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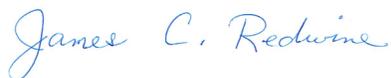


Semi-Annual Remedy Selection and Design Progress Report Plant Greene County

Prepared for Alabama Power Company

December 2020

Semi-Annual Remedy Selection and Design Progress Report Plant Greene County



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ABBREVIATIONS

ACM	Assessment of Corrective Measures
ADEM	Alabama Department of Environmental Management
Alabama Power	Alabama Power Company
CCR	coal combustion residuals
CEC	cation exchange capacity
CFR	Code of Federal Regulations
COI	constituent of interest
CSM	conceptual site model
EPA	U.S. Environmental Protection Agency
MNA	monitored natural attenuation
Site	Ash Pond at Plant Greene County
SEM	scanning electron microscopy
SSE	selective sequential extraction
SSL	statistically significant level
USGS	U.S. Geological Survey
XRD	X-ray diffraction
XRF	X-ray fluorescence

1 Introduction

In accordance with the U.S. Environmental Protection Agency's (EPA's) coal combustion residuals (CCR) Rule 40 Code of Federal Regulations (CFR) § 257.97(a), the Alabama Department of Environmental Management's (ADEM's) Admin. Code r. 335-13-15-.06(8)(a), and Part C of Administrative Order No. 18-097-GW, this *Semi-Annual Remedy Selection and Design Progress Report* has been prepared for the Ash Pond at Plant Greene County (Site). Specifically, this report has been prepared to describe the progress made in evaluating the selected remedy and alternative remedies and designing a remedy plan in the second semi-annual period of 2020.

In June 2019, Alabama Power Company (Alabama Power) completed an Assessment of Corrective Measures (ACM; Anchor QEA 2019) to address the occurrence of arsenic, cobalt, and lithium in groundwater at statistically significant levels (SSLs). In the ACM, the following remedies were considered feasible for corrective measures for groundwater:

- Monitored natural attenuation (MNA)
- Hydraulic containment
- Permeable reactive barrier walls
- Geochemical manipulation via injections (i.e., enhanced natural attenuation)
- Vertical barrier walls

As required by the Administrative Order, MNA was proposed as the main groundwater corrective action remedy for the Site. Source control measures—specifically, consolidation, dewatering, and capping of the ash (source) and emplacement of a vertical barrier (slurry) wall around the consolidated footprint—were already planned as part of pond closure.

Additional assessment work has been completed in 2020 to evaluate and demonstrate MNA and geochemical manipulation as corrective measures at the Site. Groundwater samples and solids (precipitates) were collected from select wells, and groundwater sampling results were used to perform geochemical modeling, which predicted attenuating species under Site geochemical conditions. Well solids were analyzed to determine attenuating phases for the constituents of interest (COI; arsenic, cobalt, and lithium) at the Site. Solids analysis also provides insight into the stability of the attenuating mechanisms. The well solids were analyzed as follows:

- Elemental analysis by X-ray fluorescence (XRF) to determine the chemical composition of the matrix (e.g., iron compounds, aluminosilicates, and carbonates) and presence of COI
- X-ray diffraction (XRD) to determine crystalline mineral phases
- Scanning electron microscopy (SEM) and associated elemental analysis to confirm mineral phases and attenuating mechanisms
- Selective sequential extraction (SSE) to determine the association of COI with attenuating phases and the relative binding strength of attenuated COI, and to provide a sense of permanence

- Cation exchange capacity (CEC) and exchangeable COI concentrations for samples that contain clay minerals

In addition, concentration versus time and concentration versus distance graphs were created to help determine if attenuation is occurring with time and/or distance from the ash pond. Any data obtained during on-site investigations or to evaluate corrective action alternatives will be included in the subsequent *Semi-Annual Groundwater Monitoring and Corrective Action Reports*.

2 Summary of Work Completed

Site investigations and preliminary design work have continued at the Site to support remedy selection and design. As discussed in the ACM (Anchor QEA 2019), completing a final long-term corrective action plan is often a multi-year process. Additional assessment work has been completed since June 2020, and laboratory work has been performed to support MNA and in situ geochemical manipulation as discussed in the ACM. MNA and geochemical manipulation are both geochemically based, such that site-specific geochemical data and analyses can be applied to both technologies.

Laboratory analysis of groundwater and precipitates (attenuating solids) was conducted to support MNA and geochemical manipulation. The major rationale for these investigations includes the following:

- Identifying attenuating mechanisms
- Gaining an understanding of the stability of the attenuating mechanisms
- Identifying potential geochemical manipulation approaches for COIs based on Site geochemical conditions and attenuation processes already occurring naturally

In the previous reporting period (January through June 2020), the following field and laboratory investigations were performed:

- Evaluated groundwater analytical data (primarily graphing) to look for evidence of natural attenuation occurring in space and time.
- Collected groundwater samples from background and impacted wells and performed a complete chemical analysis on the samples to enable groundwater geochemical modeling and the development of a geochemical conceptual site model (CSM).
- Performed geochemical modeling using the U.S. Geological Survey (USGS) computer program PHREEQC with the WATEQ4F thermodynamic database.
- Collected precipitate samples from the bottom of monitoring wells.
- Analyzed precipitate samples by XRF and XRD.

The following investigations were begun in the previous reporting period but completed in the current reporting period:

- SEM to directly observe attenuating mineral phases
- SSE to determine association of COI with attenuating phases, determine relative strength of attenuation, and provide a sense of permanence
- CEC to assess ion exchange as an attenuation mechanism

The work performed since the completion of the June 2020 progress report includes the following:

- Installing and sampling on-site and off-site horizontal delineation wells
- Completing SEM, SSE, and CEC testing on well solids samples

- Analyzing and synthesizing the laboratory data described above to develop a geochemical CSM and to evaluate MNA and geochemical manipulation
- Conceptualizing other corrective action options in the context of site-specific conditions, should MNA or geochemical manipulation not perform as expected

2.1 Preliminary Data Analysis

Results from existing groundwater data analysis, geochemical modeling, and well solids analyses provide evidence for attenuation mechanisms for arsenic, cobalt, and lithium, as summarized in Table 1. The attenuating mechanisms identified include sorption on iron oxides and oxyhydroxides; precipitation and co-precipitation with iron (arsenic and cobalt) and manganese (lithium) minerals; and cation exchange on clay minerals (lithium and possibly cobalt).

2.1.1 Concentration Versus Time and Concentration Versus Distance Graphs

Existing groundwater data were used to generate concentration versus time and concentration versus distance graphs to determine if attenuation is occurring over space and/or time and to assess natural attenuation rates. Arsenic, lithium, and cobalt were plotted on the y-axis. For the concentration versus distance graphs, the distance between the pond boundary and the monitoring well was plotted on the x-axis. No trends are apparent for the concentration versus distance graphs, though this could change as more data become available with continued monitoring. For the concentration versus time plots, the time between sampling events (in days) was plotted on the x-axis. Figures 1 and 2 show that arsenic and lithium concentrations are decreasing with time in well GC-AP-MW-18¹, which provides evidence for natural attenuation. Similar evidence from other wells is expected after closure, as closure activities (including the slurry wall) cut off the source of COI to groundwater.

2.1.2 Laboratory Analyses

Well solids (precipitates) were previously collected and were analyzed as follows:

- XRF to determine the chemical composition of the matrix (e.g., iron compounds) and presence of COI
- XRD to determine mineral phases
- SEM to directly observe attenuating phases
- SSE to determine association of COI with attenuating phases, determine relative strength of attenuation, and provide a sense of permanence
- CEC to assess ion exchange as a mechanism for attenuation

All samples with sufficient volume were analyzed by XRF. A select number of samples were chosen to be analyzed by XRD to determine predominant mineralogy. Samples for XRD analysis were selected

¹ No cobalt SSL in well GC-AP-MW-18

by looking at a variety of data, including, but not limited to, XRF data, field parameters, sample location, chemical analysis, and recovered sample mass.

The XRF chemical analysis of the well solids (Table 2) showed a relationship with at least one COI and elements associated with natural attenuation (iron, calcium, and/or manganese) detected in samples from 12 monitoring wells. The relationship of arsenic and iron is shown in Figure 3. Solids from upgradient wells were used to define the geogenic (natural) relationship of arsenic to iron (open circles and orange dashed line in Figure 3). Arsenic values above the line represent arsenic enrichment in iron compounds, which demonstrates arsenic attenuation in downgradient wells. XRD identified goethite, an attenuating iron oxide, in solids from one well (Table 3).

SEM and associated elemental mapping were conducted on select samples to confirm mineral phases and attenuating mechanisms. SEM results indicate that the solids collected from both GC-AP-MW-1 and GC-AP-MW-11 are a mix of quartz, iron-rich, and feldspar grains. In GC-AP-MW-1, extensive alteration with coatings of aluminum and iron material were observed on many quartz grains, and much of the iron material appears to be precipitates. In GC-AP-MW-11, extensive alteration, with heavy coatings of aluminum, iron, and (rare) calcium material were observed (Figure 4). The colors on Figure 4 are not natural but are added to show the locations of the various elements analyzed.

Based on the results from the XRF and XRD analyses and sample volume, samples were selected for SSE. SSE targets a series of operationally defined mineral fractions. In SSE, samples are leached with increasingly aggressive solutions to determine the chemical associations and mechanisms of attenuation. Generally, COIs released in each successive step represent stronger sequestration and greater stability than the previous step. The fractions, from most to least environmentally available, are as follows:

- F1 – Water soluble
- F2 – Exchangeable (e.g., clay minerals)
- F3 – Reducible (e.g., poorly crystalline metal oxides such as iron oxides)
- F4 – Oxidizable (e.g., crystalline oxide and crystalline sulfide minerals)
- F5 – Residual (e.g., silicate phases)

The F4 and F5 fractions represent relatively stable (permanent) attenuating mechanisms, provided Site geochemical conditions do not change drastically.

Figure 5 shows the results of SSE for four samples from the Site. Interpretation by COI includes the following:

- Arsenic – Bound primarily in the F4 (oxidizable) and F5 (residual) fractions, though some samples also show an association with the F2 (exchangeable) fraction. This is consistent with

the identification of crystalline iron oxides from the other investigations and possibly barium arsenate (predicted by geochemical modeling).

- Cobalt – Bound primarily in the F4 (oxidizable) fraction, though some cobalt is associated with all fractions. This is consistent with the identification of crystalline iron oxides from the other investigations.
- Lithium – Bound primarily in the F2 (exchangeable/clay), and in some samples F4 (oxidizable) and F5 (residual) fractions. This is consistent with the other investigations identifying cation exchange (F2) as the main attenuating mechanism.

Select samples with suspected clay content were submitted for CEC testing. CEC was variable in the samples, ranging from 15 to 432 milliequivalents per kilogram (Table 4). Exchangeable lithium was detected in solids from two downgradient wells, indicating attenuation of lithium by clay minerals.

2.2 Groundwater Geochemical Equilibrium Modeling

Geochemical equilibrium modeling was performed to help determine what is controlling the mobility and attenuation of arsenic, lithium, and cobalt, as well as the behavior of other species (such as iron) that influence the behavior of arsenic, lithium, and cobalt.

The Geochemist's Workbench software was used to plot Eh-pH data on Pourbaix stability diagrams to assess geochemical stability of controlling phases as needed. Figures 6 through 9, based on geochemical modeling and Site groundwater Eh-pH conditions, predict the attenuating species included below. In Figures 6 through 9, blue fields indicate dissolved/mobile species, and yellow fields indicate solid/attenuated species. The Pourbaix stability diagrams indicate the following associations and attenuating mechanisms, by COI:

- Arsenic associated with iron oxides (e.g., goethite and ferrihydrite; Figure 6), and barium arsenate (Figure 7)
- Cobalt associated with cobalt-iron oxides (Figure 8)
- Lithium possibly associated with manganese minerals (Figure 9)

These mineral associations are well documented in the scientific literature for arsenic, cobalt, and lithium.

Geochemical modeling was performed using PHREEQC with the WATEQ4F thermodynamic database to evaluate charge balance, calculate aqueous speciation, and determine saturation indices for minerals in the groundwater samples collected. Saturation index calculations can be useful in inferring potential solid phases present in an aquifer and controls on water chemistry and reactivity of an aqueous solution toward specific mineral phases. Geochemical modeling results indicate that iron oxides (e.g., goethite and ferrihydrite) are stable. Arsenic concentrations are likely controlled by sorption to iron oxides, and a barium arsenate mineral phase is also predicted to be stable. Geochemical modeling suggests that lithium concentrations may be controlled by precipitation of lithiophorite (lithium-

aluminum-manganese hydroxide). Note that SSE and CEC data indicate most lithium is in an exchangeable form, which is consistent with lithiophorite. Cobalt concentrations are likely controlled by adsorption to iron oxides and possibly coprecipitation in a cobalt-iron-oxide phase.

Groundwater in downgradient wells is slightly supersaturated and/or close to equilibrium with respect to amorphous iron hydroxide (e.g., ferrihydrite) and iron carbonates (siderite), and supersaturated with respect to crystalline iron oxides (goethite, hematite, and magnetite).

2.3 Geochemical Conceptual Site Model

The investigations described previously and geochemical equilibrium modeling were used to develop an initial geochemical CSM, including probable attenuating mechanisms for arsenic, lithium, and cobalt, and the relative stability of those mechanisms. The initial CSM for the Site is as follows:

- Multiple lines of evidence for arsenic, cobalt, and lithium attenuation
- Aerobic (upgradient) to suboxic (downgradient), and acidic conditions in groundwater
- Redox buffered by iron oxide (+/- carbonate) equilibria
- Arsenic attenuation by sorption to iron oxides and possibly precipitation of barium arsenate
- Cobalt attenuation by adsorption on, and co-precipitation with iron oxides
- Lithium attenuation by ion exchange on oxides and clay minerals

As supported by SSE results and the scientific literature, incorporation of arsenic and cobalt into iron minerals, arsenic into barium arsenate, and lithium into manganese oxides are relatively stable attenuation mechanisms.

3 Planned Activities and Anticipated Schedule

The following conceptual-level feasibility study activities are planned for the next reporting period (January to June 2021) to evaluate MNA, geochemical manipulation, and possibly other corrective action technologies:

- Continue to compare site-specific corrective actions to the evaluation criteria in the CCR Rule, with emphasis on deficiencies that could eliminate a corrective action from further consideration
- Continue to determine how corrective actions could be integrated with pond closure, such as dewatering and associated water treatment systems
- Develop plans for additional Site investigations and associated laboratory work to determine MNA capacity, rates, and stability; and plans for laboratory treatability and/or field pilot tests to determine the effectiveness of geochemical manipulation as needed

Section 2 describes substantial evidence for the occurrence of natural attenuation at the Site. The EPA's four phases (or tiers) of MNA (EPA 2015) are as follows:

- Phase 1 – Demonstrate area of impacts (plume) is stable or shrinking
- Phase 2 – Determine mechanisms and rates of attenuation
- Phase 3 – Determine system capacity and stability
- Phase 4 – Design performance monitoring program and identify alternative remedies

The MNA work performed at the Site to date primarily supports Phase 2 (specifically mechanisms) of attenuation, though some information has been collected that supports all four phases. To advance MNA at the Site, additional work needs to be performed with respect to rate, aquifer capacity, and stability (permanence) of MNA.

Though substantial evidence for natural attenuation exists for the Site, natural attenuation is expected to increase as source control measures are implemented (i.e., dewatering, consolidation, slurry wall, and capping). MNA will almost certainly be one component, if not the only component, of corrective action. MNA could be implemented immediately upon pond closure.

The longer-term schedule for developing a groundwater corrective action system at the Site is as follows:

- Collect additional soil samples and perform associated laboratory work to determine MNA capacity, rates, and stability (first and second quarters 2021)
- Perform laboratory treatability studies and implement field pilot tests as needed (second and third quarters 2021)
- Prepare a Remedy Selection Report (fourth quarter 2021)
- Develop a Corrective Action Groundwater Monitoring Program (fourth quarter 2021)

During the next reporting period, other potential remedies identified in the ACM will continue to be evaluated with respect to technical feasibility, ability to attain target standards, and ease of implementation. Based on the site-specific evaluation, additional studies may be implemented.

The schedule of activities above is considered typical and will be affected by the pond closure activities and schedule. For example, some of the activities could be performed sooner, to enable integration of corrective action with pond closure. Similarly, pond closure activities might delay implementation of some of the items above.

Pursuant to 40 CFR 257.97(a) and ADEM Admin. Code r. 335-13-15-.06(8)(a), semi-annual status progress reports will continue to be finalized in June and December until a final remedy plan is developed. Upon developing a final remedy plan, the Remedy Selection Report will be prepared describing the remedy plan and how it demonstrably meets the requirements of § 257.97 and r. 335-13-15-.06(8). Details regarding adaptive management triggers and criteria will be included in the Corrective Action Groundwater Monitoring Program.

Alabama Power will continue groundwater monitoring at the Site and will submit the next *Semi-Annual Remedy Selection and Design Progress Report* by June 12, 2021.

4 References

Anchor QEA (Anchor QEA, LLC), 2019. *Assessment of Corrective Measures*. Greene County Ash Pond. Prepared for Alabama Power Company. June 2019.

EPA (U.S. Environmental Protection Agency), 2015. *Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites*. Office of Solid Waste and Emergency Response Directive 9283.1-36. August 2015.

Tables

Table 1
Lines of Evidence for Attenuation Mechanisms

Mechanism	Geochemical Modeling	XRF	XRD	SSE	CEC
Sorption on iron oxides (arsenic, cobalt)	X	X	X	X	
Precipitation of barium arsenate	X				
Co-precipitation in iron oxides (cobalt)	X			X	
Cation exchange on clays (cobalt, lithium)		X		X	X

Notes:

CEC: cation exchange capacity

SSE: selective sequential extraction

XRD: X-ray diffraction

XRF: X-ray fluorescence

Table 2
Bulk Chemistry by XRF

Well ID	Arsenic	Cobalt	Iron	Manganese	Aluminum	Calcium	Magnesium	Potassium	Silicon
GC-AP-MW-1	336	ND	263,630	ND	19,150	760	ND	4,350	190,000
GC-AP-MW-10	517	ND	234,930	ND	11,460	15,350	ND	3,910	160,000
GC-AP-MW-11	644	ND	231,160	ND	18,090	2,480	ND	5,410	133,000
GC-AP-MW-16	5,128	ND	212,580	ND	3,240	245,920	ND	820	37,000
GC-AP-MW-23	3	ND	15,220	ND	16,130	1,430	ND	4,330	370,000
GC-AP-MW-29	ND	ND	14,960	ND	13,960	360	ND	4,780	375,000

Notes:

Direct analysis of lithium is not possible with portable XRF due to X-ray physics limitations.

Units are in milligrams per kilogram

ND: below limit of detection

XRF: X-ray fluorescence

Table 3
Minerals Identified in Well Solids Samples by XRD¹

Well ID	Quartz	Calcite	Goethite
GC-AP-MW-1	X	--	X
GC-AP-MW-10	97	3	--
GC-AP-MW-11	100	--	--
GC-AP-MW-16	17	83	--
GC-AP-MW-17	100	--	--
GC-AP-MW-23	100	--	--
GC-AP-MW-29	100	--	--

Notes:

1. Estimated concentration (weight %) reported where available

--: not detected

X: Positive identification, not quantified

XRD: X-ray diffraction

Table 4
Cation Exchange Capacity of Well Solids Samples

Well ID	Aluminum	Boron	Calcium	Lithium	Magnesium	Potassium	Sodium	Sum
GC-AP-MW-29	<0.003	<0.003	8.0	<0.005	3.5	0.34	3.5	15.3
GC-AP-MW-1	0.10 J	<0.05	120	0.072 J	30	3.5	53	207
GC-AP-MW-11	<0.03	<0.03	250	0.43	61	6.5	115	432

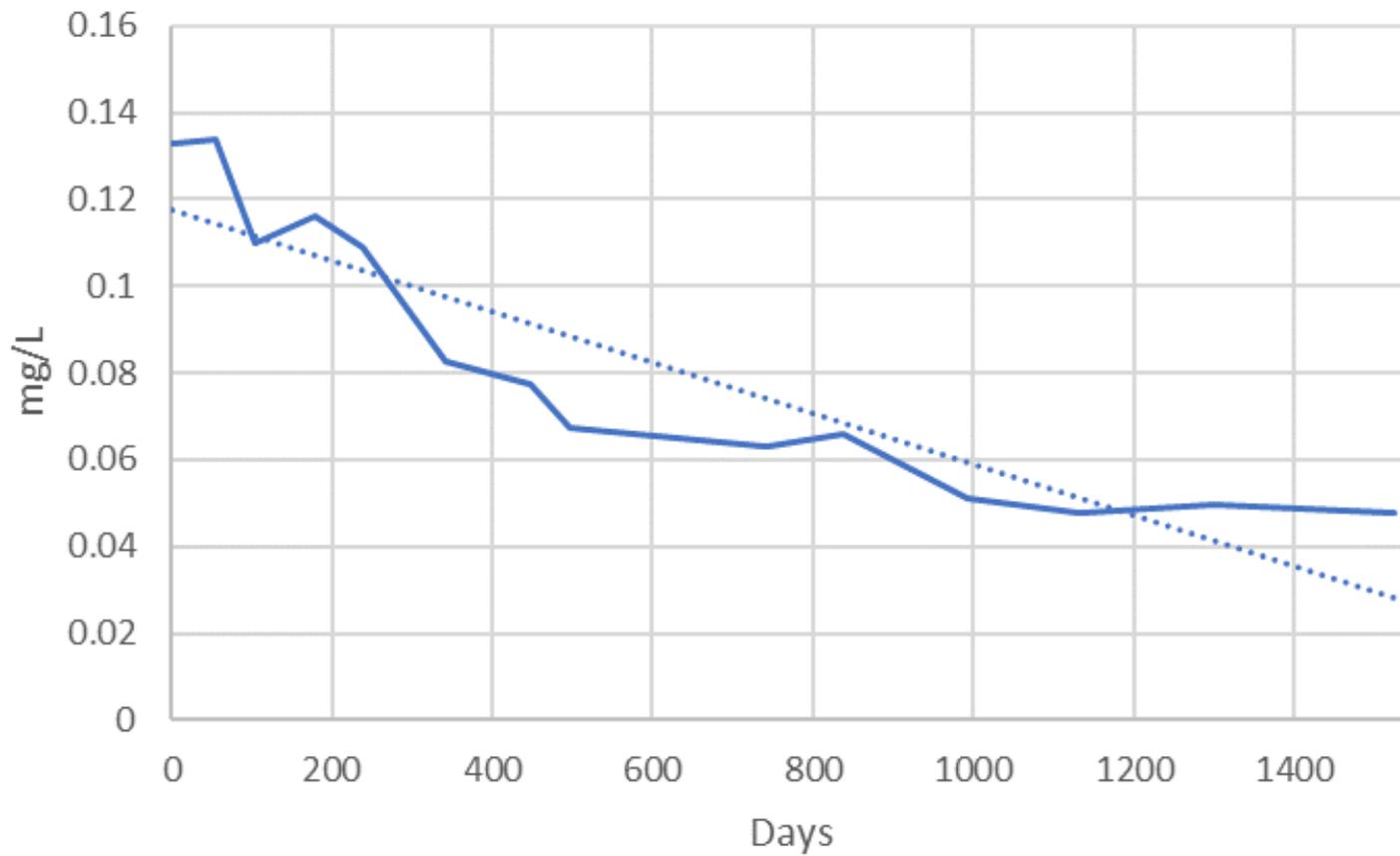
Notes:

Units are in milliequivalents per kilogram

<: Indicates the compound was analyzed for but not detected

J: Detected but results below method reporting limit

Figures

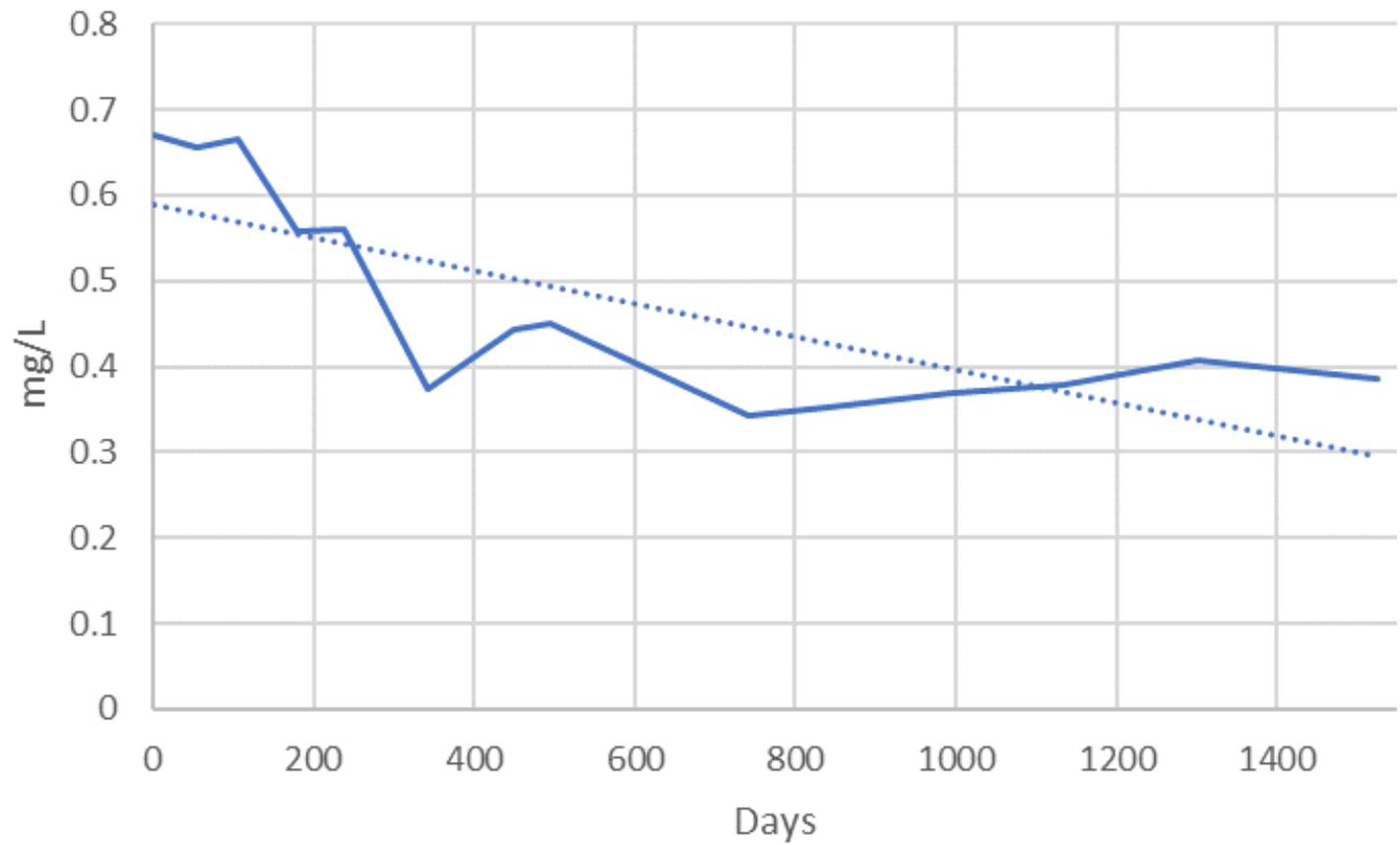


Note:
mg/L: milligrams per liter

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Figure 1
Arsenic Concentration Versus Time in GC-AP-MW-18
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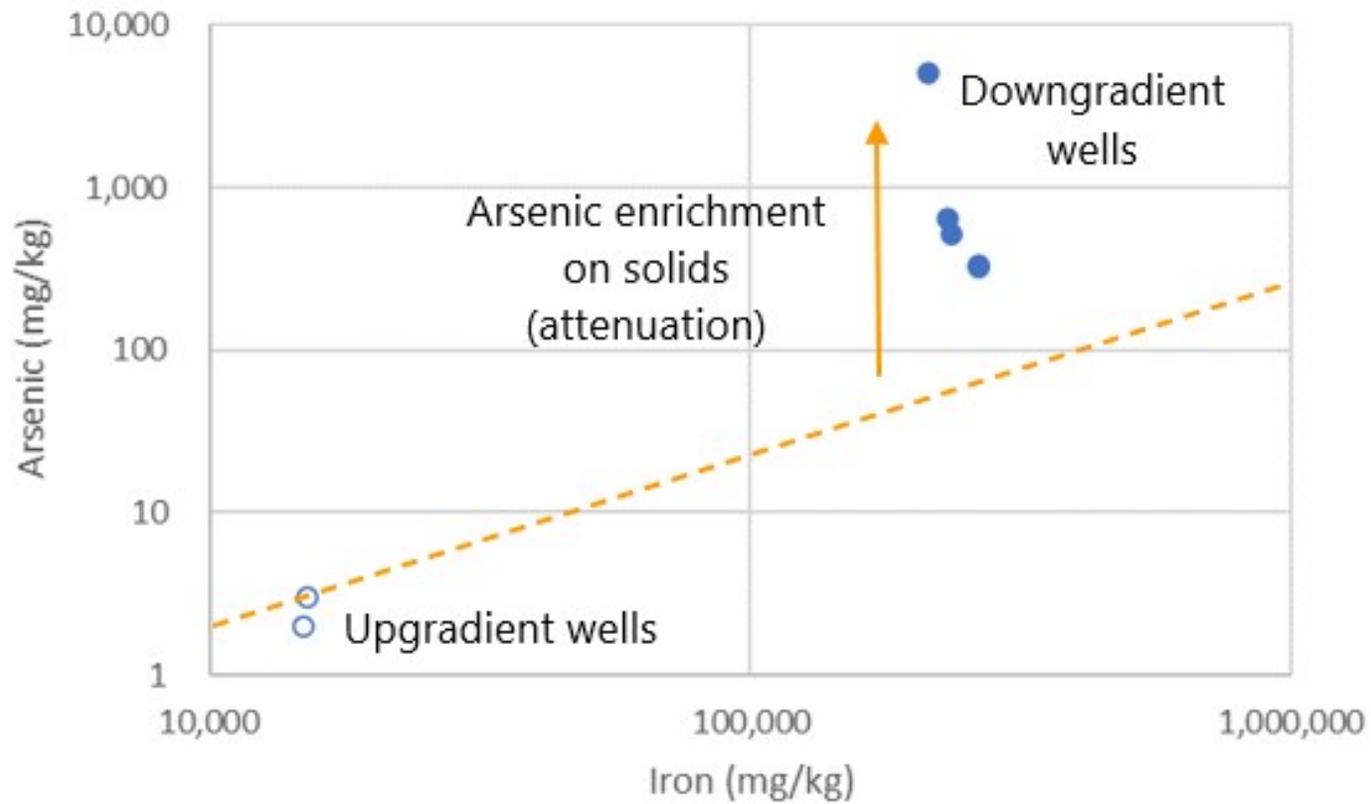


Note:
mg/L: milligrams per liter

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Figure 2
Lithium Concentration Versus Time in GC-AP-MW-18
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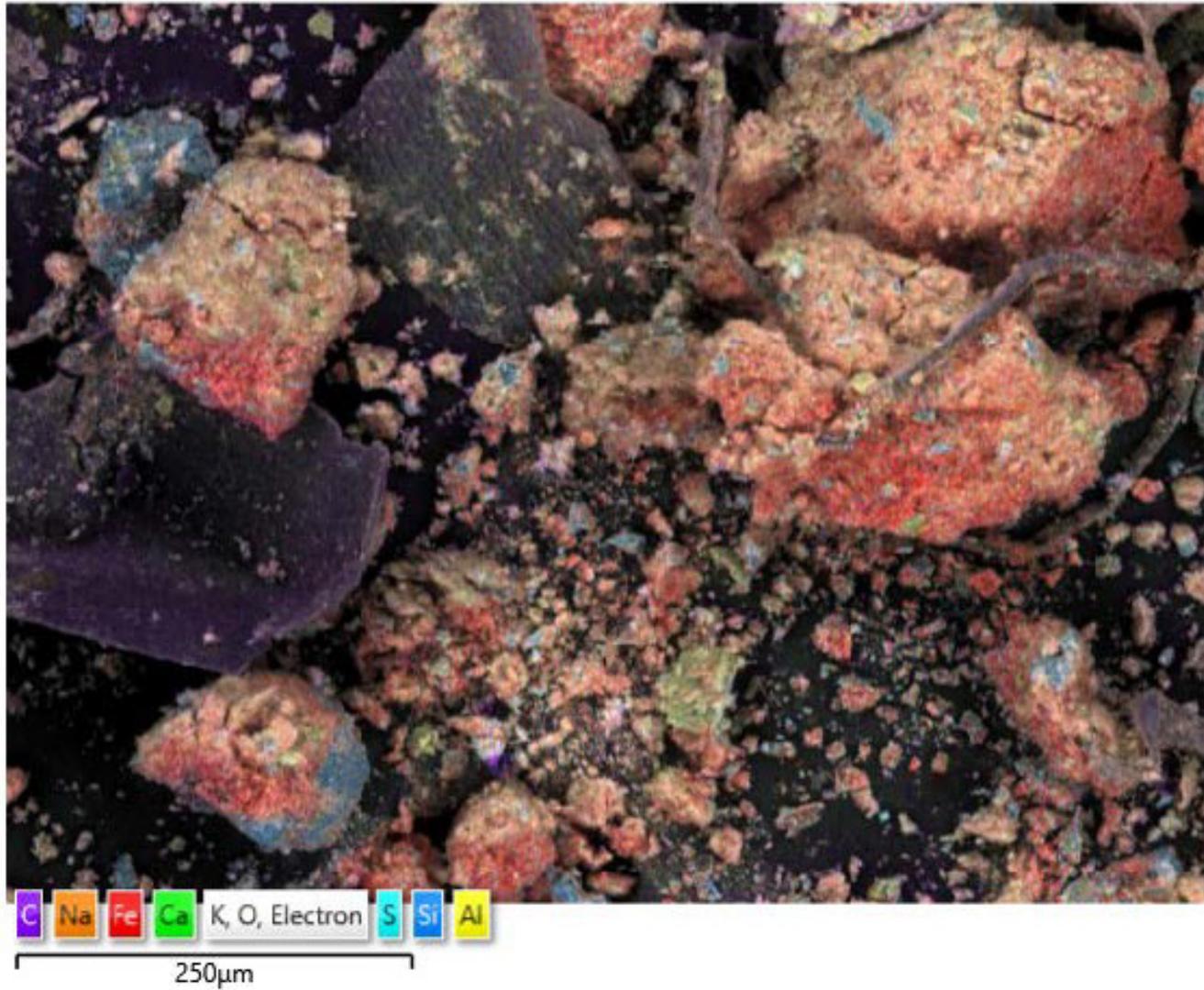
Note:
mg/kg: milligrams per kilogram

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Figure 3
Bulk Chemistry Relationship Between Arsenic and Iron

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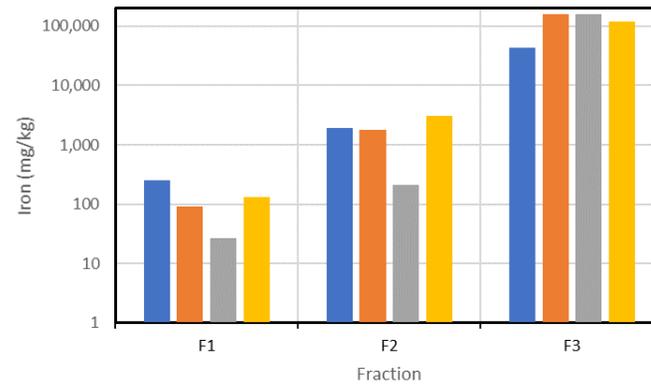
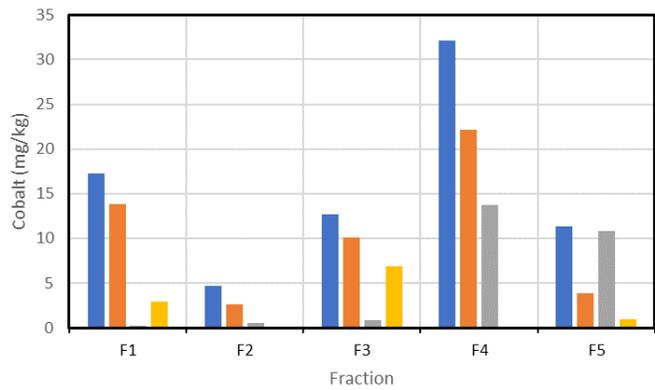
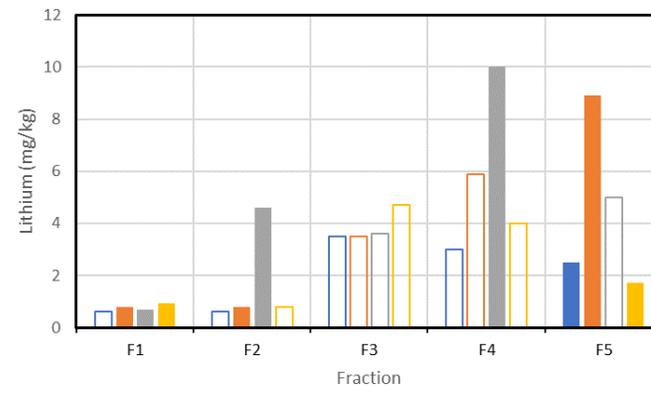
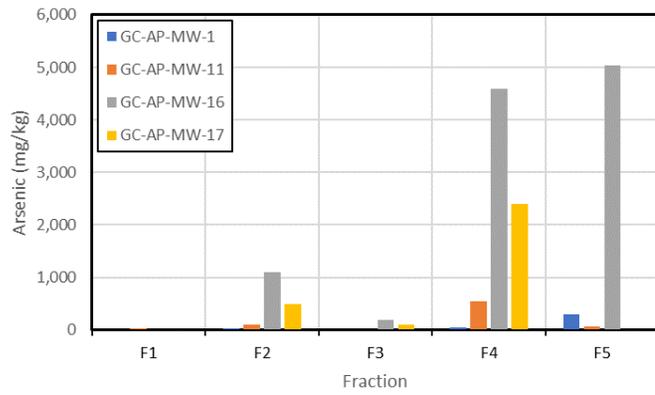


Note:
μm: micron

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Figure 4
SEM Results for GC-AP-MW-11
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Notes:

Non-detect results shown as unfilled bars plotted at detection limit.

mg/kg: milligrams per kilogram

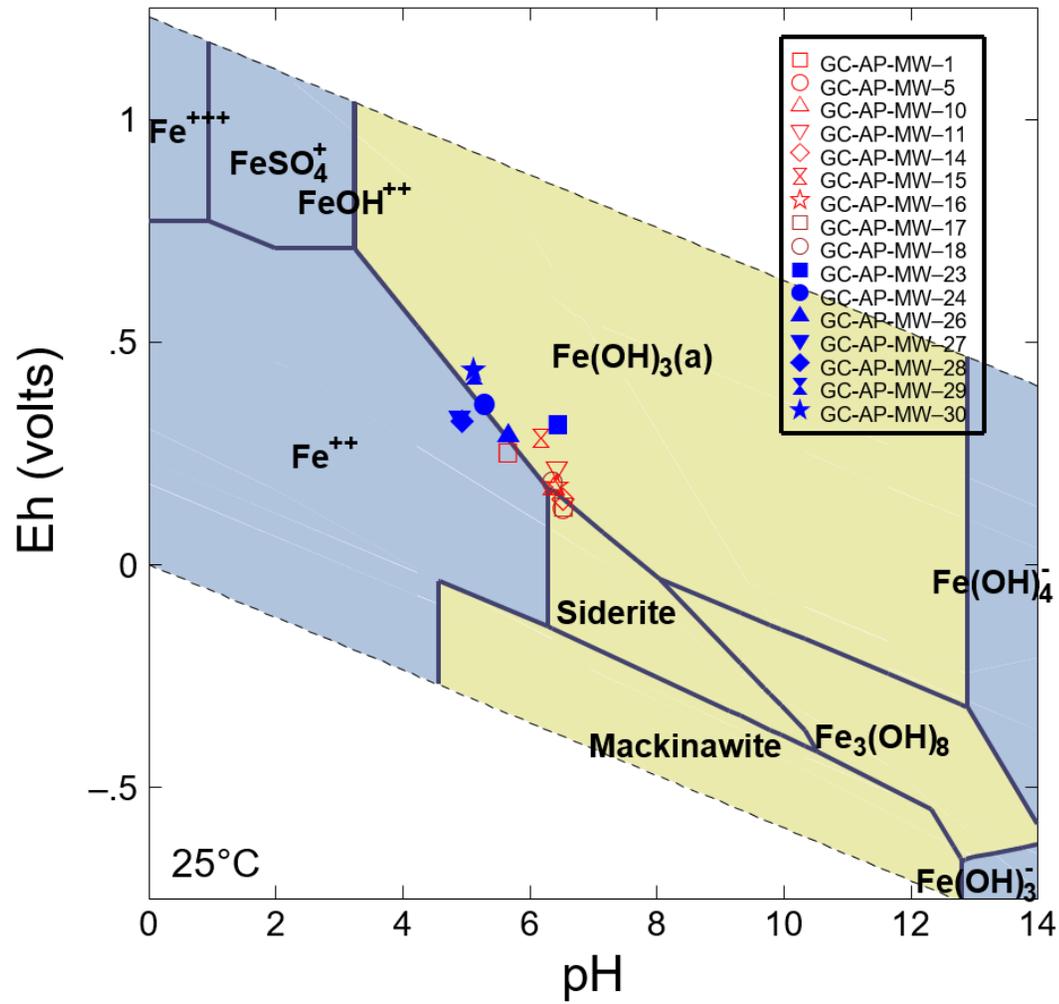
F1 – Water soluble

F2 – Exchangeable (e.g., clay minerals)

F3 – Reducible (e.g., poorly crystalline metal oxides such as iron oxides)

F4 – Oxidizable (e.g., crystalline oxide and crystalline sulfide minerals)

F5 – Residual (e.g., silicate phases)



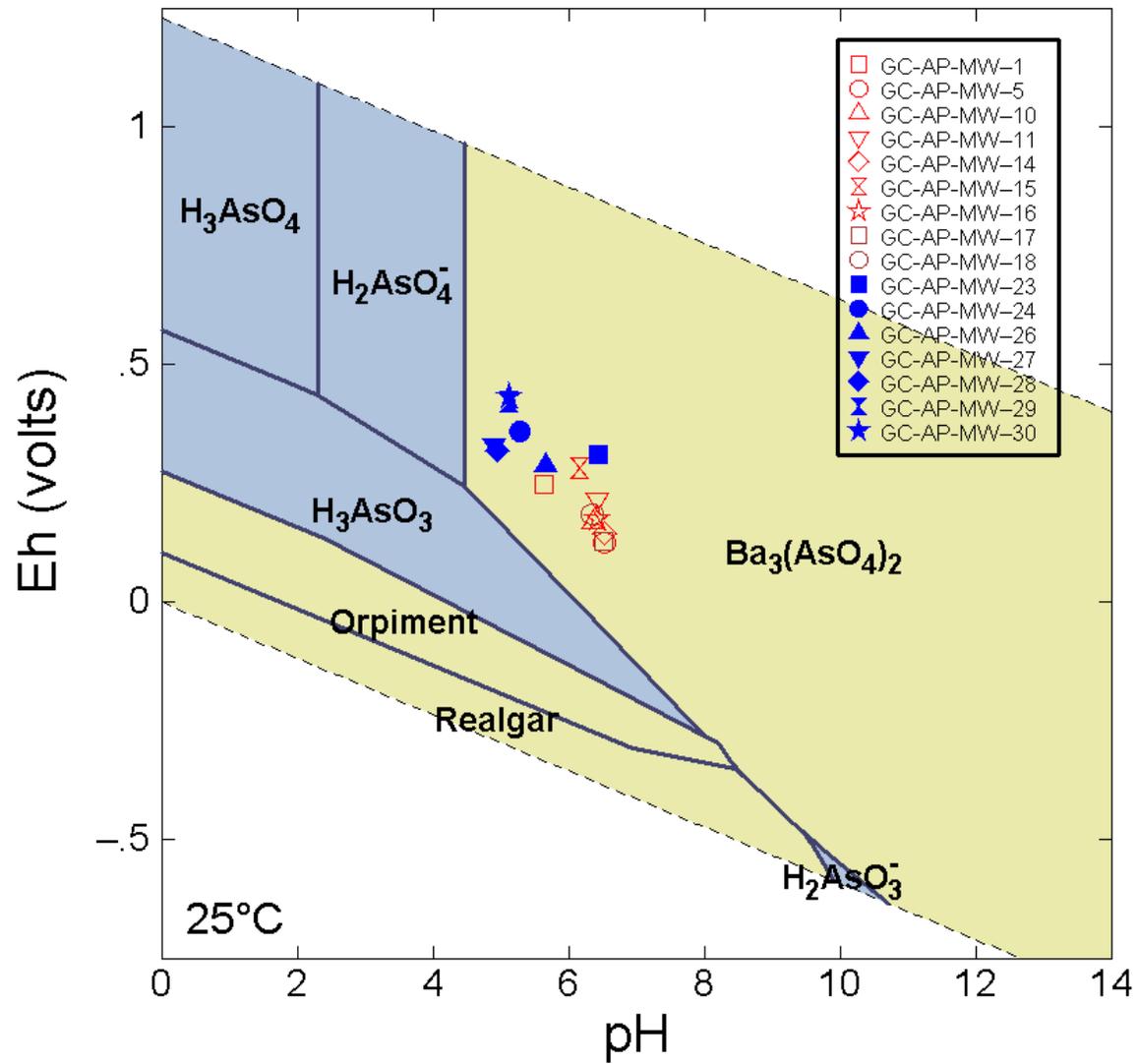
Note:
Blue fields indicate dissolved/mobile species. Yellow fields indicate solid/attenuated species.

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Figure 6
Eh-pH Stability Diagram for Dissolved and Solid Iron Phases

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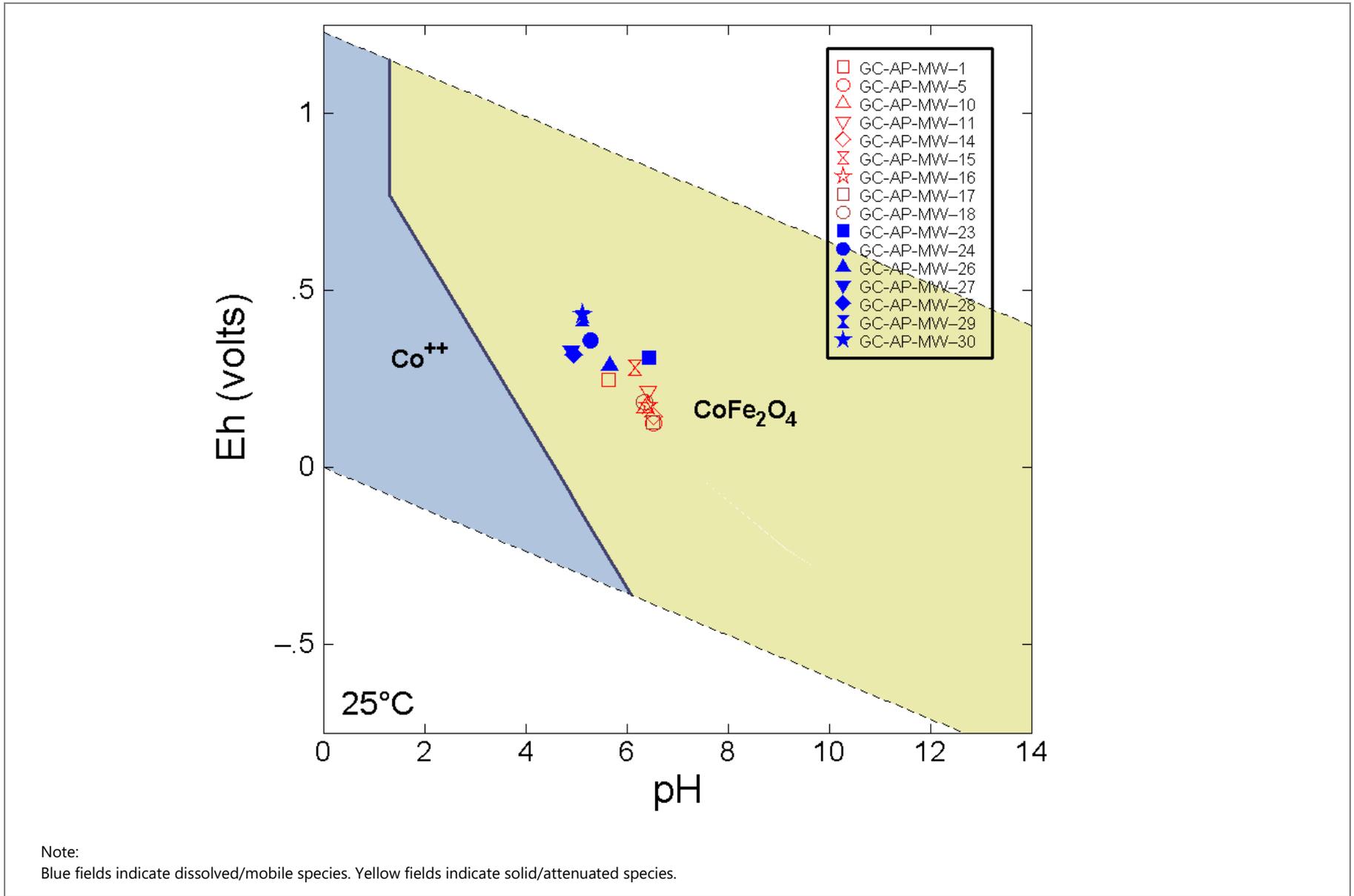


Note:
Blue fields indicate dissolved/mobile species. Yellow fields indicate solid/attenuated species.

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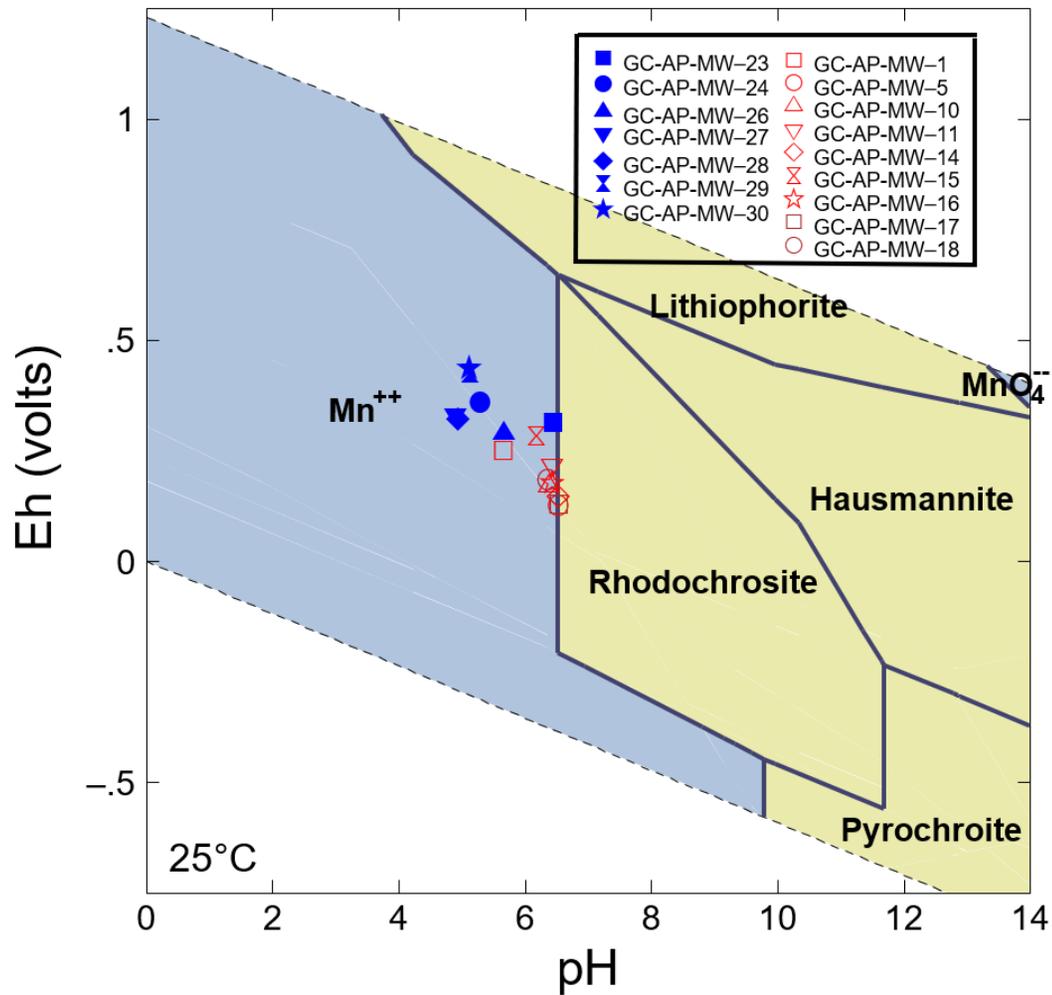
Figure 7
Eh-pH Stability Diagram for Dissolved and Solid Arsenic Phases
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Figure 8
Eh-pH Stability Diagram for Dissolved and Solid Cobalt Phases
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Note:
Blue fields indicate dissolved/mobile species. Yellow fields indicate solid/attenuated species.

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Figure 9
Eh-pH Stability Diagram for Dissolved and Solid Manganese Phases

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