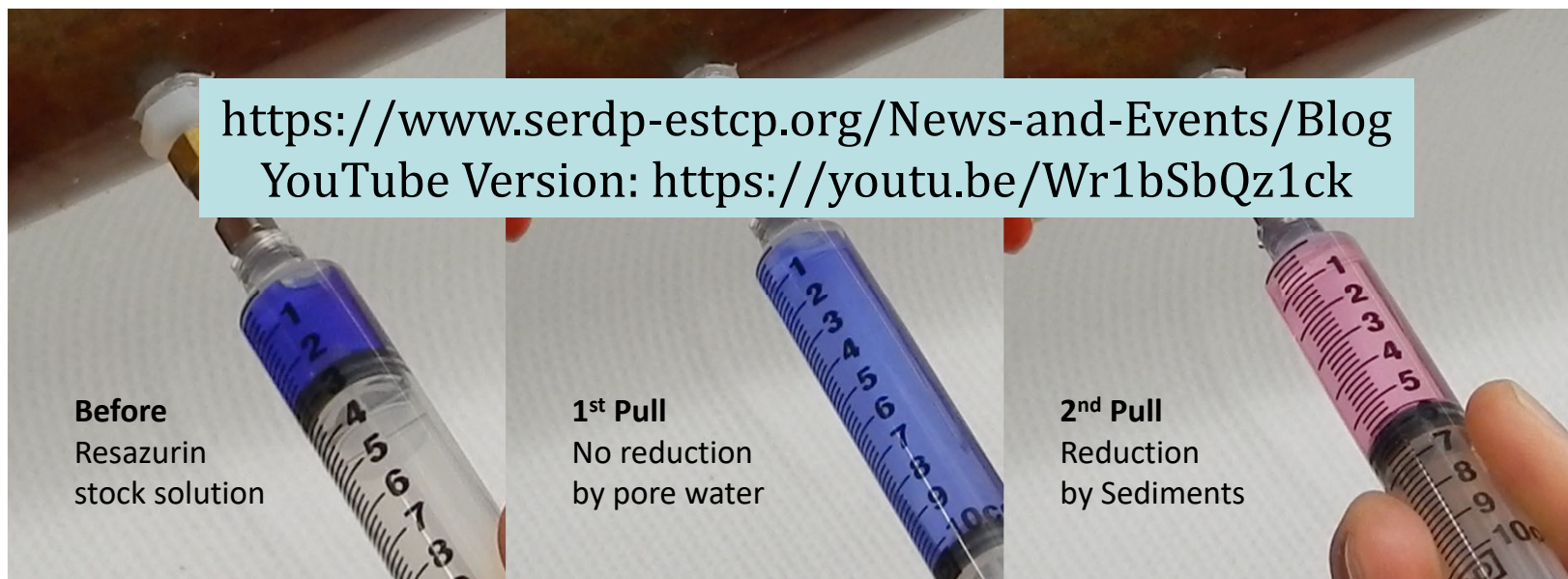


1. Reactive Mineral (Intermediate) Phases

SERDP ER-2308 (Tratnyek and Johnson)

Reactive Surface Area on Minerals:

- Not reflected in remote solution phase measurements (e.g., ORP)
- Chemical reactivity probe (CRP) like resazurin shows reactivity
- Resazurin: (1) purple = oxidized, (2) pink = reduced.



1. Reactive Mineral (Intermediate) Phases

Kocur, Johnson et al. (in prep.)

■ Hypothesis:

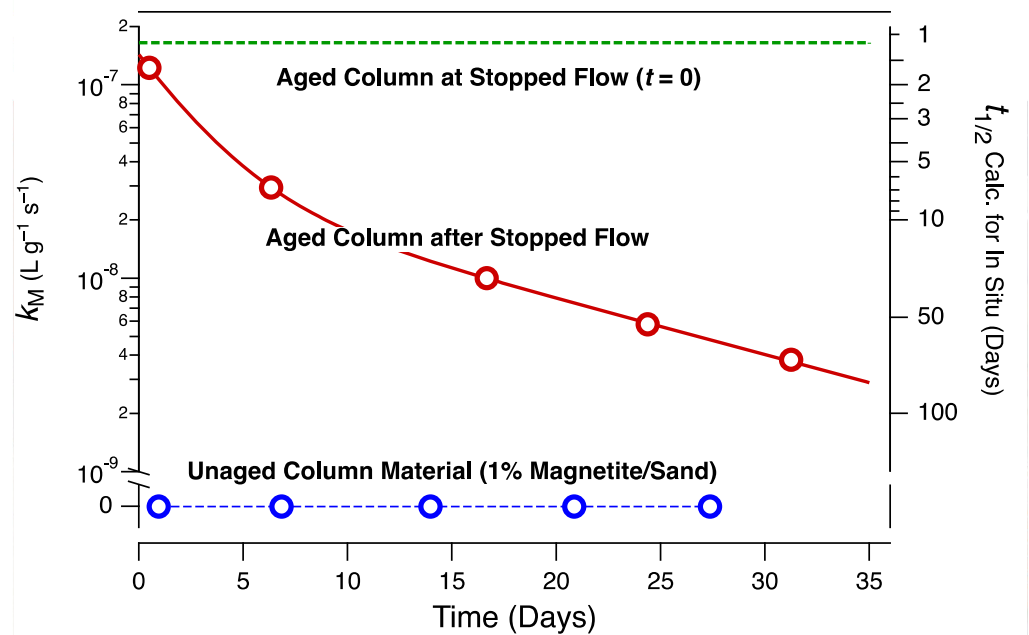
- Active precipitation leads to
- Metastable phases that serve as
- Reactive mineral intermediates (RMIs), which may cause
- Abiotic natural attenuation

■ Characteristics of RMIs:

- Formed *in situ* +
- Highly reactive =
- Metastable intermediates
- Transient or steady-state
- Can't be isolated
- Can degrade contaminants

[Home](#) > [Program Areas](#) > [Environmental Restoration](#) > [Contaminated Groundwater](#) > [Persistent Contamination](#) > ER-2621 Project Overview

Field Assessment of Abiotic Attenuation Rates using Chemical Reactivity Probes and Cryogenic Core Collection



1. Reactive Mineral (Intermediate) Phases

Culpepper et al. (2018) ESPI 20: 1340-1349

■ Hypothesis:

- Active precipitation leads to
- Metastable phases that serve as
- Reactive mineral intermediates (RMIs), which may cause
- Abiotic natural attenuation

■ Characteristics of RMIs:

- Formed *in situ* +
- Highly reactive =
- Metastable intermediates
- Transient or steady-state
- Can't be isolated
- Can degrade contaminants

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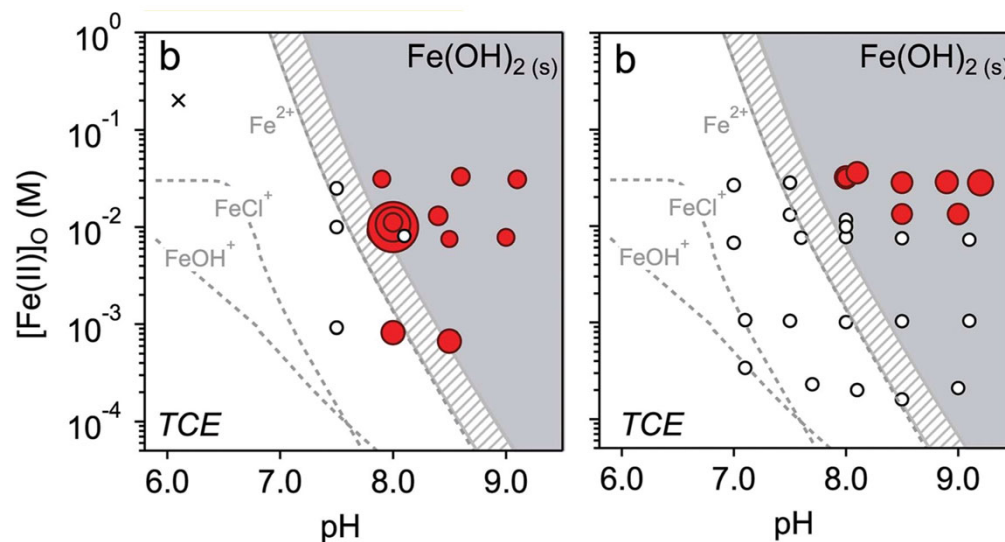
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Reduction of PCE and TCE by magnetite revisited†

Cite this: DOI: 10.1039/c8em00286j

Johnathan D. Culpepper,^{1b} Michelle M. Scherer,^{1b} Thomas C. Robinson,^{1b} Anke Neumann,^{1b} David Cwiertny,^{1b} and Drew E. Latta^{1b}*



1. Reactive Mineral (Intermediate) Phases

Qin et al. (2018) ES&T 52: 13887-13896

■ Hypothesis:

- Active precipitation leads to
- Metastable phases that serve as
- Reactive mineral intermediates (RMIs), which may cause
- Abiotic natural attenuation

■ Characteristics of RMIs:

- Formed *in situ* +
- Highly reactive =
- Metastable intermediates
- Transient or steady-state
- Can't be isolated
- Can degrade contaminants

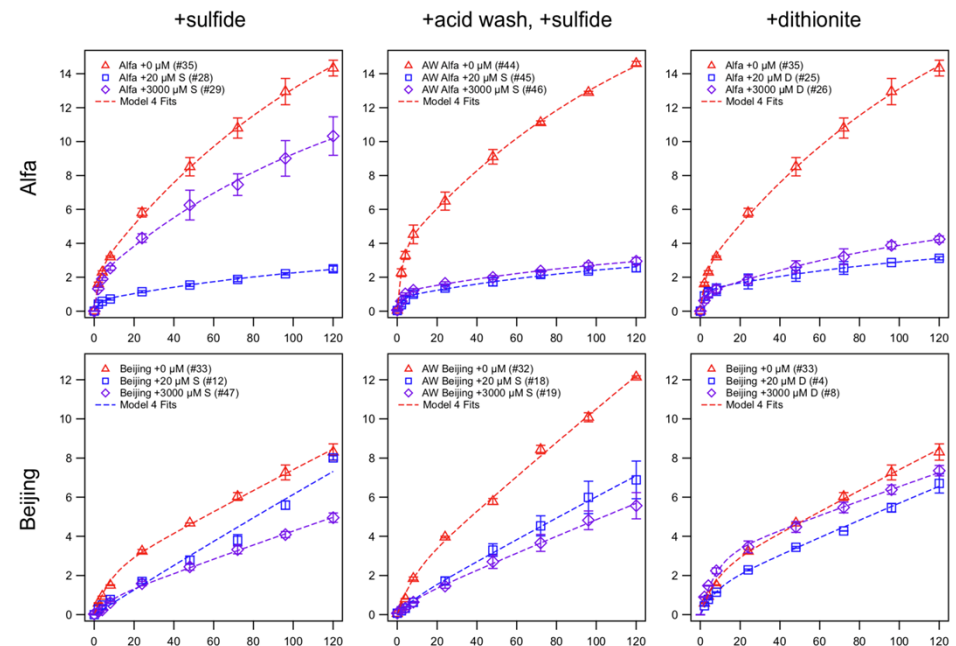


Cite This: Environ. Sci. Technol. XXXX, XXX, XXX-XXX

Article
pubs.acs.org/est

Modeling the Kinetics of Hydrogen Formation by Zerovalent Iron: Effects of Sulfidation on Micro- and Nano-Scale Particles

Hejie Qin,^{†,‡} Xiaohong Guan,^{*,†,‡,§} Joel Z. Bandstra,[§] Richard L. Johnson,^{||} and Paul G. Tratnyek^{*,||,Ⓞ}



2. Sulfidation of Fe/FeO

Fan et al. (2017) ES&T 51: 13070-13085

ENVIRONMENTAL
Science & Technology

ACS AuthorChoice

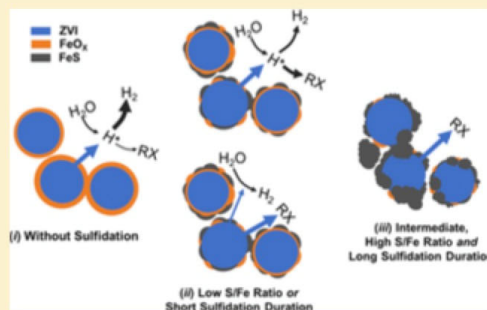
Critical Review

pubs.acs.org/est

Sulfidation of Iron-Based Materials: A Review of Processes and Implications for Water Treatment and Remediation

Dimin Fan,[†] Ying Lan,[‡] Paul G. Tratnyek,^{*,‡,⊕} Richard L. Johnson,[‡] Jan Filip,[§] Denis M. O'Carroll,^{||,⊕} Ariel Nunez Garcia,[⊥] and Abinash Agrawal[#]

ABSTRACT: Iron-based materials used in water treatment and groundwater remediation—especially micro- and nanosized zerovalent iron (nZVI)—can be more effective when modified with lower-valent forms of sulfur (i.e., “sulfidated”). Controlled sulfidation for this purpose (using sulfide, dithionite, etc.) is the main topic of this review, but insights are derived by comparison with related and comparatively well-characterized processes such as corrosion of iron in sulfidic waters and abiotic natural attenuation by iron sulfide minerals. Material characterization shows that varying sulfidation protocols (e.g., concerted or sequential) and key operational variables (e.g., S/Fe ratio and sulfidation duration) result in materials with structures and morphologies ranging from core–shell to multiphase. A meta-analysis of available kinetic data for dechlorination under anoxic conditions, shows that sulfidation usually increases dechlorination rates, and simultaneously hydrogen production is suppressed. Therefore, sulfidation can greatly improve the efficiency of utilization of reducing equivalents for contaminant removal. This benefit is most likely due to inhibited corrosion as a result of sulfidation. Sulfidation may also favor desirable pathways of contaminant removal, such as (i) dechlorination by reductive elimination rather than hydrogenolysis and (ii) sequestration of metals as sulfides that could be resistant to reoxidation. Under oxic conditions, sulfidation is shown to enhance heterogeneous catalytic oxidation of contaminants. These net effects of sulfidation on contaminant removal by iron-based materials may substantially improve their practical utility for water treatment and remediation of contaminated groundwater.



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2. Sulfidation of Fe/FeO (History)

<https://zenodo.org/record/2561103>



"PREPRINT EXTENDED ABSTRACT"
Presented Before the Division of Environmental Chemistry
American Chemical Society
Anaheim, CA. April, 2-7, 1995

REACTION MECHANISMS INVOLVED IN THE REDUCTION OF HALOGENATED HYDROCARBONS WITH SULFATED IRON

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February 9

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*Environmental Research Laboratory,
US EPA
Athens, GA 30605.

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Halogenated hydrocarbons are a class of major environmental contaminants of worldwide concern. Among the individual organic chemicals, the most prevalent at Superfund sites are trichloroethylene (TCE) and perchloroethylene (PCE) [1]. The use of metallic iron for treatment of such compounds in waste waters has been the focus of research over the last few years [2-7]. Reaction rates and products formed were thoroughly investigated in this research but a mechanism that satisfactorily describes the process has not been reported. Matheson and Tratnyek [8] attributed the reductive action of iron to three possible mechanisms-- direct electrolytic reduction, reduction by hydrogen produced by iron corrosion with water, and reduction by the produced ferrous ions. Senzaki [4], and recently Matheson and Tratnyek [9], have pointed out the importance of the iron surface for the dechlorination process. We have investigated the role of sulfur in initiating the dehalogenation of organic compounds in aqueous media [10]. The present communication reports some observations on the dehalogenation mechanism.

The role of sulfur:

Initially, two grades of iron were used to investigate the reduction of TCE and PCE. Results indicated that laboratory grade iron filings, whose average particle size was 420 um and sulfur content was >180 ppm, were reactive and resulted in production of appreciable amounts of ethyne, ethene, and ethane within 24 hours of reaction. Extra pure iron, at a particle size of 6 to 9 um and a sulfur content of 22.1 ppb, proved unreactive even after 1 month of reaction time. This result suggests that, in spite of the large surface area of the extra pure iron relative to laboratory grade variety, it is not effective in reducing these two halogenated hydrocarbons. Inclusion of sodium hydrogen sulfide in the reaction medium containing the extra pure iron, however, resulted in very fast production of the ethyne, ethene, and ethane. Other inorganic sulfur compounds produced the same effect but with varying lag times. Therefore, it was concluded that sulfur plays an important role in the dehalogenation reaction.

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The role of zero valent iron and iron sulfide:

Experiments were carried out to investigate the reductive capability of iron sulfide alone without zero valent iron. Results indicated that neither freshly prepared iron sulfide nor commercial iron pyrite alone was capable of dehalogenation of TCE or PCE. However, the inclusion of extra pure iron in these experiments resulted in dehalogenation of both TCE and PCE. The reaction products were ethyne, ethene, and ethane. Inclusion of magnesium metal instead of the extra pure iron in these experiments also resulted in dehalogenation. In the latter case, however, the reaction product was mainly ethyne. In another experiment, hydrogen gas was bubbled into an aqueous solution of TCE in the presence of iron sulfide. Reduction of TCE took place and ethyne was detected in the head space.

The results of these experiments indicated that, for dehalogenation to occur, both iron sulfide and hydrogen must be present in the reaction medium. In fact, sulfur is a common impurity in iron and its content varies according to the purity grade. The following reactions occur when iron, with sulfur impurities, reacts with water leading to the formation of hydrogen and iron sulfide (both are necessary for the dehalogenation process):



Because dissolution of iron in water increases in acidic media, lowering the pH was found to accelerate the dehalogenation reaction. Inclusion of sulfur compounds was recently reported to increase the rate of reduction of carbon tetrachloride [11]; this may be attributed to increased iron sulfide formation.

Other transition metal sulfides:

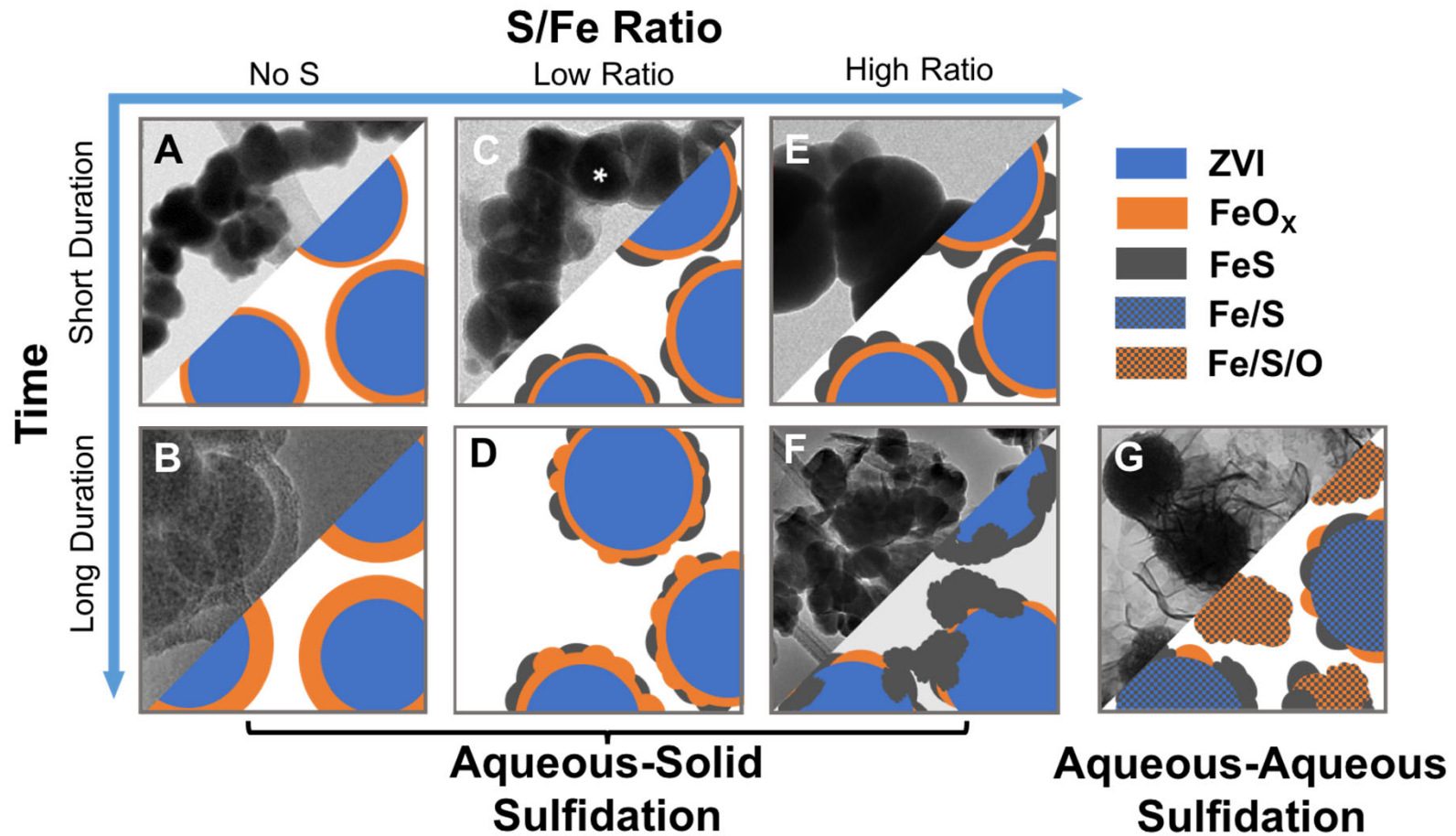
To further investigate the mechanism, the effects of using the sulfides of other transition metals in place of iron sulfide were examined. These experiments were carried out in the same way as the iron sulfide studies using magnesium metal as the source of molecular hydrogen. Sulfides of nickel, copper, zinc and cadmium were tested. The results indicated that both nickel and copper sulfides were able to reduce TCE and PCE, leading to the formation of ethyne, ethene and ethane in addition to a relatively large amount of an unidentified gas. The amounts of the dicarbon atom gases are about 1 to 2 orders of magnitude less than those produced from iron sulfide under the same conditions. Zinc and cadmium sulfides did not react.

According to Harris [12], the separation of the d orbital of the transition metals from the p orbital of sulfur in metal sulfides decreases from left to right across the periodic table. It appears that this same trend was followed in the reaction of the tested metal sulfides as dehalogenating agents. In this respect, nickel and copper occupy middle places to the right of iron and their sulfides are less reactive than iron sulfide. Zinc and cadmium occupy places at the far right of the first and second rows of the transition metals and their sulfides were not reactive. This trend coincides with our experimental results using the metal sulfides.

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2. Sulfidation of Fe/FeO (Conceptual Model)

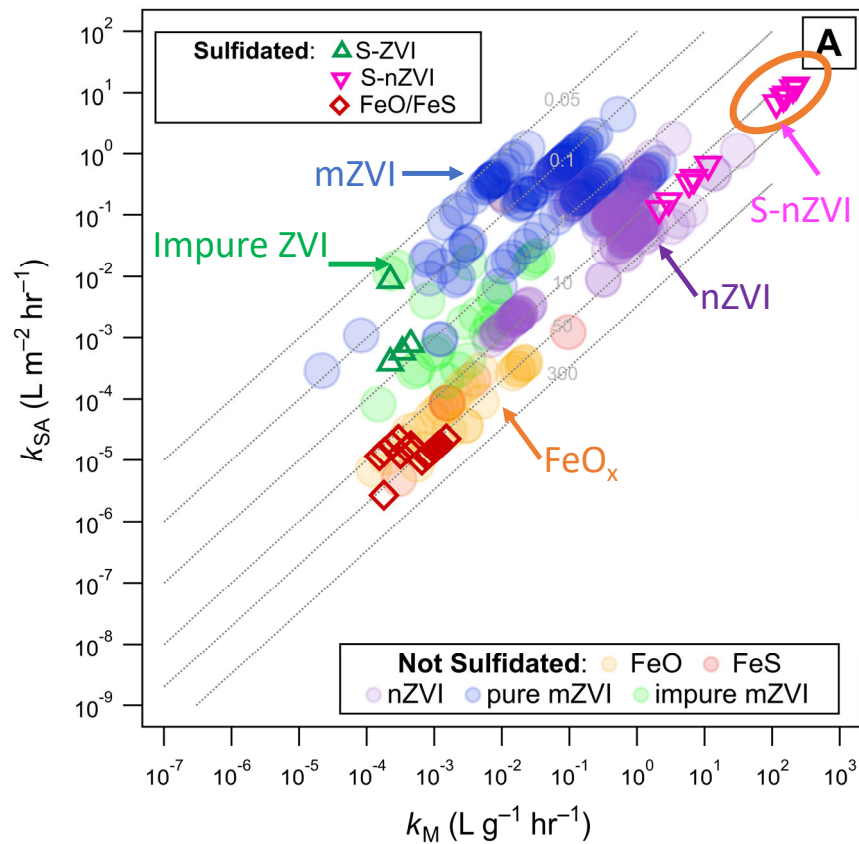
Fan et al. (2017) ES&T 51: 13070-13085



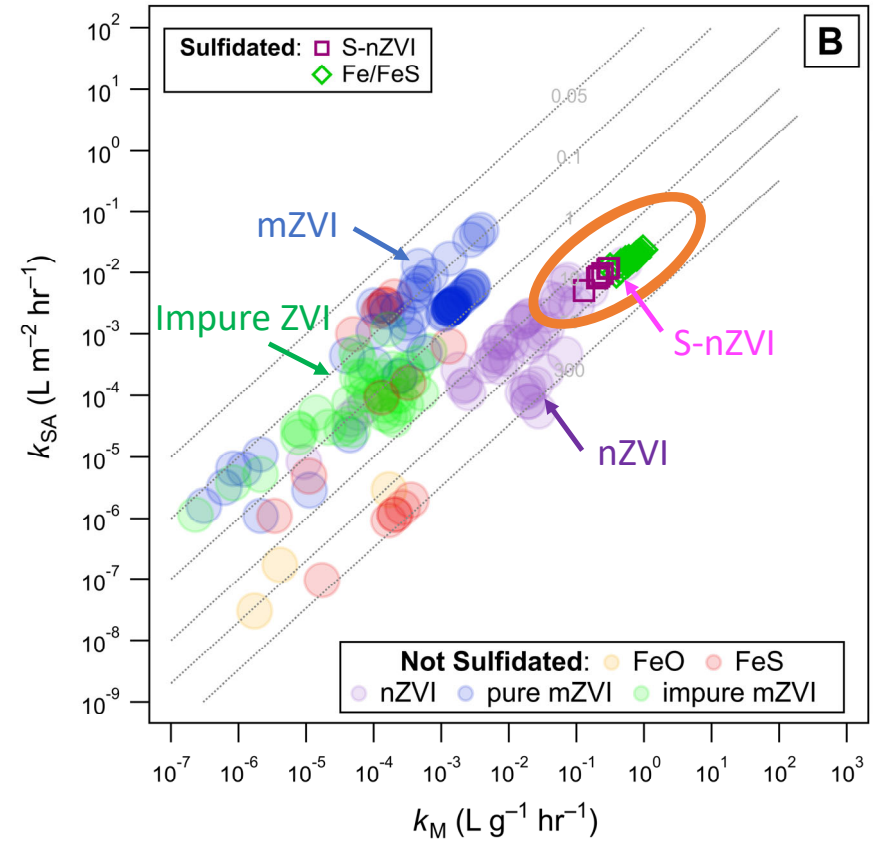
2. Sulfidation of Fe/FeO (Kinetics)

Fan et al. (2017) ES&T 51: 13070-13085

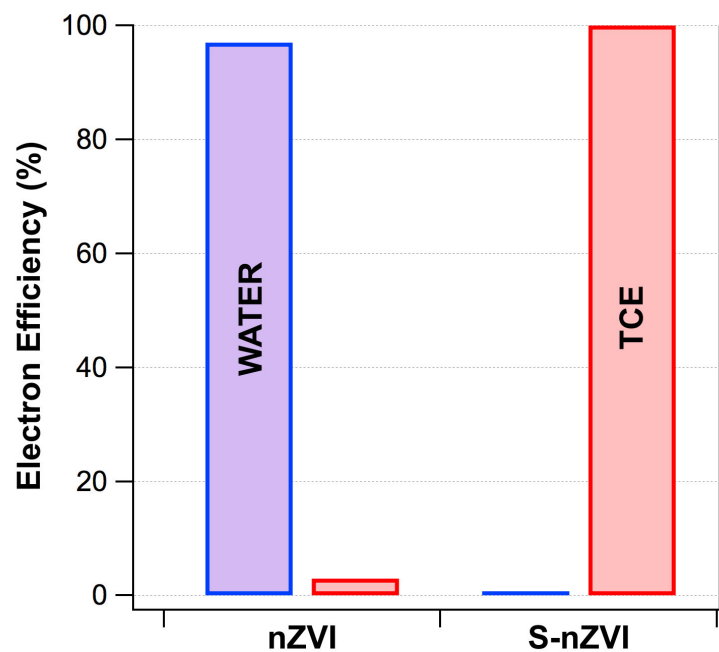
Carbon Tetrachloride



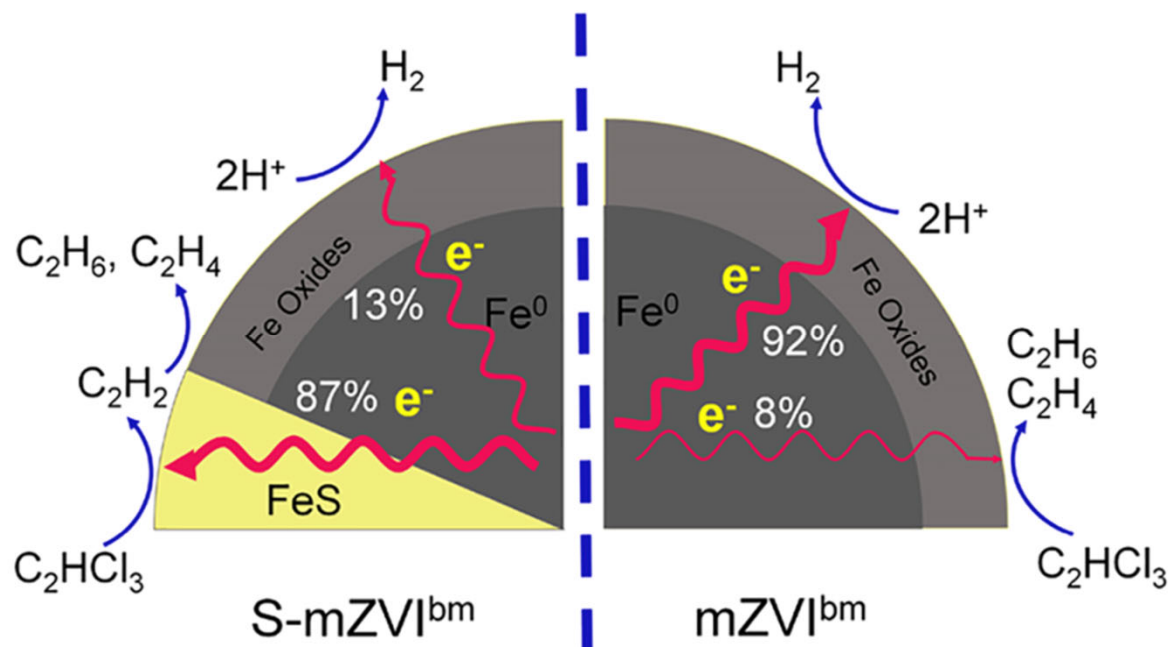
Trichloroethylene



2. Sulfidation of Fe/FeO (Efficiency)



Fan, O'Brien, et al. (2016)
 Env. Sci. Technol. 50: 9558-9565
Sulfidation of nZVI for Improved Selectivity during ISCR



Gu, Wang, He, et al. (2017)
 Env. Sci. Technol. 51: 12653-12662
Mechanochemically Sulfidated mZVI: Pathways, Kinetics, Mechanisms, Selectivity

2. Sulfidation of Fe/FeO (Engineering Practice)

■ Precursors to Sulfidation

- S-impurities in ZVI (Wolfe, Lipczynska)
- FeS minerals (Hayes, Reinhard, etc.)

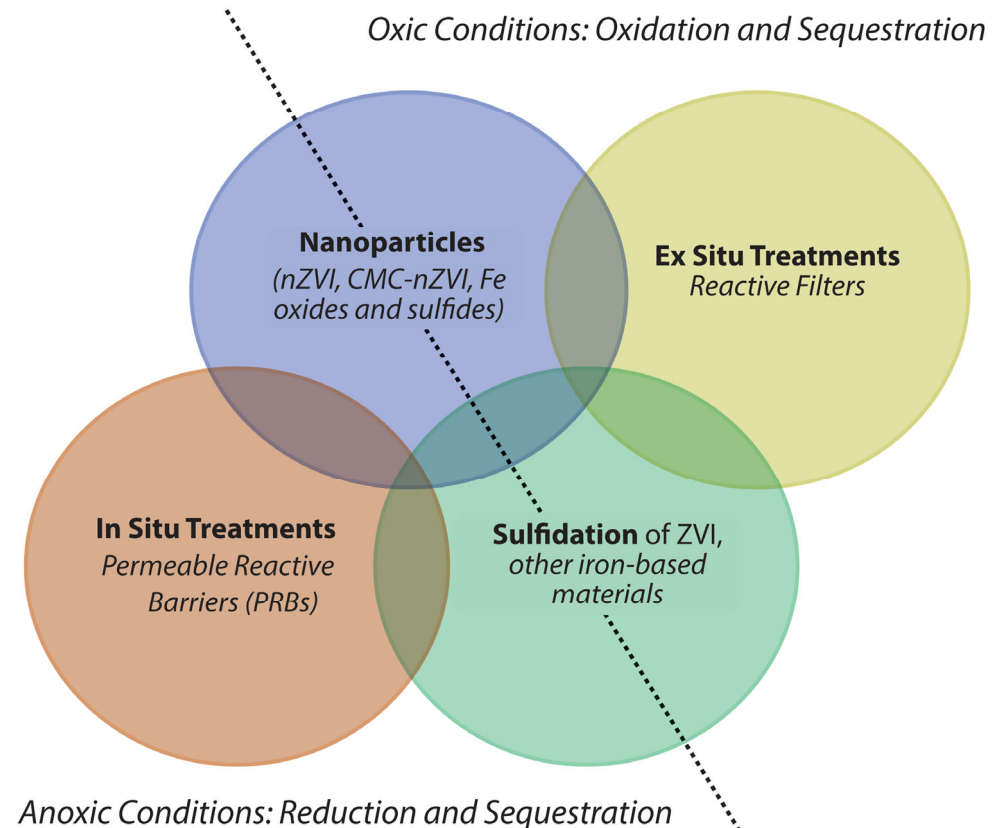
■ Benefits of Sulfidated ZVI

- Contaminant reduction kinetics/products
- Efficiency of CoC vs. water reduction

■ Technology Transfer

- Replaced bimetallic and nano ZVI in academic research
- Already several vendors of sulfur modified ZVI
- Vendors of other FeS amendments
- Consultant's Toolkit?

Fan, Tratnyek, et al. (2017) Env. Sci. Technol. 71: 13070-13085



Summary and Forecast

- **In Situ Chemical Reduction (ISCR): The Role of Reactive Mineral Intermediate Phases and Sulfidation.** P.G. Tratnyek, R.L. Johnson, C. Kocur, and Y. Lan. Paul Tratnyek (Oregon Health & Science University)
- **Abiotic Dechlorination of Trichloroethene by Naturally-Occurring Ferrous Minerals under Aerobic and Anaerobic Conditions.** C.E. Schaefer, P. Ho, E. Berns, and C. Werth. Charles Schaefer (CDM Smith, Inc.)
- **Abiotic Degradation of PCE and TCE by Magnetite and Clay Minerals.** M.M. Scherer, D.E. Latta, J. Culpepper, T. Robinson, A. Neumann, J. Entwistle, R. Deep, E. Suchomel, and L. Kane. Michelle Scherer (University of Iowa)
- **Naturally-Occurring and Biologically-Mediated Abiotic Transformation of Trichloroethene in Low-Permeability Formations.** D.L. Freedman, H. Wang, R. Yu, R. Iery, L. Slater, D. Adamson, F. Day-Lewis, and A. Danko, David Freedman (Clemson University)
- **Documenting In Situ Reactive Iron Mineral Formation without Drilling: A New Monitoring Well-Based Sampling Approach.** J. Martin Tilton, J. Ford, S.M. Ulrich, D. Liles, S. Justicia-Leon, C. Divine, D. Taggart, and K. Clark. Jennifer Martin Tilton (Arcadis)
- **Field Test Yields Aerobic Abiotic Trichloroethene Degradation Rate, Sorption and Diffusion Coefficients for Low Permeability Fractured Rock.** R.M. Allen-King, R. Kiekhaefer, and R. Dishman. Richelle Allen-King (University at Buffalo, SUNY)

Acknowledgements (Funding) and Disclaimer

■ Research Grants

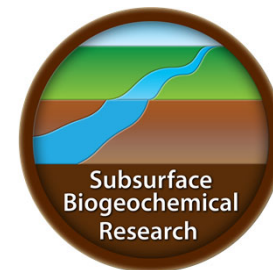
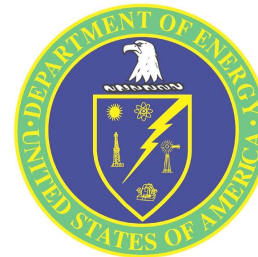
- SERDP/ESTCP (DOD)
- BER/SBR (DOE)
- CBET/ECS (NSF)

■ Site Projects

- Geosyntec
- Jacobs

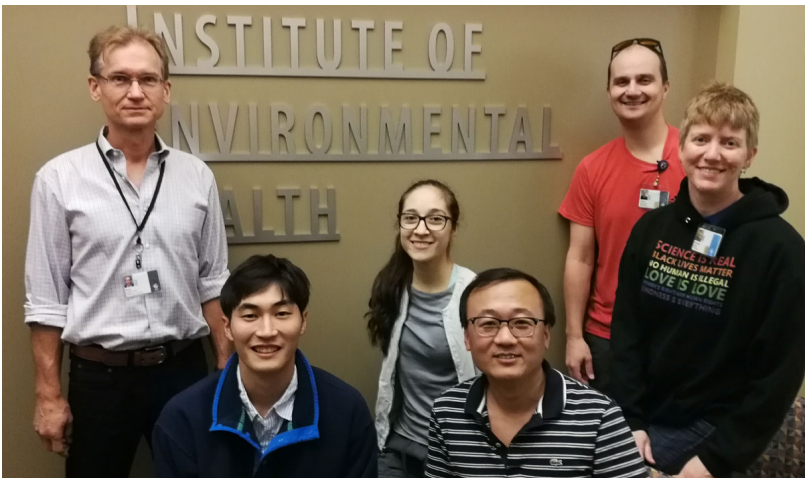
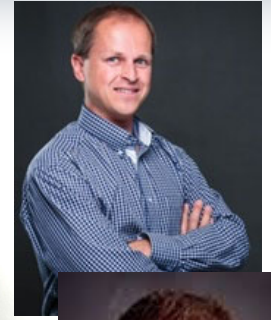
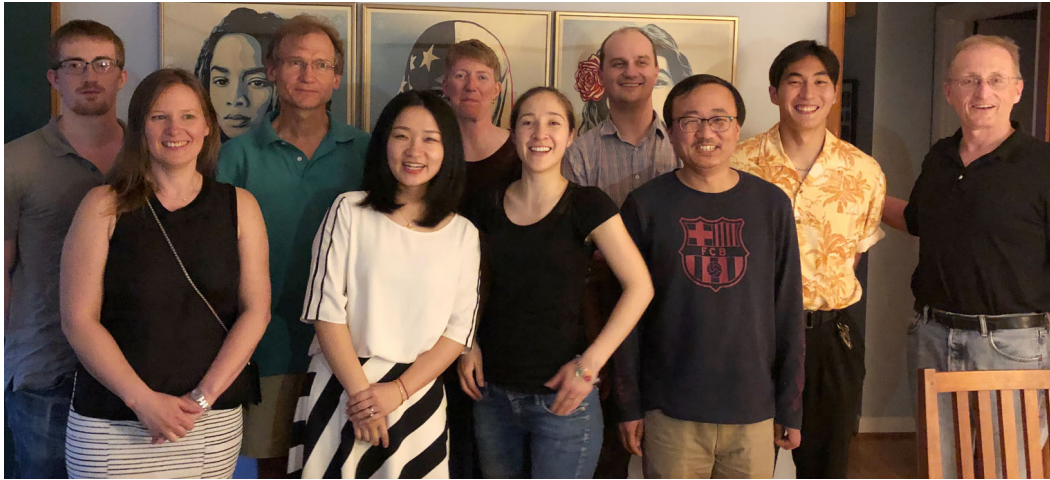
■ Material Testing

- Hepure/ARS, GMA,
- Adventus/Peroxychem,
- Peerless, Connelly, Provectus, BASF,
- Onmaterials/Regenesis, Toda, NANO IRON



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Acknowledgements (Collaborators)



Further Information



ISCR Book Chapter



Sulfidation Review



Push-Pull Video



Tratnyek Lab

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