# The Ocean's Cobalt Cycle and its Correlations with other Metals

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I have read Stephanie Gonzalez Briones's thesis draft and agree that it is complete and of high enough quality to warrant the time and effort of an external reviewer to provide substantive comments.

THESIS ADVISOR

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Dr. Nicholas Hawco
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For my husband Shane, my son Damian, my mother Angela and godmother Sylvia. Thank you for always believing in me

**Acknowledgement**

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## Abstract

The metal cobalt is an essential nutrient for many important marine organisms, but its distribution across the oceans is not well known. When cobalt concentrations correlate with phosphate it is acting as a nutrient to marine organisms, but when it correlates with manganese it is normally an indication that there is a strong geological influence. Other metals such as manganese and phosphate are prominent elements in seawater compared to cobalt which is why they are used as proxies to cobalt (Zeng, 2019). Cobalt concentrations for over 100 samples from the TARA Oceans expedition were measured across the global ocean. The focus is on four regions: the North Pacific, South Pacific, West Pacific and the North Atlantic, which demonstrate how other elements can trace the cobalt cycle in the ocean. Cobalt exhibits similar behavior to phosphate in some regions and manganese in others. In the North-east Pacific region, Mexican and Central American coastal waters had a small correlation with manganese: cobalt concentration is higher when manganese is high. In the Southeast Pacific and South American coast, an increase in cobalt is detected when manganese is elevated. Cobalt concentrations from the Western Pacific region have not been reported previously. We observed increased cobalt concentrations off the coast of Australia, New Caledonia, and the coast of Papua New Guinea due to input from river systems from the land masses, as well as at the equator, to the upwelling of deep nutrient rich waters. Interestingly, Co and phosphate are correlated in the North Atlantic and Caribbean Sea. In this paper cobalt is traced by two metals from different sources that can paint a picture of the metal's cycle and influence. By correlating cobalt with these two metals that are more easily measured elements, we can broaden our understanding of the cobalt cycle and its sources.

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## 1. **Introduction**

Phytoplankton are essential and the foundation of a healthy ocean. They require a range of nutrients that are classified as macronutrients and micronutrients for growth that translates to a strong ecosystem. Macronutrients, including nitrate and phosphate are needed in relatively large quantities as nitrate and phosphate are essential for the synthesis of proteins and nucleic acid (Rhee G-Yull , 1978). On the other hand, micronutrients which include iron and cobalt, are needed in smaller quantities but are vital for the physiological processes of phytoplankton. In some regions the limited amount of iron can restrict phytoplankton growth even if there are macronutrients available (Sunda WG, 1995). Some micronutrients can act as co-limiting factors, where the availability of one nutrient can influence the utilization of another This depicts the balance between macronutrients and micronutrients for phytoplankton to grow.

Cobalt is a nutrient but is not considered as important for marine primary production compared to other nutrients like iron or nitrogen. However, cobalt is a metal cofactor in cobalamin ($B_{12}$), which has been observed to help promote phytoplankton and zooplankton growth and increases in chlorophyll a (Wang, 2023). However, even with cobalt present, it may not be enough for phytoplankton to have a strong chlorophyl signal. Primary producers can be affected without an external vitamin B source where they can suffer blocked cell growth and have an impaired central metabolism. Cobalt forms part of the vitamin $B_{12}$ structure that is vital for phytoplankton growth (Bertrand, 2007). Experiments were carried out with in situ incubation using vitamin B supplements where phytoplankton and zooplankton communities were observed and where there was a positive impact on chlorophyll in 87.5% of the supplemented incubations (Wang, 2023). In the Ross Sea, incubation experiments have indicated that both iron and vitamin B12 are limiting nutrients. Adding iron yielded significant phytoplankton growth, but when vitamin B12 was added there was a greater increase. However, vitamin B12 alone did not yield greater growth (Bertrand, 2007). In other incubation experiments in the eastern boundary of the South Atlantic Ocean, there is no significant phytoplankton growth caused by the individual addition of iron or nitrogen but combined demonstrated to have a positive impact. Once the nitrogen-iron co-limitation has taken place the addition of cobalt or cobalt containing vitamin B12 further enhances phytoplankton growth (Browning, 2017). Limiting amounts of cobalt can contribute to a limiting food web as zooplankton feeds off of phytoplankton essentially cutting the microbial loop short.

Cobalt cycling is influenced by different processes. In the North Pacific there is a strong correlation between Co and Mn as noted by the GEOTRACES Japan cruise that took place there. High concentrations of total dissolved cobalt (tdCo) and dissolved cobalt (dCo) are noted in the Alaskan Stream (AS) of up to 220 pmol $kg^{-1}$, this was similar to tdMn and dMn. Cobalt is spread wider than Mn in a zone approximately 26.5-27.0 $\boldsymbol{\sigma_\theta}$ where the North Pacific Intermediate Water (NPIW) and Equatorial Pacific Intermediate Water (EqPIW) exist. High values of labile particulate (lp) lpCo/ total dissolved (td) tdCo ratio occur in surface water at lower latitudes due to phytoplankton uptake, while dCo/ dMn ratio varies from 0-0.174 in North Pacific (Zheng, 2019). In the Kamchatka Peninsula there is high Co concentration of 90 pmol kg-1 but along the 47º N, there was a maxima in the surface water but it is evenly distributed at intermediate depths.

In the North-east Pacific waters cobalt is analyzed in the San Francisco Bay along with manganese and the salinity of the bay. Co has a similar profile to manganese which is high at the surface and depleted with depth. In this San Francisco/ Sacramento transect the dCo is high measuring between 50 and 1,200 ng $1^{-1}$ in March 1980, that can be due to continental weathering (Knaur et. al, 1982). Cobalt and manganese have similar profiles and similar vertical distribution, this “implies the same biogeochemical pathways” (Knaur et. al, 1982). However, the amount of cobalt is about 10-20 times less than manganese. The Co is higher in the bay compared to the ocean water, and it is believed to be higher in the bay due to continental weathering. Cobalt and salinity mirror each other and so where there is low salinity at the surface there is high cobalt concentration and as the salinity increases with depth, cobalt decreases.

In the Ross Sea at Antarctica, cobalt and phosphate have a similar vertical distribution that is higher during the springtime compared to the summer (M.A. Saito, 2010). During the austral summer 2005-2006 the vertical distribution of cobalt was similar to that of soluble phosphate. This indicates cobalt and phosphate have a strong correlation. There is a strong spring seasonal signal for dCo with most spring samples being between 45-85 pM while the summer had a significant decrease of about 30 pM which is below biological activity and where phosphate was depleted the concentration was about 20 pM. In this sea, Zn seems to have influence in the phytoplankton diversity so it is the limiting nutrient and cobalt was found to be present in a much lower concentration.

Throughout many of the studies conducted across the ocean, phosphate and manganese seem to have a correlation to cobalt and in some cases cobalt can be detected in lower quantities in the ocean compared to manages, but phytoplankton express a higher concentration suggesting cobalt is preferred by them.

In this work, we report cobalt concentrations from the TARA Oceans Expedition cruise which took place between May 28, 2016 and October 27, 2018, beginning in Lorient, France.

## 2. Methods

### 2.1 Sampling

Samples were collected on the TARA Pacific Expedition cruise which took place between May 28, 2016 and October 27, 2018 leaving from Lorient, France (Figure 1). This cruise route started from the North Atlantic Ocean, and moved to the Caribbean and followed Central America moving south to the Panama Canal. From there, it navigated the South Pacific Ocean westward and following Polynesian islands north until reaching Japan. From Okinawa the cruise navigated south towards Fiji and New Zealand, then moving to Australia and back up towards Hong Kong before crossing the Pacific Ocean back to the United States. This route totaled 125,00 km worldwide (FoundationTaraOcean.org) with the Pacific route totaling to 110,00 km (Gorsky, 2019). The samples were collected day and night at an average cruising speed of 9 knots when the wind was not exceeding Beaufort scale 5 (Gorsky, 2019). During the day there were two surface samplers deployed at the same time collecting biotic and abiotic organisms. While at night only plankton and neustons were sampled that were >300 m at 5 meters of depth (Gorsky, 2019). Any gaps between the sampling locations were due to rough seas or lack of permits (Gorsky, 2019). The cruise was manned by 6 sailors and between 2 to 7 scientists that included 2 resident engineers.

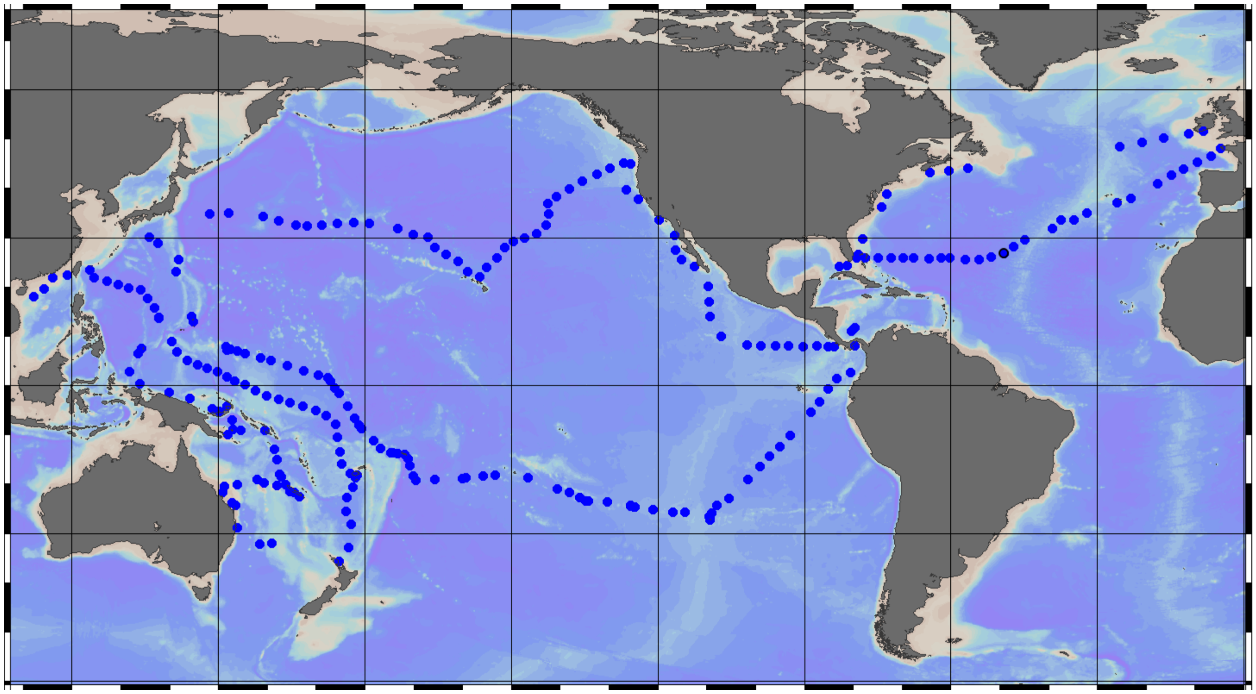

Figure 1. Map of locations samples were collected from during the TARA expedition. Each blue dot represents sample sites.

**2.2 Measurements**

We adhered to the cobalt sampling protocol as described by Saito et al. 2003. In summary, cobalt concentrations were measured by adsorptive cathodic stripping voltammetry on a mercury drop electrode. A multi-mode electrode (MME) was used with the 663 VA stand that was connected to an Autolab potentiostats (Metrohm USA). Two Dosino 800 automatic burette were used for liquid handling. Nova 1.11 software was used to generate and analyze this data.

Prior to analysis, 12 mL of a seawater sample was UV-oxidized in the Metrohm 909 UV oxidation digester to remove organic matter. Samples were digested for 1 hour. 10 mL of UV-oxidized seawater was transferred to 12 mL perfluoroalkoxy (PFA) vials and adjusted to pH 8 using a solution containing 0.52 M EPPS and a varied amount of ammonium hydroxide to reach the desired pH of 8. Once samples were neutralized, 25 µl of 400 µM dimethylglyoxime (DMG), an addition 50 µl of 1.5 M EPPS and 1.5 ml of 1.5 M sodium nitrite ($NO_2$) were added to the seawater sample and the solution was transferred into the analysis cup.

First the adsorptive cathodic stripping voltammetry  was initialized by analyzing Station ALOHA seawater to test performance. Once the water sitting in the cup was done running a vial of test sea water was run as a control. We have the purging step with high purity $N_2$ gas to remove oxygen then Nitrite was automatically added to the vials so it can ease the machine's reading. Once that was done we had the adsorption step at -0.6 V for 180 s. Lastly, the scan steps at 10 V/s between -0.6and -1.4 V . Peak height at-1.1 V were measured manually, and concentrations were derived from linear regression of 4 standard additions containing 50 pM Co. Samples with standard addition regressions with $R^2 < 0.99$ were removed and reanalyzed. We also analyzed samples a second time if their concentrations were too high (compared to the standard additions), if the pH was too low or if software stopped running. Then the data was compared to the set of data sent to us from USC to make sure the numbers measured were within range of the other data.

Prior to adding samples, a test seawater was measured at the beginning of the analytical session to ensure instrument functioning and a low Co sample from Station ALOHA was used as an internal laboratory standard. The Aloha water was noted to test at an average of 27.2 pM This test run was repeated 4 times until the right amount of EPPS was found for the samples to neutralize them from their pH 2 to pH 7-8. The average amount of EPPS added to the samples was 50 µl with 25 µlof DMG 1.5 µl of $NO_2$. The $R^2$ acceptable for the measurements were above 0.96 anything below that was flagged and in most cases those samples had an issue that needed to be addressed. Most samples had an average of .99 $R^2$.

More trace metal data were provided by Rachel Kelley and Seth john from Seth John's lab at USC (Kelly, 2020).

## 3. Results

All the samples tested, there were close to 200 samples, were from the TARA Ocean Expedition that were provided to us by Seth John's lab. The dataset of additional parameters was compiled by Rachel Kelly and Seth John, but reflects methods made by various researchers as described in Pierella Karlusich et. al 2020. These samples were divided into four regions for comparison. The regions are the North Pacific, South Pacific, West Pacific and North Atlantic Ocean.

### 3.1 North Atlantic

There are two routes of sample collections in the Atlantic Ocean, there is a northern upper and southern lower transect in the North Atlantic Ocean. In the Northern transect, there is a significant amount of chlorophyll in the Irish coast and moving towards the United States east coast that ranges from 0.3 to 1 mg $m^{-3}$, and these areas also display a very high Co concentration that ranges from 101- 230 pM (Figure 2). In the southern transect at the North Atlantic Gyre, cobalt is elevated 40°N of the poles, measuring with high chlorophyll a. Below 40°N, our measurements show a lower amount of Co, between 27.40 and 57.80 pM. which also correspond to very low concentrations of chlorophyll. The highest concentrations of Co, along with high chlorophyll, are mostly associated with the continental shelf, with the exception of 5 stations between the Iberian Margin and the Bay of Biscay, that are still near land. These patterns could be due to coastal sources related to runoff, or input from continental sediments. This is consistent with a positive correlation between Co and Mn, which is derived from land-based sources. Atmospheric deposition is focused further south, mostly between the equator and 30N.

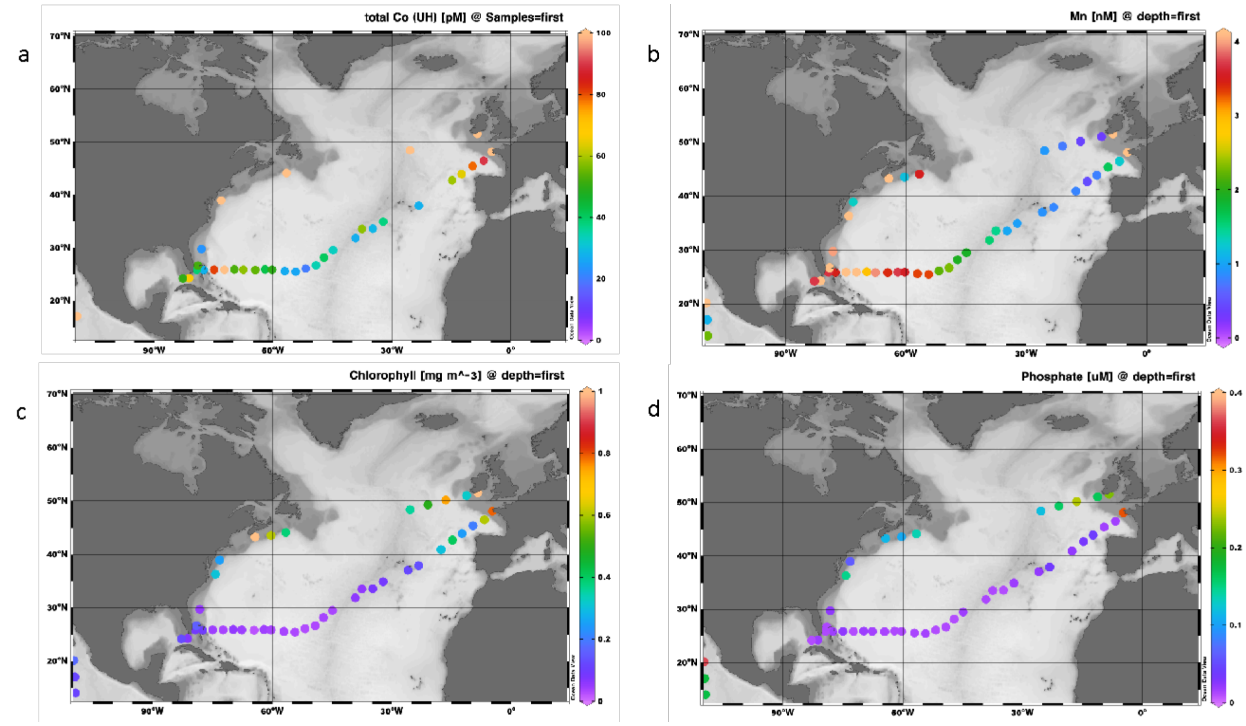


Figure 2. North Atlantic Ocean. A) Co concentration is high at the continents and has a small decrease moving south with an increase as it gets closer to the Caribbean. B) Mn concentration is high in France and begins to decrease in the lower transect as it moves south but it increases west of 40ºW with an intensity of up to 5 nM near Florida. C) Chlorophyll in the lower transect decreases west of 30ºW but has a higher concentration in the northern transect. D) Phosphate is low at a concentration of 0 µM in the lower transect but has a significant concentration in the upper portion with an average of 0.15 µM.

Mn is measured between 2.5 to 5 nM as the samples get closer to the Caribbean. However, after further inspecting the region and plotting phosphate v. cobalt and Mn v. cobalt (figure. 3) a different result emerges. The surface water map displays a higher concentration of cobalt on the continental shelf and that is similar to Mn, but upon plotting both nutrients we see a positive correlation with phosphate concentration rather than Mn. In the eastern United States there is upwelling which brings to the surface nutrients from deep within the Atlantic. This can have a biological influence on cobalt concentration in this region.

## North Atlantic Ocean

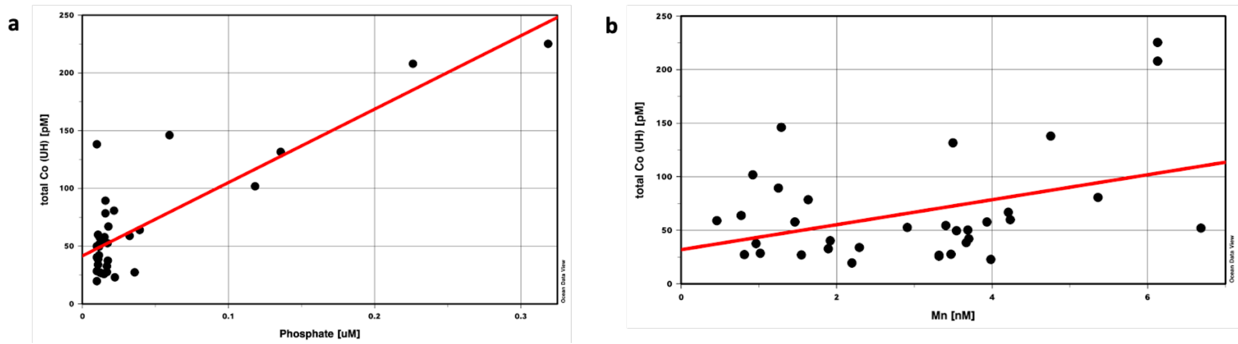


Figure 3. A) Cobalt vs Phosphate in the North Atlantic Samples with trend line (dCo = 635.57] x phosphate + 41.50, R = 0.84363). B) Cobalt vs Manganese with trendline (dCo = 11.67] x Mn + 31.87, R = 0.391511).

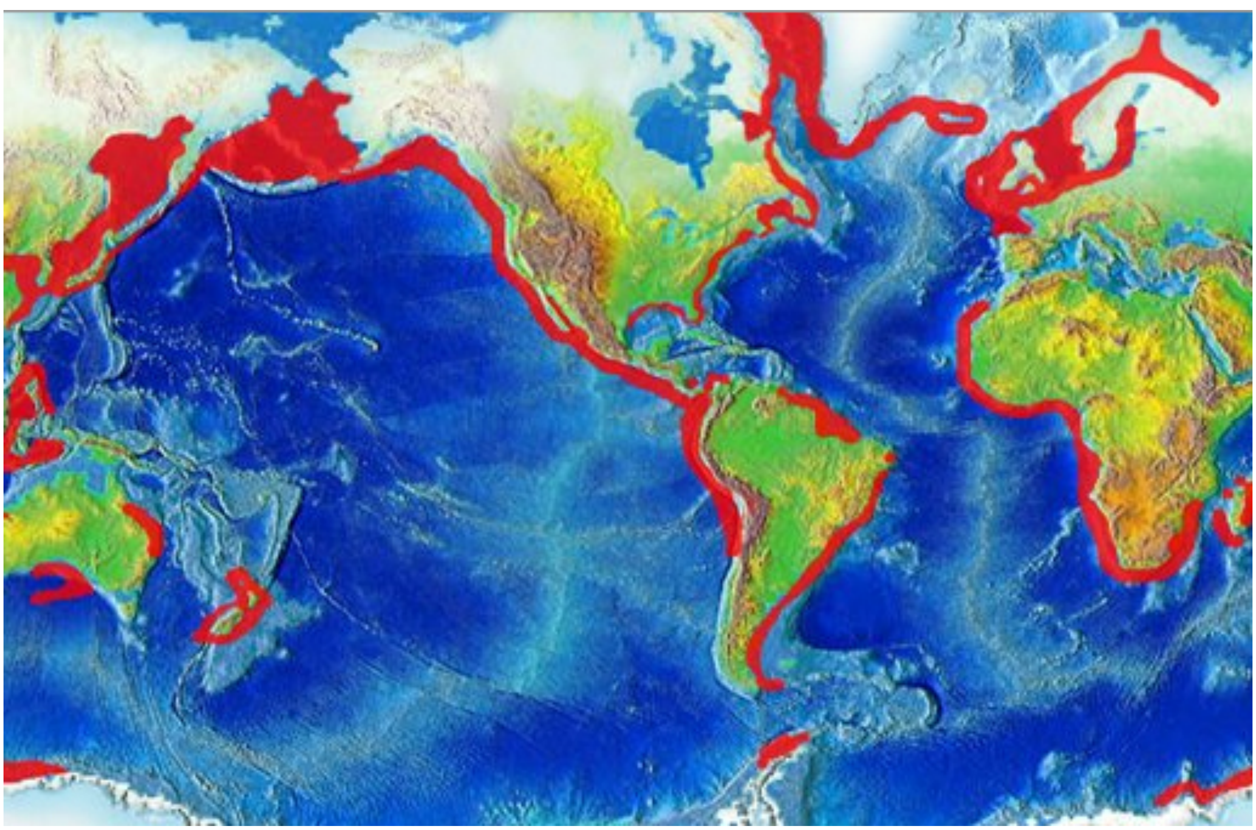

Figure 4. Upwelling map from NOAA
https://oceanservice.noaa.gov/education/tutorial_currents/03coastal4.html

### 3.2 North Pacific Ocean

The North Pacific sample region includes coastal waters from the United States, Mexico and Central America (Figure 5). Looking at this region, we can see a high cobalt concentration near Washington/ Oregon. Moving south there is a significant decrease in cobalt closer to the Northern Californian coast, but an even greater drop in cobalt concentration is noted as the transect continues to move south. The Coast of Mexico and Central America has a similar concentration of around 60 pM with some hot spots that register higher concentrations. One thing to note is that station OA207 at the coast of Washington, reports high Co, approximately 100 pM. Upon reviewing chlorophyll, we can tell there is approximately 0.55 mg $m^{-3}$ at this station, which is twice as high as nearby samples. At this same station we have high Mn that reads around 4 nM, but there is also low phosphate at around 0.2 uM. This spike in chlorophyll may be due to runoff going into the Pacific Ocean from the Columbia River. Moving southward Co is still elevated, between 50 and 80 pM, along the coast of Mexico. There is a trend of higher-than-normal Co and a significant amount of Mn within the Central America area.

As the cruise moved from the Northern Pacific coast towards Hawai'i there is a decline in Co concentration just as P starts to decrease as well. However, while Co is decreasing as the transect moves westward the correlation follows closely that of Mn in the same direction. In this region cobalt may have a geochemical influence in cobalt concentration.

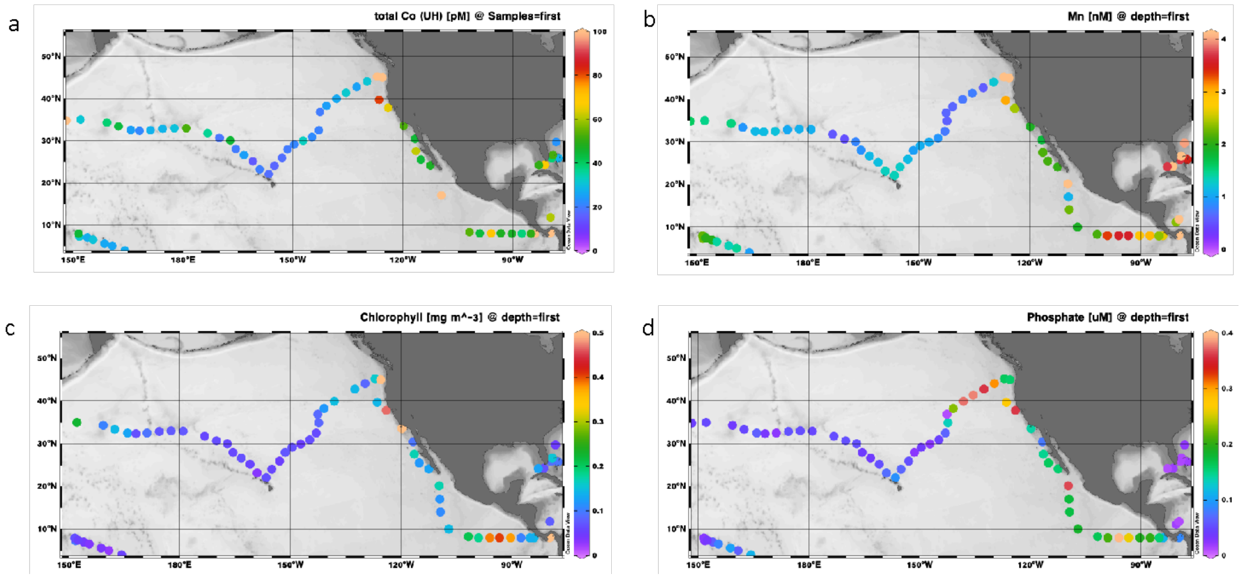


Figure 5. North Pacific concentrations. A) Co is high at a station off the coast of Washington and slowly decreases as the samples are collected southwardly into the coast of Mexico and Central America. Co also decreases from Washington to Hawai'i and has a small peak as it continues into the West Pacific Ocean. B) Mn displays a high concentration at the highest sample site and decreases as it moves south into Latin America with a spike in Central America. C) Chlorophyll is present at the North American coast, but it decreases along the Hawai'ian route with an increase as it moves westward. D) Phosphate follows a similar pattern to Co with the exception that there are higher concentrations southward along the California coast. Phosphate decreases as the trajectory moves into Hawai'i and remains low.

### 3.3 South Pacific Ocean

In the South Pacific Ocean samples were taken as the ship sailed westward. In the northern part of South America (Columbia), we see two stations with a mildly high cobalt concentration of around 40 pM and there is also an elevated amount of Mn in the area that ranges between 2-2.5 nM (figure 6). As the cruise moved towards Easter island, we saw a decline in cobalt concentration from 50 to 13 pM. Off the coast of Ecuador, there are two locations with high Co from 80 to 100 pM. Elevated surface cobalt is believed to be from upwelling from the Eastern South Pacific oxygen depleted zone that delivers a large dCo to the surface ocean (Hawco et al., 2016). Between the coast of South America and the central South Pacific gyre, Mn decreases in concentration. Near Easter Island, chlorophyll is very low, ~0.03 mg $m^{-3}$, while phosphate and Mn are elevated relative to the western South pacific gyre. West of Easter Island, dCo varies between 14 and 18 pM, but remains low compared to other regions. Here there is almost no chlorophyll detected and the measurement of Mn is below 1 nM. Phosphate is also low in this general area. Similar east west trends between cobalt and other nutrients (Phosphate, Mn) indicate similar sources from upwelling along the South American coast and then uptake by phytoplankton, as those waters move into the South Pacific gyre. The correlation between cobalt and Mn is stronger than the correlation between cobalt and phosphate in this general area indicating a geochemical influence for dCo.

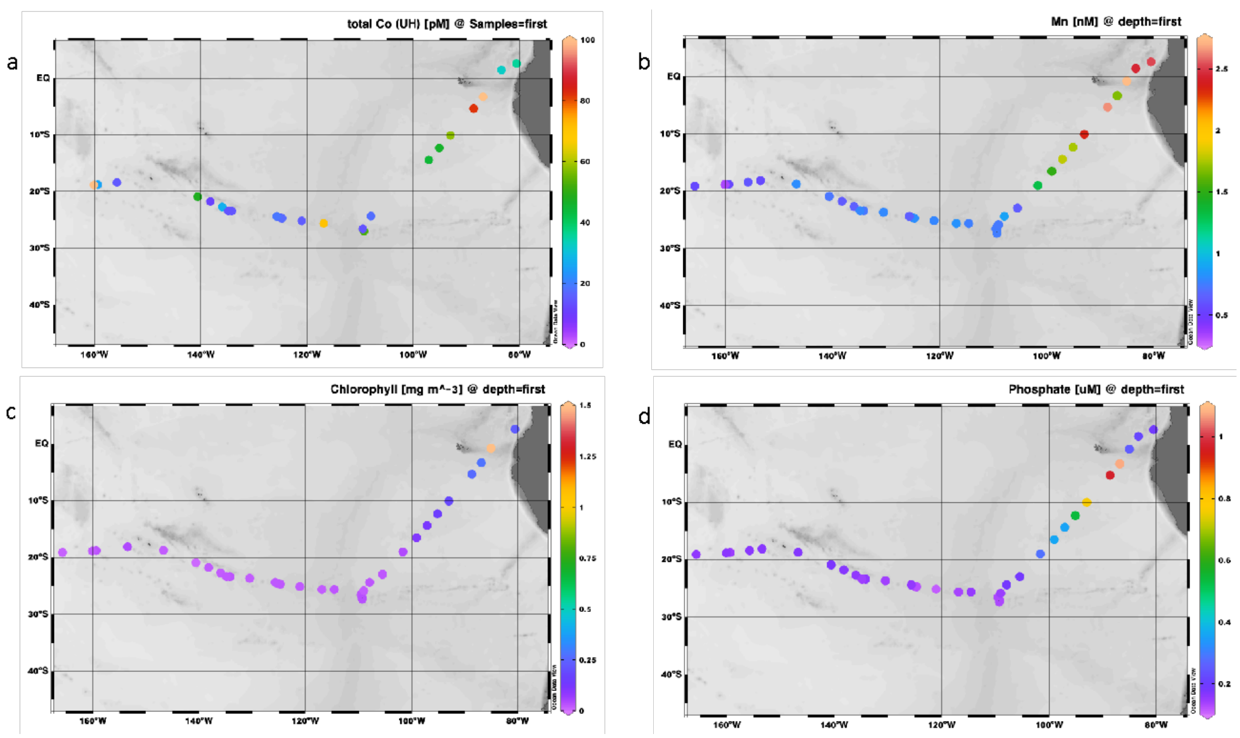


Figure 6. South Pacific Ocean. A) Co. concentration is high around the Ecuador/ Colombian shores and decreases moving southward. B) Mn concentration is higher at the northernmost sample site compared to west of Easter Island. C) Chlorophyll is low at the highest sampling site and drops to 0 mg $m^{-3}$ as it moves close to Easter Island and westward. D) Phosphate concentration is moderate moving away from the Ecuadorian coast and into open water. The concentration drops below 0.2 µM as it moves westward

### 3.4 West Pacific Ocean

The Western Pacific is a region with a diverse cobalt concentration that can be connected to changes in phosphate and Mn in different areas of this region. Upwelling makes the equatorial region higher in phosphate compared to other open ocean waters. In the equator, we can see that

Co is present at an average of 40 pM at 140° E and also 180° E. This higher amount of Co is probably due to upwelling.

Several other hotspots of high Co are found in other parts of the region. In Aotearoa, north Island of New Zealand, there is a hot spot where Co was measured at about 90 pM and there is also a spike in phosphate with a concentration registered at about 0.23 uM. However, there are 2 samples between New Zealand and Australia that report a similar phosphate concentration, this is probably due to high phosphate from upwelling in the Southern Ocean. Nonetheless, the Co concentration at this location is around 30 pM (see red arrow), compared to >40 pM at the equator. Although upwelling of phosphate may lead to higher concentrations of Co, it is not necessarily the case in the Southern Ocean.

Between the 1960s and 1981 on the island of New Caledonia, mining was prevalent in the Coulée River watershed that released high amounts of trace metals such as Ni, Mn, Fe and Co (Darrenougue, 2018). On this island there is a location that has a high amount of Mn: 2.58 nM, where we can also see a high amount of Co, measured at 85 pM. Just north of the island of Papua New Guinea, the phosphate concentration is lower compared to other equatorial samples, but the Co concentration is between 40 to 100 pM, however, high Mn is registered at 4.37 nM. This difference in the phosphate to Co relationship may be due to a lot more riverine input being deposited from Papua New Guinea, which must not be a large source of phosphate. This anomaly in Papua New Guinea differs from the Mn concentrations that are significantly higher in concentration in the samples collected just above that island, which seems to correlate to the amount of Mn present and the higher level of Co detected (figure 7).

There are three transects that have similar correlations with phosphate and Co. On the top transect (between Japan and Samoa), phosphate is present at a concentration from less than 0.05 to about 0.205 uM and when compared to Co in the same area we have a concentration between 10 and 60 pM. The middle transect (Taiwan to Fiji) also has a significant amount of phosphate with a range of 0.05 and 0.15 uM and this relates to a significant amount of Co with a range of 10 to 60 pM with also a location that has a higher concentration. Finally, in the lower transect (along the coast of Papua New Guinea and the Solomon Islands), there is a decrease in phosphate with an average concentration of 0.05 uM but the concentration of Co seems to remain within 30 to 40 pM. In the West Pacific region there is a steady range between 20- 40 pM of Co that begins from the islands and continues into the equatorial waters. This suggests that Co correlates with both Mn, closer to the island, and phosphate, closer to the equator.

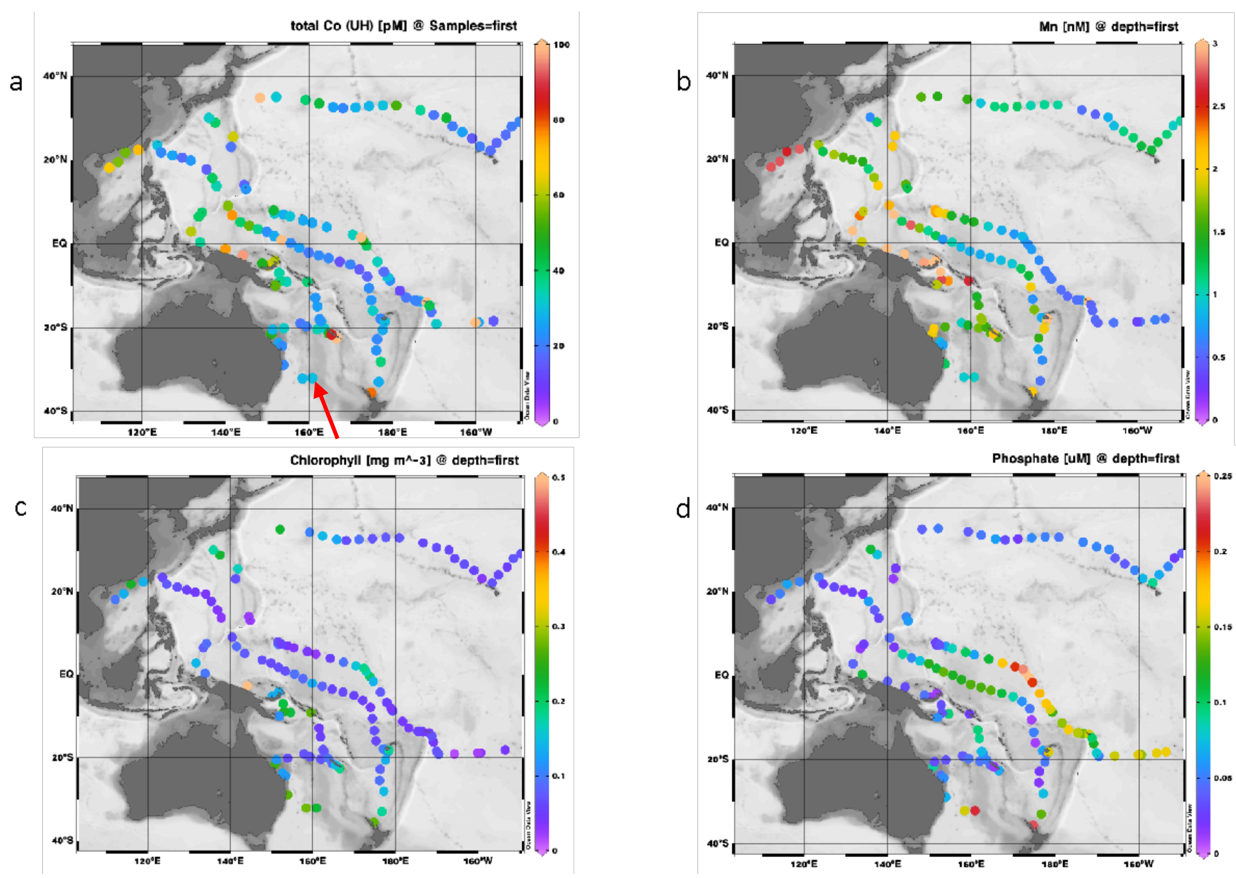

Figure 7. Western Pacific Ocean. A) Co has an average of < 40 pM on the top transect but it increases as the cruise moved towards Asia. The middle transect has a steady average between 20 pM and 30 pm with some samples displaying more or less concentration. The bottom transect has a higher variability with 5 samples indicating high Co concentration at the shores of different islands. B) Mn displays a small concentration below the equator on the top transect but there is a higher concentration in the middle transect in the same area. The bottom transect has a higher concentration that can be due to river and dust input. C) Chlorophyll indicates that there is a low amount of phytoplankton in this region. D) Phosphate on the top transect below the equator has the highest concentration of all 3 but it begins to drop as it moves to Asia. The middle transect has less phosphate concentration and the bottom transect has the smallest concentration recorded.

## 4. Discussion

| Region | Mn | | | Phosphate | | |
|---|---|---|---|---|---|---|
| | Slope | Intercept | r | Slope | Intercept | r |
| North Atlantic | 11.66 +- 0.10 | 31.87 +- 0.35 | 0.391511 | 635.56 +- 2.615 | 41.50 +- 0.199 | 0.84363 |
| North Pacific | 30.60 +- 0.29 | -3.01+- 0.340 | 0.665996 | 72.14 +- 1.317 | 33.61 +- 0.225 | 0.23538 |
| South Pacific | 16.62 +- 0.30 | 12.21 +- 0.41 | 0.578422 | 77.64 +- 0.77 | 13.71 +- 0.31 | 0.812011 |
| West Pacific | 10.94 +- 0.09 | 17.22 +- 0.18 | 0.567123 | -26.69517 | 37.01 +- 0.171 | -0.0649348 |

Table 1. Regional slope intercepts for Mn and phosphate.

In this paper Co is compared to Mn and phosphate because they are good tracers that are readily available in the ocean. Manganese has a geological source such as the weathering of rocks, hydrothermal vents, and the erosion of mineral-rich sediments. A positive correlation with manganese in seawater can reflect the input from these geological sources. Phosphate is a good biological tracer whose sources are upwelling regions that bring nutrient rich water to the surface from the deep. A positive correlation links their concentration biologically.

### 4.1 North Atlantic Ocean

A surprising finding was the difference in correlation between cobalt and phosphate in the North Atlantic compared to other parts of the ocean (table 1) . The slope of the North Atlantic Ocean is 635 compared to the slope of the West Pacific Ocean which is -26. The scatter plot (figure 3) indicated a positive correlation between cobalt and phosphate comparable to cobalt and Mn. The following figures will clarify why it was thought that cobalt could have a positive correlation with Mn in this region. Cobalt can be used directly by phytoplankton for primary production or it can be part of the co-limiting factors that involve other trace metals. As phytoplankton increase, co concentration at the surface can decrease due to primary producers' uptake of the metal. The Sahara Desert blows aerosols onto the surface waters of the Atlantic which was thought to have a greater influence than it actually does (van Hulten, 2016). The sources of manganese and cobalt might differ along the US east coast. For example, riverine inputs, sediment resuspension, and atmospheric deposition might introduce varying amounts of these metals independently. Upwelling might bring phosphate to the surface but not necessarily manganese, leading to decoupled inputs of these elements.

**4.2 North Pacific Ocean**

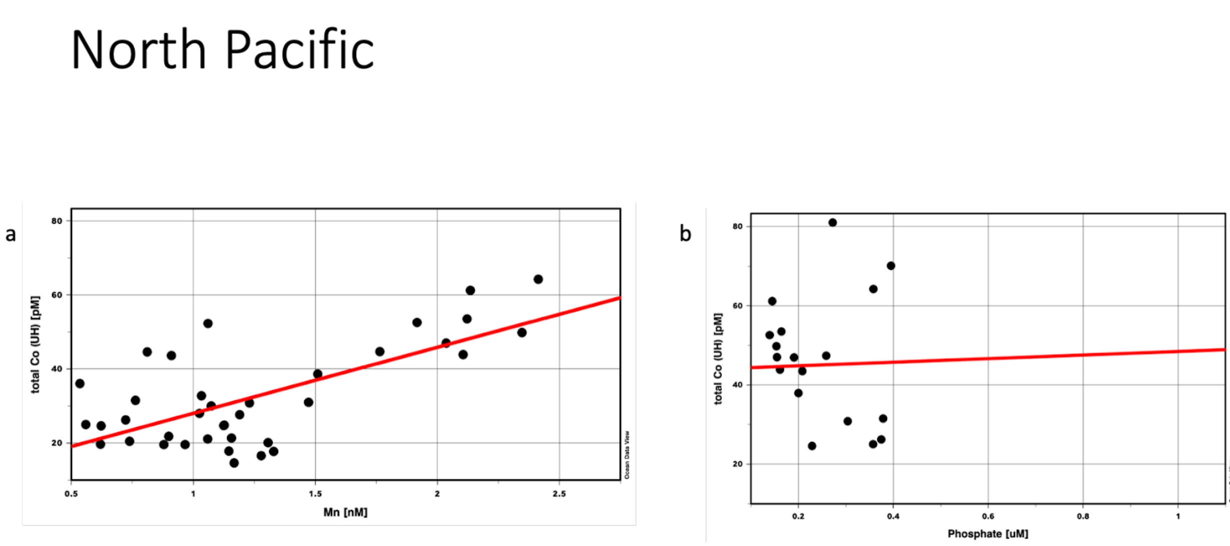


Figure 8. Concentrations of cobalt compared to phosphate and Mn in the North Pacific Ocean. A) indicated a stronger correlation to Mn than phosphate in this region.

In both the north and south Pacific Ocean cobalt correlates stronger with Mn than phosphate. The western Pacific is influenced by river inputs from the continent that seems to overpower the upwelling influence of the same coastlines.

**4.3 West Pacific Ocean**

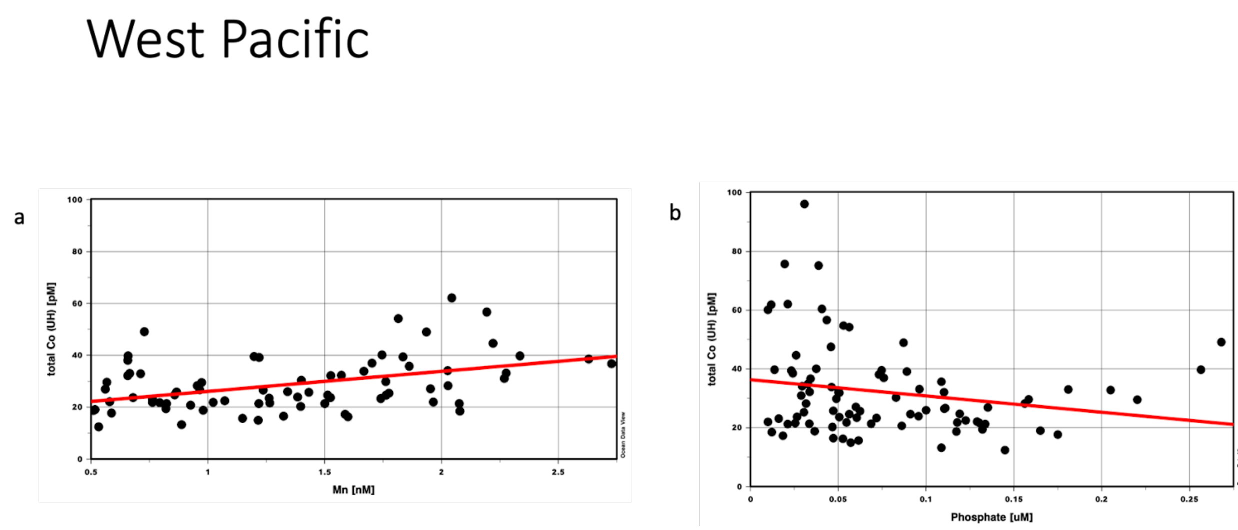


Figure 9. Concentrations of cobalt in the Western Pacific region. A) positive correlation between cobalt and Mn. B) negative correlation between cobalt and phosphate.

Co concentration in the Western Pacific Ocean ranges from highest concentration in New Caledonia and it decreases as the stations move to Papua New Guinea, New Zealand, and Australia. While Mn concentrations are 3 nM in Papua New Guinea they are >3 nM New Zealand which is similar to the concentration in New Caledonia. In this archipelago it looks like lands that are “volcanically” made have higher Co concentrations so the weathering can be a factor of high input.

In the North Atlantic Ocean, phosphate traces dissolved cobalt, highlighting a positive correlation between the two elements that indicates significant phytoplankton uptake. This uptake reduces the concentrations of dissolved cobalt and phosphate in seawater, creating a clear linkage between their distributions. In the Pacific Ocean, however, cobalt concentrations are notably higher along the west coast compared to other sources, such as those from Asia or the east coast. This elevated cobalt input is primarily attributed to upwelling and coastal runoff, which introduce greater amounts of cobalt-rich waters into the marine environment, thereby influencing its distribution and availability for phytoplankton uptake.

## 5. Conclusion

This study highlights the intricate dynamics between dissolved Co and other trace metals on the ocean surface, specifically comparing its correlation with Mn and phosphate. Mn originating from geological sources such as rock weathering, hydrothermal vents, and sediments erosion, indicates a positive correlation with Co, reflecting the input from these geological processes. Phosphate serving as a biological tracer, shows a different correlation pattern between Co due to its biological sources from upwelling regions that bring nutrient-rich water to the surface.

A key finding is the varying correlation between Co and phosphate in the North Atlantic Ocean to other ocean regions. In the North Atlantic, there is a strong positive correlation exists with a slope of 365 (table 1) indicating significant phytoplankton uptake. This contrasts sharply with the West Pacific Ocean, where the slope is -26 (table 1), suggesting different influencing factor. Co was thought to have a strong correlation to Mn due to aerosols from the Saharan Desert (van Hulten 2016) but in fact it plays a lesser role than originally theorized.

In the Pacific Ocean, Co shows a stronger correlation with Mn than phosphate, especially in regions influenced by river inputs and coastal runoff such as the Western Pacific. Here Co concentrations are highest near volcanic lands like New Caledonia suggesting weathering significantly contributes to elevated Co levels.

Overall, this study reveals that Co’s distribution across the ocean is governed by both geological and biological processes, with reginal variations, this highlights the complexity of these interactions. The significant correlation with Mn and phosphate provide insight into Co’s biogeochemical cycling, influenced by geological and biological sources as well as biological uptake. Future research should expand on these findings by including broader sampling sites and seasons to further understand the dynamics of Co and its interaction with other trace metals in ocean the surface water.

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