



Soil Quality Investigation of an Abandoned Mine Area Using Geochemical and Geospatial Approach in Jantang Village

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Abstract – The physical and chemical environmental impact in a mining area is inevitable, particularly for open pit mining areas. The impact could affect soil and water quality where mining activities, such as land clearing, blasting and hauling, occur. Thus, environmental monitoring in mining areas should be taken to measure the impact of mining activity for reclamation purposes. The objective of this research focuses on the measure of environmental impact on soil quality in terms of the nutrient content in an abandoned mine area at Jantang village, Lhoong, Aceh Besar. The research was conducted by collecting 15 soil samples, followed by laboratory analysis using atomic absorption spectrophotometry to investigate sampled 'soil's nutrients which are pH, Carbon (C-organic), Nitrogen (N-total), Phosphor (P-availability), and Ferro substance (Fe-concentration). In addition, to estimate the soil properties at locations outside the sampling area, a spatial interpolation method called inverse distance weight with an optimum power was used. The result shows that the soil is acidic, with low C-organic in the range of 0.02%–1.84%, N-total 0.02%–0.16%, and P-availability 0.55%–3.75%. In contrast, the Fe-concentration is very high, at 3000–3400 ppm.

Keywords: Soil quality, Geochemical Survey, Atomic Absorption Spectrophotometry, Spatial Interpolation.

Introduction

Iron ore is the source of primary iron for the world's iron and steel industries. It is essential for the production of steel, which is essential to maintain a strong industrial base. Almost all (98%) iron ore is used in steelmaking. Steel is an alloy of iron and carbon that is vital to the global economy. Its unique strength, formability, versatility, recyclability, and low cost make it an ideal material for the construction industry, shipbuilding, motor vehicle manufacture, railway construction, bridge building, heavy industry, machinery manufacture, and engineering applications (Holmes and Lu, 2015). Iron ore is mined in about 50 countries, including Indonesia.

According to Rochani *et al.* (2008), Indonesia has great iron mineral resources, comprising primary iron ore (17%), iron sand (8%), and lateritic iron ore (75%). Primary iron ore is found spread out in South Kalimantan, West Kalimantan, Belitung, Lampung, Papua, and Aceh. Iron ore reserves in Aceh are spread in several areas, such as Aceh Besar, Pidie, Aceh Barat Daya, Aceh Selatan, Subulussalam, Gayo Lues, and Aceh Timur, with total deposits exceeding 290 million tonnes (ESDM, 2019). Jantang village, located in Lhoong sub-district Aceh Besar, was once an area with iron ore as the main mineral deposit. Research conducted by Rahwanto *et al.*, 2013, revealed that iron ore in that area was mainly hematite (Fe_2O_3).

The exploitation of the mineral deposit should be carried out properly to increase local community welfare and minimize environmental impact. Environmental impact is a sensitive issue in a series of mining activities because of its ability to degrade land's physical and chemical properties. One of the environmental impact examples is the presence of heavy metals in the soils close to an extremely large open cast iron mine pit in China

(Niu *et al.*, 2021). Heavy metal pollution affects plant growth and genetic variation. It also alters the activity of soil microbial communities (Xie *et al.*, 2016). Soil microbes affect soil environmental quality because they are responsible for soil's nutrient content (Chu, 2018).

Iron ore in Jantang village was mined using the open-pit mining method. The open-pit mining process begins with land clearing, followed by topsoil removal. It is the first step in the physical preparation of the mine site. It leads to the first significant visual impact, removes wildlife habitat, and predisposes the surface to accelerated erosion by wind and water (Spitz and Trudinger, 2019). This first stage of mining activities can reduce soil nutrients and increase toxic substances, which can later affect soil acidity (Boularbah *et al.*, 2021). The geochemical survey is carried out to measure the impact of the mining activities on the land by systematically measuring one chemical element or more in rock or soil sediment. Using geochemical surveys and evaluation to measure soil quality has been a new research hotspot in recent thirty years (Wu *et al.*, 2018). The geochemical survey can also be used in mineral exploration to identify anomalies to indicate an economic mineral deposit (Syahroni, 2010).

This research investigates the soil quality in an abandoned iron ore mine area at Jantang village. The research was carried out by conducting a geochemical survey to measure soil's acidity and nutrient properties, such as Carbon (C-organic), Nitrogen (N-total), Phosphor (P-availability), and Ferro (Fe) substance.

Materials and Methods

Time and site

The research was conducted in May 2021 in an abandoned mining area at Jantang village, located in Aceh Province. There were 15 soil samples collected over the area, and sample analysis was done at the Soil and Plant Research Laboratory, Agriculture Faculty of Syiah Kuala University. This study combines both descriptive and quantitative methods through field observation and analysis of laboratory results by using spatial interpolation and map visualization.

Data collection

The sample locations were designed in such a way to represent the whole interest area. Therefore, the sampling locations were distributed sparsely within the investigated area (Figure 1). In total, 15 samples were taken from the selected locations. The samples were dug at 20–30 cm depth with the 500-gram weight each. The sampling activity was carried out according to standard procedure using a digging tool and rubber hand glove to prevent contamination of other substances. The sample locations were recorded using a GPS device, and each sample was labeled systematically.

Soil samples were collected and labeled systematically in the selected locations. Their acidity was measured using a pH meter, their location coordinates were using a pH meter, and their location coordinates were recorded using a GPS device. The samples are then handed over to the laboratory to be analyzed. The expected results are soil nutrient parameters, such as C-organic, N-total, P-availability, and Fe concentration.

Data processing

The soil nutrient parameters are analyzed using atomic absorption spectrophotometry (AAS). Some samples were determined as testing datasets. The rest of the datasets were estimated with inverse distance weight (IDW) spatial interpolation for all parameters, such as soil pH and nutrients at locations outside the sampling area. The interpolation is performed using a Power (P) series starting from 1 to 5. Cross-validation was performed to figure out the estimation accuracy using the testing dataset. The Root Mean Squared Error (RMSE) was used to measure the accuracy and define the optimum P-value. The result of each parameter interpolation model was visualized on a map.

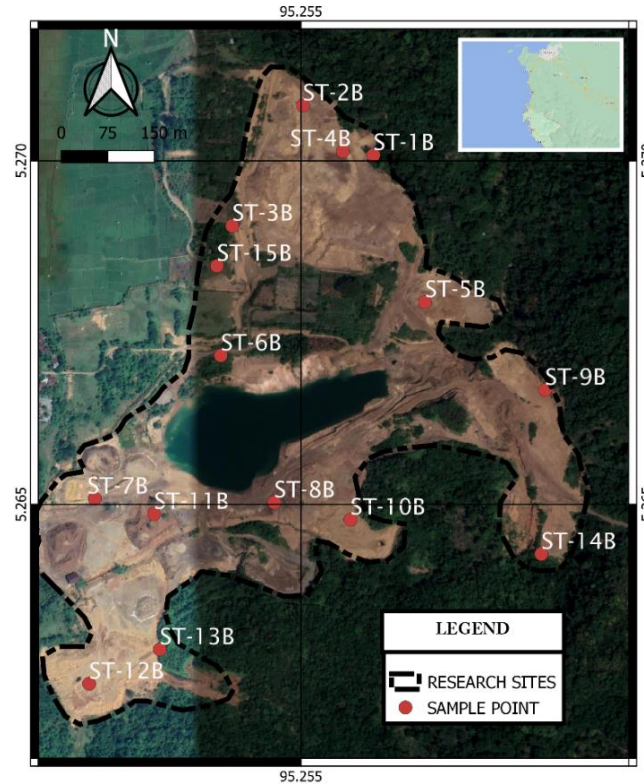


Figure 1. Sampling points.

Results

As aforementioned above, 15 samples were collected and tested at the Soil and Plant Research Laboratory, Agriculture Faculty of Syiah Kuala University, to obtain the soil's C-organic, N-total, P-availability, and Fe concentration. A pH meter tested only soil's acidity directly on the sample location. All the processes, from the sample acquisition to the sample testing, are in accordance with the applicable standards. The detailed results are presented in Table 1 and Table 2.

The soil analysis result is summarized in Table 3. The table listed some descriptive statistical parameters, such as minimum and maximum values, mean, variance, and standard deviation.

Table 1. Laboratory analysis results at Locations ST-1B to ST-8B

Location	Latitude	Longitude	pH	C-Organic (%)	N-Total (%)	P-Availability (ppm)	Fe (%)
ST-1B	05° 16' 12.3"	095° 15' 21.8"	5.5	1.84	0.16	0.6	0.30
ST-2B	05° 16' 14.9"	095° 15' 18.1"	3.5	0.26	0.04	1.6	0.33
ST-3B	05° 16' 08.6"	095° 15' 14.4"	7	1.16	0.08	3.75	0.31
ST-4B	05° 16' 12.5"	095° 15' 20.2"	3.5	0.22	0.03	3	0.33
ST-5B	05° 16' 04.6"	095° 15' 24.5"	4.5	0.31	0.03	1.35	0.33
ST-6B	05° 16' 01.8"	095° 15' 13.8"	6.8	0.98	0.08	0.55	0.32
ST-7B	05° 15' 54.4"	095° 15' 07.2"	3.8	0.29	0.02	0.9	0.34
ST-8B	05° 15' 54.1"	095° 15' 16.6"	4.5	0.23	0.02	0.55	0.34

Table 2. Laboratory analysis results at Locations ST-9B to ST-15B

Location	Latitude	Longitude	pH	C-Organic (%)	N-Total (%)	P-Availability (ppm)	Fe (%)
ST-9B	05° 16' 00.0"	095° 15' 30.8"	6	0.81	0.09	0.65	0.34
ST-10B	05° 15' 53.2"	095° 15' 20.6"	3.5	0.22	0.02	1.35	0.34
ST-11B	05° 15' 53.5"	095° 15' 10.3"	5.5	0.26	0.02	1.75	0.33
ST-12B	05° 15' 44.6"	095° 15' 06.9"	3.5	0.23	0.02	0.95	0.34
ST-13B	05° 15' 46.4"	095° 15' 10.6"	6	1.63	0.09	0.65	0.33
ST-14B	05° 15' 51.4"	095° 15' 30.6"	7.5	0.67	0.07	0.6	0.34
ST-15B	05° 16' 06.5"	095° 15' 13.6"	5.5	1.3	0.13	1.55	0.30

Table 3. Summary of the laboratory analysis results

Parameter	Min	Max	Mean	Variance	Std. Deviation
pH	3.50	7.50	5.10	1.90	1.38
N-total (%)	0.02	0.16	0.06	0.45	0.67
C-organic (%)	0.22	1.84	0.7	0.57	0.75
P-availability (ppm)	0.55	3.75	1.32	0.94	0.97
Fe (%)	0.3	0.34	0.33	0.01	0.10

Discussion

Soil Acidity/Basicity

The interpolation model of pH value throughout the mine area is shown in Figure 2. The result shows that the 'soil's pH throughout non-vegetation soil is acid with a pH level below 7, whereas in some locations with vegetation, the pH is neutral with a pH level of 7. Based on the map, it can be seen that the pH level tends to increase as it gets closer to settlement or forest areas. According to Hardjowigono (1987), the soil becomes acid because of the high concentration of H⁺ ions compared to OH⁻ ions.

Soil acidity/basicity is classified in more detail by Pusat Penelitian Tanah/Center for Soil Research (1987). Levels of pH less than 4.5, 4.5–5.5, 5.5–6.5, and 6.6–7.0 are very acidic, light acid, and neutral, respectively. In addition, pH 7.6–8.5 is classified into light bases, and a pH higher than 8.5 is a base. By referring to the mean pH value of 15 soil samples, it can be concluded that most soil in the mining area is acidic.

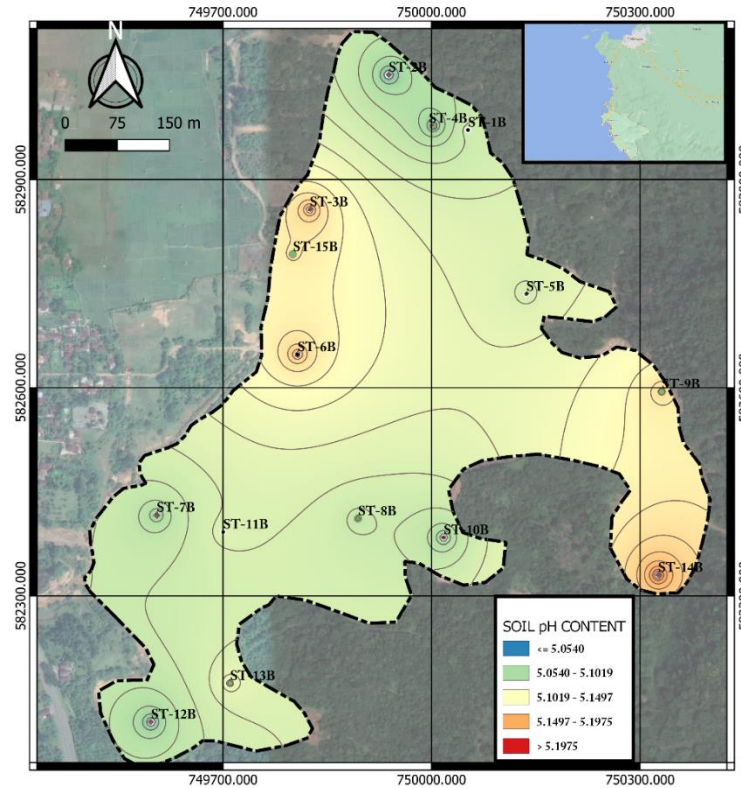


Figure 2. pH interpolation map

N-total Content

Central for Soil Research classified the N-total content into some classes. N-total less than 0.1%, 0.1%–0.2%, 0.3%–0.5%, 0.6%–0.75%, and higher than 75% is classified as very low, low, moderate, high, and very high, respectively. The result of laboratory analysis figured out that the N-total content from 15 soil samples is 0.02%–0.13%. Therefore, it can be classified as very low to low. This condition could be caused by the loss of vegetation from the land clearing activity in the mining area.

Figure 3 shows the N-total interpolation map. Based on the map, it can be observed that the N-Total content throughout the area is very low. The higher content in the northern area indicates that the loss of organic soil nutrients in the southern part is higher than in the north.

Phosphor Content (P-Availability)

Phosphor availability in soil depends on pH, Fe, Al ion, and organic decomposition rate (Susanto, 2005). The low pH and organic elements could decrease 'the soil's phosphor content. According to Central for Soil Research, the phosphor content in soil can be classified into very low, low, moderate, high, and very high when P is less than 10 ppm, 11–20 ppm, 21–40 ppm, 41–60 ppm, and higher than 60 ppm, respectively.

The laboratory result shows that phosphor content in the interest area is 0.6–4.0 ppm. Thus, it is classified as very low. As discussed above, the pH in the area is low, and organic N-total content makes this finding, not a surprise.

Figure 4 is the interpolation map for phosphor content. At a glance, it can be seen that the pattern is similar to the N-total content interpolation map, with the value in the northern part being slightly higher than in the south; thus, it indicates the same phenomenon.

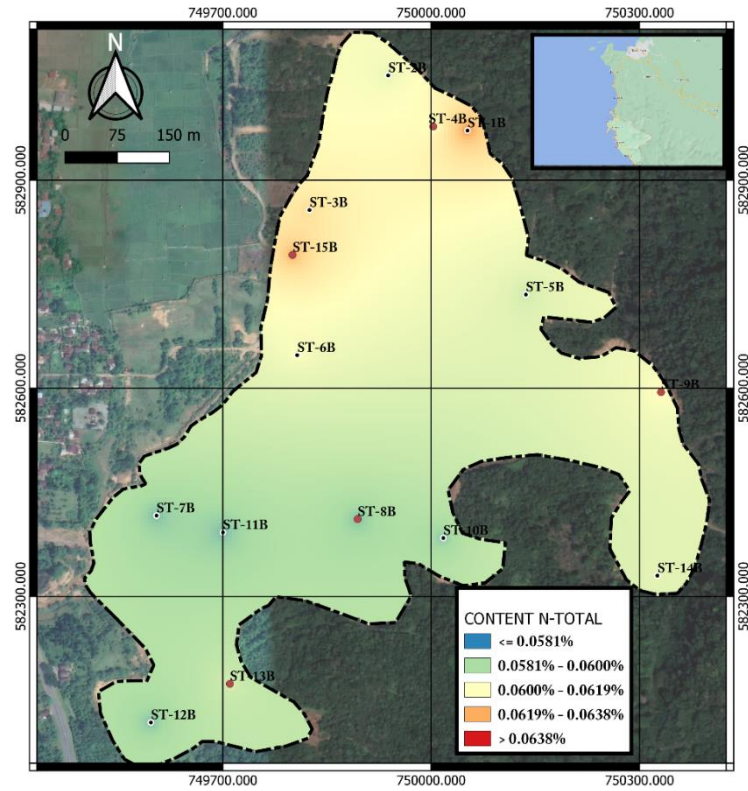


Figure 3. N-total interpolation map

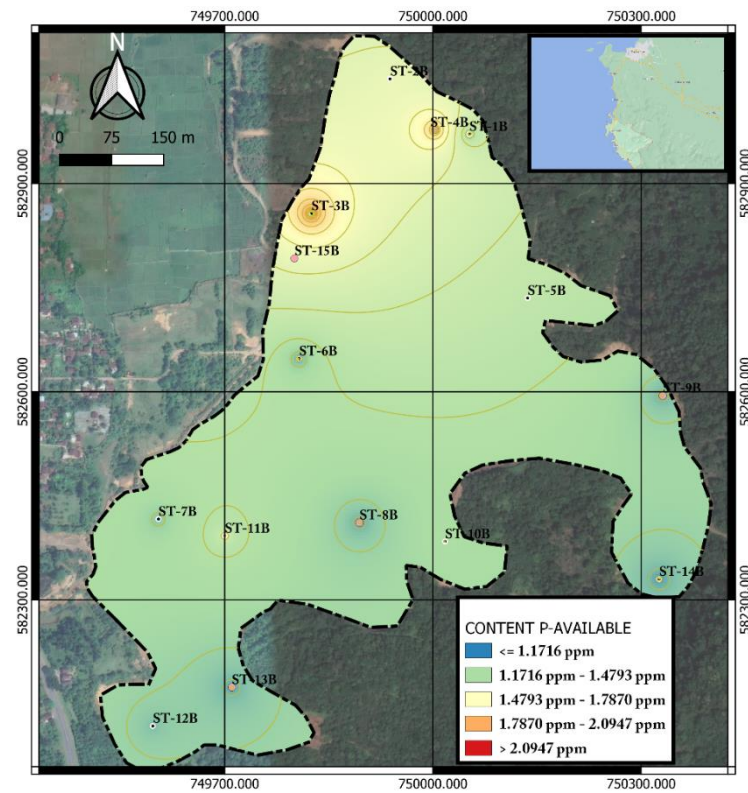


Figure 4. Phosphor interpolation map

C-organic Content

C-organic can be used to indicate organic content in the soil. Less content of organic substances can cause soil infertility. The Central for Soil Research had classified the C-organic content into some classes. Soil with C-organic content less than 1%, 1%–2%, 2.1%–3.3%, 3.4%–5%, and above 5% is classified into very low, low, moderate, high, and very high classes, respectively.

The C-organic content in the research area has a minimum value of 0.22% and a maximum of 1.84%. Thus, according to the classification system, the soil can be classified into low – low. Figure 5 shows the C-organic content in the research area. It can be seen that mostly the northern part has a higher value and only a small part in the south. In the middle area around the water sump, the C-organic content is very low compared to the other areas. It means the content of organic substances is really low, with the lowest soil infertility rate.

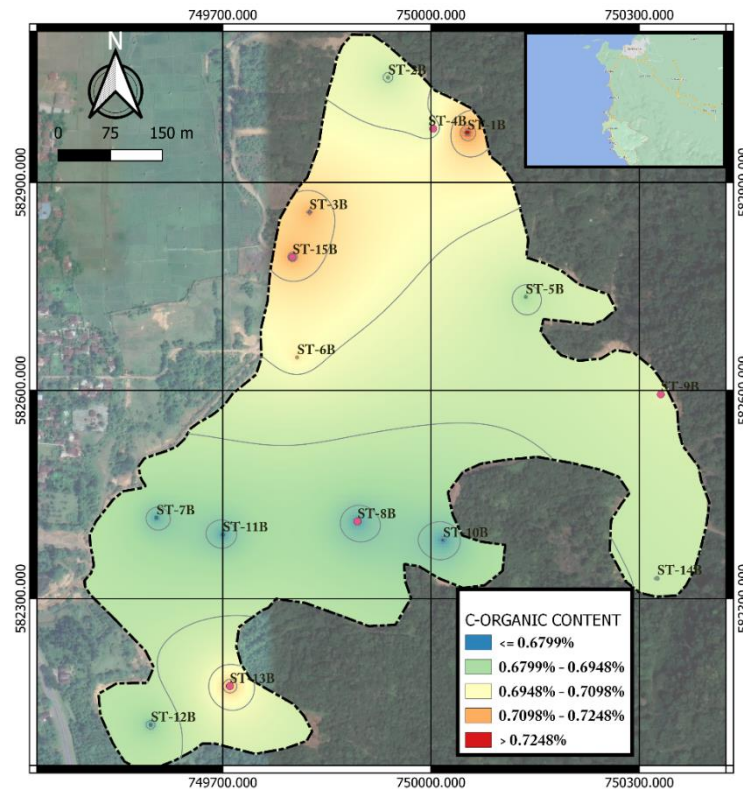


Figure 5. C-organic interpolation map

Fe Content

One element required in soil for plant growth is Fe. However, excessive Fe content in soil is poisonous that causes illness or death for plants. According to Havlin and Soltanpour (1981), the threshold for Fe content in the soil is 4.8 ppm. In addition, other researchers reported various threshold values, such as above 250 ppm (Dorlodot *et al.*, 2005), 10–500 ppm (Asch *et al.*, 2005), 100 ppm in soil with pH 3.7, and 300 ppm in soil with pH 5 (Sahrawat *et al.*, 1996).

Taking any of those thresholds, the Fe content in the interest area is far beyond the threshold, with more than 3,000 ppm. Figure 6 shows the spreading of Fe content in the soil in the mining area. Based on the interpolation map, it can be observed that the Fe content generally is over the threshold value for the whole area, with a higher concentration in the middle to the southern part.

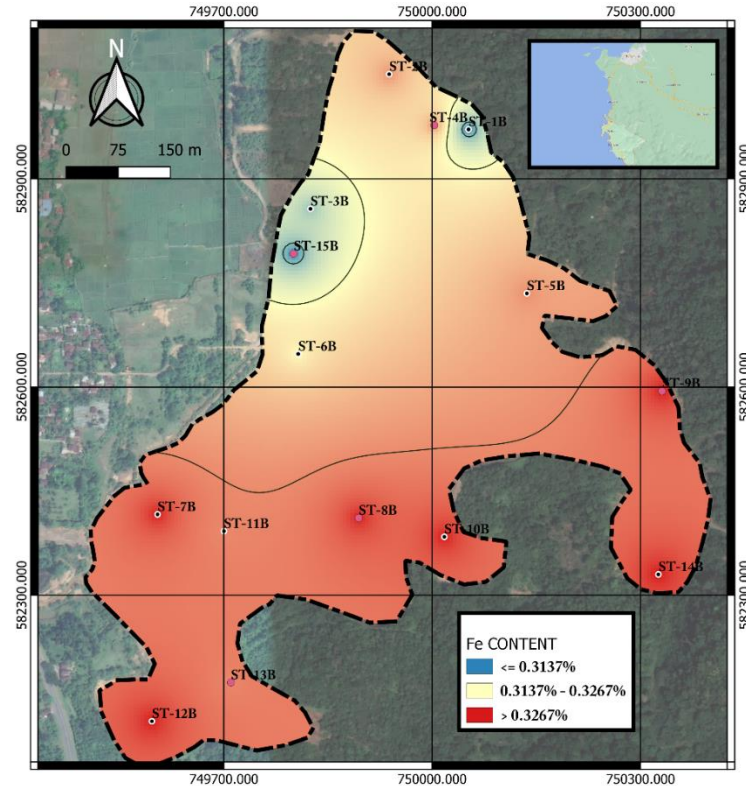


Figure 6. Fe-content interpolation map

Conclusion

Environmental monitoring, including soil quality in the mining area, should be carried out to measure the impact of mining activities for reclamation purposes. This research found that the soil in the abandoned mine area in Jantang village, Lhoong sub-district, Aceh Besar is acid soil with low pH levels. According to the Center for Plant Research classification system, some significant soil nutrients, such as Carbon, Phosphor, and Nitrogen, are low to very low. Moreover, the content of Ferro substances is very high. It is poisonous for plant growth and can cause illness or death to plants.

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