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Troilus Gold Project -

Prediction of ARD Potential in the J4, 87, and Southwest Ore Zones -

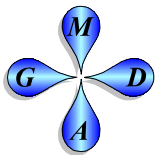
Phase 2: Kinetic Testing and Site- Specific ARD Criteria

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REPORT SUMMARY

Troilus Gold Corp. has asked the Minesite Drainage Assessment Group (MDAG) to develop criteria for three-dimensional ARD models of its three main ore zones: J4, 87, and Southwest (SW). Generic criteria were developed in the Phase 1 report (MDAG 2024a, and see Chapter 2 of this Phase report). This Phase 2 report carries the work further by confirming site-specific ARD criteria for the Troilus site based on longer-term kinetic testing and decades of on-site monitoring.

Because of these two Phases, more than 158,000 drillcore assays from J4, 87, and SW can be mathematically converted to more reliable, surrogate ABAs. The value of these surrogate ABAs includes the following.

- 1) They provide a detailed estimate of the total amounts of rock in each ore zone that can eventually release ARD.
- 2) They can be combined with the Troilus Gold three-dimensional mining model for integrated assessments of mine planning, economics, and environmental protection.
- 3) When combined with the three-dimensional mine model, they provide year-by-year estimates of the rock eventually releasing ARD, highlighting the extent and amount of ARD mitigation planning needed each year.

Based on a review of past minesites like Troilus, there are distinctive characteristics that show a particular site deviates from standard ARD prediction rules. The need for specialized site-specific ARD criteria is clear for these sites. However, reviews of past ML-ARD studies at Troilus show that these past studies incorrectly applied standard rules. This is why ARD predictions at Troilus have ranged from no ARD, ARD within several years, to ARD after 1,500 years. This ambiguous and unacceptable range in ARD predictions have been corrected and clarified in these Phase 1 and Phase 2 reports.

Past and recent ML-ARD work for Troilus have provided (1) four sets of laboratory-based humidity cells nominally containing 1 kg of sample for a total of 23 cells, (2) one set of 123 on-site field columns holding up to approximately 300 kg of rock, and (3) decades of full-scale site monitoring that includes tens of millions of tonnes of waste rock. By combining all these datasets, the prediction of ARD at Troilus and the applicable ARD predictive criteria become clear, based on variations in rates of sulphide oxidation and acid generation and on variations in scale.

Based on comparisons with the International Kinetic Database (IKD) containing 707 humidity cells from 91 sites around the world, Troilus rates of oxidation and acid generation are relatively low. On the other hand, Troilus leaching rates for copper and zinc in mg/kg/wk are relatively typical.

Because Troilus is an exception to generic ARD prediction rules, specialty kinetic tests are being run by the National Research Council of Canada (NRC). This includes six humidity cells with variations in cycle length and relative humidity, with the intent of destabilizing silicate neutralization and causing ARD which has not happened. The cells are periodically closed and sealed with oxygen-consumption (oxycon) testing measuring the ongoing slow consumption of oxygen.

This oxycon testing also includes monitoring of rising carbon dioxide to levels that repeatedly indicate the presence of calcite (solid-phase calcium carbonate in mineral form), although the regular cell cycles would have dissolved and rinsed the calcite out of the samples. This discrepancy of calcite being present in Troilus rock when it should not be is similar to near-neutral conditions being present at Troilus when ARD was predicted to be present. These are due to significant sensitivities with scale at Troilus, where conditions at small scales are significantly different from conditions at larger scales.

This scale dependency for calcite and carbon dioxide has also been documented in the “FluidFlower” experiments at the University of Bergen in Norway. FluidFlower studies confirm that CO₂, carbonate-bearing water, and calcite do not conform to typical expectations, and this is also the case for Troilus rock.

Additional testing has confirmed the following observations for Troilus.

- Aqueous concentrations of sulphate, which represent the rates of sulphide oxidation and acid generation in Troilus rock, are relatively low and many other aqueous elements and water-chemistry parameters correlate with sulphate.
- The neutralization of acidity is accomplished by calcium-bearing non-carbonate minerals, particularly plagioclase minerals. The calcium-bearing minerals can successfully neutralize acidity to above pH 6.0 on all scales, but the neutralization becomes more efficient (requiring less calcium-mineral dissolution) as scale increases.
- Scale plays a major role in the prediction of ARD in Troilus rock, with ARD becoming less likely as scale increases. This is accompanied by decreasing values of the criterion for the Net Potential Ratio (NPR) that separates ARD-releasing rock from non-ARD-releasing rock at Troilus.
- There are complex interactions, including positive and negative feedback loops, among silicate-mineral weathering, carbonate-mineral weathering, temperature, air-phase CO₂, and sulphide oxidation.

Therefore, Troilus is a member of the small group of minesites not adhering to normal ARD prediction rules. The characteristics of this group include the following.

- ABA results indicated ARD should be widespread, but no full-scale ARD was detected at sites over decades.
- Small-scale kinetic tests produced ARD, although no full-scale ARD was detected on site after decades.
- Calcite and carbonate minerals represented a minor portion of Total NP, with ongoing weathering of rock producing small amounts of carbonate detected in ABA.
- Laboratory-measured Neutralization Potentials (NP) such as by the U.S. EPA 600 (Sobek) method were relatively the same among samples and did not change significantly over years to decades of weathering.
- Aqueous alkalinity could be accounted for by ingassing of atmospheric carbon dioxide

(atmospheric CO₂ capture).

- Minerals like biotite, magnetite, and epidote theoretically contributed substantially to Total NP, but apparently were not reacting sufficiently fast to provide much neutralization.
- Plagioclase minerals apparently provided most of the silicate neutralization.
- Acid-generating sulphide minerals were primarily pyrite and pyrrhotite with some chalcopyrite and molybdenite, and their levels ranged from significant “trace” amounts (<~0.1%S) up to ~5%S.
- Rates of sulphide oxidation and acid generation at these sites were generally low (see Chapter 5 of this Phase 2 report for comparisons to the International Kinetic Database).

Overall, much of the full-scale monitoring shows a Net Potential Ratio (NPR) criterion for full-scale mine-rock piles at Troilus between 0.5 and 1.0, with 1.0 being the safer criterion selected here and in the Phase 1 study (MDAG, 2024a).

1. INTRODUCTION

1.1 An Explanation of Acid Rock Drainage (ARD) and Its Prediction

Metal leaching (ML) and acid rock drainage (ARD) are often water-quality issues for minesites (e.g., Price, 2009; Morin and Hutt, 1997 and 2001). As a result, the accurate prediction and control of ML-ARD at proposed minesites are high priorities of various levels of government.

ARD is caused by oxidation of sulphide minerals, particularly iron-bearing sulphides like pyrite and pyrrhotite. Whether sulphide minerals are present or not, weathering can still lead to accelerated metal leaching (ML). For example, the simple dissolution of carbonate minerals can release metals.

Put simply, ML-ARD potential is synonymous with potential for on-site inorganic water contamination. If a significant potential exists at a site, then mitigative measures would be needed to prevent this water from migrating offsite and into the surrounding environment.

A primary analytical tool for predicting ARD potential is called “Acid-Base Accounting” or ABA. ABA consists of several laboratory analyses that, when combined, predict whether a sample (1) will never release ARD and will remain net acid neutralizing or (2) will eventually be net acid generating and release ARD after some “lag time”. This was discussed in detail in the related Phase 1 report (MDAG, 2024a) and is summarized in this report in Chapter 2.

Nevertheless, solid-phase analyses like ABA, often called “static testing”, are not sufficient to predict ARD reliably. Additional testwork is needed, involving repeated rinsing with water and draining the water for chemical analyses (Price, 2009). This is often called “kinetic testing” and is the main focus of this Phase 2 report.

For example, the analyses for static-test ABA typically require one day or less. It would be naive to believe that 24 hours of static testing can predict ARD reliably over many years to decades. Additionally, many years of monitoring and study have shown that Troilus rock does not obey the generic predictive ARD criteria. Instead, Troilus rock contains more Neutralization Potential (NP) and less ARD potential than generic criteria suggest. This is also explained in the corresponding ML-ARD Phase 1 report (MDAG, 2024a).

A major explanation for this site-specific sensitivity involves the mineralogy of Troilus rock engaging in complex reactions and interactions. Complex interactions, including positive and negative feedback loops, among silicate-mineral weathering, carbonate-mineral weathering, temperature, air-phase CO₂, and sulphide oxidation are relatively well documented on large and planetary scales (e.g., Kasting, 2019; Penman et al., 2020). On a catchment scale, the release and uptake of CO₂ into carbonate minerals can be dynamically balanced in some cases with little loss or gain of carbonate minerals (Liu et al., 2023; Xu et al., 2024).

These complex interactions and feedback loops have not been considered or studied in much detail at the greatly reduced scales down to minesite components. For example, when silicate neutralization is dominant, the fact that carbonate minerals might play little to no role in the

neutralization of acid generation from sulphide oxidation runs counter to most interpretations of acid-base accounting (ABA). This is indeed the case for Troilus, as shown in the Phase 1 report (MDAG, 2024a) and here in this Phase 2 report.

1.2 The Approach and Objectives in This Report to Predict ARD

Troilus Gold Corp. has asked the Minesite Drainage Assessment Group (MDAG) to develop criteria for three-dimensional ARD models of its three main ore zones: J4, 87, and Southwest (SW). Generic criteria were developed in the Phase 1 report (MDAG 2024a, and see Chapter 2 of this Phase 2 report). This Phase 2 report carries the work further by confirming site-specific ARD criteria for the Troilus site based on longer-term kinetic testing and decades of on-site monitoring.

As a result, of these two Phases, more than 158,000 drillcore assays from J4, 87, and SW can be mathematically converted to more reliable, surrogate ABAs. The value of these surrogate ABAs includes the following.

- 1) They provide a detailed estimate of the total amounts of rock in each ore zone that can eventually release ARD.
- 2) They can be combined with the Troilus Gold three-dimensional mining model for integrated assessments of mine planning, economics, and environmental protection.
- 3) When combined with the three-dimensional mine model, they provide year-by-year estimates of the rock eventually releasing ARD, highlighting the extent and amount of ARD mitigation planning needed each year.

1.3 The Structure of This Report

This report starts by summarizing the findings of the ML-ARD Phase 1 study for Troilus in Chapter 2. Then, Chapter 3 reviews past and recent studies for ML-ARD at Troilus, explaining where past studies were correct or wrong.

Chapter 4 presents some results of the past and recent kinetic testing, with Chapter 5 showing that Troilus rates of oxidation and acid generation are relatively low compared with the International Kinetic Database (IKD).

Because Troilus is an exception to generic ARD prediction rules, Chapter 6 discusses some specialty kinetic tests conducted specifically for Troilus. Chapter 7 then clarifies how ARD potential and prediction for Troilus rock vary significantly with scale and with rates of sulphide oxidation.

This Phase 2 study confirms the predictive approach and ARD criteria for Troilus used in the Phase 1 report (MDAG, 2024a).

2. SUMMARY OF THE ML-ARD PHASE 1 STUDY (MDAG, 2024a)

2.1 Introduction

Troilus Gold Corp. has asked the Minesite Drainage Assessment Group (MDAG) to develop criteria for three-dimensional Acid-Rock and Metal Leaching Drainage (ML-ARD) models of its three main ore zones: J4, 87, and Southwest (SW). These criteria were developed in this report by extrapolating acid-base accounting (ABA) results from many dozens of drillcore samples, and from dozens of subsamples from on-site ML-ARD leach columns, to more than 158,000 drillcore assays. In effect, the analytical results from many dozens of carefully selected ABA samples were used to convert mathematically more than 158,000 assays into surrogate ABAs.

The two main steps are:

- 1) identify additional, unmeasured Neutralization Potential (NP) in Troilus rock, and
- 2) extrapolate this to drillcore assays.

The value of these surrogate ABAs includes the following.

- 1) They provide a detailed estimate of the total amounts of rock in each ore zone that will eventually release ARD.
- 2) They can be combined with the Troilus Gold three-dimensional mining model for integrated assessments of mine planning, economics, and environmental protection.
- 3) When combined with the three-dimensional mine model, they provide year-by-year estimates of the rock eventually releasing ARD, highlighting the extent and amount of ARD mitigation planning needed each year.

2.2 Prediction of ARD Potential in Troilus Rock

ARD prediction is partly based on the Total Acid Potential (TAP) that all the sulphide minerals can generate during full oxidation. As explained below, nearly all total sulphur in Troilus rock consists of potentially acid-generating sulphide, and thus total sulphur is nearly synonymous with sulphide. This is important because the ~158,000 assays include total sulphur, allowing the simple mathematical conversion from total sulphur to TAP in the assays.

ARD prediction is also partly based on Total Neutralization Potential (TNP). The ratio of TNP to TAP is the Total Net Potential Ratio ($TNPR = TNP / TAP$). If TNP significantly exceeds TAP, then there is excess TNP and ARD is not expected. If TNP is less than TAP, then ARD is expected after some lag time.

While TAP is easy to estimate for the ~158,000 assays because total sulphur was measured, Total NP was not measured due to the large complexity and difficulty of detecting and calculating Total NP in Troilus rock. Figure 2-1 on the next page shows the complexity of NP in Troilus rock, and the determination of Total NP is summarized in more detail below.

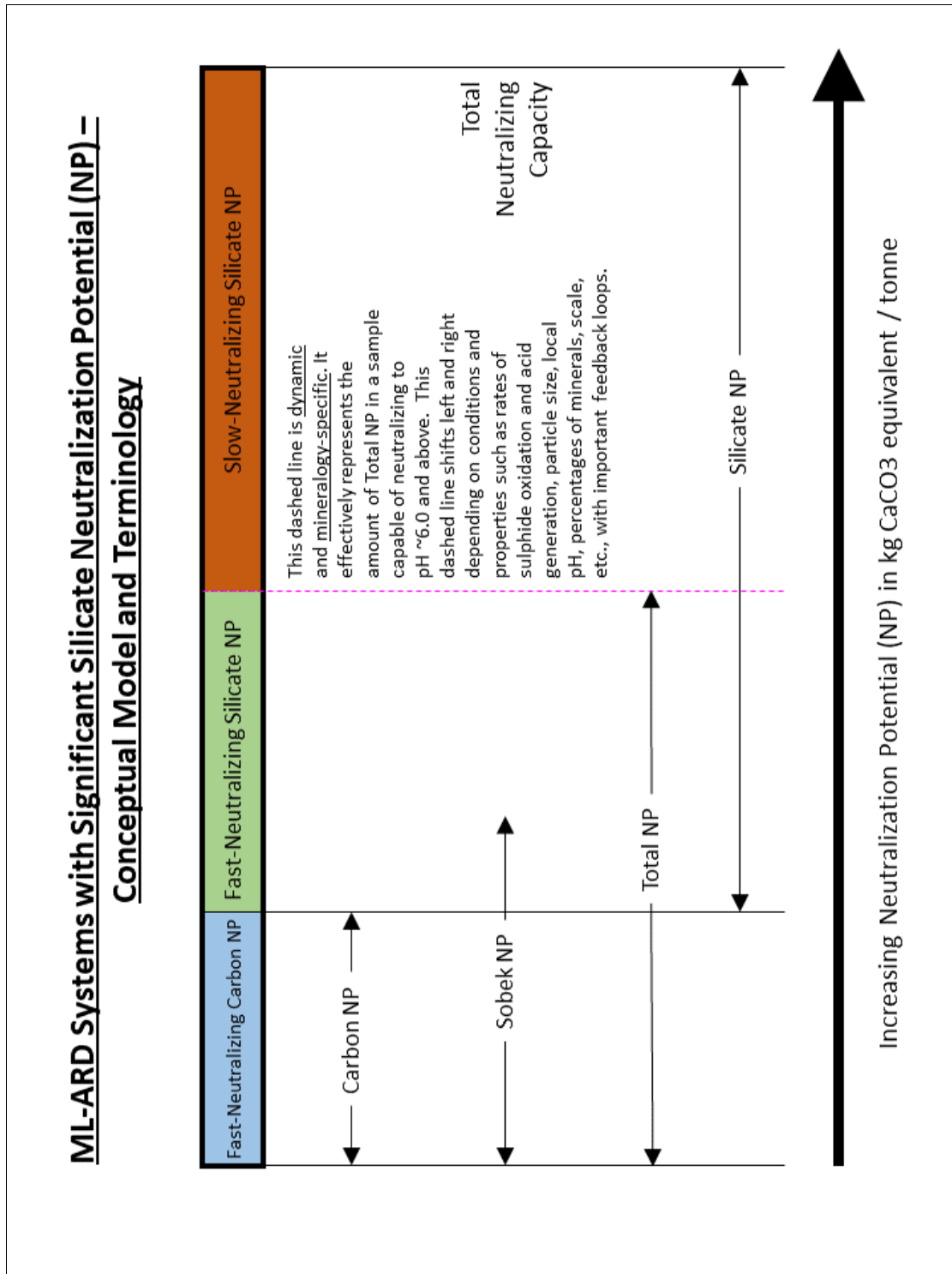


Figure 2-1. Conceptual model and terminology for various Neutralization Potentials in Troilus rock.

2.3 Geology and Mineralogy

The Troilus gold deposits are generally hosted in the Troilus Diorite, with lesser amounts in porphyritic felsic intrusions. The two main Ore Zones of sulphide-hosted gold and copper mined to date are 87 and J4, containing chalcopyrite, pyrite, and pyrrhotite. Thus, sulphur is an important primary geochemical constituent of Troilus rock, and also an important part of ARD predictions to calculate Total Acid Potential (TAP). Recently, the Southwest (SW) Zone has been upgraded to a third full ore zone.

Troilus is primarily a gold (Au) and copper (Cu) site. Nevertheless, it also contains minor amounts of silver (Ag), zinc (Zn), and lead (Pb), as well as traces of bismuth (Bi), tellurium (Te), and molybdenum (Mo). Ore grade rock is identified by its gold-equivalent content, which is a mathematical combination of gold, copper, and silver in a sample.

Gold mineralization is spatially correlated with the presence of sulphides, although the sulphide content does not directly correlate with gold and copper grade. Nevertheless, ore generally contains a higher ARD potential than waste rock due to its higher sulphur levels.

Gold-copper mineralization occurs mainly on the physical boundary of the Troilus Diorite (metadiorite, also reportedly appearing as gabbro), within breccias, amphibolite, and quartz - chlorite (\pm tourmaline) felsic vein swarms. Disseminated mineralization accounts for roughly 90% of Troilus ore, while quartz veining accounts for the remainder.

Five main lithological units are recognized in the Troilus area:

- 1) mafic to felsic volcanic sequence;
- 2) diorite (metadiorite) and brecciated diorite;
- 3) cross-cutting felsic dikes;
- 4) mafic to ultramafic intrusive; and
- 5) younger, post-deformation granitic intrusions crosscutting these other rock units.

Thus, there are many rock units at Troilus, but there are only a few major rock units in each of the J4, 87, and SW Ore Zones.

Details of the geology and mineralogy of each of the three ore zones were discussed in separate chapters of the Phase 1 report (MDAG, 2024a). For example, based on tens of thousands of drillcore assays, total sulphur in the ore zones is generally lognormally distributed, allowing the calculation of well defined statistical parameters like the mean and the standard deviation. Based on the major rock units, the sulphur statistics for each unit, and the three-dimensional locations within each ore zone, approximately 30 samples from each ore zone were selected for solid-phase ML-ARD analyses like acid-base accounting (ABA).

2.4 Results of Acid-Base Accounting (ABA) in the Phase 1 Report

Traditional ABA including various types of Neutralization Potential (NP) was conducted on:

- 89 ML-ARD samples selected from the three ore zones that were:
 - generally proportional to the major rock units in each ore zone,

- based on tens of thousands of assays in each zone, particularly of potentially acid-generating sulphur with well-defined means and standard deviations, and
 - collected over wide three-dimensional distributions in each zone.
- 34 subsamples of J4 rock placed in 13 on-site columns holding up to ~300 kg, with 11 columns (Columns 1 to 11) containing future waste rock with various sulphur levels and two columns (Column 12 and 13) containing existing J4 waste rock that has oxidized and weathered for at least 13 years; Column 12 is currently releasing ARD and Column 13 is not.

Paste pH, measured in a mixture of deionized water and pulverized sample of rock, ranged from 8.4 to 10.1. Therefore, all samples were alkaline at the time of analysis, with no acidic conditions detected. These values of paste pH indicated (1) the samples contained additional NP not detected by the standard procedures of Carbon NP and Sobek NP (see Figure 2-1), and (2) the lowest pH values between 8.2 and 8.4 corresponded to sulphur levels above 1 to 2%S, suggesting at least 1%S would be needed to eventually create ARD.

The range of total sulphur in the 89 ML-ARD samples spans nearly three orders of magnitude, from 0.01%S to 7.15%S. This large range is expected because the 87 ML-ARD samples were selected based on standard deviations above and below the mean sulphur level in each rock unit in each zone.

In general, the intrusive rock units (diorite, granite, and gabbro) have lower total-sulphur levels than the extrusive rock units (various volcanics and tuffs, and QFP). This confirms that these 89 ML-ARD samples generally reflect the variabilities of total sulphur seen in more than 158,000 Troilus assays, which was in fact a major objective of these ML-ARD samples. Most of the total sulphur is composed of potentially acid-generating sulphide, and thus total sulphur and sulphide can be used interchangeably. For the 89 ML-ARD samples and the more than 158,000 drillcore assays, Total Acid Potential (TAP in kg CaCO₃ equivalent / tonne) is calculated by: %S(total) * 31.25.

Neutralization Potential (NP) represents the amount of acidity that Troilus rock can neutralize upon the oxidation of sulphur. As part of ABA, NP is typically measured by procedures that require less than 24 hours and thus primarily detect fast-neutralizing minerals like carbonates (see Figure 2-1). However, kinetic studies and on-site monitoring show that Troilus rock contains more NP than detected by these short-term methods, which is summarized in more detail below.

Net balances of acid potential and neutralization potential were calculated mathematically by division to obtain values of Total-Sulphur-Based Net Potential Ratio (TNPR) using both Sobek NP (“Sobek TNPR”) and Carbon NP (“Carbon TNPR”). The generic criterion to distinguish net-acid-generating from net-neutralizing samples was 2.0 for Sobek TNPR and 0.5 for Carbon TNPR.

These TNPR values showed that nearly two-thirds (64%) of the 89 ML-ARD samples were not predicted to release ARD at anytime. The remaining 36% are predicted to release ARD eventually after various lag times, but this is based on the false assumption that measured Sobek NP represents all neutralization in Troilus rock (shown in Figure 2-1 above).

In general, total sulphur levels below 0.15%S were associated with higher TNPR values that would not release ARD, while total sulphur levels above 1.3%S were associated with lower TNPR values

that would eventually release ARD after various lag times. By individual ore zone and rock unit, the mean sulphur levels of some but not most rock units corresponded to a Sobek TNPR less than 2.0 and were thus capable of eventually releasing ARD. Due to logarithmic statistics, this means that less than 50% of many rock units would release ARD.

The dominant chemical element in the 89 Troilus ML-ARD samples, analyzed by four-acid-digestion ICP-MS and x-ray-fluorescence (XRF) whole-rock procedures, was silica, reflecting the known aluminosilicate minerals and quartz, of which some provide additional neutralization (see Figure 2-1 above). Silica was followed in abundance by aluminum, iron, calcium, sodium, magnesium, and potassium. At lower and “trace” levels, the elements that frequently exceeded by three times their general crustal abundances were bismuth, copper, molybdenum, and tellurium, consistent with known and potentially economic elements at Troilus. Less frequent exceedances were seen for antimony, arsenic, cadmium, cesium, potassium, lithium, lead, nickel, rubidium, selenium, thallium, tungsten, uranium, and zinc. However, solid-phase levels rarely correlate with leaching rates into water. Thus, leaching tests of Troilus rock on various scales are being conducted separately (discussed here in the ML-ARD Phase 2 report and in MDAG, 2024b). Nevertheless, correlations of some elements with total sulphur or Neutralization Potential suggest these elements might have higher leaching rates during active sulphide oxidation and neutralization.

2.5 On-Site ML-ARD Columns

At the Troilus Gold site, 11 ML-ARD columns were built and filled with up to about 100 kg of fresh J4 drillcore, representing future mine rock. An additional two ML-ARD columns were filled about 300 kg of J4 rock from the existing J4 waste-rock pile that has been exposed and oxidizing for 14 to 28 years. Column 12 contains brown, well-oxidized, and acidic, existing J4 rock with abundant fine particles. Column 13 contains grey, near-neutral existing J4 rock with abundant fine particles. There is a visible distinction at Troilus between the weathered brown rock and the relatively unweathered grey rock.

The pre-testing paste pH values indicated all rock subsamples from these columns were near neutral, and the initial effluents from all columns were initially near neutral. However, within a few weeks, the effluent pH from Column 12 with brown rock fell below 4.5 and eventually reached a typical ARD pH around 3.5. In contrast, the pH from Column 13 with existing grey rock remained near neutral, typically around pH 6.0-6.5 but with some higher and lower values. For the existing J4 waste-rock pile containing tens of millions of tonnes, this pH range is also typical of pH measured after mine closure at Monitoring Station STP-09.

Pre-testing ABA results for the column subsamples were consistent with the 89 ML-ARD samples discussed above, based on a Sobek TNPR criterion of 2.0 and a Carbon TNPR criterion of 0.5. Thus:

- 1) Higher levels of total sulphur are associated with lower, but still near-neutral paste pH.
- 2) Total sulphur levels below 0.15%S are net neutralizing.
- 3) Total sulphur levels above 1.3%S (like Column 12) are net acid generating and capable of releasing ARD after various lag times.
- 4) Total sulphur levels between 0.15%S and 1.3%S (like Column 13 and the samples studied by the

National Research Council of Canada, NRC, 2023) require additional information on Silicate Neutralization Potential (Figure 2-1 above) for ARD predictions, which is the focus of this Phase 2 report.

- 5) The amount of Total NP in Troilus rock may depend on the amount of total sulphur and its oxidation rate rather than being a certain numerical value (vertical dashed line in Figure 2-1). The additional NP not currently detected in Troilus rock can cause TNPR values to increase significantly and thus to have less ARD potential than reported at this point. This is the focus of this Phase 2 report.

2.6 Estimation of Fast-Neutralizing Silicate NP from Solid-Phase Calcium in a Sample in the Phase 1 Report

Based on advanced, state-of-the-art techniques by the National Research Council of Canada (NRC), the detailed mineralogy including various forms of plagioclase has been measured in samples of existing J4 waste rock at Troilus Gold. Rates of oxygen consumption by sulphide minerals, which in turn results in acid generation, were also measured in two samples, with particle sizes of approximately 1 and 5 mm. These rates were 69 mg CaCO₃/kg/week (basically equivalent to mg SO₄/kg/wk) for the fine 1 mm rock and 21 mg CaCO₃/kg/week for the coarser 5 mm rock.

In order to estimate the amount of unmeasured, Silicate Neutralization Potential (Silicate NP, Figure 2-1) in these samples, databases on reaction rates of silicate minerals and their total capacities to neutralize were combined into the spreadsheet-based MDAG Silicate NP Model. This Model was then applied to the state-of-the-art mineralogy of Troilus rock by NRC.

This showed that the NRC samples of Troilus rock contained a total Silicate NP of 160 kg of CaCO₃ equivalent/tonne of rock, plus about 2 kg/t of Carbon NP, for a Theoretical Total Neutralizing Capacity of 162 kg/t as depicted in Figure 2-1. Notably, when the Silicate Neutralization Rate was separated into rates for each relevant silicate mineral, at least 95% of the Rate could be attributed to the two calcium-rich plagioclase minerals, bytownite and labradorite.

Combined, bytownite and labradorite in the NRC sample represent a Fast-Neutralizing Silicate NP of only 24 kg/t (14 + 9.9 kg/t) for ARD predictions, while accounting for at least 95% of active neutralization by silicate minerals but only 7.7% of the entire rock mass. In other words, while this sample has a Silicate NP of 160 kg/t, only 15% (24/160) of this Silicate NP is sufficiently reactive to fully neutralize at the acid-generation rate, particle size, and particle-scale pH in the NRC samples. At the current, relatively slow near-neutral rates, the amounts of bytownite and labradorite would persist and neutralize for up to several centuries.

These observations led to several complex observations and predictions. For example:

- If the rate of sulphide oxidation and acid generation did not decrease by at least 95% of the current initial rates within weeks to months, ARD could appear from this sample.
- However, if this ARD results in a pH below the current particle-scale of pH 3.5, then the Silicate Neutralization Rate would increase. For example, if pH fell to 3.0 at the current acid-generation rate after all bytownite was consumed, then the rate of neutralization from labradorite would accelerate sufficiently to neutralize overall pH

above pH 6.

- At slower rates of acid generation such as from coarser particles, additional silicate minerals can contribute significant neutralization, like andesine, which also means that there would then be additional Fast-Reacting Silicate NP above the 24 kg/t from bytownite and labradorite.
- At some faster rates of oxidation, neutralization by bytownite and others would no longer be able to “keep up” and ARD would appear, unless pH around mineral grains falls below 3.5 to cause a higher rate of Silicate Neutralization Rate from the remaining silicate minerals.

Based on the mineralogy of the rock tested by the National Research Council of Canada, the amount of Fast-Neutralizing Silicate NP relative to the calcium-rich plagioclase minerals can be estimated from (1) measured solid-phase concentrations of total calcium and (2) the sample’s solid-phase Calcium Molar Ratio based on [(calcium + sodium)/calcium]. This equation (“Equation 7-5”) is: Fast-Neutralizing Silicate Neutralization Potential (kg CaCO₃ eq / t) =

$$\text{Total \%Ca in sample} * [(1.167 * \text{Sample Calcium Molar Ratio}) - 0.167] * 25 \text{ kg CaCO}_3/\text{t} / \% \text{Ca}$$

Below a Sample Calcium Molar Ratio of 0.144, the Fast-Neutralizing Silicate NP is set at zero.

This equation and the stepwise approach of Table 2-1 below to obtain Total NP and Total TNPR were tested on subsamples of the on-site ML-ARD Columns. For Column 12 with ongoing release of ARD around pH 3.5, its 10 subsamples all had Total TNPR values less than the criterion of 1.0. On the other hand, all but one of the 10 subsamples of near-neutral Column 13 had Total TNPR values greater than 1.0. Thus, this approach and equation were successful for predicting ARD potential in existing J4 rock.

Silicate-mineral neutralization in these Troilus samples is remarkably similar to that documented more than 10 years ago at certain other minesites.

- ABA results indicated ARD should be widespread, but no full-scale ARD was detected at the sites over decades.
- Small-scale kinetic tests produced ARD, although no full-scale ARD was detected on site after decades.
- Calcite and carbonate minerals represented a minor portion of Total NP, with ongoing weathering of rock producing small amounts of carbonate detected in ABA.
- Aqueous alkalinity can be accounted for by ingassing of atmospheric carbon dioxide (CO₂ capture).
- Minerals like biotite, magnetite, and epidote theoretically contributed substantially to Total NP, but apparently were not reacting sufficiently fast to provide much neutralization.
- Plagioclase minerals apparently provided most of the silicate neutralization, but they were sometimes at relatively lower levels than seen at Troilus in the samples tested by National Research Council of Canada (2023).
- Individual plagioclase minerals were not separated as done for Troilus, but tended to be more sodium-rich than Troilus, and thus with less neutralization and at slower rates.

Table 2-1. The stepwise site-specific approach to calculating Silicate NP in Troilus rock based only on the most reactive feldspar minerals of bytownite and labradorite		
Step 1	Obtain measured total calcium and sodium in weight-% in a sample using four-acid-digestion ICP-MS or XRF analytical techniques	Solid-phase Total Calcium and Sodium are measured
Step 2	Calculate the amount of measured %Ca that is not in plagioclase minerals such as calcite and tremolite ¹ , and subtract it from measured Total Calcium	Plagioclase %Ca = Total %Ca - Non-Plagioclase %Ca ¹
Step 3	Multiply Plagioclase %Ca from Step 2 by an equation including the Sample Calcium Molar Ratio to obtain its most reactive neutralizing fraction; zero if Calcium Molar Ratio < 0.144	Fast-Neutralizing %Ca = Plagioclase %Ca * [(1.167 * Sample Calcium Molar Ratio) - 0.167], if Ratio ≥ 0.144
Step 4	Obtain Fast-Neutralizing Silicate NP reflecting only the most reactive silicate mineral in Troilus rock by mathematical conversion to typical units	Fast-Neutralizing Silicate NP in kg CaCO ₃ equivalent/tonne = Fast-Neutralizing Plagioclase %Ca * 25
Step 5	Obtain the Total NP of the sample	Total NP in kg/t = Fast-Neutralizing Silicate NP plus Carbon NP ¹
Step 6	Calculate Total TNPR and apply a criterion of 1.0 with Total TNPR < 1.0 potentially capable of releasing ARD after some lag time	Total TNPR (kg/t) = Total NP / (Total Sulphur in %S * 31.25)
<p>¹ If calcite and its Carbon NP are not available separately (which is the case for most of the ~158,000 drillcore intervals), its %Ca is automatically included as Plagioclase %Ca in Step 2, and thus calcite is downgraded to a feldspar mineral as a safety factor with significantly less NP than reality; when the amount of tremolite is not known (which is the case for virtually all of the ~158,000 drillcore intervals), then Plagioclase %Ca = Total %Ca in Step 2 and the calculations in these Steps are designed for this situation based on Sample %Ca rather than Plagioclase %Ca as explained in the text.</p>		

- Acid-generating sulphide minerals were primarily pyrite and pyrrhotite with some chalcopyrite and molybdenite, and their levels ranged from trace amounts ($< \sim 0.1\%S$) up to $\sim 5\%S$.
- Rates of acid generation at some sites were generally lower than at Troilus, around 7 mgCaCO₃ equivalent/kg/wk under near-neutral conditions and around 20-30 mg/kg/wk under acidic conditions, which was attributed to trace amounts of molybdenite that may suppress sulphide oxidation.

2.7 Surrogate ABA Results from the Assay Databases for J4, 87, And SW Zones in the Phase 1 Report

A major objective of this report is to use the analytical results from dozens of carefully selected ABA samples and from on-site ML-ARD columns to convert mathematically more than 158,000 drillcore assays into surrogate ABAs.

These surrogate ABAs for $\sim 158,000$ drillcore intervals can meet the following requirements.

- 1) They provide a detailed estimate of the total amounts of rock in each ore zone that will eventually release ARD.
- 2) They can be combined with the Troilus Gold three-dimensional mining model for integrated assessments of mine planning, economics, and environmental protection.
- 3) When combined with the three-dimensional mine model, they provide year-by-year estimates of the rock eventually releasing ARD, highlighting the extent and amount of ARD mitigation planning needed each year.

The surrogate ABAs for drillcore were obtained following the stepwise procedure in Table 2-1 above. This table summarizes the procedure for estimating Fast-Neutralizing Silicate Neutralization Potential (NP), based on a sample's measured amounts of solid-phase calcium and sodium, which is then added to Carbon NP to obtain Total NP. Total NP is then mathematically divided by a sample's Total Acid Potential based on a sample's total sulphur level multiplied by 31.25. This division yields Total Total-Sulphur-Based Net Potential Ratio (Total TNPR). A Total TNPR value less than 1.0 for a drillcore interval is predicted to eventually release ARD after some lag time.

Several general observations can be made about these surrogate ABAs from drillcore assays of roughly 158,000 core intervals.

- There were no carbon analyses for J4 drillcore, less than 200 for 87 drillcore, and 7009 valid carbon analyses for SW. Therefore, the rapid and strong neutralization provided by calcite in Troilus rock is not well known or defined. As explained in Table 2-1, the unknown amount of calcium associated with calcite in nearly all drillcore intervals was "downgraded" and made much slower neutralizing by considering it part of Silicate NP.
- Assays and chemical analyses are subject to minimum and maximum detection limits and mathematical division is not possible with zero values in the divisor. As a result, some artifacts appear such as spikes in certain statistical ranges.
- The Bulk Total TNPR of each ore zone can be calculated using mathematical division of the sum of all intervals' surrogate Total NP by the sum of all intervals' Total Acid

Potential (TAP). Bulk Total TNPR values for all three ore zones are above 1.0 with SW Zone having the highest bulk value. Thus, on average and in bulk, all Troilus rock will not release ARD, although smaller-scale amounts could do so.

- Overall, the statistical distributions of Total NP and of Total TNPR are generally lognormal. Thus, as single ore zones, the proportions of all rock, as ore + waste or as waste only, can be reliably calculated for J4, 87, and SW Zones, which is one of the Phase 1 objectives. For example about twice the percentage of J4 Zone waste rock (27%) is predicted to release ARD compared with SW Zone rock (14%), although in bulk and on average ARD would not be released based on Bulk Total TNPR.
- The other objectives of three-dimensional distributions of surrogate Total TNPR and the year-to-year TNPR levels during mining can be met by importing the surrogate ABAs into Troilus Gold's mine model for the three ore zones.

3. PAST STUDIES AND PREDICTIONS FOR METAL LEACHING AND ACID ROCK DRAINAGE (ML-ARD) AT TROILUS

For more than 30 years, predictive studies for ML-ARD have been conducted at Troilus, with predictions ranging from no ARD, ARD after several years, and ARD only after 1,500 years. Nearly 30 years after mining first started, no ARD has been detected in the monitoring data at Troilus. In 2010 when mining stopped, 14 years ago, impending ARD was expected within a year or so but ARD has not appeared.

Troilus Gold Corp. has found this uncertainty on ARD to be unacceptable. This is the fundamental reason for these Phase 1 (MDAG, 2024a) and Phase 2 (this document) ML-ARD reports and for supporting studies and documents like National Research Council of Canada (2023 and in preparation). To be clear, ARD has been detected on smaller scales at Troilus as explained in these Phase 1 and 2 reports, and the reasons for this scale dependency have been overlooked in past studies but are clarified here. Normally undetected neutralization by silicate minerals, particularly plagioclase minerals, is the main reason.

Therefore, this chapter starts with a summary of other minesites that share the ARD anomaly and scale dependency with Troilus. Then the remaining subsections review 30 years of ARD studies at Troilus and explain where their predictions of ARD were reasonable or wrong. This includes the recent kinetic testing (2023 and 2024) used in subsequent chapters of this Phase 2 report to explain and justify ARD predictions.

3.1 Other Minesites with ARD Anomalies Similar to Troilus

As explained in Section 7.5 of the Phase 1 ML-ARD report (MDAG, 2024a), Troilus is not the only minesite where major contradictory predictions on ARD have occurred (Morin and Hutt, 2011, Morin et al., 2001). Troilus and these other minesites form a small “group” or “class” of minesites where normal procedures for ARD prediction fail on the full site scale but apply on small scales.

Typical characteristics of this ARD-anomaly group include the following.

- ABA results indicated ARD should be widespread, but no full-scale ARD was detected at sites over decades.
- Small-scale kinetic tests produced ARD, although no full-scale ARD was detected on site after decades.
- Calcite and carbonate minerals represented a minor portion of Total NP, with ongoing weathering of rock producing small amounts of carbonate detected in ABA.
- Laboratory-measured Neutralization Potentials (NP) such as by the U.S. EPA 600 (Sobek) method were relatively the same among samples and did not change significantly over years to decades of weathering.
- Aqueous alkalinity could be accounted for by ingassing of atmospheric carbon dioxide (atmospheric CO₂ capture).
- Minerals like biotite, magnetite, and epidote theoretically contributed substantially to Total NP, but apparently were not reacting sufficiently fast to provide much neutralization.

- Plagioclase minerals apparently provided most of the silicate neutralization.
- Acid-generating sulphide minerals were primarily pyrite and pyrrhotite with some chalcopyrite and molybdenite, and their levels ranged from significant “trace” amounts (<~0.1%S) up to ~5%S.
- Rates of sulphide oxidation and acid generation at these sites were generally low (see Chapter 5 of this Phase 2 report for comparisons to the International Kinetic Database).

3.2 Enviromine (1993)

The first major ARD study for Troilus was conducted by Enviromine (1993), more than 30 years ago and a few years before mining started in 1996.

Enviromine reported:

“Enviromine personnel systematically sampled some 977 specimens from the drill cores and ground cores in Chapais. A total of 141 static and 30 kinetic AMD prediction tests were performed from 81 waste rock samples and 60 ore specimens collected in the 87 and J4 zones. The overall evaluation indicated that both mineral types were non-acid producers. Moreover, 68 major oxides chemical determinations as well as relative mineralogical reconstitutions carried out using modal calculations were also performed. Mechanical strength of waste rock and ore was evaluated using micro-Deval and MgSO₄ determinations; these measurements were done to better estimate the AMD production potential of the different minerals present in the two zones. Leachate tests were also conducted on waste rock and ore type samples; they were run using protocol from the Quebec Hazardous Waste Regulation (QC1000-85).

“Interpretation of the results indicated that the acid mine drainage production potential is negative as measured in the laboratory. This conclusion is based on the B.C. Research interpretation guide (B.C. Research Initial and Confirmation Tests), the fairly high mechanical resistance of the rock samples and the mineralogical composition of the specimens collected from the 87 and J4 zones at Troilus site.”

Thus, Environmine predicted there would be no ARD from ore and waste rock at Troilus, which was also concluded for bench-scale tailings. Some reasons for this prediction remain valid, whereas other reasons are no longer acceptable based on recent methods and procedures (Price, 2009).

The ABA results of these samples were interpreted using Net Neutralization Potentials [NNP in kg CaCO₃ equivalent/tonne = Neutralization Potential (NP) - Acid Potential (AP)]. Many results were somewhat positive, which was incorrectly accepted as net neutralizing since site-specific NNP criteria can be in the positive range. Some NNP values were negative but with averages of mostly positive NNP values. Averaged NNP values are not valid predictors of ARD.

NP values were relatively constant among the samples, so that variations in sulphur content and its corresponding Acid Potential were the key parameters for ARD predictions. In hindsight and with other case studies (Section 3.1 of this Phase 2 report), relatively constant NP is one sign of

significant silicate neutralization.

The rate of sulphide oxidation and acid generation in Troilus rock were relatively slow because “the mechanical strength properties of the waste rock are very high and indicate that the release and exposure of sulphides to oxidation will be slow”.

This led Enviromine (1993) to consider four classes of Troilus rock with distinctive ARD potentials:

- 1: high sulphide content and high rock competency: low to moderate ARD risk
- 2: low sulphide content and high rock competency: low ARD risk
- 3: high sulphide content and low rock competency: certain ARD risk
- 4: low sulphide content and low rock competency: low to moderate ARD risk

This effect of rock competency and its correlation with small-scale ARD at Troilus was discussed in Section 6.6.1 of the Phase 1 report (MDAG 2024a) and shown in photographs in that section, and also discussed by SRK (2011 and 2014).

Some methods used in this study by Enviromine (1993) were not compatible with current methods and were not reliable. For example, the “kinetic tests” that ran for up to only 27 days, rather than for at least 40 weeks, were the “B.C. confirmation test” where acid and then *Acidithiobacillus ferrooxidans* were added to a sample to determine if additional acid would be generated. As there was no reason to expect additional acid generation based on this procedure, then all ABA samples that indicated potential for ARD (negative NNP values) were manually changed to net neutralizing.

Theoretical mineral “reconstitution” in Troilus rock, instead of direct identification of minerals, was done using x-ray-diffraction (XRF) solid-phase analyses in weight-% oxides. Despite the main rock unit being diorite sometimes appearing as a more-mafic gabbro, Enviromine (1993) erred by assuming no calcium occurred as plagioclase but only as mafic minerals. Sodium and potassium occurred as albite (sodium-rich plagioclase) and orthoclase, respectively. This led to an overestimation of ferromagnesium minerals. In turn, this led to other important, site-specific fast-neutralizing Troilus minerals like calcium-rich plagioclase being underestimated. In any case, the generally true observation was made that “ferromagnesian minerals and alteration minerals such as hornblende, biotite, chlorite and other alteration minerals are probably [slow-neutralizing] acid consumers... [which] manifests itself over a longer term than [carbonate minerals]”.

3.3 Beak International Incorporated (2000)

Beak (2000) summarized the observations of a site visit to Troilus in July 1998

- sulphide minerals in the waste rock include chalcopyrite, sphalerite, pyrite and pyrrhotite
- sulphide mineralization is related to structure within the rock, and sulphide minerals are concentrated on fracture surfaces, etc.; thus, sulphide content cannot easily be correlated with particular rock types within the deposit
- as sulphide minerals are concentrated on fracture surfaces (exposed during blasting) and may be exposed to additional grinding during waste rock transport and disposal, they may be more concentrated in the fine fraction of the waste rock pile (and thus exposed to oxidation) than in the overall rock unit
- waste rock contains significant fine material, including blast hole cuttings which comprise

approximately 0.1% of the total material”

Beak (2000) also summarized past ABA results for Troilus:

- “1998 ABA results indicate that a sulphide content greater than 0.2% will result in an NP/AP ratio below 4, indicating potential for acid generation [*MDAG Note: this is consistent with 0.15% S found in the MDAG Phase 1 ML-ARD study*]
- there appears to be no correlation between gold or copper concentrations, and either NP (carbonate content) or AP (sulphide content) in the rock units
- a majority of historical samples (including those from 1998) including all rock types have an NP/ AP ratio below 4, indicating potential for release of acidity (and metals) [*MDAG Note: this is consistent with many NP/AP (NPR) ratios found in the MDAG Phase 1 ML-ARD study, but this did not reliably represent the potential for ARD release*]
- low NP/AP in individual samples is most often due to an elevated sulphur content, not reduction in carbonate content [*MDAG Note: this is consistent with relatively constant laboratory-measured NP values in the MDAG Phase 1 ML-ARD study such as Figure 7-9*]
- average NP and AP values are consistent throughout rock types, with the exception of mafic volcanics; essentially 100% of mafic volcanic samples have a significant potential to generate acid, compared to approximately 25% for the other rock types
- the lack of a relationship between the sulphide content and other characteristics (rock type, gold content, copper content) imply that segregation of reactive and non-reactive material is not practical”

Thus, based on an NPR (=NP/AP) criterion of 4, “a majority of historical samples (including those from 1998) including all rock types have an NP/ AP ratio below 4, indicating potential for release of acidity (and metals).” However, this conclusion for ARD is unreliable primarily because (1) the NP did not include fast-neutralizing silicate NP and (2) the NPR criterion for carbonate-NP systems (not Troilus) is typically around 2 and for predominantly silicate-NP systems (like Troilus) is around 1, rather than 4 used by Beak (2000)

In fact, as typical for predominantly silicate-NP systems, carbonate content can be (1) can be relatively stable, (2) a product rather than a reactant for neutralization, and (3) relatively unimportant for ARD predictions. Yet, Beak (2000) stated for ARD predictions at Troilus that “low NP/AP in individual samples is most often due to an elevated sulphur content, not reduction in carbonate content” and Troilus should “analyse waste rock initially for percent sulphur, sulphide, and carbonate” and no silicate minerals.

Beak (2000) then explained:

“Seven Humidity cells were established on October 19, 1999 to determine potential loadings of metals and acidity to the environment from the oxidation of sulphides in waste rock (5 humidity cells) and tailings (2 humidity cells). This interim report summarizes the results of the first 21 weeks of the tests. The tests are being continued, on a reduced sampling schedule, for an additional 20 weeks, at which time a final report will summarize the results of the entire test program.”

Few details are known about the origin and pre-test characteristics of the samples in these seven cells

beyond their name (Table 3-1). Notably, each week of humidity-cell testing was not analyzed, leading to greater uncertainties in overall mass balances and averages (Morin and Hutt, 2007).

607922	607928
607938	607940
607945	Tails #1
Tails #3	

¹ See Chapter 4 of this Phase 2 ML-ARD report for the results of these cells combined with other sets of cells.

Some observations about the seven humidity cells were:

- humidity cells have been running for 21 weeks
- pH is typically decreasing slowly, from initial values above 9.0, and remain above 7.0...
- ...
- the sulphate concentration has decreased to approximately 2.0 mg/L in leachate from waste rock cells after approximately 13 to 15 weeks; tailings cell leachate is in the range of 5 to 10 mg/L sulphate in the same time period...”
- ...
- an average of 3.4% (range 1.3% to 5.6%) of NP has been leached from the humidity cell material during the first 21 weeks of the test
- this equates to adequate NP being available for the cells to remain at neutral pH for approximately 8 years, at current leaching rates
- an average of 3.9% (range 2.1% to 5.2%) of AP has been leached from the humidity cell material
- all cells currently remain at neutral pH”

For the seven humidity cells, Beak (2000) noted the notably low rates of sulphide oxidation: “the sulphate concentration has decreased to approximately 2.0 mg/L in leachate from waste rock cells after approximately 13 to 15 weeks; tailings cell leachate is in the range of 5 to 10 mg/L sulphate in the same time period”.

Over the first 21 weeks, “an average of 3.4% (range 1.3% to 5.6%) of NP has been leached..., remain[ing] at neutral pH for approximately 8 years, at current leaching rates [and] an average of 3.9% (range 2.1% to 5.2%) of AP has been leached”. According to this, on average (not for each cell), the NP will slightly outlast the AP and there should be no ARD on average. However, this incorrectly assumes the carbonate is reacting, whereas more-abundant silicate minerals not included in Beak’s NP values were neutralizing and would far outlast the AP. Therefore, the Beak (2000) prediction of ARD in eight years (1) ignored the substantial silicate NP that would maintain near-

neutral conditions and (2) is shown to be wrong on the full scale after 24 years of monitoring.

No later report containing additional weekly data for these cells could be found. The weekly results labeled “Beak (2000)” are shown below starting in Chapter 4 of this ML-ARD Phase 2 report.

3.4 Lamontagne (2000)

In the years since closure at Troilus in 2010, surface drainage and its chemistry from the existing J4 waste-rock pile, plus additional upstream drainage, has been monitored downstream at Station STP-9. However, during operation and for a few years starting in 1999, there were other “STP monitoring stations” (STP1 to STP7) in and around the J4 waste-rock pile as it was being built (Lamontagne, 2000). Through time, these other STP sites were buried under the expanding J4 pile and thus could no longer be monitored.

In 1999 through 2001, the lowest pH measured at these internal STP locations was 6.13, with a maximum of 8.54 and an average of 6.95. Electrical conductivity ranged from 16 to 808 uS/cm, with an average of 234 uS/cm. Based on aqueous sulphate concentrations as indicators of waste-rock-affected drainage water, some STP sites showed variations of an order of magnitude or more, indicating proportions of non-affected and mine-affected J4 water varied significantly through time. The highest sulphate concentration was 705 mg/L, roughly similar to recent concentrations at STP9. The other elements measured at these early STP sites, apparently as total rather than dissolved concentrations, were iron, copper, and zinc, with none showing good correlations with pH or sulphate.

3.5 Lawrence Consulting (2019 and 2021)

Lawrence Consulting (2019) conducted a static-test ML-ARD study including acid-base accounting (ABA) along the eastern and northern edges of the existing J4 waste-rock pile (Figure 3-1). Despite not recommending kinetic testing, two years later Lawrence Consulting (2021) discussed the results and ARD predictions for six humidity cells of J4 waste rock. This work culminated in a prediction of ARD after 1,500 years.

Lawrence Consulting (2019) reviewed and discussed some previous work and data.

- “In reviewing the previous studies, SRK (2015a) concluded that the most common result was uncertainty about the possibility of ARD in J4 waste rock. In another study by Hallam Knight Piésold (1995), which was not reviewed by SRK, it was concluded that the test data indicated that the waste from the J4 pit has a minor propensity to generate acid, which appeared to increase with proximity to ore. Samples tested in the Hallam Knight Piésold report averaged 0.61% total sulphur, with neutralization potential (NP) values averaging 18 kg CaCO₃ equivalent/t and an overall NP/AP ratio (NPR) of 0.83. In contrast they found that waste rock from the Z87 pit to be non-acid generating, being lower in sulphide content and with higher NP.”

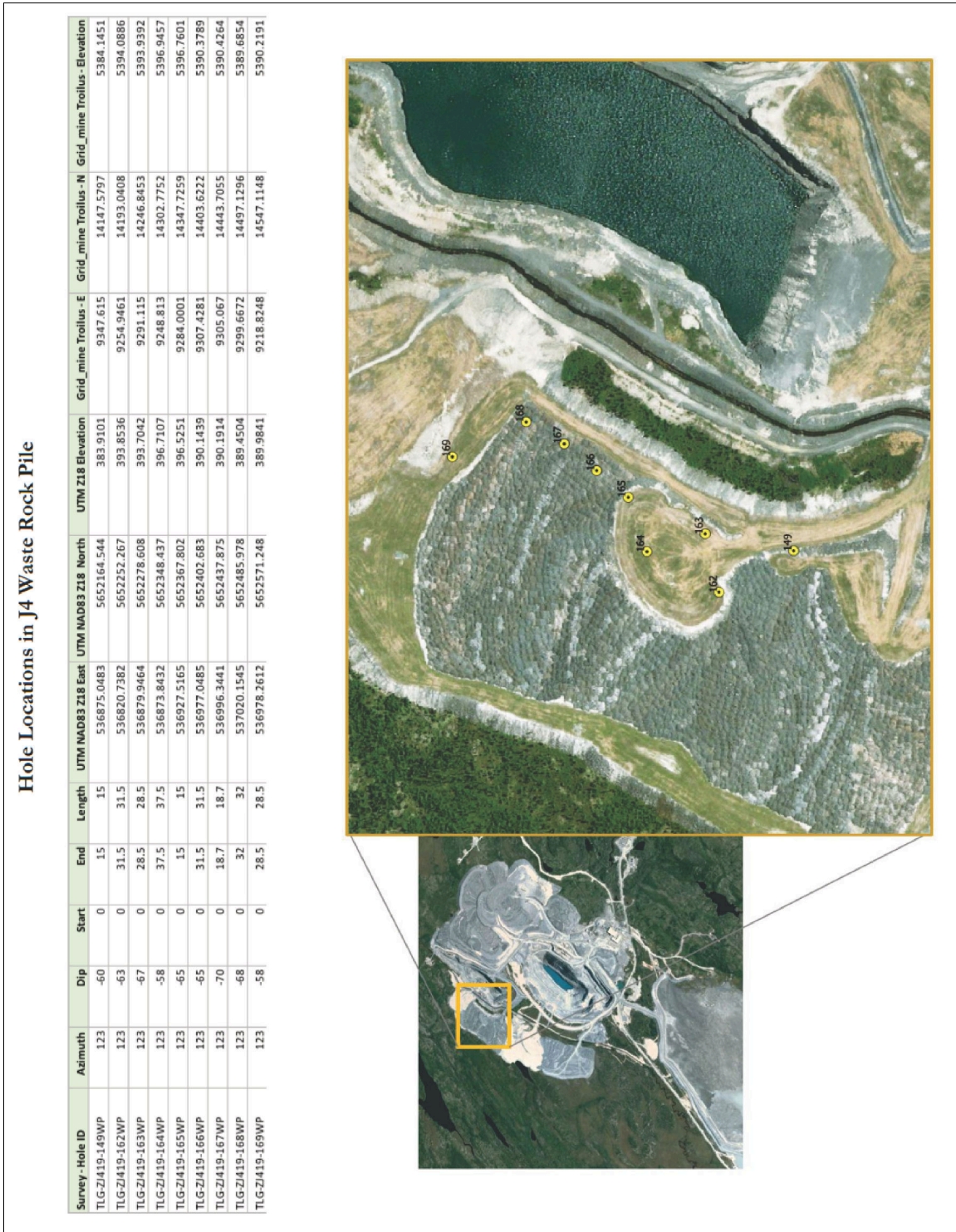


Figure 3-1. Map of nine drillholes along the eastern and northern edges of the existing J4 waste-rock pile at Troilus, from which 50 samples were collected for ML-ARD characterization by Lawrence Consulting (2019).

- “In an earlier study, geochemical tests directed by SRK had been carried out on 18 samples taken from 3 depth intervals at 6 surface excavations at different locations on the J4 waste pile (SRK 2011). The results were very similar to the Hallam Knight Piésold (1995) data. The total sulphur average for all sampled locations was 0.54%. Neutralization potentials (NP) based on carbonate assays were lower than measured by the Modified Sobek method, averaging 4.2 kg CaCO₃ /t. NPR values varied according to sample location, but all values were low, ranging from 0.06 and 0.5 based on carbonate NP, thereby classifying the pile as potentially acid generating (PAG). It was cautioned, however, that extrapolation of the results from just six near-surface locations to the entire pile creates uncertainty. The SRK report also indicated a metal leaching potential for molybdenum, silver, gold, bismuth, sulphur, and selenium.”

- “Since 2011, SRK have also been reporting on the results up to the end of 2016 of a water quality monitoring program that has been carried out since 2009 to evaluate the water quality of drainage from the J4 waste rock pile and, since 2014, in the J4 pit lake (SRK 2011; SRK 2015b; SRK 2016; SRK 2017). Drainage from the waste pile emerges as a seep at the southeast corner of the pile and is sampled at a monitoring station designated STP-09. Water quality at STP-09 has remained quite stable over the monitoring period. The pH, initially around 7.5, has dropped slightly but has remained stable in the range 6.5 to 7 since 2010. Alkalinity values have also remained stable, although values fluctuate with seasonal differences in water flow. The major ions are sulphate and calcium, which are also stable. There is a close correlation between the two ions, indicating that sulphide oxidation is occurring with concurrent neutralization by carbonates. *[MDAG Note: The alternative explanation that neutralization by calcium-bearing silicate minerals like the dominant plagioclase minerals was not considered.]* SRK have concluded that that there was still enough buffering capacity in the waste rock to neutralize any acid production that might be taking place. Concentrations of potassium, magnesium and silica at STP-09 have been low but their presence also indicates some degree of silicate dissolution, further supporting the inference that sulphide oxidation is taking place.... using average values, the molar ratio of [sulphate] to [calcium + magnesium + potassium + sodium + silica] is equal to 1.06. This indicates that indicating that oxidation is taking place with accompanying neutralization by carbonate and to a much lesser extent, silicates. Using median instead of average values gives a ratio of 1.09.”

- “Minor ions [at STP9] are all quite stable and in low concentration, with none exceeding Metal and Diamond Mining Effluent Regulations (MDMER) guidelines. Nickel and zinc have the highest concentrations around 0.1 and 0.05 mg/L, respectively. Copper and cobalt are also present at around 0.01 mg/L. Copper concentrations appear to have increased very slightly over the 8-year period.”

- “The pH and alkalinity values for water in the J4 pit lake have remained quite stable. pH values have been in the range 7.5 to 8.0 and alkalinity around 70 to 80 mg/L. Sulphate values have steadily increased from around 300 mg/L to around 500 mg/L over the 3-year monitoring period. Corresponding calcium concentrations have been around 200 mg/L. As at STP-09, zinc and nickel are the predominant minor ions, have been around 0.1 and 0.02 mg/L respectively. Zinc concentrations appear to have been increasing over the monitoring period.”

- “In 2015, SRK was requested by First Quantum Minerals to develop an Emergency Acid Rock Drainage (ARD) Contingency Plan for the J4 waste rock pile (SRK 2015b). The plan was considered necessary to mitigate the acidic drainage that was predicted by SRK to occur at some time in the future.... It was assumed that the seepage would pass into groundwater and reach the J4 pit where it would mix with the pit lake. SRK calculated that there would be sufficient alkalinity in the J4 pit to neutralize acidity for an indefinite duration. According to the worst-case assessment, neutralization was predicted to last up to 40 years.... It should be noted, however, that SRK were also of the opinion that given the observed low rate of reactivity and the relatively low sulphur content of the waste rock, any ARD formation should be delayed by decades or even centuries.”

New observations and findings from Lawrence Consulting (2019) include:

- “The static test program was carried out on 50 samples of waste rock, taken from the J4 waste pile [see Figure 3-1 above in this Phase 2 ML-ARD study], by drilling 9 holes at locations along the eastern side of the pile selected by Troilus geologists. The tests and analyses performed were: elemental analysis of the head samples; leaching tests carried out by the MEND SFE, TCLP and SPLP methods; acid base accounting; inorganic carbon analyses; and Net Acid Generation (NAG) tests.” Only three of these 50 samples were not predominantly diorite, which some past studies labeled as gabbro.
- “The results of this study have produced very similar results to the numerous studies that have been carried out previously on samples from different areas of the J4 rock pile.”
- “The J4 waste rock can, therefore, be given a preliminary classification as being predominantly potentially acid generating (PAG).” *[MDAG note: This is an incorrect explanation of “PAG” which in reality stands for potentially ARD releasing or net acid generating (Price, 2009).]*
- “However, on the basis of this study, previous studies, and on site operating and monitoring data, it appears that the sulphides (predominantly pyrite) have a low reactivity. Despite the acid potential of the waste rock, no acid generation has yet been observed in the seepage from the pile, which is being routinely monitored.”
- “A detailed previous study... concluded that ARD could take decades or even centuries to appear. This [Lawrence Consulting] analysis indicates that the time for ARD to appear could be 1500 years.... Factors that could explain this behaviour include low sulphide reactivity and the large particle size of the waste rock coupled with the very low surface exposure of sulphides due to the predominantly disseminated occurrence of the mineral.”
- “Since the sulphide content of blasted rock is often found to be concentrated in the finer fractions, screening would also improve the geochemical properties of the rock by reducing the acid potential and therefore further reduce the risk of ARD.” *[MDAG Note: This was not shown to apply to Troilus and the “often found to be” was not supported by data. If this were true for Troilus, and probably is not, removing the finer portion could result in ARD from these finer fractions when no ARD has yet been detected at Troilus.]*

- “However, in the case of the J4 waste rock, it should be recognized that the J4 waste rock pile, comprising 22 million tonnes of material, including the monitoring of its drainage for many years, represents a very large-scale kinetic test from which sulphide oxidation rates have been estimated and actual drainage water quality can be measured. It is unlikely, therefore, that carrying out a typical program of laboratory kinetic tests in humidity cells, could produce better data. Therefore, a standard kinetic test program is not recommended.” *[MDAG Note: Two years later, Lawrence Consulting (2021) produced a report involving six typical humidity cells, which “confirmed the previous [2019] conclusions for the rock represented by the samples tested” as summarized below.]*
- A “small laboratory kinetic test program using laboratory humidity cells on a small number, say 6, samples already evaluated in the static test program and selected based on their sulphur and carbonate contents to provide a range of samples with varying potentials to generate ARD. The objective would be to determine sulphide oxidation rates.... analysis of the J4 rock samples using QEMSCAN or similar mineralogical/petrographic analytical technique to confirm the predominant sulphide mineral mode of occurrence, reported to be disseminated in current geological reports.” *[MDAG Note: There was no emphasis on silicate minerals or on carbonate potentially being created during neutralization.]*
- “Paste pH values ranged from 6.9 to 10.1, with an average of 8.3 [and a median of 9.7], indicating no acidic oxidation products were present.”
- “Sulphate-sulphur contents of samples were low or below detection, indicating that the samples were not oxidized to any significant degree. Sulphide-sulphur contents were, therefore, similar to total sulphur assays, ranging from 0.1% to 1.82 %, with an average of 0.51%. Sulphide-sulphur values were used to calculate acid potential (AP). Based on sulphide values, the average AP of the 50 samples was 15.9 kg CaCO₃ equivalent/tonne rock.”
- “Neutralization potential (NP) values were measured by the Modified NP method (NP (Mod)) *[MDAG Note: this was one of the altered 1991 Modified methods not recognized by the federal ML-ARD Prediction Manual (Price, 2009)]* also calculated from inorganic carbon assays (NP(C)). NP(C) values were found to be lower than the corresponding NP(Mod) values, ranging from <1.7 to 15 kg CaCO₃ equivalent/tonne rock, with an average of 5.8 kg/t. NP(Mod) and NP(C) values were poorly correlated. Since NP(C) values represent the contribution made by carbonate minerals to NP, both NP values were used in subsequent calculations for ARD classification.”
- “ARD classification criteria as follows:
 - Potentially acid generating (PAG): $NPR < 2$
 - Non-acid generating (Non-PAG): $NPR > 3$
 - Uncertain range: $2 \leq NPR \leq 3$
 Based on these criteria, 47 of the 50 samples can be classified as PAG, 1 as Non-PAG and 2 as Uncertain.” *[MDAG Note: Thus, virtually all the existing J4 waste rock was apparently capable of releasing ARD.]*
- “As long as carbonate is available for reaction in the rock mass, then acidity is neutralized and

drainage will remain non-acidic. The time to depletion of carbonate can, therefore, be considered to also be the predicted time to the appearance of ARD.” *[MDAG Note: This is the primary flaw in the ARD predictions by Lawrence Consulting: only carbonate was assumed to neutralize acidity, and that no carbonate was being produced or preserved by silicate neutralization.]*

- “Net Acid Generation (NAG) tests were conducted on 25 samples, selected on the basis of the acid-base accounting results. The results showed that 17 samples were classified as potentially acid forming (PAF) or potentially acid forming - low capacity (PAF-LC). 8 samples were non-acid forming (NAF). These data indicate that some samples classified as PAG by acid-base accounting were not confirmed as potentially acid generating. This could be due to mineralogical factors (e.g. pyrite is less reactive and its disseminated occurrence reduces its surface exposure) or that sulphide oxidation was incomplete due to the oxidizing reagent used in the tests being depleted by competing reactions.” *[MDAG Note: again the emphasis is on sulphide oxidation with no consideration for silicate neutralization that is not sufficiently reactive during the short-term NAG test.]*
- “Revision of the ARD classifications to include consideration of the NAG test results indicates that the sulphur cutoff value can be increased from 0.1% to 0.2% sulphide-sulphur, and the NPR value, delineating PAG/Uncertain PAG and Non-PAG rock, can be reduced from 3 to a value between 1.5 and 2.0. Additional testwork could be carried out to refine these values, although the overall conclusion that the rock in the J4 waste pile can be given a preliminary classification of PAG would not change to any significant extent.”

The second report, by Lawrence Consulting (2021), explained the 2019 static testing was followed by kinetic testing of six samples tested in humidity cells for 58 weeks. The six samples of existing J4 waste rock were “selected based on their sulphur and carbonate contents to provide a range of samples with varying potentials to generate ARD ... to confirm that acidic drainage from the J4 pile will likely not appear for a very long time, if at all”. This “confirmed the previous [2019] conclusions for the rock represented by the samples tested”.

Also,

“the principal focus was on analyzing the oxidation and neutralization rates to compare previous conclusions by LCL and others that, despite the potential for acid generation of 47 of the 50 J4 waste rock samples, the availability and reactivity of the sulphides are very low and acid generation, if it occurs at all, would take hundreds of years to appear. The results of this kinetic test program have confirmed the previous conclusions for the rock represented by the samples tested.”

The six samples tested in the humidity cells are listed in Table 3-2. Some results are presented below starting in Chapter 4 of this ML-ARD Phase 2 report, labeled as “Lawrence (2021) Cells”.

Table 3-2. Six samples of existing J4 waste rock tested in humidity cells by Lawrence Consulting (2021)^{1,2}						
<u>Cell</u>	<u>Sample³</u>	<u>Paste pH</u>	<u>Total Sulphur (%S)</u>	<u>Inorganic Carbon Based NP (kg/t)</u>	<u>Modified NP (kg/t)⁴</u>	<u>Net Potential Ratio⁴</u>
HC-1	A0119852	9.1	0.54	9.2	10.3	0.62
HC-2	A0119855	9.3	0.83	11.7	14.4	0.56
HC-3	A0119870	9.9	0.28	6.7	15.9	1.85
HC-4	A0119878	9.7	0.52	5.8	8.1	0.51
HC-5	A0119879	10.0	0.15	5.0	9.0	1.99
HC-6	A0119894	9.1	1.08	3.3	9.7	0.29
¹ See Chapter 4 of this Phase 2 ML-ARD report for the results of these cells combined with other sets of cells.						
² Two different sets of pre-test solid-phase analyses were provided by Lawrence Consulting (2021), with the set from that report's Table 4 shown here.						
³ All samples were J4 diorite collected from the eastern and northern edges of the existing J4 waste-rock pile. The first two samples included some minor granite (felsic intrusives).						
⁴ Net Potential Ratio (NPR) was measured and calculated in a manner inconsistent with the federal ML-ARD prediction Manual (Price, 2009) using a Modified NP, and does not reflect the additional "unmeasured" silicate NP known to be important in Troilus rock.						

3.6 On-Site Field Columns by Troilus Gold Corp

To test for additional NP and to reliably detect NP, various scales of geochemical kinetic testing have been and are being conducted on Troilus rock in laboratories and on site, as explained here and in Subsections 3.7 and 3.8 below.

In 2021, Troilus constructed 13 on-site ML-ARD columns (Table 3-3), open at the top to ambient air and to precipitation, and with small angled holes drilled downward along the columns' lengths to ensure the rock would be exposed to air (Figure 3-2). The columns have an internal diameter of 30 cm with a height of 1.5 m, except Columns 12 and 13 with a height of 3.0 m. Recent kinetic testing has focused on subsamples of Columns 12 and 13 as explained below in Subsections 3.7 and 3.8.

The contents and results of these columns have already been discussed in Section 6.6 of the ML-ARD Phase 1 report (MDAG, 2024a). A few observations from that document are repeated here.



Figure 3-2. A photograph of the 13 on-site ML-ARD columns, with Columns 12 and 13 containing hundreds of kg of existing, weathered J4 waste rock.

Table 3-3. Thirteen on-site field columns of existing and future J4 rock						
<u>Column</u>	<u>Content</u> ¹	<u>Mass (kg)</u>	<u>Total Sulphur (%S)</u>	<u>Sobek NP (kg/t)</u>	<u>Carbonate NP (kg/t)</u>	<u>NPR</u> ²
C1	low-sulphur non-brecciated diorite (Unit I2J)	92.97	0.12	15	4.5	4.00
C2	mean-sulphur non-brecciated diorite (Unit I2J)	70.79	0.29	16	6.8	1.77
C3	high-sulphur non-brecciated diorite (Unit I2J)	98.33	0.70	16	4.5	0.73
C4	low-sulphur brecciated diorite (Unit I2J;BR)	98.52	0.11	16	6.8	4.65
C5	mean-sulphur brecciated diorite (Unit I2J;BR)	64.48	0.25	18	6.8	2.30
C6	high-sulphur brecciated diorite (Unit I2J;BR)	98.92	0.72	19	4.5	0.84
C7	mean-sulphur undifferentiated volcanics (Unit V)	76.93	1.01	18	6.8	0.57
C8	mean-sulphur felsic intrusives (Unit I1)	97.50	0.46	16	6.8	1.11
C9	composite J4 ore (composite Ore units)	105.58	1.55	14	4.5	0.29
C10	mean-sulphur non-brecciated diorite (Unit I2J)	72.74	0.31	16	4.5	1.65
C11	mean-sulphur brecciated diorite (Unit I2J;BR)	65.48	0.24	16	4.5	2.13
C12 ³	existing heavily oxidized J4 waste rock	260.70	1.58	18	<4.5	0.36
C13 ³	existing relatively unoxidized J4 waste rock	317.52	0.47	17	5.5	1.16
¹ See Chapter 3 of the ML-ARD Phase 1 report (MDAG, 2024a) for details.						
² Net Potential Ratio (NPR) was measured and calculated in a manner inconsistent with the federal ML-ARD prediction Manual (Price, 2009) using a Modified NP, and does not reflect the additional “unmeasured” silicate NP known to be important in Troilus rock.						
³ Average value of 10 subsamples.						

The 11 smaller columns contain approximately 65 to 106 kg of future J4 waste rock collected from drillcore. In contrast, larger Columns 12 and 13 were filled with 261 kg and 318 kg, respectively, of existing J4 waste rock taken from two separate locations in the existing J4 waste-rock dump. In this way, Columns 12 and 13 are similar to existing J4 waste rock tested earlier by others (see Subsections 3.3 and 3.5 above) and were the source of samples for more recent kinetic testing (see Subsections 3.7 and 3.8 below).

Column 12 contains heavily oxidized, brown J4 waste rock with abundant fine-grained particles taken from the vicinity of Test Pit M4 (Figure 6-19) reported by SRK (2011). It has been exposed and oxidizing for 14 to 28 years. Its brown colouring suggests it is relatively reactive, fast weathering, and acid generating. Rinse pH by SRK (2011) confirmed this M4-pit rock had acidic pH values between 3.7 and 5.4 with total-sulphur levels up to 1.4%S. In contrast, all other test pits had near-neutral rinse pH values of 6.9 to 8.6 with total sulphur typically less than 0.50%S. This is consistent with the findings of Enviromine (2000) in Subsection 3.2 above where low physical competency accompanied by higher sulphur levels of some J4 rock results in high ARD potential.

Column 13 contains relatively unoxidized, grey J4 waste rock with abundant fine-grained particles taken from near SRK Test Pit SE6. There is a visible distinction at Troilus between the less-abundant weathered brown rock and the more abundant relatively unweathered grey rock.

The initial effluents from all columns were initially near neutral. However, within a few weeks, the effluent pH from Column 12 with brown J4 rock fell below 4.5 and eventually reached a typical ARD pH around 3.5. In contrast, the pH from Column 13 with existing grey rock remained near neutral, typically around pH 6.0-6.5 but with some higher and lower values. This pH range is also typical of pH measured after mine closure at Monitoring Station STP-09, which monitors flow from the full-scale, existing J4 waste-rock pile with tens of millions of tonnes of rock.

The ARD results from the columns through 2023 are consistent with the Sobek TNPR criterion of 2.0 and a Carbon TNPR criterion of 0.5 discussed in the Phase 1 ML-ARD report. Thus:

- (1) higher levels of total sulphur are associated with lower, but still near-neutral paste pH;
- (2) total sulphur levels below 0.15%S are net neutralizing;
- (3) total sulphur levels above 1.3%S (like Column 12) are net acid generating and capable of releasing ARD after various lag times;
- (4) total sulphur levels between 0.15%S and 1.3%S (like Column 13 and the samples studied by the National Research Council of Canada, 2023; see Subsection 3.8 below) require additional information on Silicate Neutralization Potential (Figure 2-1) for ARD predictions; and
- (5) the amount of Total NP in Troilus rock may depend on the amount of total sulphur and its oxidation rate rather than being a certain numerical value (vertical dashed line in Figure 2-1).

The additional NP not currently detected in Troilus rock can cause TNPR values to increase significantly and thus to have less ARD potential than reported at this point. The Phase 1 report and the subsequent chapters in this Phase 2 report address this additional Silicate NP in detail and the site-specific NPR criterion for ARD predictions.

3.7 Coalia Humidity Cells

In 2022-2023, the Coalia Research Centre in Quebec operated four humidity cells for 62 to 70 weeks. These four humidity cells (Table 3-4) were specifically chosen as subsamples from four on-site field columns (Section 3.6 above and Table 3-3). This allowed the results of these standard humidity cells to be compared with three other sets of humidity cells of Troilus rock (Sections 3.3, 3.5, and 3.8).

Table 3-4. Four humidity cells operated by Coalia Research Centre	
<u>Humidity Cell</u>	<u>A Subsample of Rock from Field Column (see Table 3-3)</u>
HC-1	Field Column 12 (acidic)
HC-2	Field Column 13
HC-3	Field Column 3
HC-4	Field Column 7

Some results are presented below starting in Chapter 4 of this ML-ARD Phase 2 report, labeled as “Coalia Cells”.

3.8 National Research Council of Canada Specialized Humidity Cells

As part of specialized kinetic testing, the National Research Council of Canada is running six humidity cells with variable times between rinsing events, and with variable relative humidities, inside sealable chambers that allow detailed high-frequency measurements of oxygen consumption (“oxycon”) and carbon-dioxide uptake-release (NRC, 2023 and in preparation). Basic objectives of this work include (1) searching for conditions that could destabilize silicate-mineral neutralization in Troilus rock and thus produce ARD, (2) understanding the passive capture and release of carbon dioxide, and (3) creating a robust model for the full-scale prediction of ARD at Troilus.

The six NRC humidity cells are subsamples of Field Column 13 (Tables 3-3 and 3-4), typical of existing low-reactivity, grey-coloured J4 waste rock. In turn, the cells are differentiated as subsamples of two particle sizes from grinding of Column 13 rock (Table 3-5).

Some results are presented below starting in Chapter 4 of this ML-ARD Phase 2 report, labeled as “NRC Cells”. Chapter 6 below specifically discusses the results of NRC oxycon testing, including evidence that calcite persists in the humidity cells despite periodic rinsing of the cells that should dissolve and remove calcite.

Table 3-5. Six specialized humidity cells operated by the National Research Council of Canada, all subsamples from Field Column 13		
Humidity Cell	Nominal Particle Size	Note
Cell 1	Coarser, ~5 mm	
Cell 2	Coarser, ~5 mm	
Cell 3	Coarser, ~5 mm	
Cell 4	Finer, ~<1 mm	some finer particles lost through basal filter
Cell 5	Finer, ~<1 mm	not mixed or disturbed
Cell 6	Finer, ~<1 mm	mixed and disturbed once, causing the oxidation rate to accelerate slightly and then return to previous slow levels

4. COMPILED RESULTS OF SETS OF KINETIC TESTS

To understand and detect better the unmeasured silicate-mineral-based Neutralization Potential (NP) in Troilus rock, the four sets of laboratory-based humidity cells and the much larger on-site field columns (discussed in Chapter 3 above) were compiled and interpreted. In this chapter, an overview of the results is provided, while subsequent chapters discuss more details.

Based on compiled pH trends through time (Figure 4-1), significantly acidic conditions below pH 5 were detected only in Field Column 12 and in its subsample placed in Coalia Cell 1. The acidic conditions in these two kinetic tests produced some aqueous concentrations notably different from the near-neutral kinetic tests, like (1) sulphate (Figure 4-2) indicating an ongoing, higher rate of sulphide oxidation and acid generation at acidic pH and (2) a lower Carbonate Molar Ratio (Figure 4-3) indicating partial rather than full neutralization of the generated acidity.

For all the remaining, near-neutral kinetic tests, pH stabilized after several initial weeks of testing generally between pH 6.0 and 8.0 (Figure 4-1). After any initial flushing of minor sulphate minerals, the rate of sulphate production, sulphide oxidation, and acid generation generally stabilized in the range of about 2 to 50 mg/L (Figure 4-2), except the field columns which contained hundreds of times more rock and a significantly lower ratio of water:rock. The units of mg/L are not often used for sulphate, and instead mg/kg of sample/week is more often used because it normalizes all samples to equivalent weight and water flushing. These normalized units are used in subsequent chapters of this Phase 2 report.

In near-neutral humidity cells, the Carbonate Molar Ratio ($= [\text{Ca}+\text{Mg}]/\text{SO}_4$, see Figure 4-3) indicates how effectively the neutralizing minerals are neutralizing acidity generated by sulphate oxidation (Figure 4-2). This is discussed in more detail in the following chapters.

As observed in past studies at Troilus (Chapter 3 above) and in the ML-ARD Phase 1 study (MDAG, 2024a), calcium is the main indicator of neutralization and correlates well with sulphate, although past studies thought the calcium was dissolved from calcite rather than from calcium-bearing silicate minerals. After an initial period of stabilization, the molar ratios with magnesium (Figure 4-4) and sodium (Figure 4-5) and iron (Figure 4-6) confirm the molar dominance of calcium in the water. Potassium rivals calcium (Figure 4-7), but potassium is not associated with significantly neutralizing minerals in Troilus rock (see the Phase 1 study). Therefore, as in the past, aqueous calcium and sulphate do correlate reasonably well (Figure 4-8), again indicating calcium-bearing minerals account for the observed neutralization while the calcite (calcium carbonate) remains present and not consumed by acid generation (see Chapter 6 below).

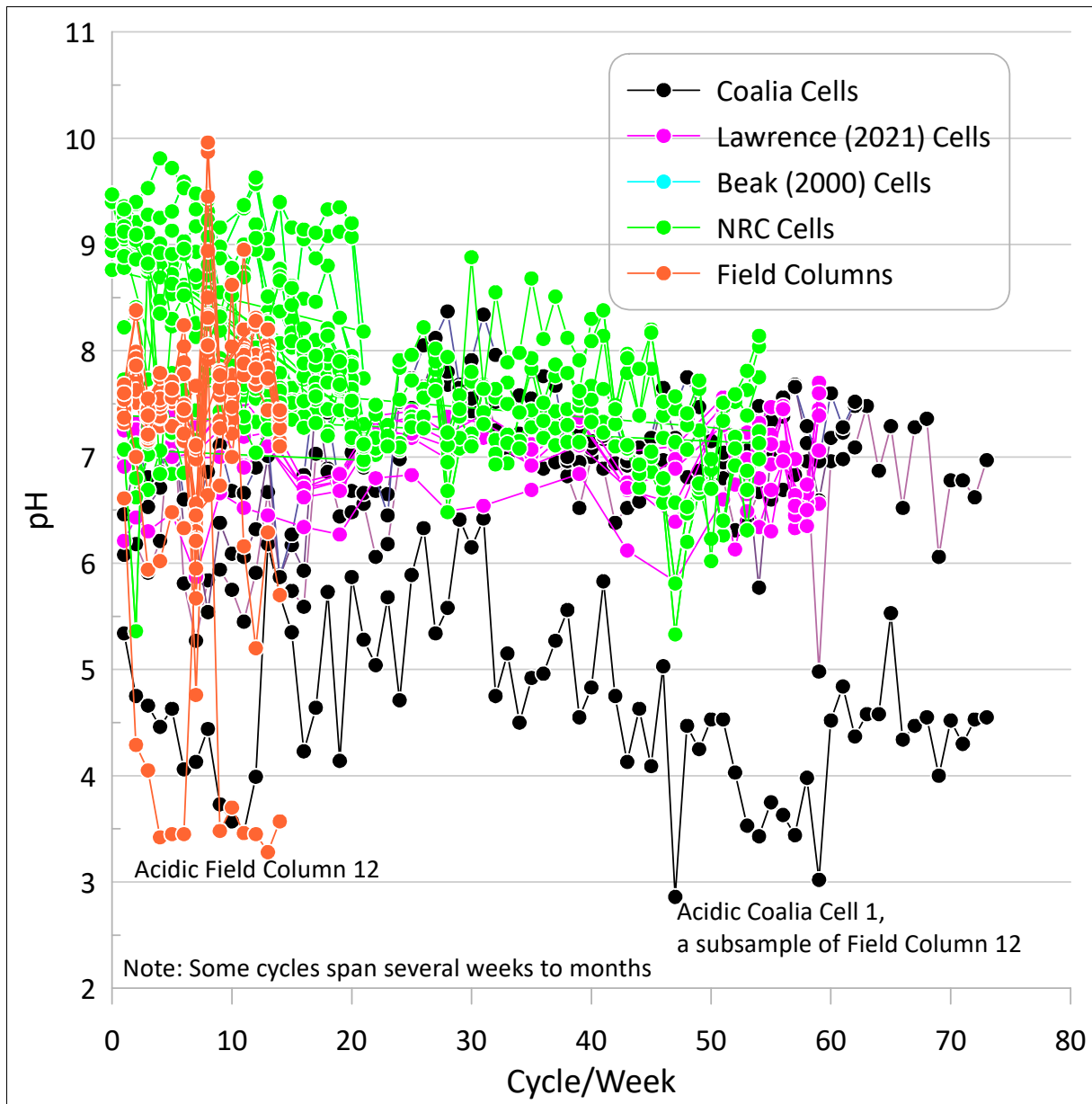


Figure 4-1. Temporal trends of effluent pH from four sets of laboratory-based humidity cells and the much larger on-site field columns.

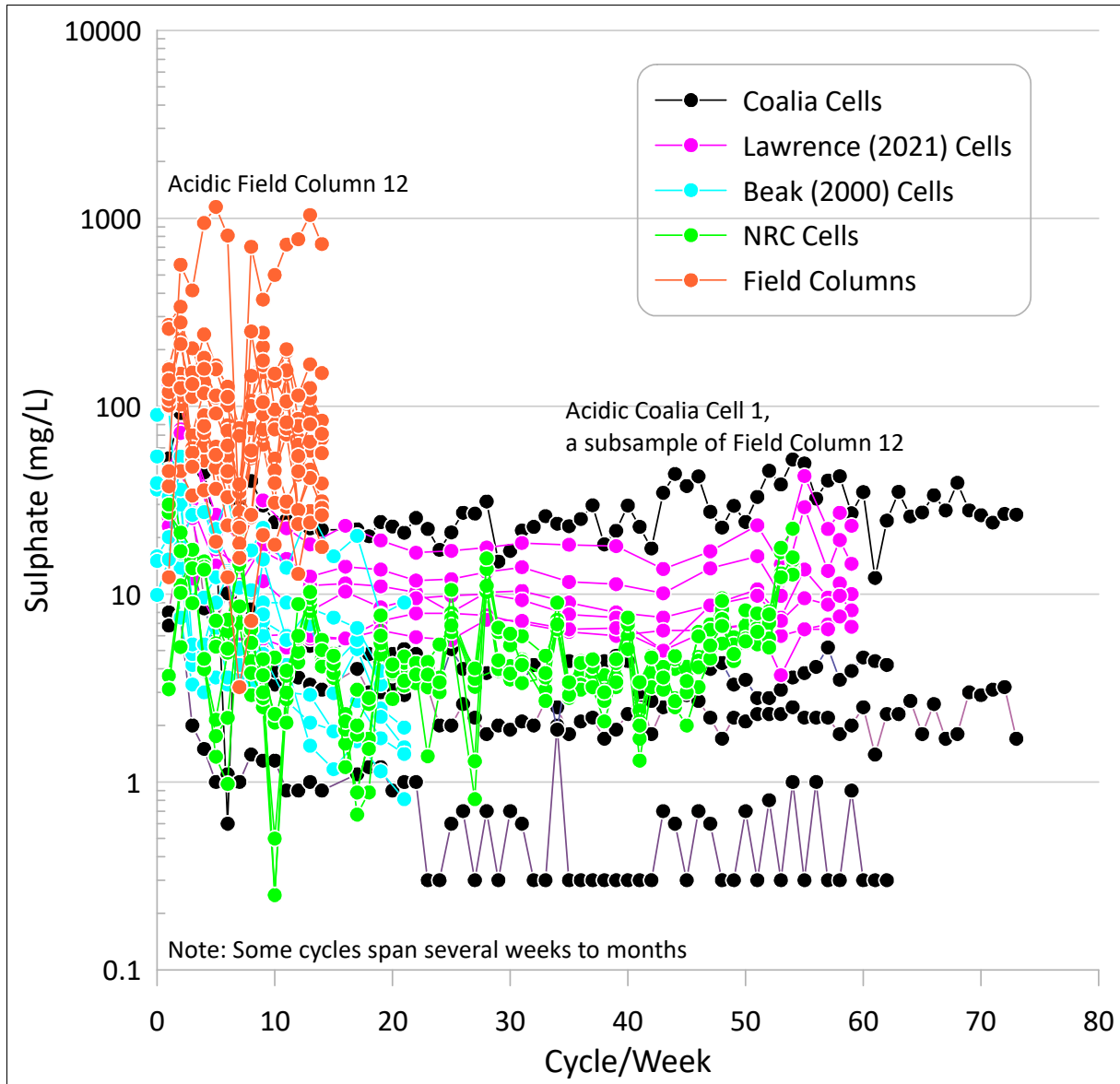


Figure 4-2. Temporal trends of effluent sulphate from four sets of laboratory-based humidity cells and the much larger on-site field columns.

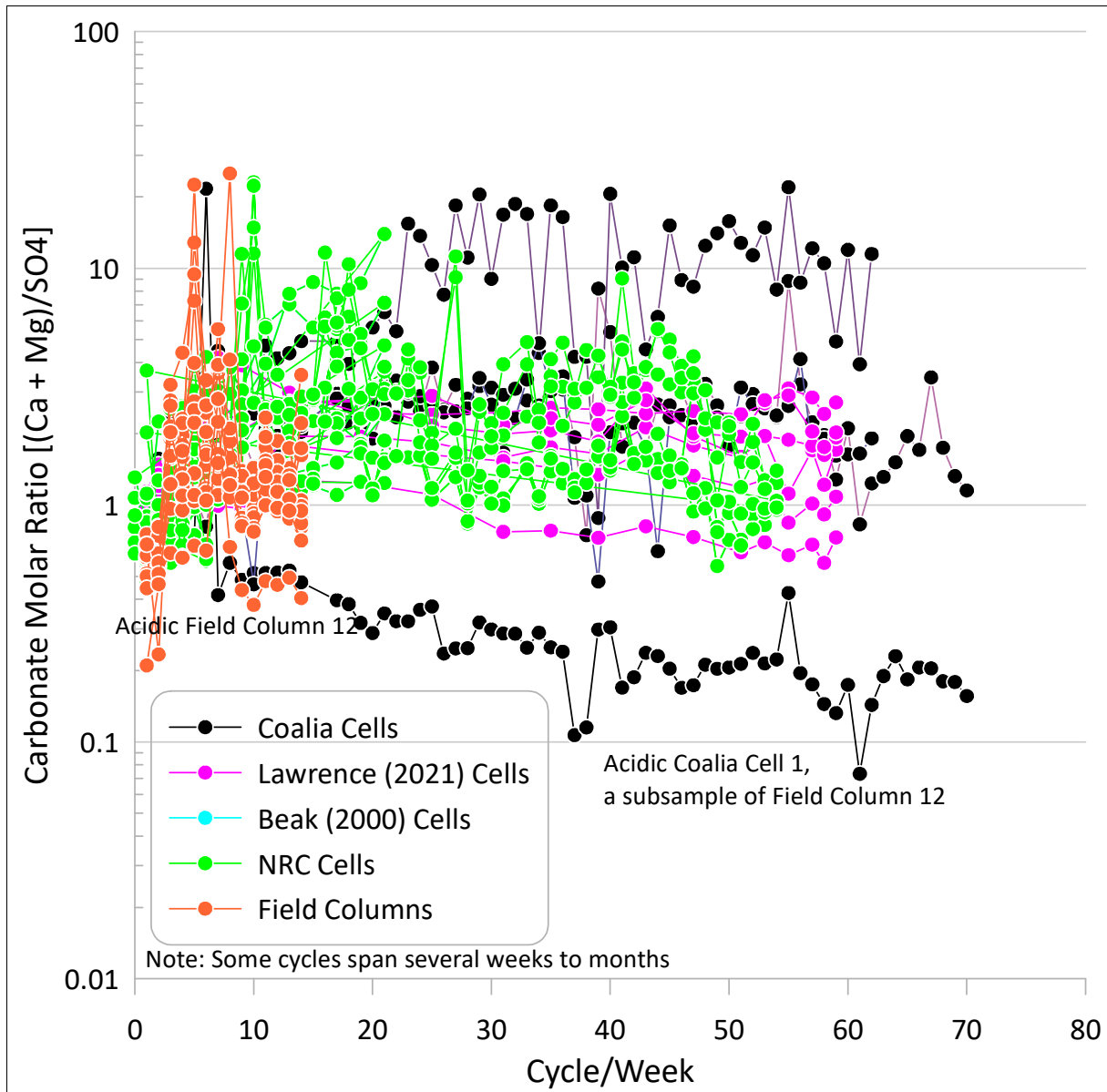


Figure 4-3. Temporal trends of effluent Carbonate Molar Ratio from four sets of laboratory-based humidity cells and the much larger on-site field columns.

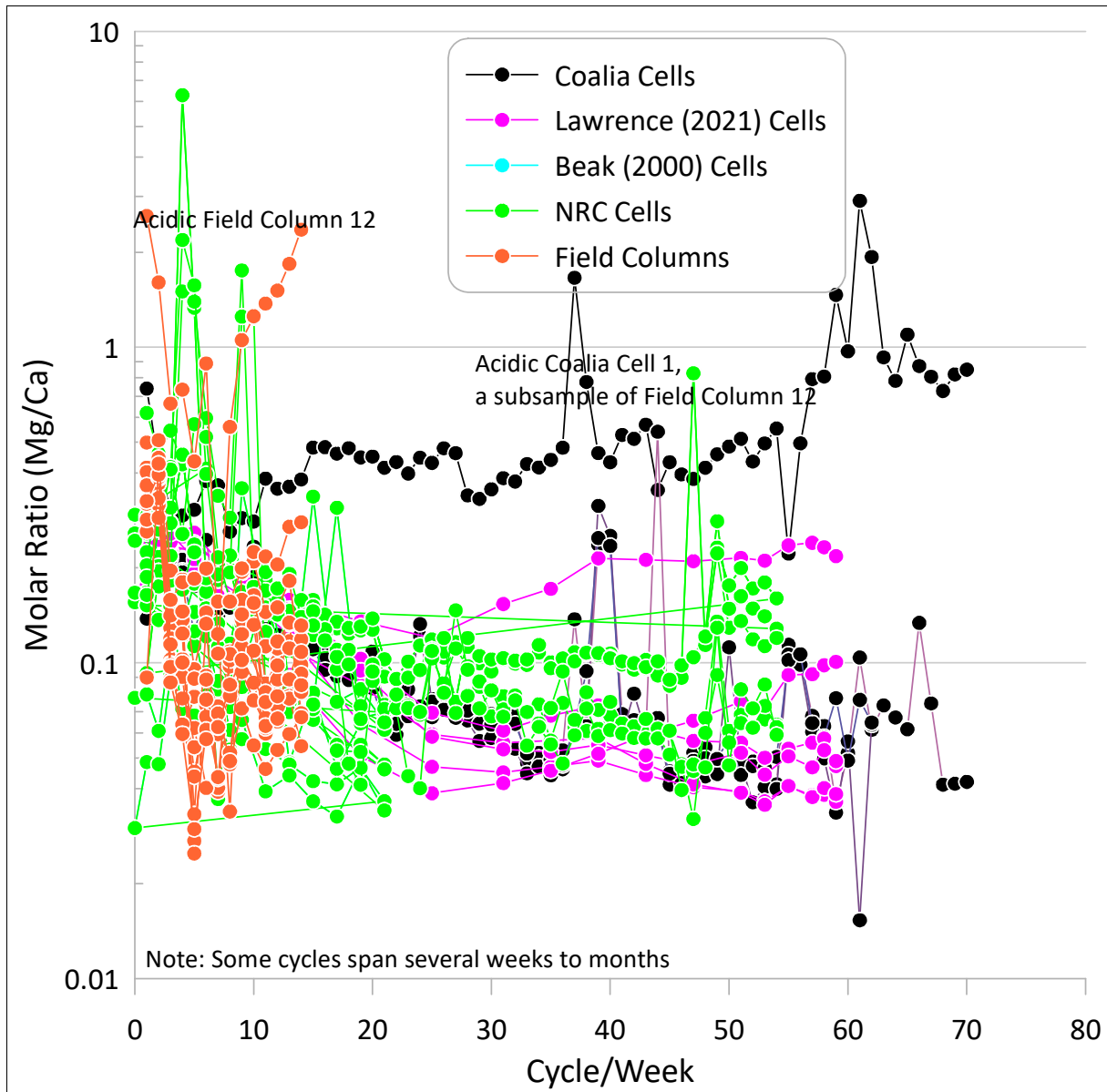


Figure 4-4. Temporal trends of effluent molar ratio of magnesium to calcium from four sets of laboratory-based humidity cells and the much larger on-site field columns.

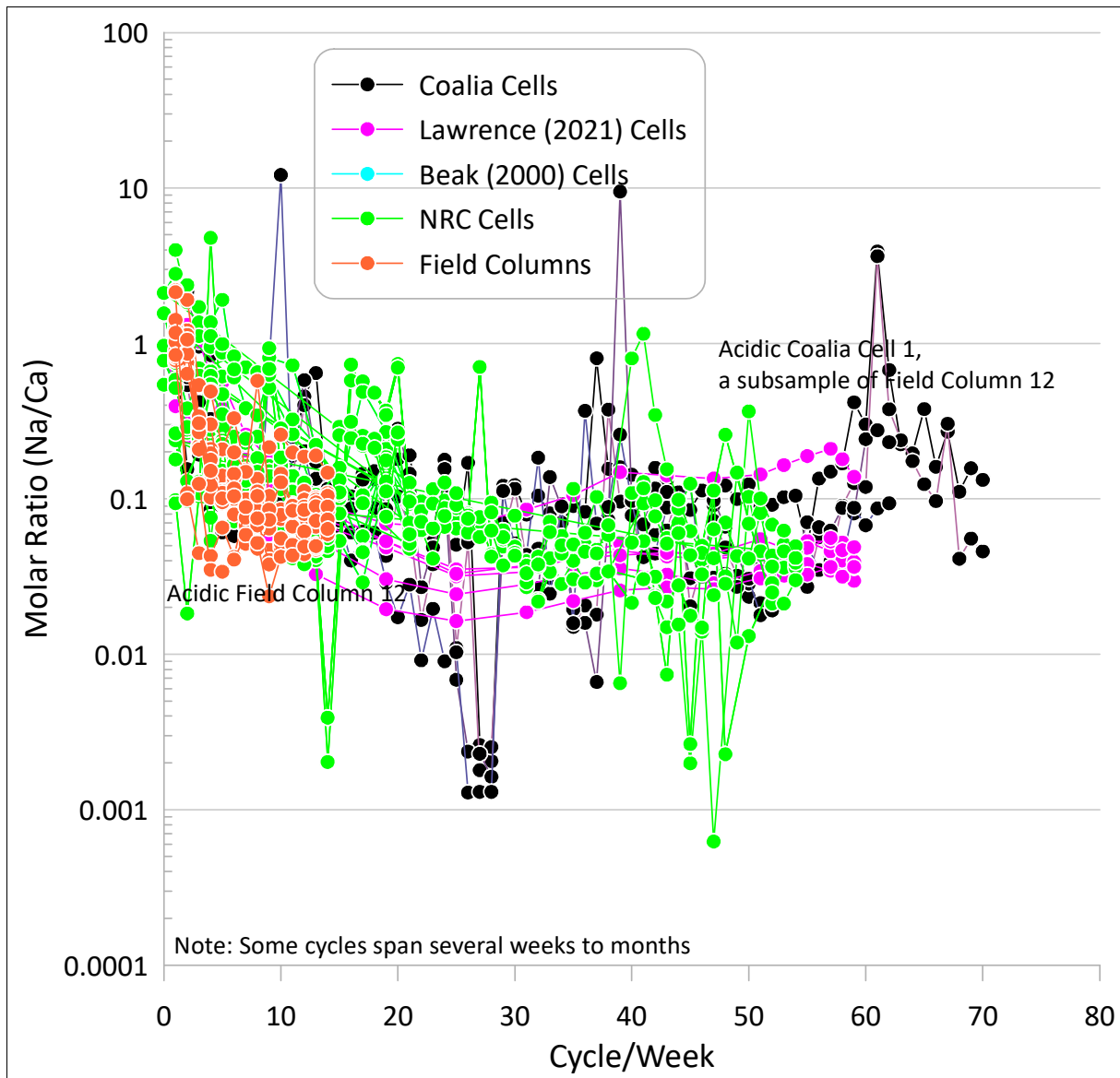


Figure 4-5. Temporal trends of effluent molar ratio of sodium to calcium from four sets of laboratory-based humidity cells and the much larger on-site field columns.

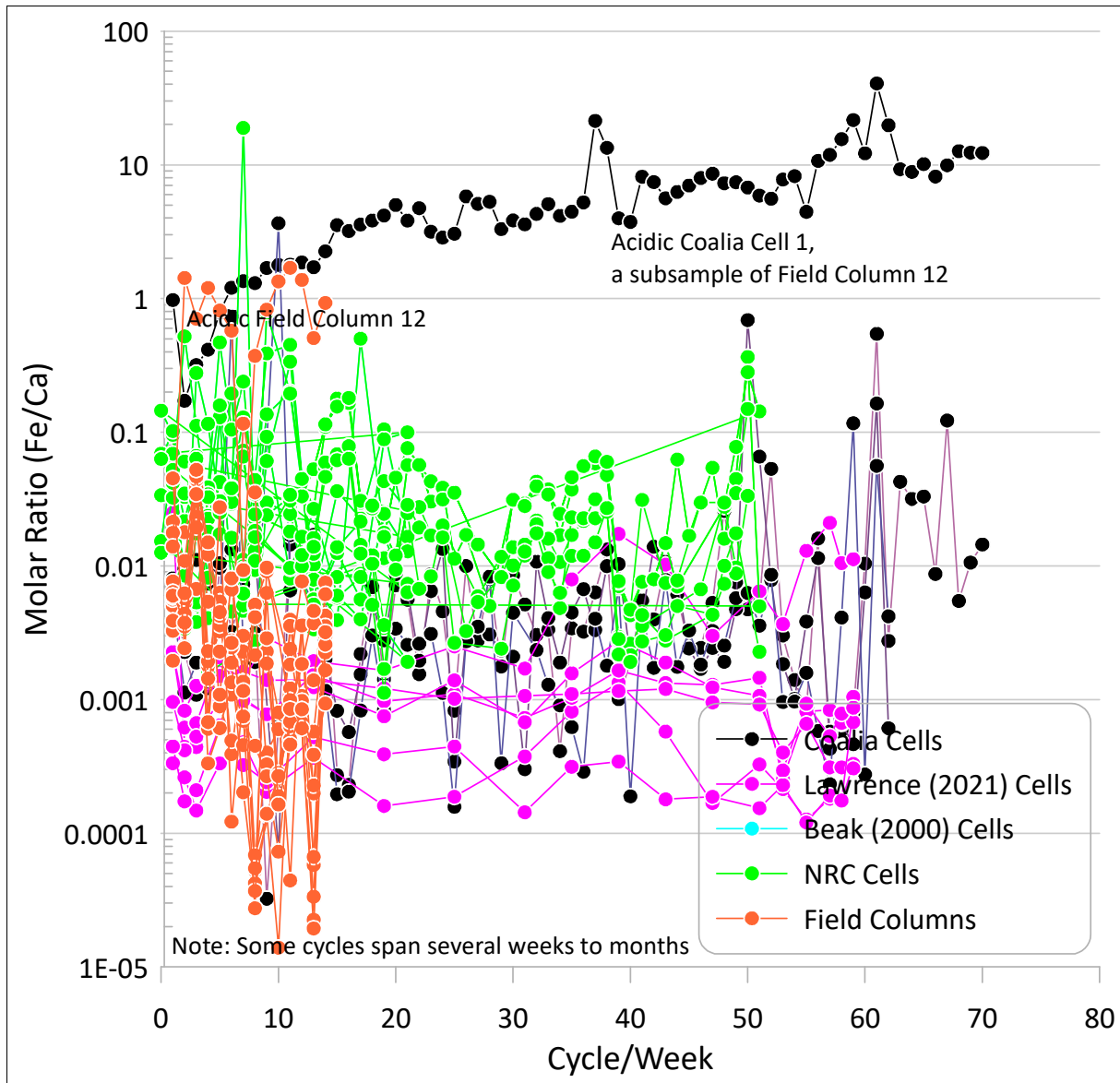


Figure 4-6. Temporal trends of effluent molar ratio of iron to calcium from four sets of laboratory-based humidity cells and the much larger on-site field columns.

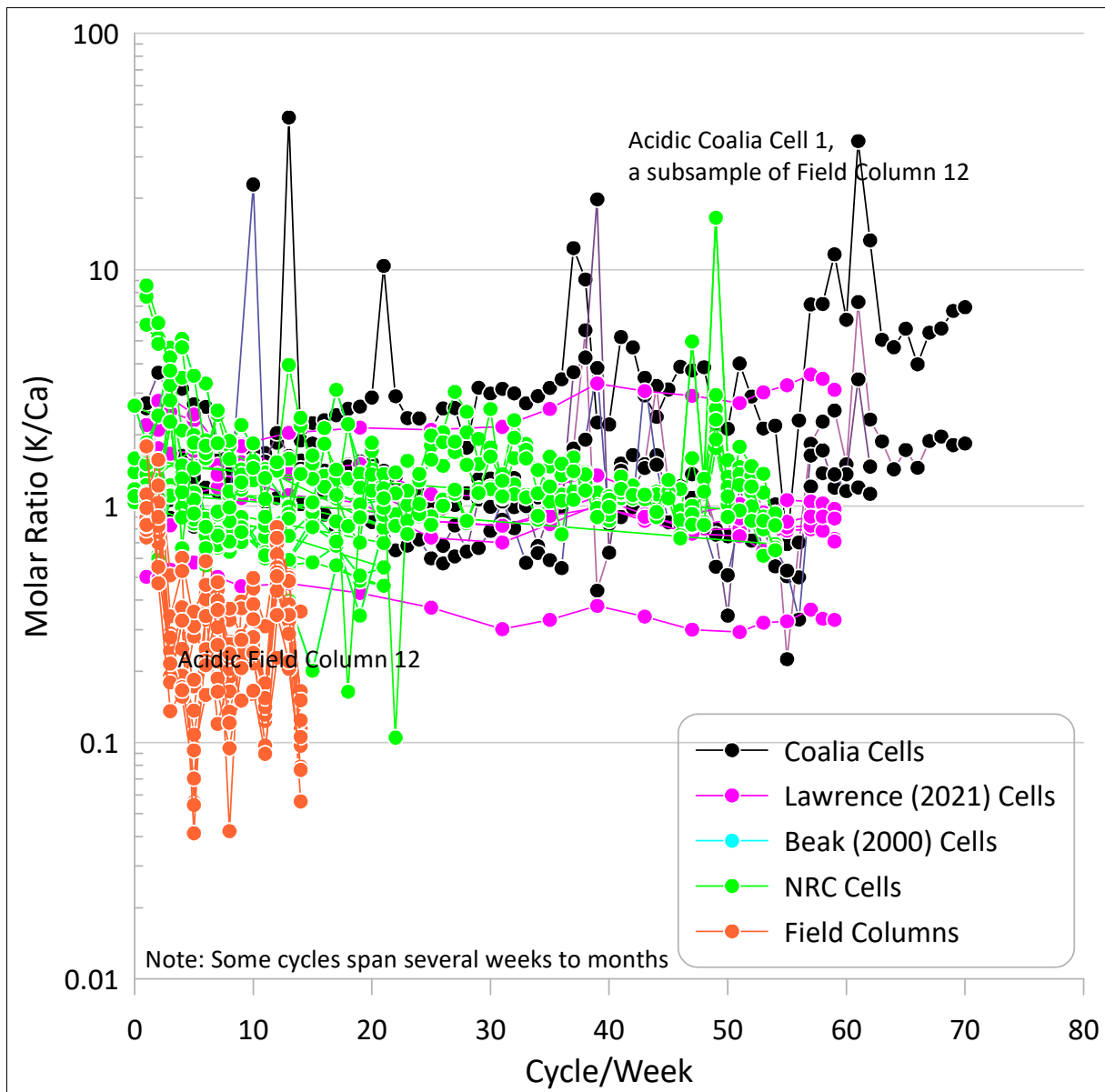


Figure 4-7. Temporal trends of effluent molar ratio of potassium to calcium from four sets of laboratory-based humidity cells and the much larger on-site field columns.

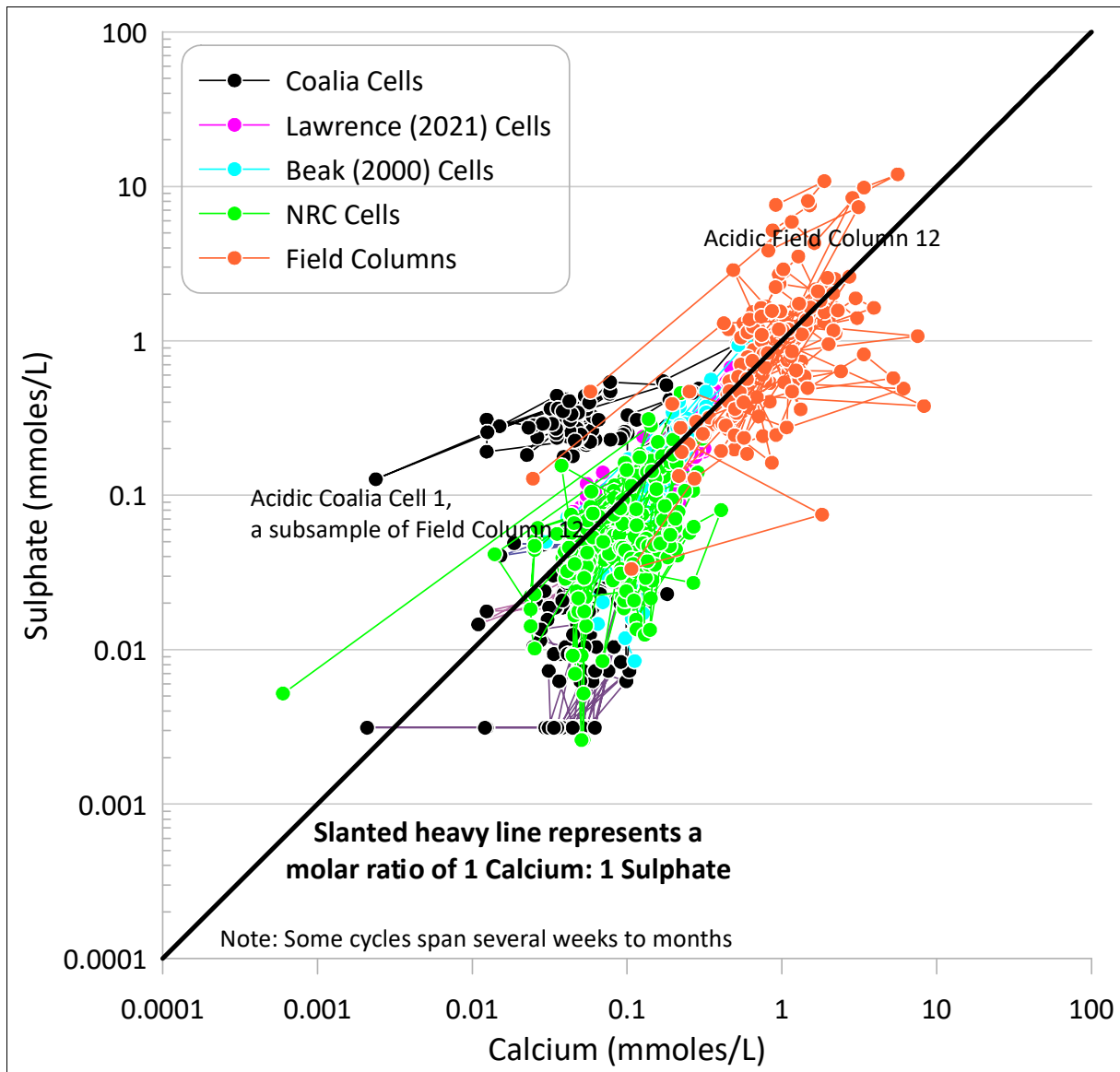


Figure 4-8. Effluent calcium vs. sulphate in mmoles/L from four sets of laboratory-based humidity cells and the much larger on-site field columns.

5. COMPARISONS OF TROILUS KINETIC RATES TO THE INTERNATIONAL KINETIC DATABASE (IKD)

For decades, a common observation about Troilus rock is that its rate of oxidation and acid generation, as reflected by its sulphate production rate in mg SO₄/kg/wk, is relatively low (see Chapter 3 above). To validate this observation, various entire-test-interval and last-five-weeks rates for Troilus humidity cells (described in Chapter 3 above) were compared to Version 24 of the International Kinetic Database (IKD, <https://www.mdag.com/ikd.html>) containing the results of 707 humidity cells from 91 sites around the world.

The six humidity cells by the National Research Council of Canada (see Section 3.8 above) are not included here. This is because they were not operated according to standard protocols. Instead, these NRC cells included variable times between rinsing events, and with variable relative humidities, inside sealable chambers that allow detailed high-frequency measurements of oxygen consumption (“oxycon”) and carbon-dioxide uptake-release (NRC, 2023 and in preparation). This is explained further in Chapter 6 below. Nevertheless, rates of oxidation from the non-standard NRC cells were generally less than 10 mg SO₄/kg/wk.

Over the entire testing intervals, the Troilus cells had sulphate production rates around and below 10 mg SO₄/kg/wk, with a few as high as 26 mg/kg/wk (Figure 5-1). This is discussed further in Chapters 6 and 7 below. However, these average Troilus sulphate-production rates do not show a clear correlation with initial solid-phase sulphide (Figure 5-1) or with lowest measured pH (Figure 5-2). Also, the Troilus sulphate rates are relatively low when compare to their measured Neutralization Potential (Figure 5-3). This suggests Troilus rock should release ARD after relatively short lag times, but the ML-ARD Phase 1 report and this Phase 2 report show that Troilus rock contains more NP than the current analytical methods can detect. In any case, Troilus rates of sulphide oxidation and acid generation are confirmed as relatively low when compared to the IKD.

On the other hand, Troilus leaching rates for copper and zinc in mg/kg/wk are relatively typical (Figures 5-4 and 5-5). Copper, zinc, and dozens of other elements are discussed further in *Troilus Gold Project - Predicted Maximum Aqueous Concentrations and Geochemical Source Terms* (MDAG, 2024b).

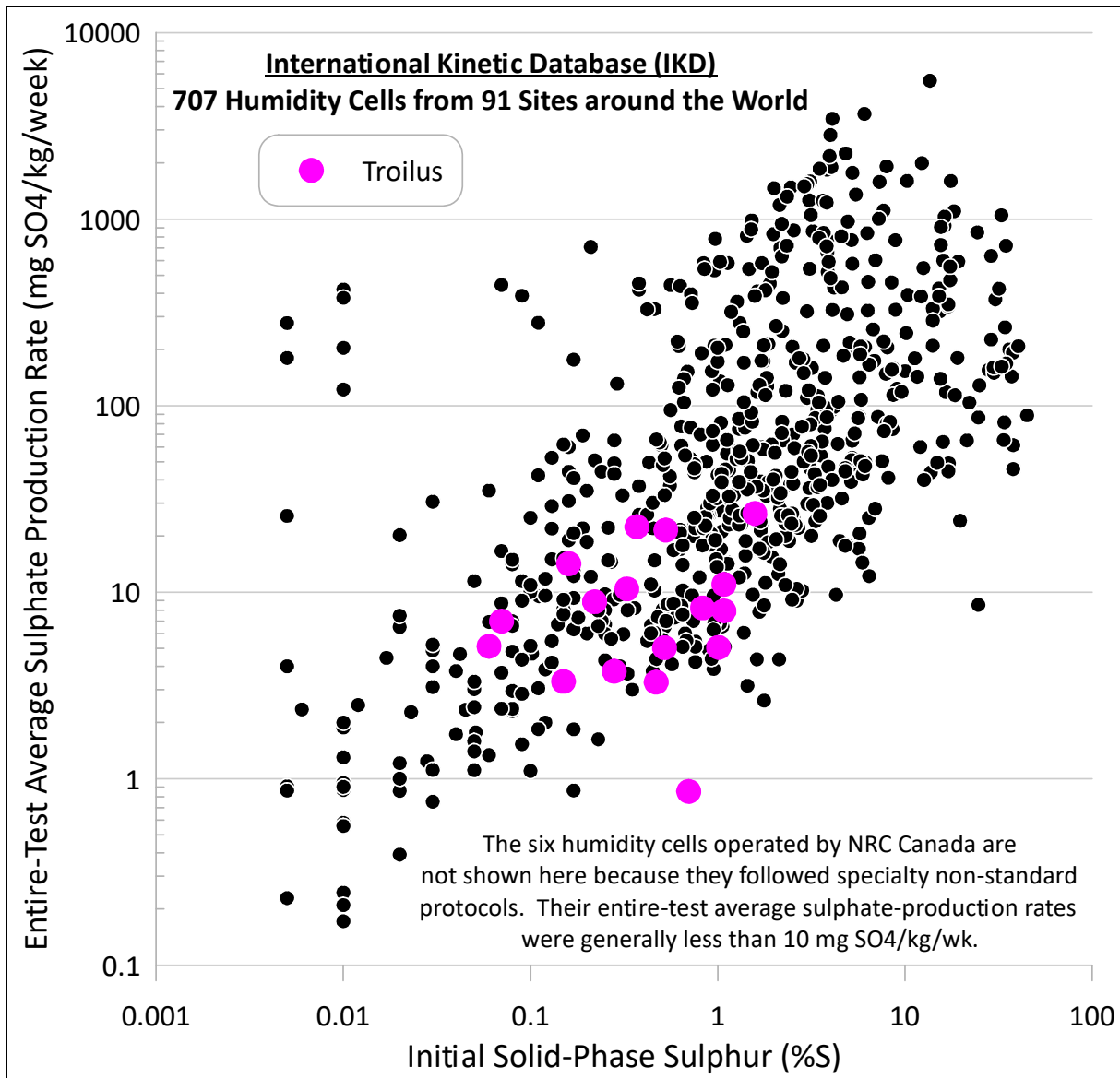


Figure 5-1. Entire-test average sulphate-production rate vs. initial solid-phase sulphur in the International Kinetic Database.

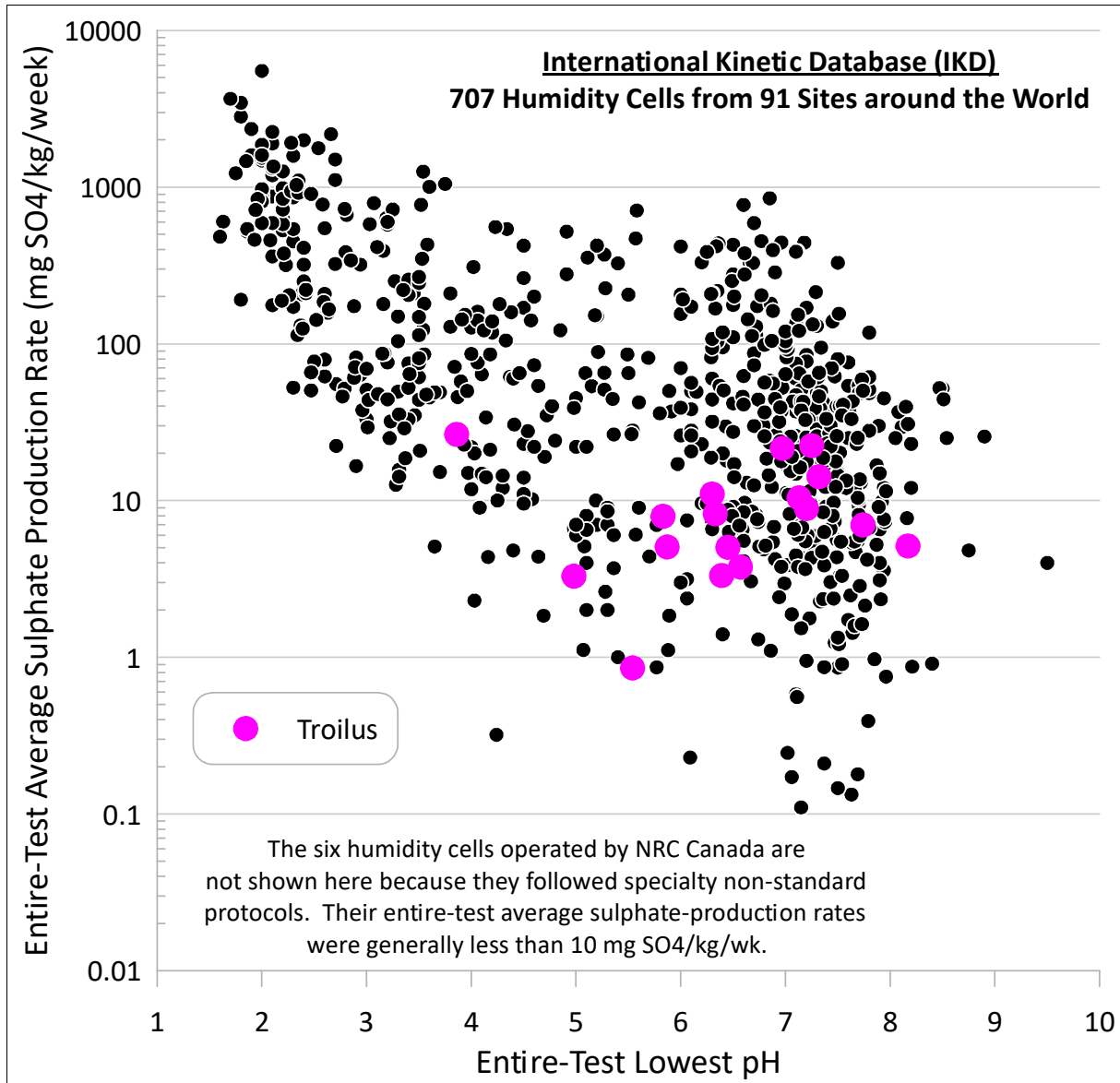


Figure 5-2. Entire-test average sulphate-production rate vs. lowest measured pH in each test in the International Kinetic Database.

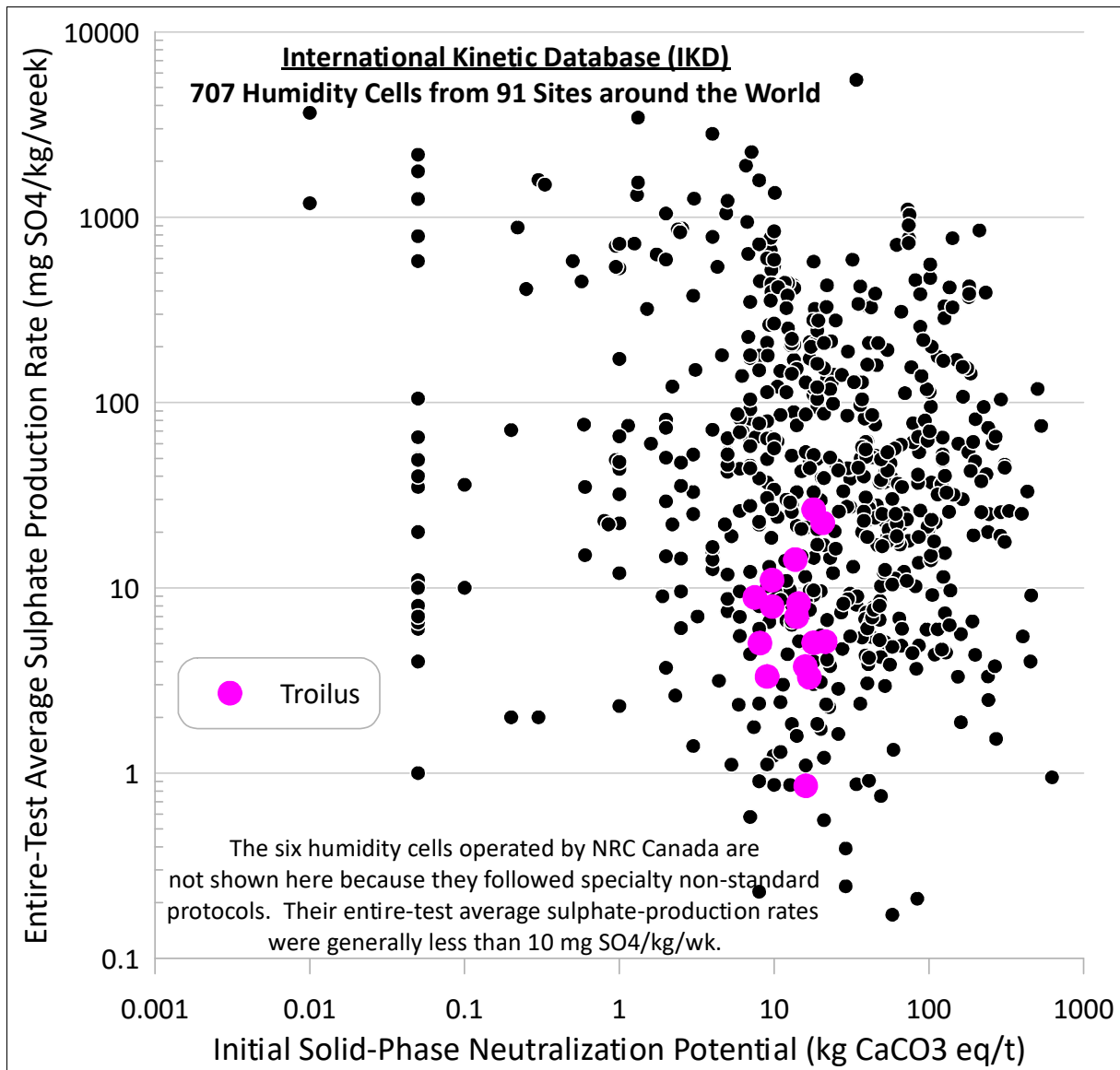


Figure 5-3. Entire-test average sulphate-production rate vs. initial measured Neutralization Potential in the International Kinetic Database.

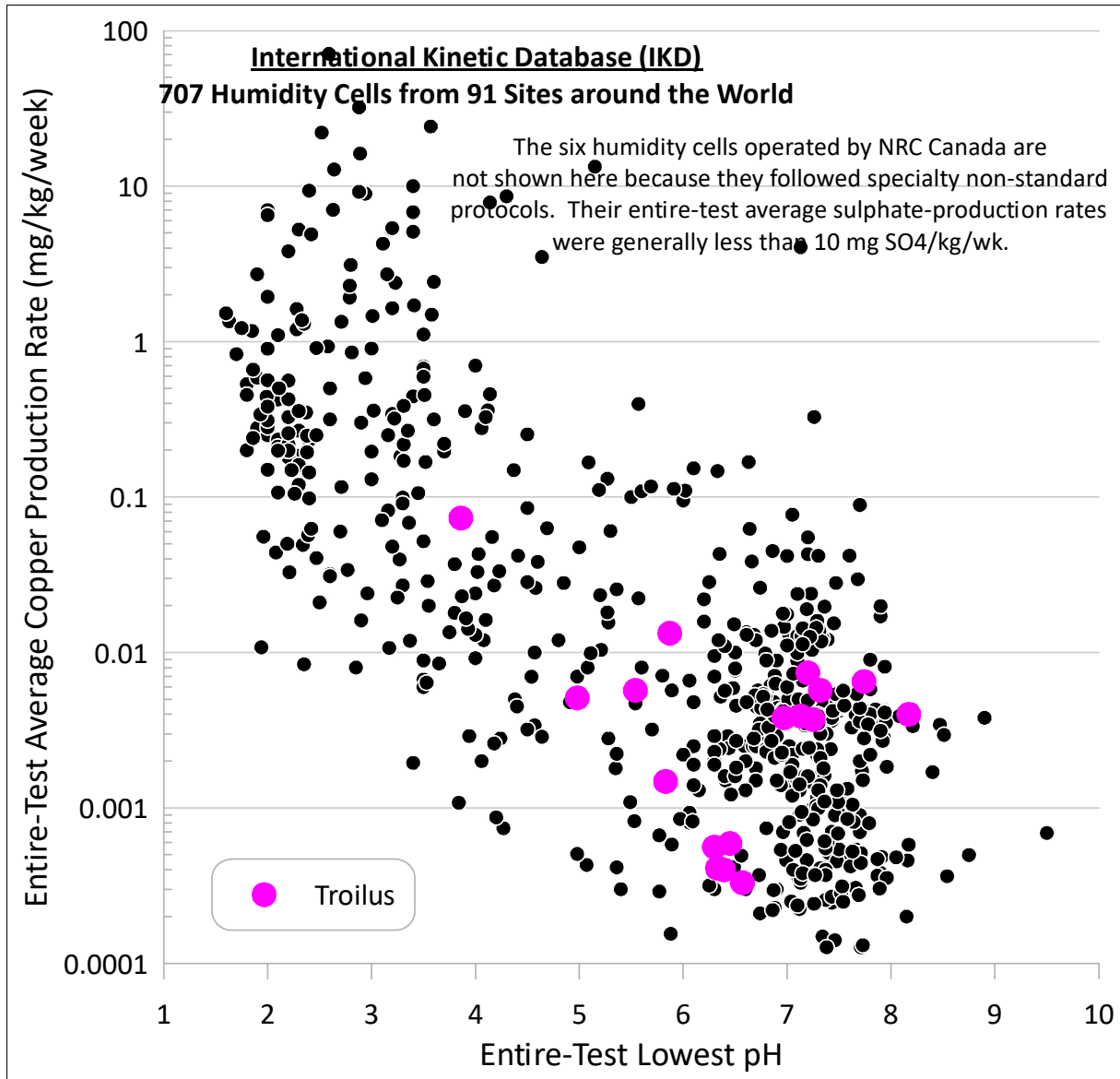


Figure 5-4. Entire-test average copper-production rate vs. lowest measured pH in each test in the International Kinetic Database.

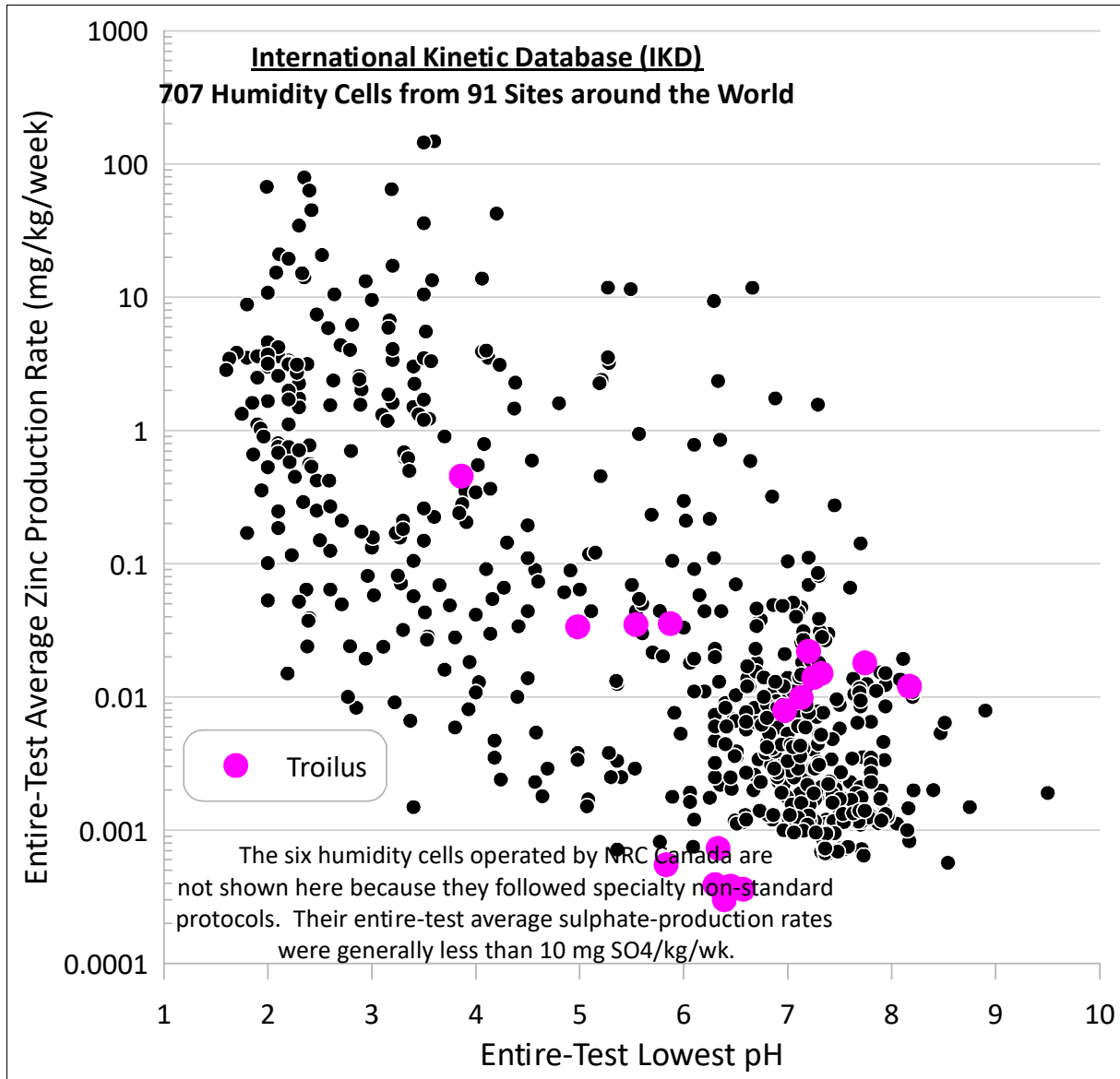


Figure 5-5. Entire-test average zinc-production rate vs. lowest measured pH in each test in the International Kinetic Database.

6. SPECIALTY KINETIC TESTING INCLUDING OXYGEN CONSUMPTION (OXYCON) AND THE UPTAKE AND RELEASE OF CARBON DIOXIDE

The six humidity cells by the National Research Council of Canada (NRC, see Section 3.8 above) were operated using non-standard protocols. These included variable times between rinsing events (cycles), and with variable relative humidities, inside sealable chambers that allow detailed high-frequency measurements of oxygen consumption (“oxycon”) and carbon-dioxide uptake-release (NRC, 2023 and in preparation). After several cycles, one sample was mixed and disturbed, which caused a small, brief acceleration in the oxidation rate, but this soon returned to previous low levels. Also, one major objective of these NRC kinetic tests was to attempt to destabilize the ongoing silicate neutralization and create ARD. So far, these cells have not been geochemically destabilized, but NRC is continuing the testwork and starting new tests.

Before NRC started the six humidity cells, three consecutive shorter-term oxycon tests were conducted over 25 days as an initial test. The three averaged oxidation rates were mathematically converted, from moles of O₂ consumed/kg/unit time, to mg SO₄/kg/wk, for comparison to oxidation rates from the other 17 non-NRC Troilus humidity cells rinsed weekly (discussed above in Chapters 4 and 5). The results showed that the three consecutive oxycon rates (the heavy magenta line in Figure 6-1) generally matched the higher rates from the 17 non-NRC cells. Thus, NRC’s custom approach to oxycon testing, including mathematically accounting for inevitable leaks in the testing chambers, was concluded to be representative.

NRC then conducted humidity-cell testing of the six samples listed in Table 3-5 above, all as crushed subsamples of Field Column 13 of Table 3-3. There are over 50 cycles of testing to date and some are continuing, but some cycles were longer than the one week used for other non-NRC Troilus cells. At Cycles 6, 12, 18, 24, 27, 33, and 39, all six chambers were sealed, and frequent measurements of oxygen (%O₂) and carbon dioxide (%CO₂) in the sealed airspace were recorded (Figures 6-2 to 6-7).

Based on oxygen consumption, these showed that the sulphide minerals in Troilus rock continued to oxidize at relatively slow rates. This was consistent with the ongoing aqueous sulphate detected in the weekly rinse waters and is discussed in more detail by NRC (2023 and in preparation) and in Chapter 5 above of this Phase 2 report.

However, the temporal trends in oxygen consumption in Figures 6-2 to 6-7 did not fully follow zero-order, first-order, or second-order equations. Instead, the trends followed complex and sometimes variable patterns. These patterns apparently reflected complexities at the surfaces of the silicate minerals, like secondary-mineral formation including crystalline to amorphous SiO₂ and Al-OH compounds (MDAG 2024b), water films, and effects of relative humidity (NRC, 2023 and in preparation; see also Chapter 7 below).

For this chapter, the more important observations pertain to CO₂ levels during oxycon testing (Figures 6-8 to 6-13), where CO₂ increased during every oxycon test and typically leveled off within a few days. These stable values were typically above the atmospheric level of 0.04% CO₂ and thus were not explained by any leaks of air into the testing chamber.

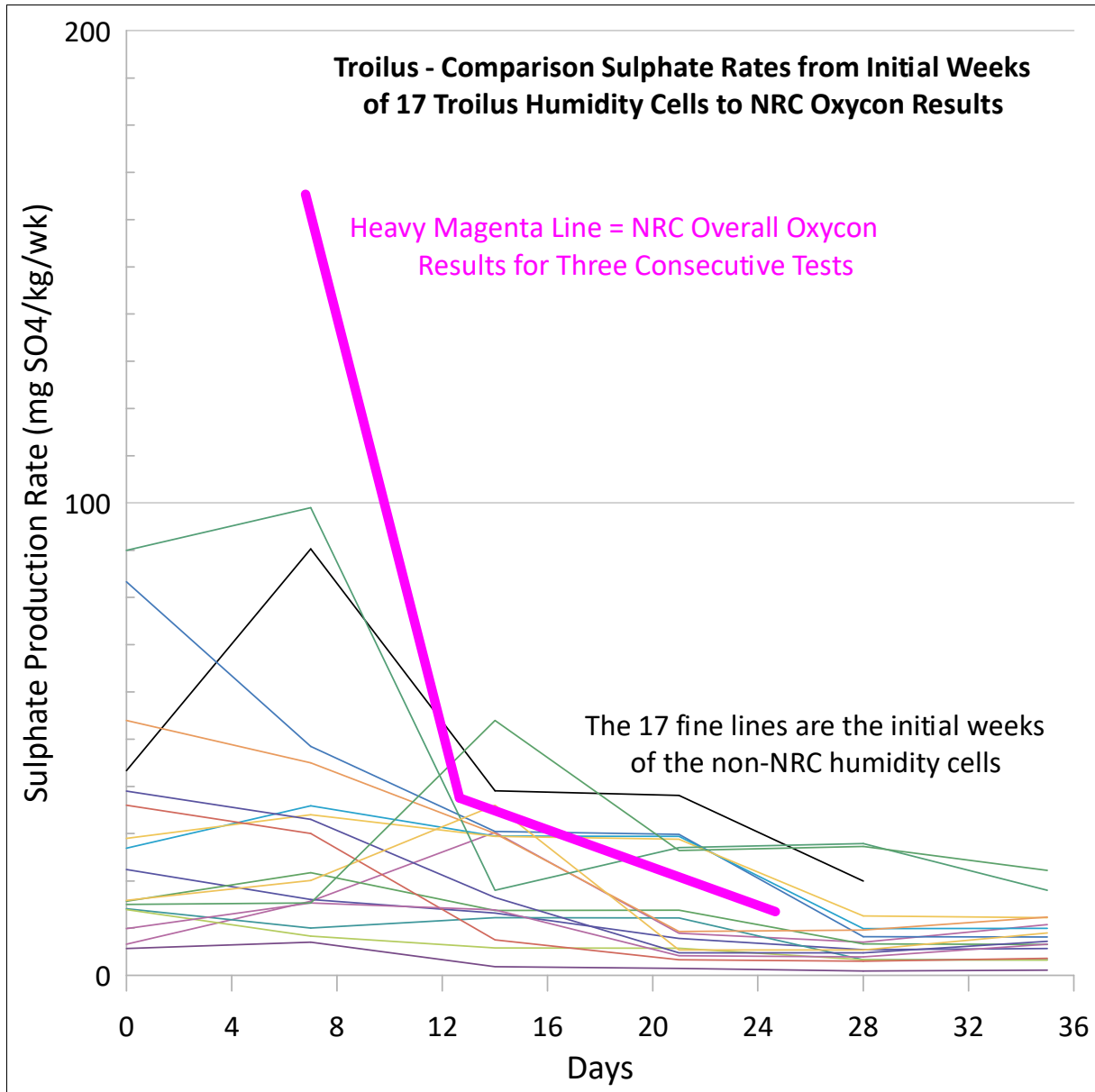


Figure 6-1. Comparison of consecutive rates of oxygen consumption (heavy magenta line) by NRC Canada with initial rates of oxidation based on sulphate production from non-NRC humidity cells.

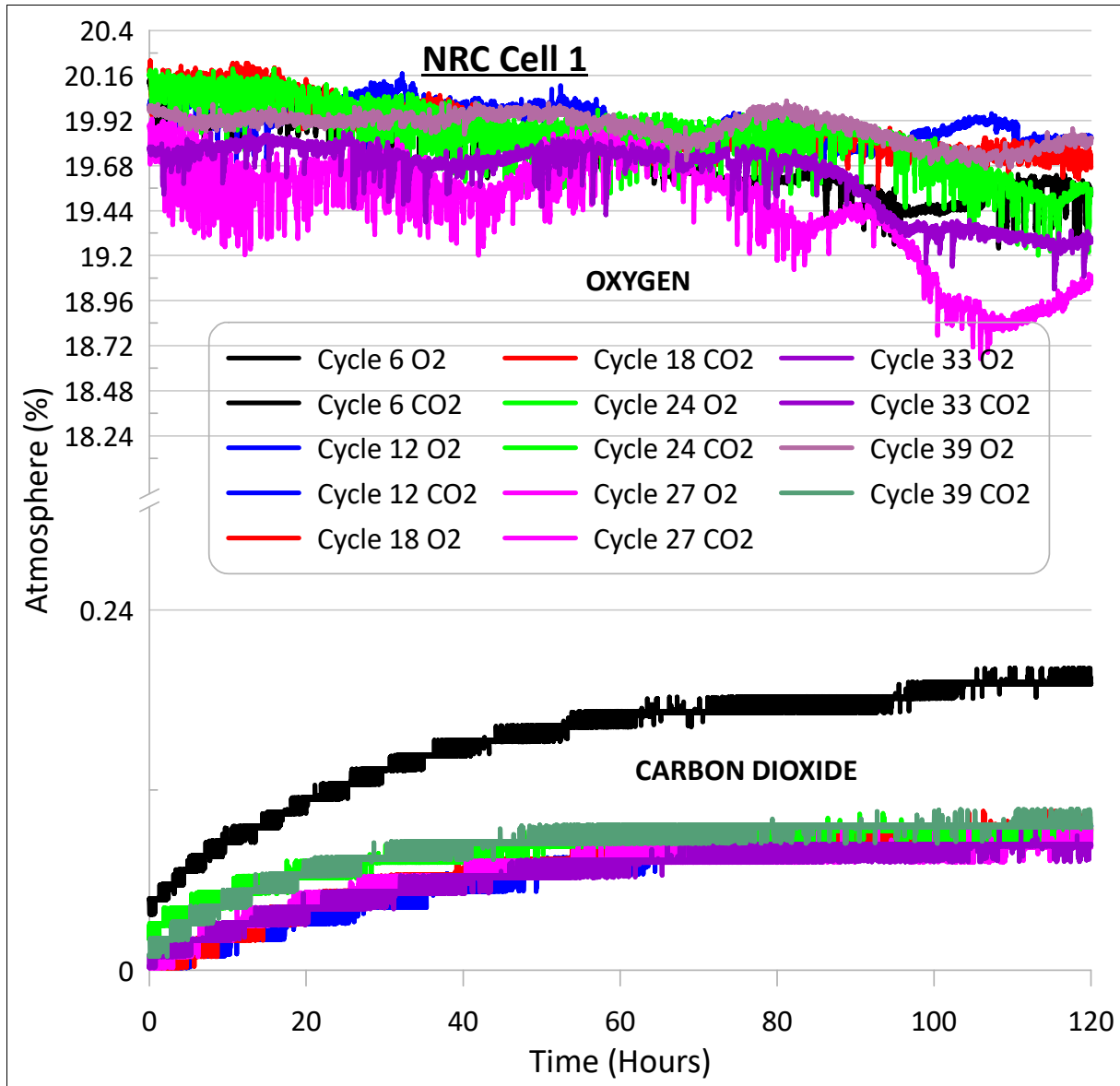


Figure 6-2. For NRC Cell 1, temporal trends of oxygen (upper lines) and carbon dioxide (lower lines) over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

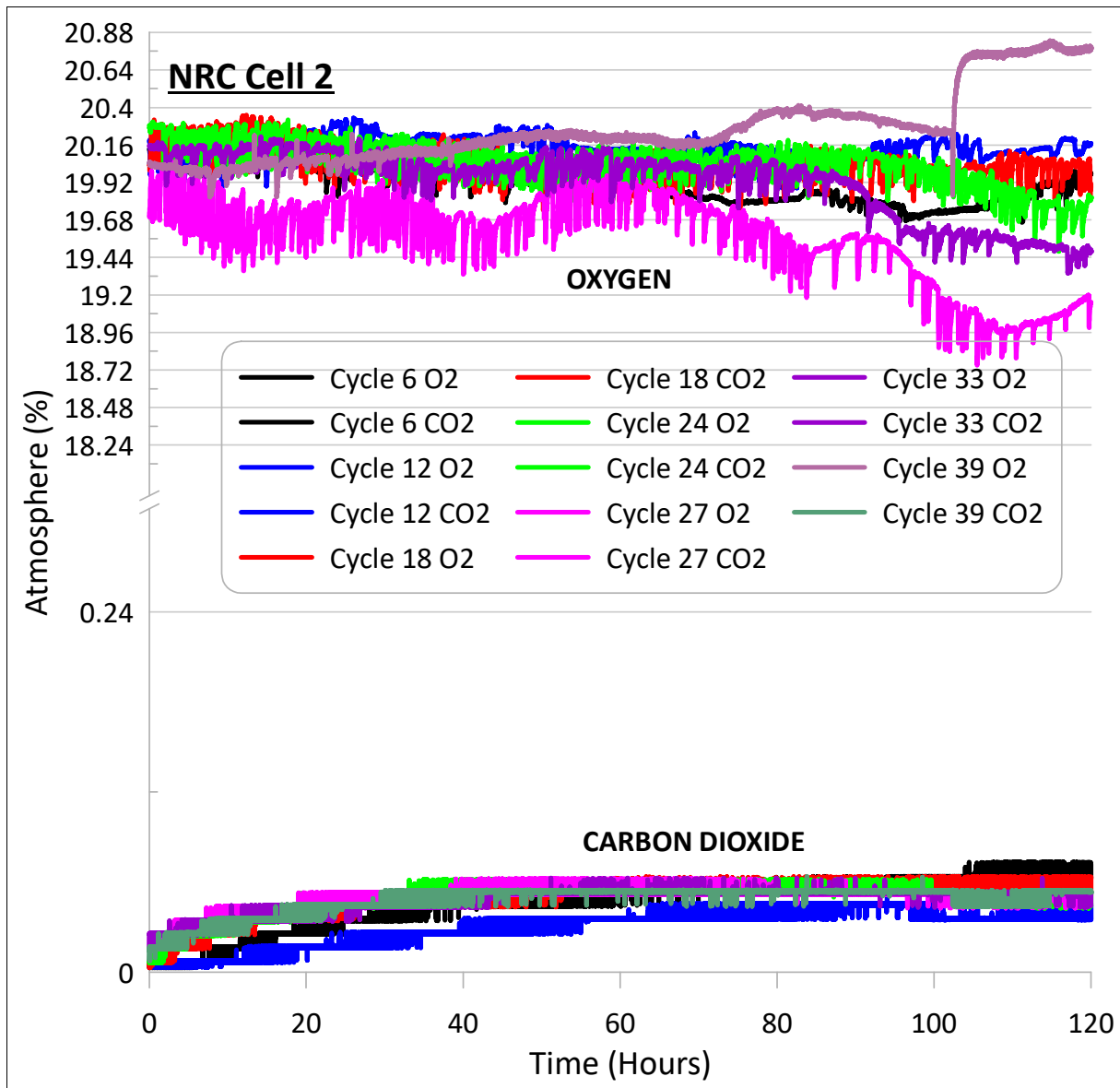


Figure 6-3. For NRC Cell 2, temporal trends of oxygen (upper lines) and carbon dioxide (lower lines) over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

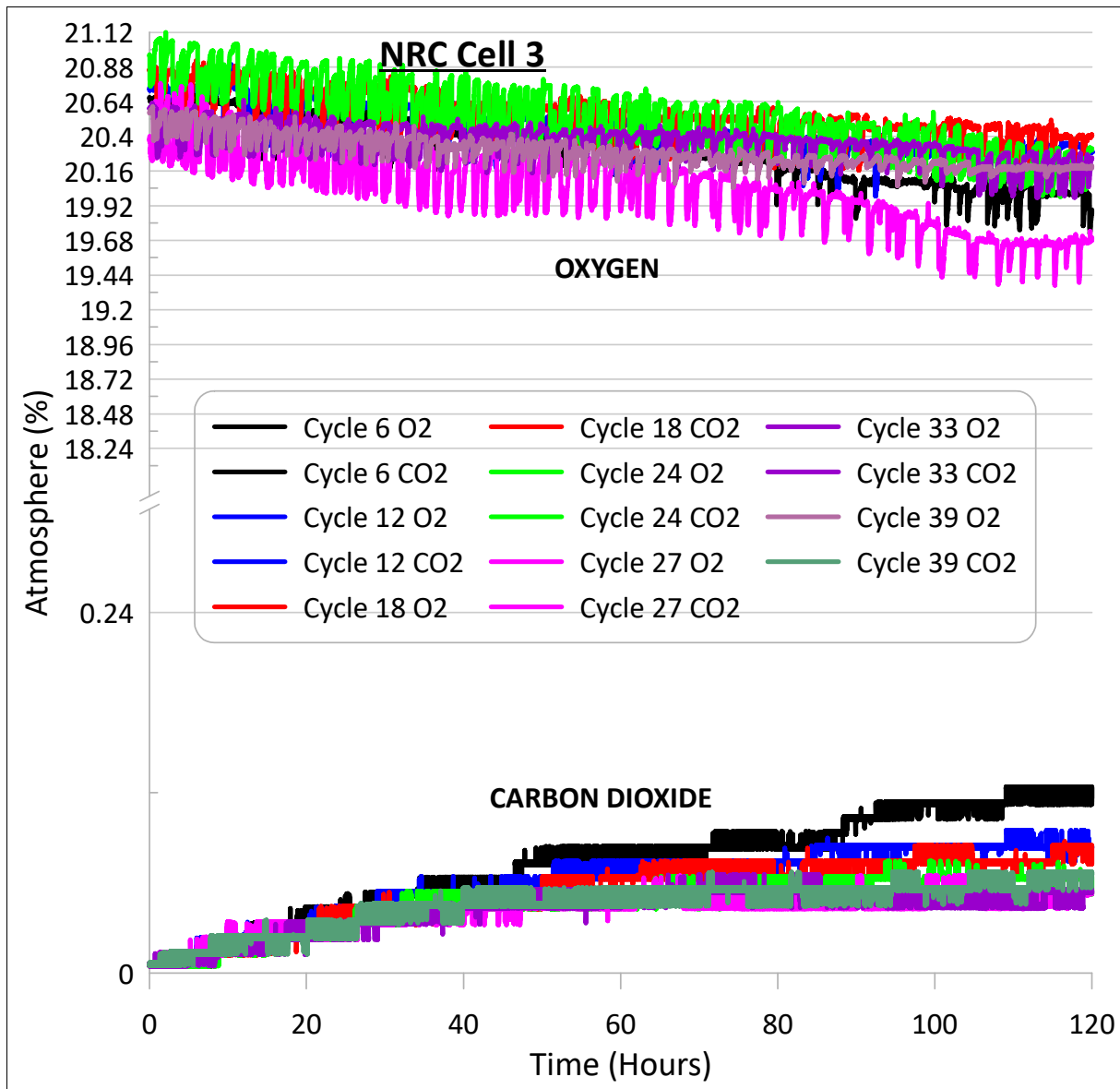


Figure 6-4. For NRC Cell 3, temporal trends of oxygen (upper lines) and carbon dioxide (lower lines) over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

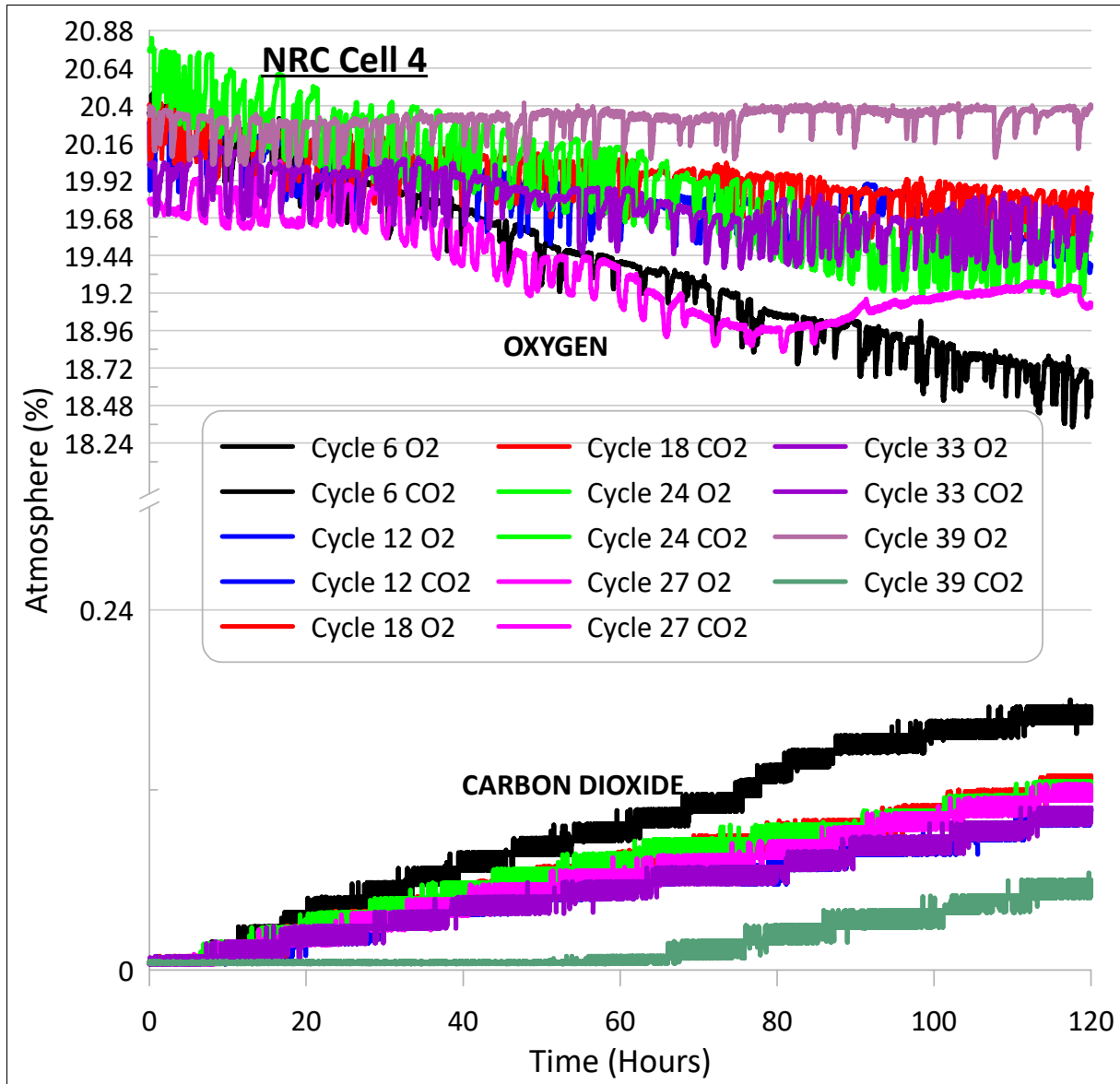


Figure 6-5. For NRC Cell 4, temporal trends of oxygen (upper lines) and carbon dioxide (lower lines) over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

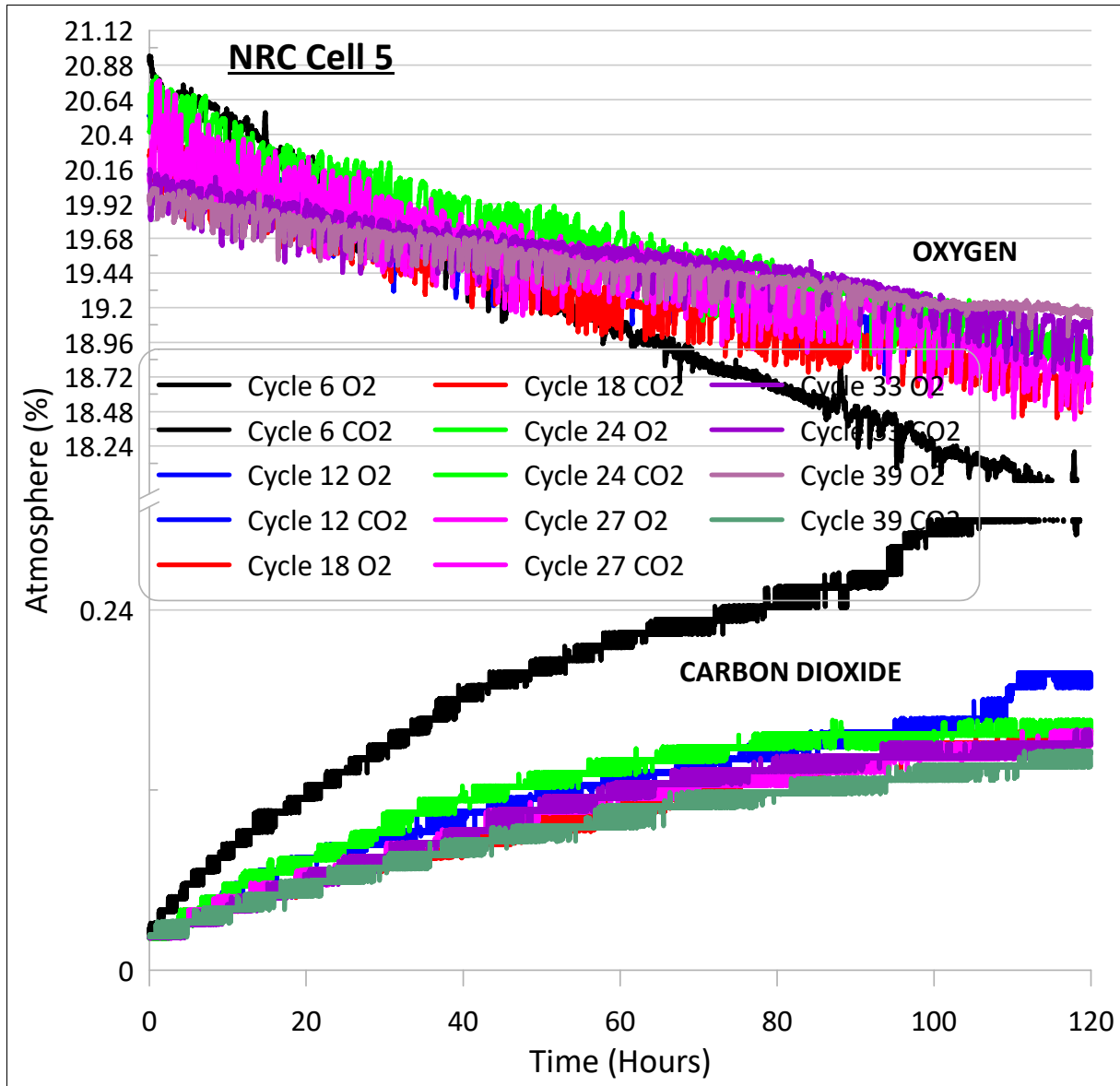


Figure 6-6. For NRC Cell 5, temporal trends of oxygen (upper lines) and carbon dioxide (lower lines) over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

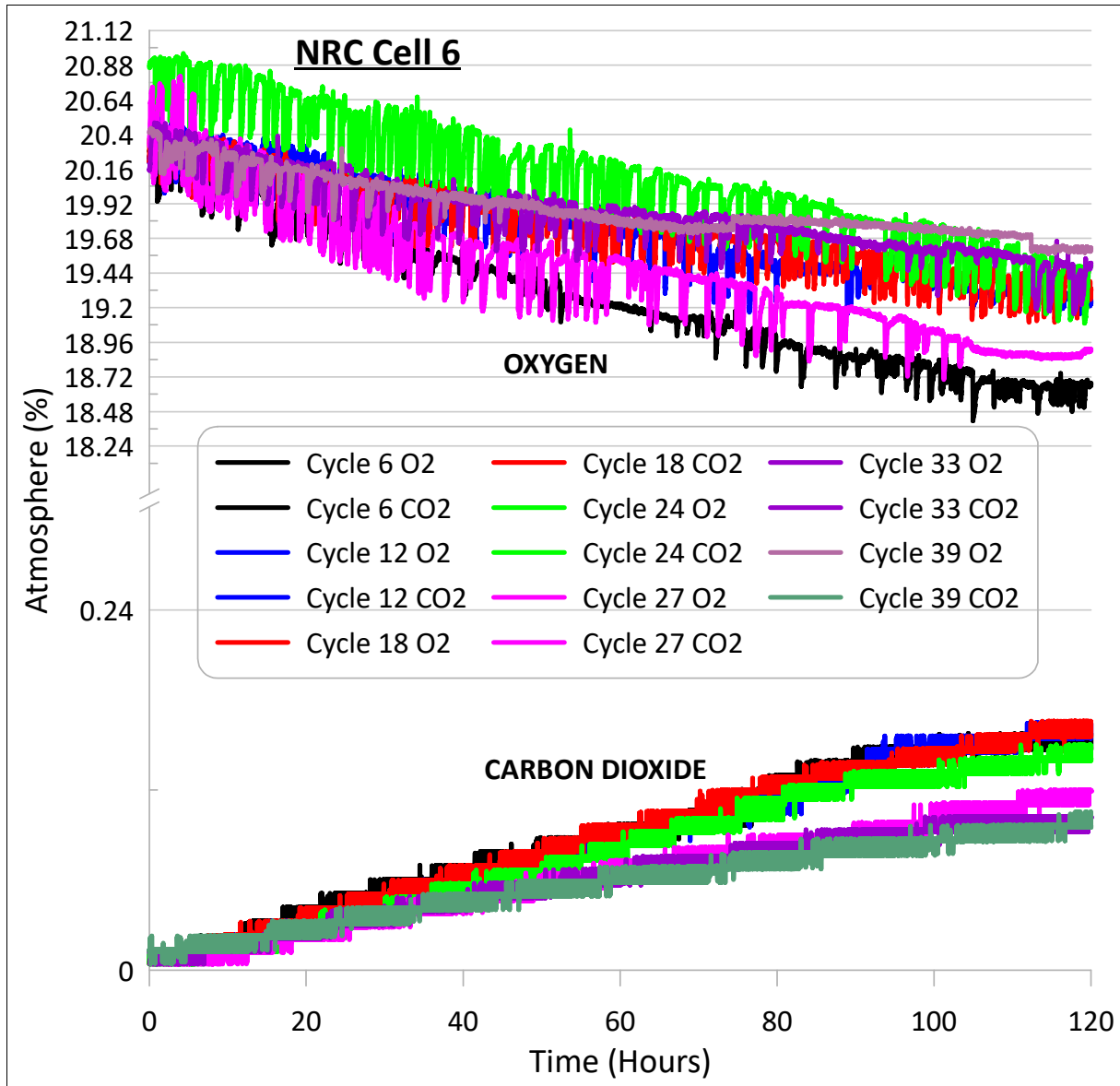


Figure 6-7. For NRC Cell 6, temporal trends of oxygen (upper lines) and carbon dioxide (lower lines) over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

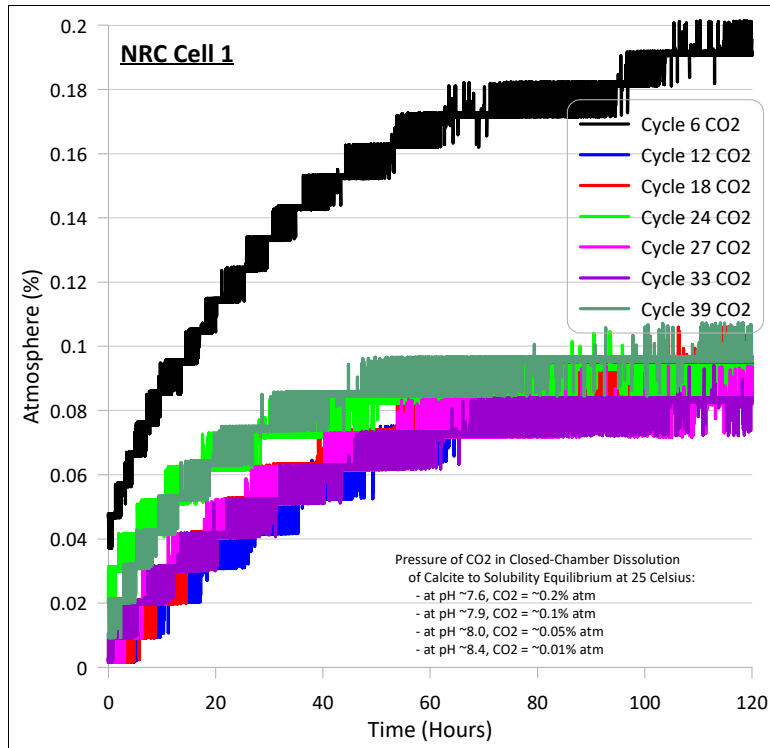


Figure 6-8. For NRC Cell 1, temporal trend of carbon dioxide over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

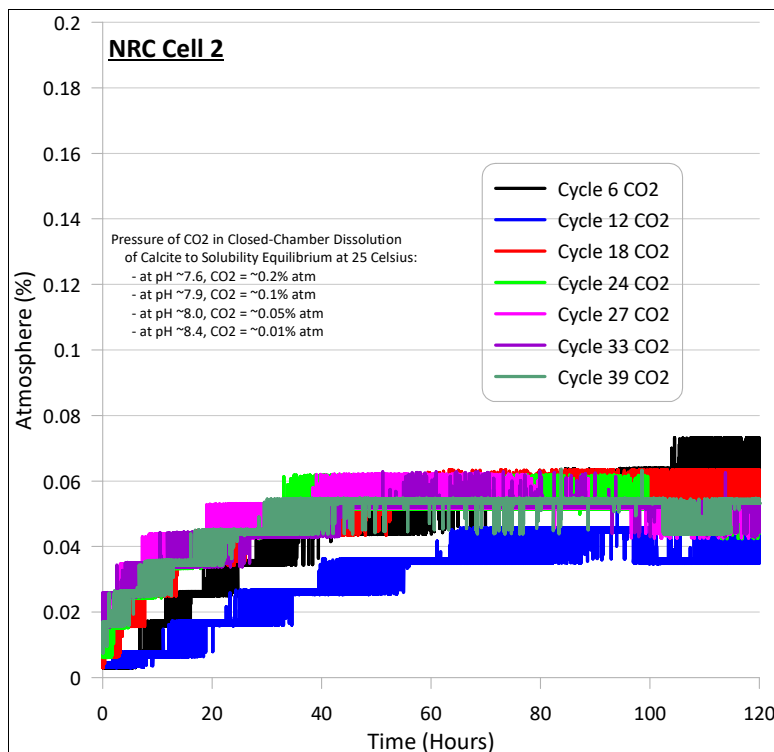


Figure 6-9. For NRC Cell 2, temporal trend of carbon dioxide over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

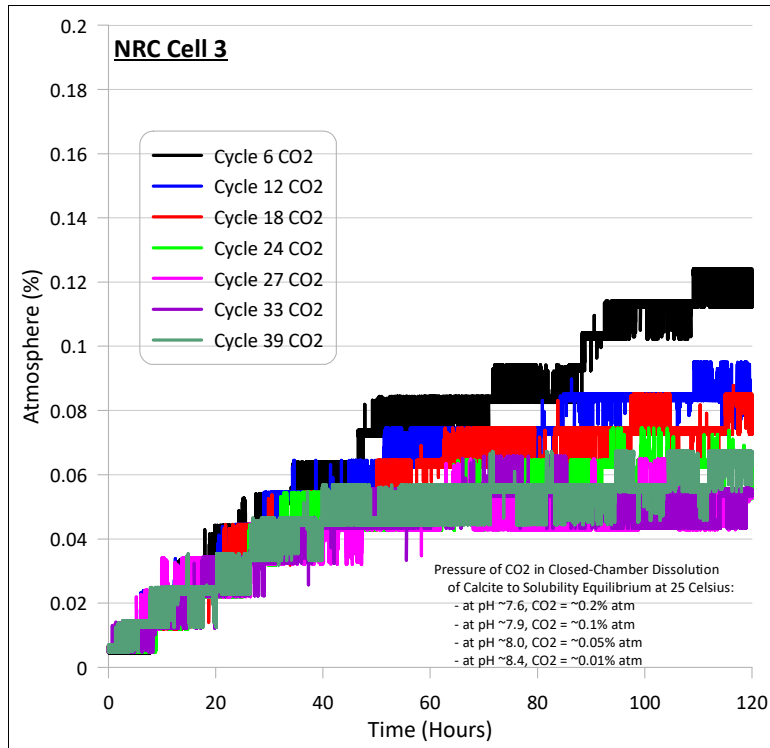


Figure 6-10. For NRC Cell 3, temporal trend of carbon dioxide over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

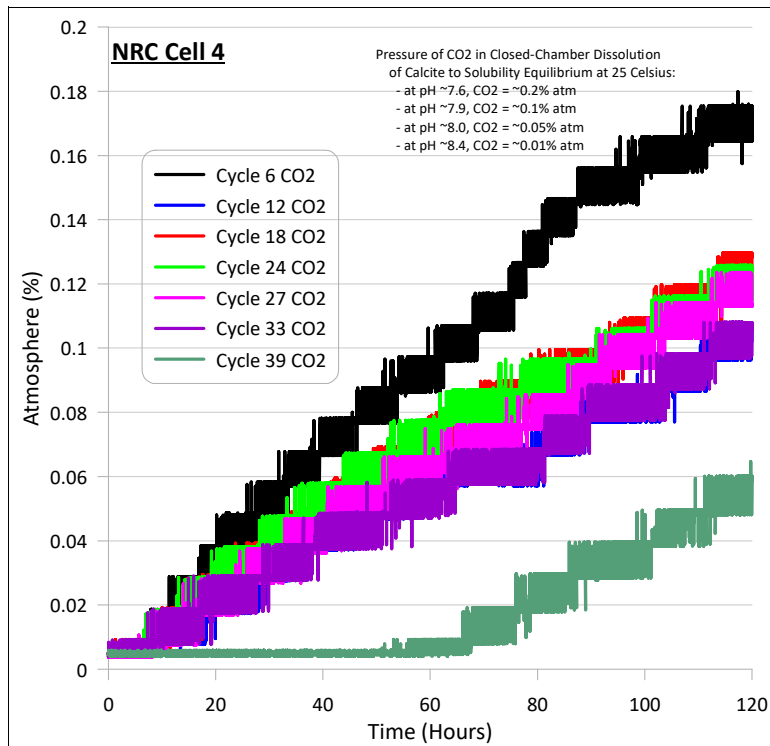


Figure 6-11. For NRC Cell 4, temporal trend of carbon dioxide over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

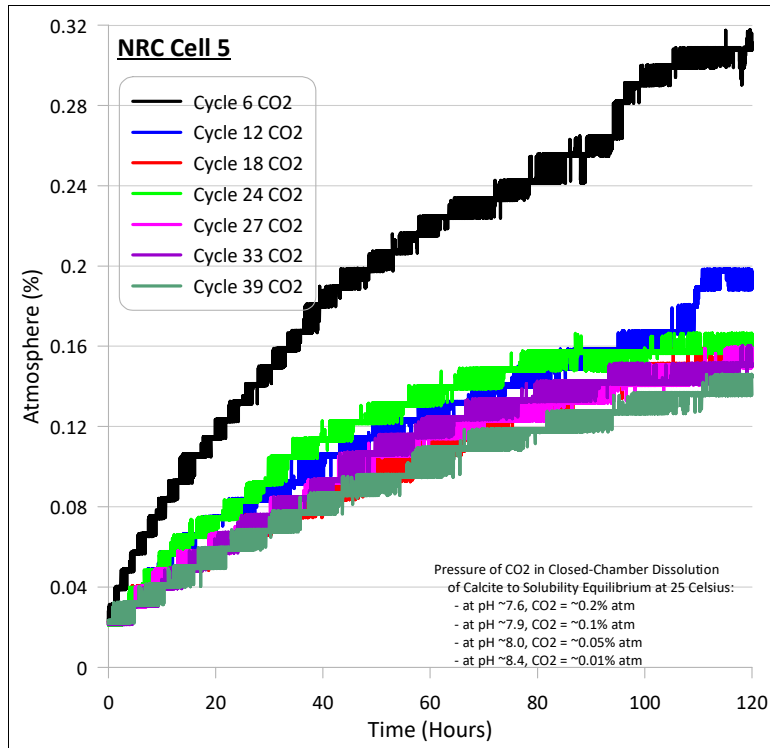


Figure 6-12. For NRC Cell 5, temporal trend of carbon dioxide over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

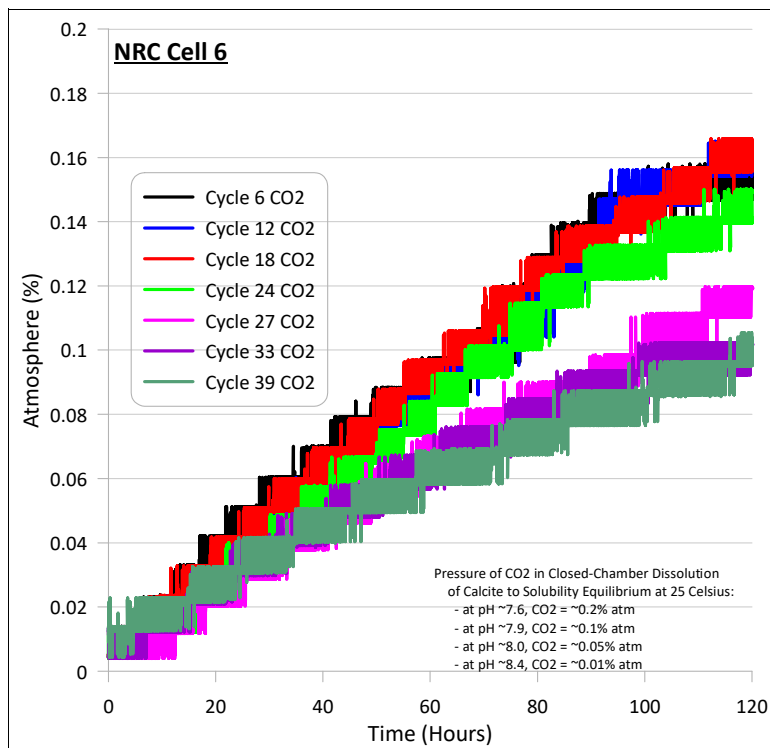


Figure 6-13. For NRC Cell 6, temporal trend of carbon dioxide over five days when the chamber was sealed at Cycles 6, 12, 18, 24, 27, 33, and 39.

The stable CO₂ levels in Figures 6-8 to 6-13 generally reflect equilibrium with calcite (CaCO₃) in a closed chamber around near-neutral pH (Figure 6-14). The problem is that several cycles of rinsing with dilute water between each oxycon test should have dissolved and removed calcite in the six NRC cells. Nevertheless, many CO₂ levels in Figures 6-8 to 6-13 show calcite was present in the samples when it should not have been.

This discrepancy of calcite being present in Troilus rock when it should not be is similar to near-neutral conditions being present at Troilus when ARD was predicted to be present. These are due to significant sensitivities with scale at Troilus, where conditions at small scales are significantly different than conditions at larger scales. Scale dependency at Troilus is discussed in more detail in Chapter 7 below.

Meanwhile, for CO₂ in particular, anomalous small-scale distributions and movements have been documented at scales less than a meter by the FluidFlower studies (Fernø et al., 2024; Nordbotten et al., 2024; <https://fluidflower.w.uib.no/>). For example:

“The state-of-the-art description of multiphase flow in porous media leads to a set of well-posed equations describing mass and momentum balance in the underground, where the flow patterns are a unique consequence of the control parameters. Preliminary FluidFlower carbon sequestration experiments at the University of Bergen (UiB) contradicts this observation: the macroscopic multiphase flow patterns vary between repeated, identical experiments on the same setup. This rebuts the common explanation of spatially random fields for non-predictable flows and implies the importance of unexplained physical phenomena.”

Thus, FluidFlower studies confirm that CO₂, carbonate-bearing water, and calcite do not conform to typical expectations, and this is also the case for Troilus rock.

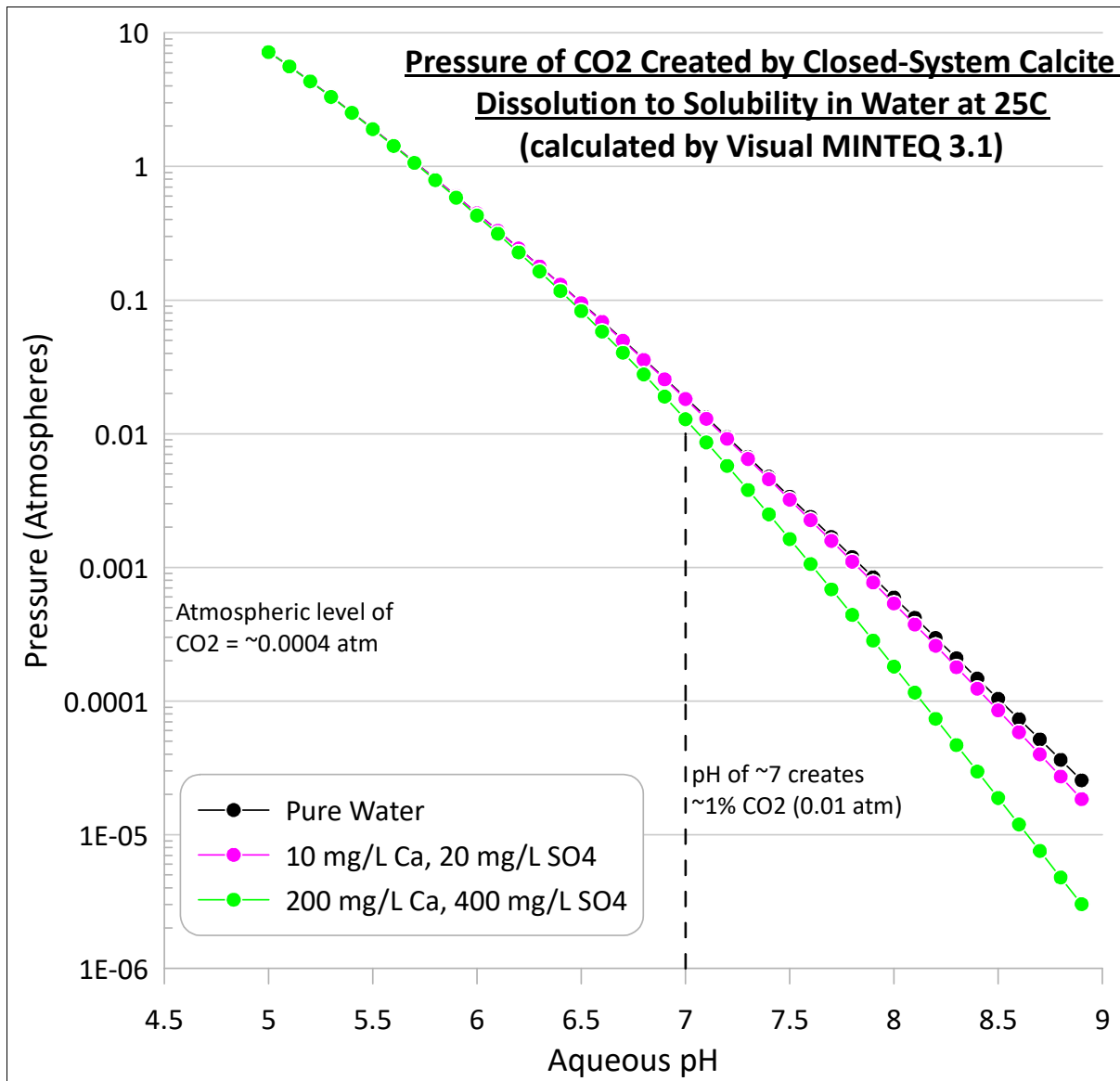


Figure 6-14. The pressure of carbon dioxide created when calcite dissolves to equilibrium in a closed chamber at 25°C; at near-neutral pH, these pressures of carbon dioxide were detected during oxycon testing by NRC Canada (see the previous figures).

7. CORRELATIONS WITH SULPHATE AND SCALE DEPENDENCIES FOR SILICATE NEUTRALIZATION IN TROILUS ROCK

Important observations related to the ARD potential of Troilus rock were identified in past studies (Chapter 3 of this Phase 2 report) and continue to be documented in recent ML-ARD studies for Troilus (other chapters in this Phase 2 report; MDAG 2024a, 2024b; NRC 2023 and in preparation). These observations are as follow.

- Aqueous concentrations of sulphate, which represent the rates of sulphide oxidation and acid generation in Troilus rock, are relatively low and many other aqueous elements and water-chemistry parameters correlate with sulphate.
- The neutralization of acidity in Troilus rock is accomplished by calcium-bearing non-carbonate minerals, particularly plagioclase minerals. The calcium-bearing minerals successfully neutralize acidity to above pH 6.0 on all scales, but the neutralization becomes more efficient (requiring less calcium-mineral dissolution) as scale increases.
- Scale plays a major role in the prediction of ARD in Troilus rock, with ARD becoming less likely as scale increases. This is accompanied by decreasing values of the criterion for the Net Potential Ratio (NPR) that separates ARD-releasing rock from non-ARD-releasing rock at Troilus.
- There are complex interactions, including positive and negative feedback loops, among silicate-mineral weathering, carbonate-mineral weathering, temperature, air-phase CO₂, and sulphide oxidation.

This chapter presents additional data and information on these observations for Troilus rock that have not been presented in detail so far.

For the six non-standard humidity cells by the National Research Council of Canada, the aqueous sulphate concentrations for more than 50 cycles are generally similar among the six cells (Figure 7-1). Despite this, the corresponding aqueous concentrations of calcium show that smaller amounts of neutralizing calcium-bearing minerals are dissolved from coarser samples (Cells 1, 2, and 3) to maintain near-neutral pH (Figure 7-2).

Shown another way, the average concentrations from the entire testing period of each NRC cell, when plotted against the average sulphate, show that, as sulphate increases from the coarser cells to the more reactive finer cells, average concentrations of several elements also increase (Figure 7-3).

When the weekly results from all 23 Troilus humidity cells (NRC and non-NRC cells) are combined and interpolated, the three-dimensional plot of weekly pH, sulphate production, and the Carbonate Molar Ratio (CMR = $[Ca+Mg]/SO_4$) shows the following (Figure 7-4).

- 1) When the sulphate production rate rises above ~60 mg/kg/wk, the CMR rises above 1.0 toward 1.5 indicating neutralization is likely involving the consumption rather than creation of carbonate minerals which cannot continue for longer before ARD appears.

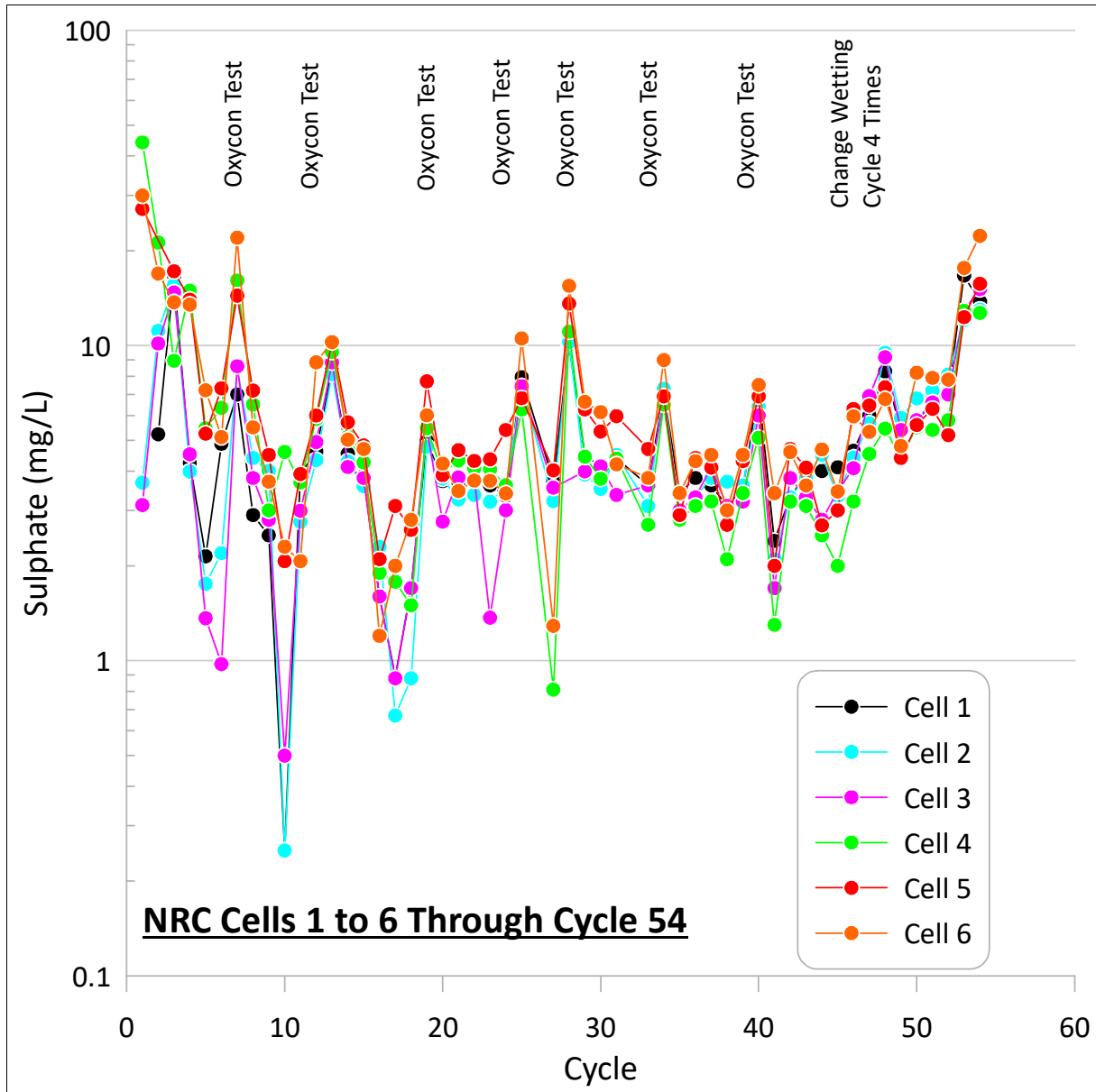


Figure 7-1. Temporal trend of sulphate from the six NRC humidity cells.

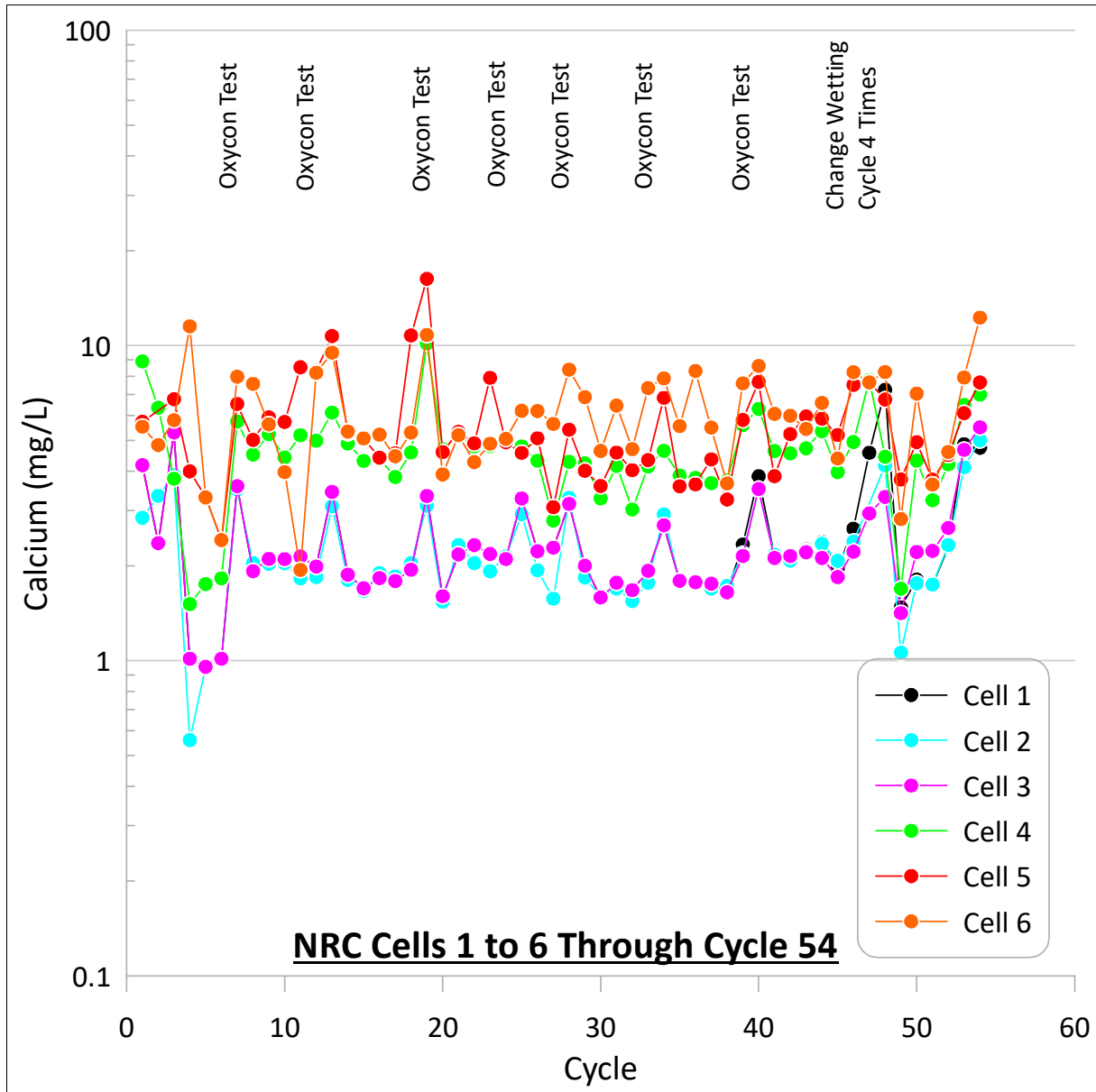


Figure 7-2. Temporal trend of calcium from the six NRC humidity cells.

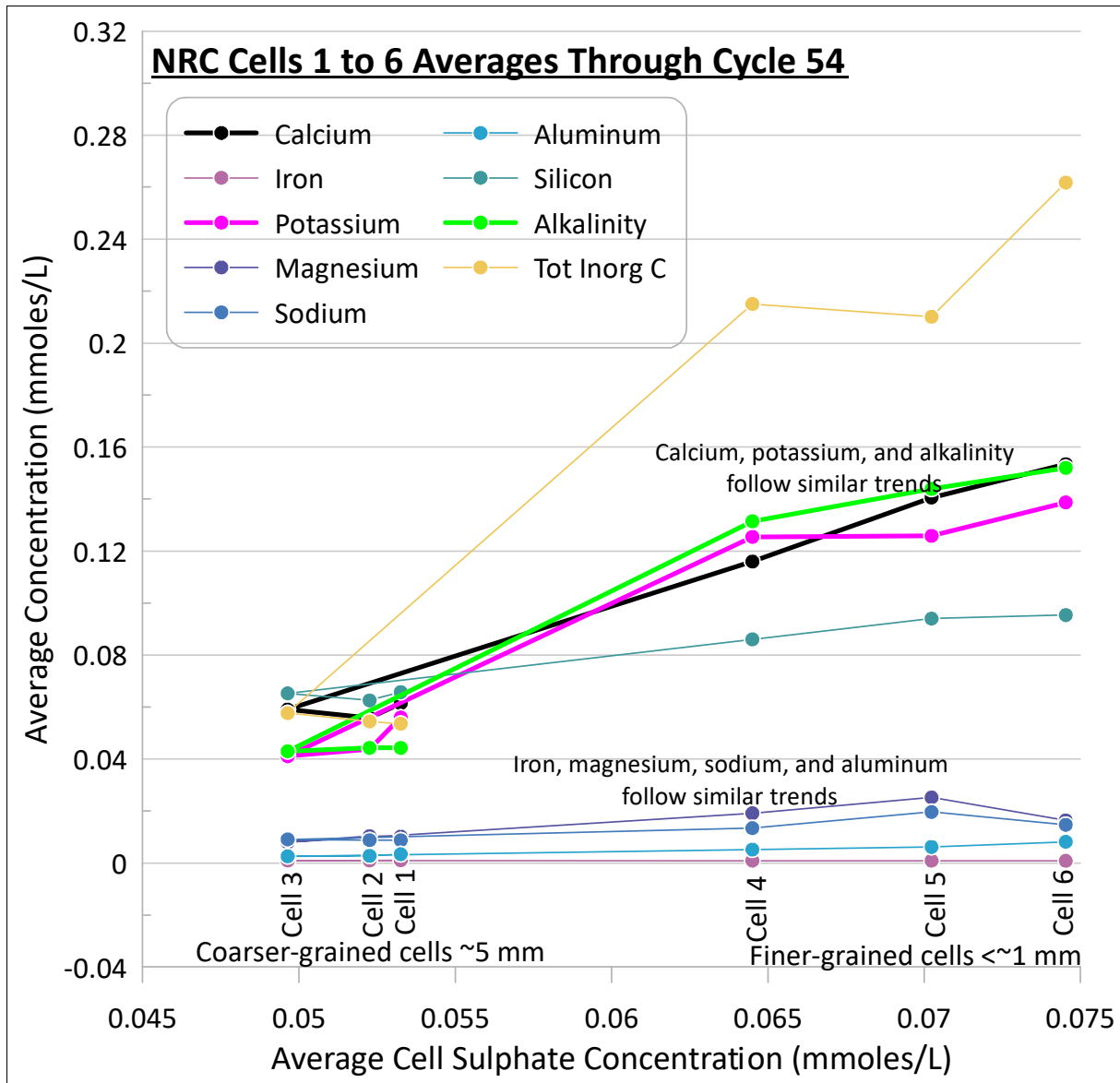


Figure 7-3. Average sulphate concentrations vs. average concentrations of other elements from six NRC humidity cells combined.

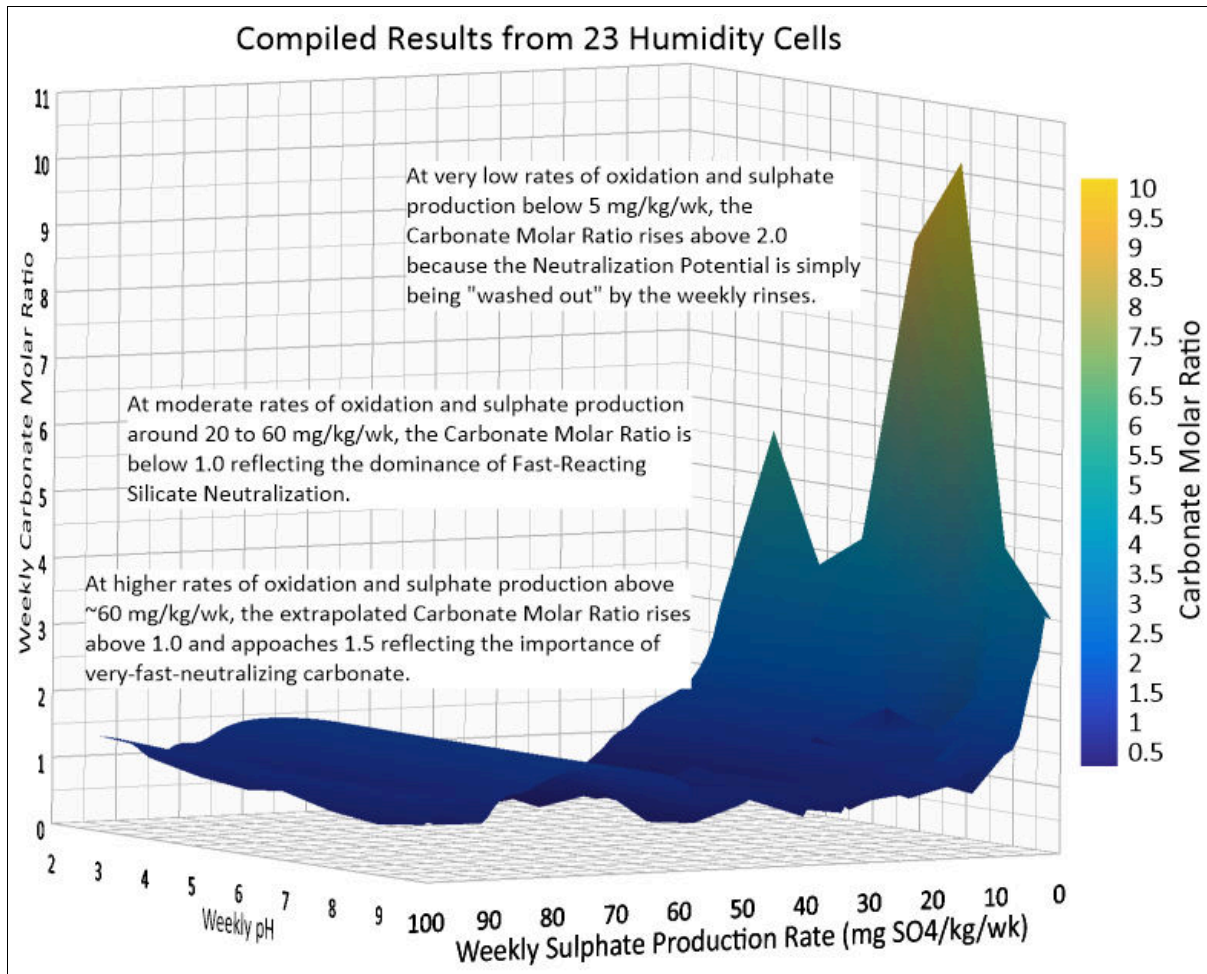


Figure 7-4. Three-dimensional interpolated surface for Weekly pH, Weekly Sulphate Production, and Weekly Carbonate Molar Ratio from all 23 Troilus humidity cells.

- 2) When the sulphate production rate is less than ~ 5 mg/kg/wk (Figure 7-4), most of the calcium and neutralization are being removed simply by the regular and thorough rinsing of the samples, causing the CMR to rise above 4.0 and approach 10.0. This gives the false impression that the NPR criterion for the full scale would be greater than 4.0, whereas in reality such regular and thorough rinsing does not occur on the full scale.
- 3) Between sulphate production rates of ~ 20 to ~ 60 mg/kg/wk, the CMR is close to 1.0 reflecting the effective neutralization of acidity by calcium-based minerals, particularly plagioclase minerals.

The previous observations above focused on small-scale humidity cells containing roughly 1 kg of rock. Nevertheless, larger scales have been tested and monitored as explained in the Phase 1 report (MDAG, 2024a), this Phase 2 report, and in predictions of full-scale maximum concentrations (MDAG, 2024b). Because these Troilus kinetic datasets span scales from ~ 1 kg to the full site scale with up to many tens of millions of rock, additional trends with sulphate and scale can be seen.

For example, Figure 7-5 of acidity vs. sulphate shows that, under acidic conditions (higher acidity concentrations), increasing scale (the groups of coloured datapoints from left to right) leads to an increasing proportion of acidity neutralization until full neutralization is achieved at the full site scale.

Figure 7-6 of alkalinity vs. sulphate shows that alkalinity increases as scale and sulphate increase.

Figure 7-7 shows that at constant pH (1) calcium increases as scale increases, and (2) the Calcium Molar Ratio (CMR), and thus the Net Potential Ratio criterion for predicting ARD, decreases as scale and sulphate increase. Much of the full-scale monitoring indicates an NPR criterion for full-scale mine-rock piles at Troilus would be between 0.5 and 1.0, with 1.0 being the safer criterion selected here and in the Phase 1 study (MDAG, 2024a).

Figure 7-8 shows that silicate minerals in smaller-scale testwork were not sufficiently reactive to reach quartz solubility (below the lower dashed line). On the other hand, full-scale surface waters and groundwaters reached levels between the solubilities of quartz and amorphous SiO_2 between the two dashed lines. The formation of secondary minerals can also reduce the rate of sulphide oxidation and acid generation if they form on sulphide-mineral surfaces.

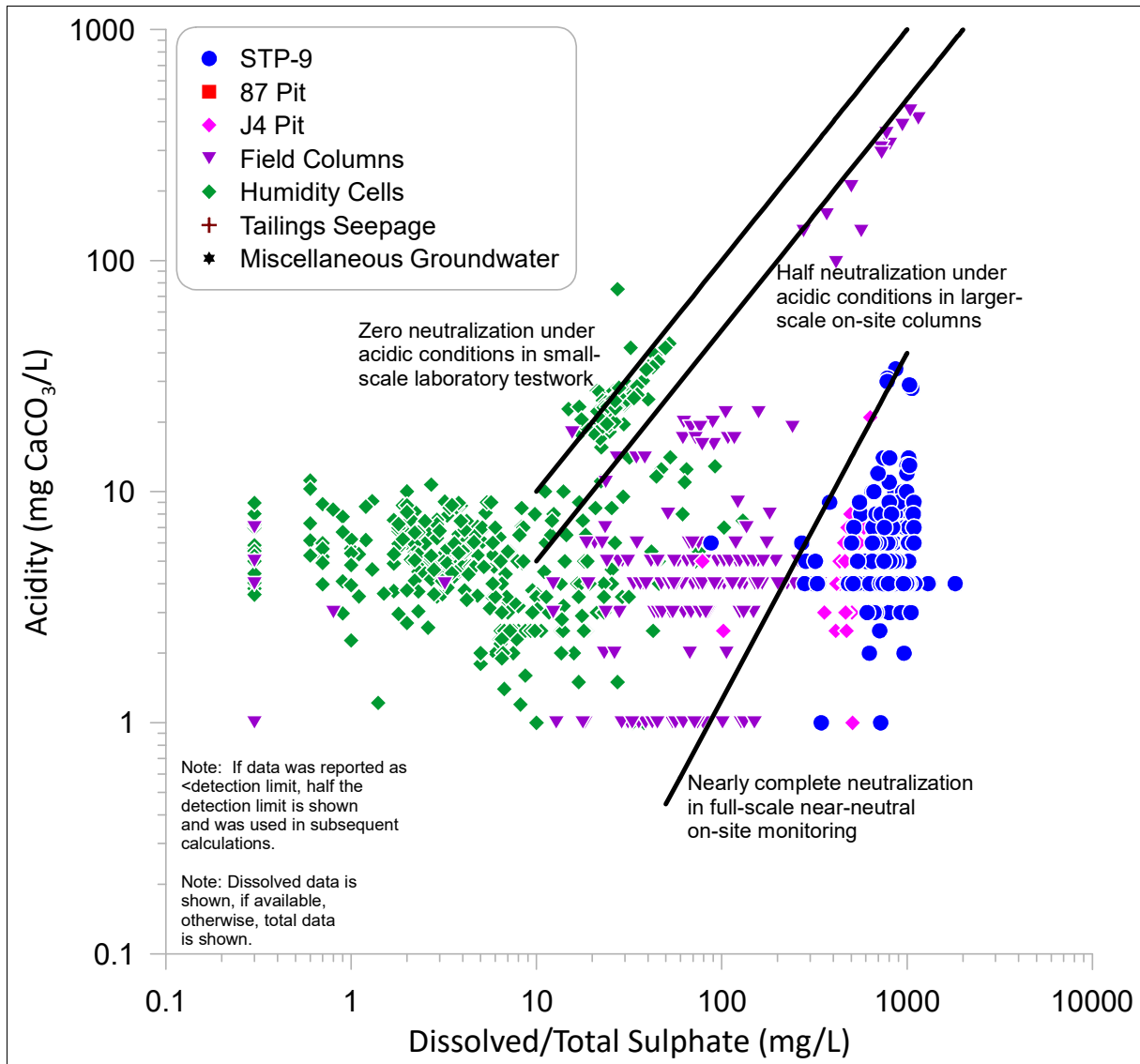


Figure 7-5. Scale dependency of acidity vs. sulphate in water at the Troilus Gold Project, showing that increasing scale (coloured groups of datapoints from left to right) increases the proportion of neutralization of acidity.

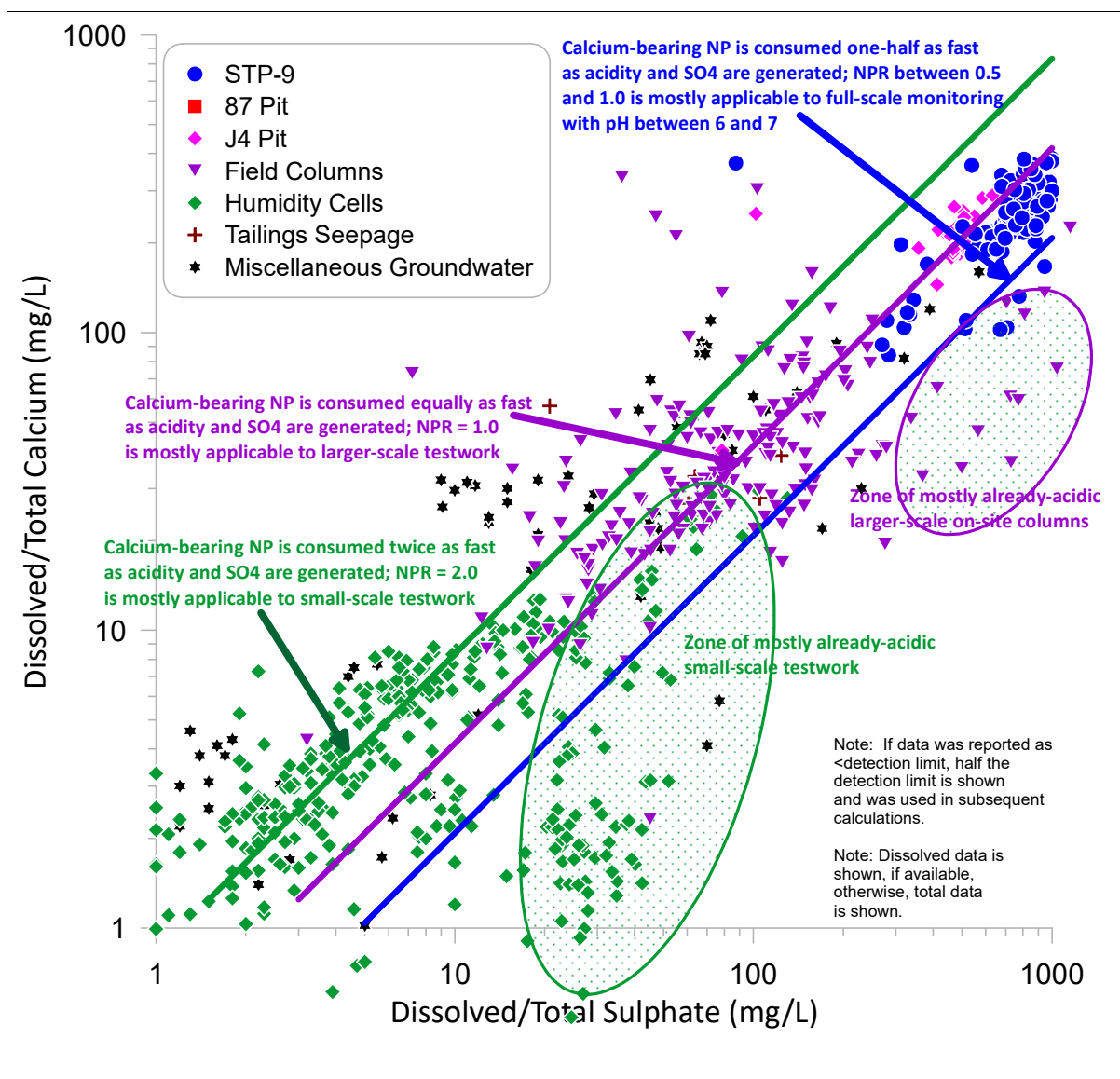


Figure 7-6. Scale dependency of calcium vs. sulphate in water at the Troilus Gold Project, showing complex trends including the Calcium Molar Ratio of calcium:sulphate (and thus the Net Potential Ratio criterion for predicting ARD) decreases as scale and sulphate increase from left to right.

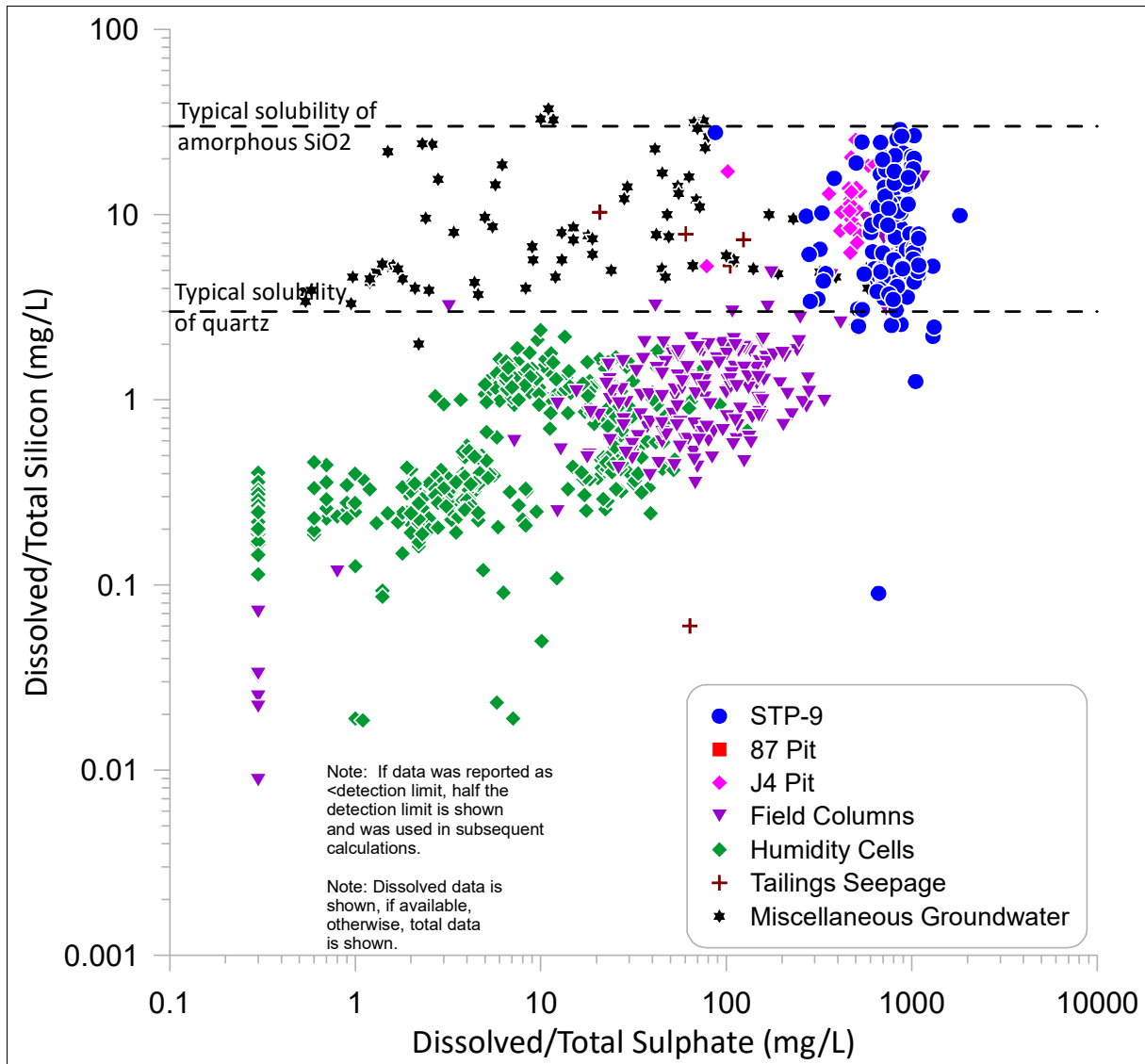



Figure 7-7. Silicon vs. sulphate in water at the Troilus Gold Project, showing that silicate minerals in smaller-scale testwork were not sufficiently reactive to reach quartz solubility (the lower dashed line), whereas full-scale surface waters and groundwaters reached levels between the solubilities of quartz and amorphous SiO₂ (between the two dashed lines).

8. CONCLUSION

Troilus Gold Corp. has asked the Minesite Drainage Assessment Group (MDAG) to develop criteria for three-dimensional ARD models of its three main ore zones: J4, 87, and Southwest (SW). Generic criteria were developed in the Phase 1 report (MDAG 2024a, and see Chapter 2 of this Phase report). This Phase 2 report carries the work further by confirming site-specific ARD criteria for the Troilus site based on longer-term kinetic testing and decades of on-site monitoring.

Based on a review of past minesites like Troilus, there are distinctive characteristics that show a particular site deviates from standard ARD prediction rules. The need for specialized site-specific ARD criteria is clear for these sites. However, reviews of past ML-ARD studies for Troilus show that these past studies applied standard rules. This is why ARD predictions at Troilus have ranged from no ARD, ARD within several years, to ARD after 1,500 years. This ambiguous and unacceptable range in ARD predictions have been corrected and clarified in these Phase 1 and Phase 2 reports.

Past and recent ML-ARD work have provided four sets of laboratory-based humidity cells nominally containing 1 kg of sample for a total of 23 cells, one set of 123 on-site field columns holding up to approximately 300 kg of rock, and decades of full-scale site monitoring that includes tens of millions of tonnes of waste rock. By combining all these datasets, the prediction of ARD at Troilus and the applicable ARD predictive criteria become clear, based on variations in rates of sulphide oxidation and acid generation and on variations in scale.

Based on comparisons with the International Kinetic Database (IKD) containing 707 humidity cells from 91 sites around the world, Troilus rates of oxidation and acid generation are relatively low. On the other hand, Troilus leaching rates for copper and zinc in mg/kg/wk are relatively typical. 

Because Troilus is an exception to generic ARD prediction rules, specialty kinetic tests are being run by the National Research Council of Canada (NRC). This includes six humidity cells with variations in cycle length and relative humidity with the intent of destabilizing silicate neutralization and causing ARD, which has not happened. The cells are periodically closed and sealed with oxygen-consumption (oxycon) testing measuring the ongoing slow consumption of oxygen.

This oxycon testing also includes monitoring of rising carbon dioxide to levels that repeatedly indicate the presence of calcite (calcium carbonate) although the regular cell cycles would have dissolved and rinsed the calcite out of the samples. This discrepancy of calcite being present in Troilus rock when it should not be is similar to near-neutral conditions being present at Troilus when ARD was predicted to be present. These are due to significant sensitivities with scale at Troilus, where conditions at small scales are significantly different than conditions at larger scales.

This scale dependency for calcite and carbon dioxide has also been documented in the “FluidFlower” experiments at the University of Bergen in Norway. FluidFlower studies confirm that CO₂, carbonate-bearing water, and calcite do not conform to typical expectations, and this is the case for Troilus rock.

Additional testing has confirmed the following observations.

- Aqueous concentrations of sulphate, which represent the rates of sulphide oxidation and acid generation in Troilus rock, are relatively low and many other aqueous elements and water-chemistry parameters correlate with sulphate.
- The neutralization of acidity, represented by sulphate, is accomplished by calcium-bearing non-carbonate minerals, particularly plagioclase minerals. The calcium-bearing minerals successfully neutralize acidity to above pH 6.0 on all scales, but the neutralization becomes more efficient (requiring less calcium-mineral dissolution) as scale increases.
- Scale plays a major role in the prediction of ARD in Troilus rock, with ARD becoming less likely as scale increases. This is accompanied by decreasing values of the criterion for the Net Potential Ratio that separates ARD-releasing rock from non-ARD-releasing rock at Troilus.
- There are complex interactions, including positive and negative feedback loops, among silicate-mineral weathering, carbonate-mineral weathering, temperature, air-phase CO₂, and sulphide oxidation.

Therefore, Troilus is a member of the small group of minesites not adhering to normal ARD prediction rules. The characteristics of this group include the following.

- ABA results indicated ARD should be widespread, but no full-scale ARD was detected at sites over decades.
- Small-scale kinetic tests produced ARD, although no full-scale ARD was detected on site after decades.
- Calcite and carbonate minerals represented a minor portion of Total NP, with ongoing weathering of rock producing small amounts of carbonate detected in ABA.
- Laboratory-measured Neutralization Potentials (NP) such as by the U.S. EPA 600 (Sobek) method were relatively the same among samples and did not change significantly over years to decades of weathering.
- Aqueous alkalinity could be accounted for by ingassing of atmospheric carbon dioxide (atmospheric CO₂ capture).
- Minerals like biotite, magnetite, and epidote theoretically contributed substantially to Total NP, but apparently were not reacting sufficiently fast to provide much neutralization.
- Plagioclase minerals apparently provided most of the silicate neutralization.
- Acid-generating sulphide minerals were primarily pyrite and pyrrhotite with some chalcopyrite and molybdenite, and their levels ranged from significant “trace” amounts (<~0.1%S) up to ~5%S.
- Rates of sulphide oxidation and acid generation at these sites were generally low (see Chapter 5 of this Phase 2 report for comparisons to the International Kinetic Database).

Overall, much of the full-scale monitoring indicates a Net Potential Ratio (NPR) criterion for full-scale mine-rock piles at Troilus would be between 0.5 and 1.0, with 1.0 being the safer criterion selected here and in the Phase 1 study (MDAG, 2024a).

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