Testing the effectiveness of mechanical magnetic extraction in riverine and lacustrine sediments

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Abstract. Rock magnetic studies often require analysing extracted magnetic grains so that the mineralogy, granulometry, and concentration of magnetic minerals could be determined accurately. Magnetic extraction is often cumbersome, tedious, and subjective as this process is carried out manually by placing strong magnet inside sediment slurries. Moreover, the magnetic mineral content in sediment is generally much less than 1% of its weight. In this study, the effectiveness of mechanical magnetic extraction using magnetic stirrer is tested for riverine and lacustrine sediments. The samples are sediments from Citarum River in West Java and from Brantas River in East Java as well as surface sediment from Lake Towuti in South Sulawesi. The effectiveness tests were carried out by comparing the magnetic properties of bulk samples with that of extracted magnetic grains. Additional tests were also carried out in the form of SEM (scanning electron microscopy) and XRD (X-Ray diffraction) analyses. Apart from the expected higher values of mass-specific magnetic susceptibility, the extracted samples also tend to have larger magnetic grains than that of bulk samples. The predominant magnetic mineral in bulk and extracted samples is magnetite, although other type of magnetic minerals might be present in extracted samples. The presence of SP (superparamagnetic) grains in extracted samples is also negligible unlike that in bulk samples. SEM and XRD analyses support these findings. Magnetite grains could easily be identified in extracted samples.

1. Introduction
Rock magnetism is one of the geophysical approaches used to investigate the condition of the earth's surface by utilizing the magnetic properties of a material. Rock magnetic method are used to identify magnetic minerals by looking at the mineralogy, granulometry, and concentrations of the magnetic minerals. However, the presence of magnetic minerals in nature is very small, i.e. less than 1% [1]. Therefore, to make a direct measurement of magnetic minerals, magnetic mineral extraction is required in the sample.
Magnetic mineral extraction is performed to separate magnetic minerals from non-magnetic minerals. In general, magnetic mineral extraction is performed manually using a bar magnet. The process is considered not too effective because when strong magnet is used then magnetically weak minerals will also be extracted. In addition, manual magnetic extraction is often a subjective method that depends strongly on the experience of the performing scientist/technician [2]. Therefore, in order to improve the extraction process of the magnetic mineral, magnetic stirrer is used in this study employing a weak magnet with intention of attracting only the strong mineral magnetic which is more objective.

The extraction of magnetic mineral using stirrer magnetic has been carried out in urban soil sample [3]. In addition, it is commonly used in visual identification of pollution sources and measurement of heavy metal concentrations in soils [3]. In this study, mineral magnetic extraction has been conducted in other types of samples. Instead of soil samples, river and lake sediments were used. The river sediment samples were obtained from two different rivers (Citarum and Brantas) to test whether the proposed magnetic extraction method is effective in different types of river sediments. The other type of sample is sediment samples from Lake Towuti. If it is successful, mechanical magnetic extraction could be used more intensively in the studies of riverine and lacustrine sediments.

### 2. Methods

Citarum River is the longest and largest river in West Java. The downstream area of Citarum are mostly volcanic rocks [4]. Near the city of Bandung, the river passes through industrial and residential areas giving rise to potential serious heavy metal contamination. Meanwhile, Brantas River is surrounded by areas with high density population as well as industries. The pollution in this river is likely anthropogenic [5]. Lake Towuti is the largest tectonic lake in Indonesia located in ultramafic region. The sediments of this lake are naturally rich in iron and nickel [6].

Sediment samples were mixed with double distilled water (DDW) and then sieved using mesh size of 325 so that only clay-sized particles were used in the analyses. The wet sieved samples were then dried at room temperature and then grinded to powdery form. Each sample was then divided into two parts, namely the bulk sample and the sample to be subjected for mechanical magnetic extraction. The magnetic extraction used an IKA Lab Disc Magnetic Stirrer. For each run, 5 mg of dried powdery sample was dissolved in 50 ml of DDW. The extraction carried out by removing the magnetic stirrer dipped in the solution every 5 minutes until no magnetic minerals could be drawn. The magnet used in the stirrer is a weak magnet so that only strong magnetic minerals could be extracted. Figure 1 shows the instrument as well as the dipped magnetic stirrer.
Both bulk and extracted magnetic samples were then subjected to a series of magnetic measurement that include measurement of magnetic susceptibility and frequency dependent magnetic susceptibility as well as IRM (isothermal remanent magnetization) and ARM (anhyysteretic remanent magnetization) analyses (ARM). In addition, non-magnetic measurements, such as SEM (scanning electron microscopy) and XRD (X-ray diffraction) analyses were also performed on the samples. The methods, instrumentations and procedures for the above analyses follow that described earlier elsewhere [7]. The results for extracted samples are then compared with that for bulk samples to find out how effective this mechanical magnetic extraction is.

### Table 1. Results of magnetic susceptibility and ARM measurement

| Sediment Source/ Sample ID | Magnetic Susceptibility | ARM | Grain Size (µm) |
|----------------------------|-------------------------|-----|-----------------|
|                            | $\chi_{LF}$ ($\times 10^{-8}$ m$^3$/kg) | $\chi_{FD}$ (%) | Extracted (Stirrer) | Bulk | Extracted (Stirrer) |
|----------------------------|----------------------------|----------------|-------------------|-----|-------------------|
| Citarum River CITA-4       | 757.00                    | 9828.90        | 5.24              | 1.03| 14                | >135 |
| CITA-8                     | 637.10                    | 20335.90       | 3.09              | 1.67| 9-14              | 3    |
| CITA-11                    | 582.50                    | 15679.00       | 4.19              | 0.67| 9-14              | >135 |
| Brantas River KB-2         | 803.72                    | 27538.60       | 1.20              | 1.28| 135               | >135 |
| KS-4                       | 257.08                    | 25502.20       | 2.63              | 0.38| 135               | >135 |
| KW-1                       | 259.56                    | 27122.74       | 2.70              | 1.47| >135              | >135 |
| Lake Towuti TOW15 SURF-67  | 818.48                    | 4224.60        | 6.51              | 0.95| 3-6               | >135 |
| TOW15 SURF-61              | 752.42                    | 3711.64        | 3.03              | 2.62| 3-6               | 3    |
| TOW15 SURF-22              | 308.60                    | 6528.18        | 4.58              | 1.46| 3                 | >135 |

In addition to measurements and analyses on bulk and extracted samples, such measurements and analyses were also carried out on manually extracted samples on sediment samples from Citarum River.
The $\chi_{LF}$ values of these manually extracted samples average $1917.83 \times 10^{-8}$ m$^3$/kg, while the average $\chi_{FD}$ (%) value is 2.20%. These results show that manually extracted samples are almost similar to that of bulk samples but are very different from that of mechanically extracted samples.

Figure 2 shows the IRM saturation curves for bulk and extracted samples from the three sediment samples. As shown in Figure 2, all bulk samples show saturated IRM values at magnetizing field of less than 300 mT inferring magnetite ($\text{Fe}_3\text{O}_4$) as the predominant magnetic mineral in these samples [9]. However, the IRM curves for extracted samples are not as obvious as that for bulk samples inferring that presence of other magnetic minerals.

![Figure 2](image_url)

**Figure 2.** Result of IRM measurement for samples from Citarum River (a), Brantas River (b) and Lake Towuti (c).
Figure 3 shows the ARM decay curves for bulk and extracted samples from the three sediment samples. The ARM decay curves for bulk samples, except for that of Lake Towuti sample, are rather similar indicating multi domain magnetite. Lake Towuti sample shows the decay curve of pseudo-single domain (PSD) magnetite. The ARM decay curves for all extracted samples are also show MD magnetite but of much greater grain sizes compared to that of bulk samples. The estimated magnetite grain sizes of the samples are listed in Table 1 following the standard Lowrie-Fuller curves [10].

Figure 3. Result of ARM measurement for samples from Citarum River (a), Brantas River (b) and Lake Towuti (c).
IRM and ARM analyses were also carried out on the manually extracted samples from Citarum River. Figure 2a and Figure 3a show that the IRM curve and the ARM curve for manually extracted sample are similar to that of bulk samples. These findings imply that mechanical magnetic extraction could separate magnetic minerals that are otherwise could not be extracted manually.

Figure 4 shows the SEM images of selected magnetic grains in bulk as well as extracted samples. The magnetic grains vary in shape from octahedral, rounded, to irregular forms. The size of the magnetic grain is predominantly less than 15 μm in size. As the SEM instrument is also equipped with EDS feature, it is possible to estimate the Fe content in the grains. The Fe content in grains from extracted samples averages above 60% compared to less than 50% for the grains from bulk samples. EDS analyses are also often used as supplement to XRD analyses [11]. Visually the SEM images of grains from extracted samples are sharper than that from bulk samples. Moreover, grains from bulk samples are often still covered by clay particles or other non-magnetic minerals. Meanwhile, the SEM images of grains from manually extracted samples are better than that from bulk samples. However, these images are still not as sharp as that from mechanically extracted samples.

![Figure 4. Result of SEM analysis for (a) Citarum River (Bulk), (b) Citarum River (Extracted (Stirrer)), (c) Brantas River (Bulk), (d) Brantas River (Extracted (Stirrer)), (e) Lake Towuti (Bulk) and (f) Lake Towuti (Extracted (Stirrer)).](image)
Figure 5 shows the results of XRD analyses for all samples. For extracted samples the peaks mainly represent magnetite while for bulk samples there also peaks of other minerals. This implies that mechanical extraction is more effective in separating magnetic minerals from other minerals. XRD analyses on manually extracted sample (see Figure 5a) also show diffractograms that are rather similar with that of bulk samples.

Figure 5. Result of XRD analysis for samples from Citarum River (a), Brantas River (b) and Lake Towuti (c).
4. Conclusions

Experimentations with mechanical magnetic stirrer on riverine and lacustrine sediment samples have shown that mechanical magnetic extraction is more effective than manual magnetic extraction in separating magnetic minerals. Using a variety of magnetic measurements, it has been shown that mechanical magnetic extraction could not only attract higher concentration of magnetic minerals but also attract only non SP grains. Larger magnetic grains could also be extracted through mechanical magnetic extraction. SEM analyses on grains from extracted samples could provide magnetic grains that are easier to find and have sharper images. Furthermore, X-ray diffractograms of extracted samples show only magnetic minerals of interest.

Acknowledgements

The authors wish to thank the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for research grants to SB. Thanks are also due to the Ministry of Education and Culture for scholarship to GCN.

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