Anisotropy of Magnetic Susceptibility (AMS) analysis for sedimentation tracing of Selorejo reservoir

S Zulaikah¹, R Azzahro¹, E S Mu'alimah¹, Y Bungkang²
¹Department of Physics, Universitas Negeri Malang, Indonesia
²Department of Physics, Universitas Cendrawasih, Indonesia

E-mail: siti.zulaikah.fmipa@um.ac.id

Abstract. We use the Anisotropy of Magnetic Susceptibility (AMS) method to describe the source and mechanism of sedimentation process at the Selorejo reservoir. Six cores of sediment were collected by conventional coring process and sliced into sub samples in order to trace the pattern of sedimentation in the horizontal section. Based on the average of magnetic susceptibility of each core we are able to distinguish the origin of sediment from the water input into the reservoir. Our result agrees with the SEM images of the magnetic mineral grains, extracted from the inputs. However, the data shows the size difference from those two inputs about one order of magnitude. The average layer-by-layer Eigen-values of the susceptibility in horizontal section are consistent, which also shows consistency of the sedimentation process along the vertical direction.

1. Introduction
The detailed study of reservoir sedimentation is still rare due to its mechanism complexity. In this case the rate is higher compared to the lake or sea sedimentation [1, 2, and 3]. The reservoir sedimentation also characterized by a complex sediment yield. These factors make this type of sediments valuable, especially for a detailed study of properties of magnetic minerals, which may give some clues to understand processes and mechanisms that occurs in the environment [4, 5, and 6]. The reservoir watershed is usually used as a water supply, irrigation, hydropower and tourism object. This makes it very important for the surrounding community, to understand the sedimentation transport process and rate to maintain the sustainability of the reservoir.

Tracing the transfer processes of the sediments from the water input through the sedimentation area up to the output is one of the important studies [7, 8, and 9]. This process can be tracked using the Anisotropy of Magnetic Susceptibility (AMS) technique, which provides useful information regarding the transport of magnetic minerals dissolved in the sediment. In the last sixty years, AMS has been used in many applications. Among the important applications are study on the sediment fabrics and depositional process on the unconsolidated tsunami deposits [10, 12], describing the deformed sedimentation rocks [13], reconstructing paleo-monsoon route [14], tracing the signature of precipitation [15], and tracing the paleo-environmental changes [16, 17]. The method provides a rapid and precise estimation of the degree and direction of preferential alignment of magnetic minerals assemblages [8]. In this paper, we describe a detailed process on a special type of sediment taken from the specific area of our research location.
2. Sample Preparation and Method
Selorejo reservoir lies in Ngantang Malang East Java Indonesia (110° 30’ - 112° 55’ E and 8° 15’ S). The location is about 48 miles in the northwest city of Malang, surrounded at least four mountains, namely mount Kawi, mount Anjasmoro, mount Arjuno and mount Kelud. The reservoir has two main water inputs, the upstream of Konto and Kwayangan River. The catchment area is about 235 km$^2$, with the maximum reservoir capacity is about 62.30 Mm$^3$. The effective reservoir capacity is 50.10 Mm$^3$.

We collected six cores of sediment that is distributed spatially for AMS analysis. We perform a conventional coring process from a sampling boat. The diameter of the cores is 2 cm and ranged from 10 cm to 32.5 cm depth. We distribute the core sampling locations to represent the important sites, which are the water input from the two rivers, Konto River (TP1, TP2) and Kwayangan River (TK1, TK2), the center of the reservoir (TT) and the water output towards the Pinjal River (DKTP). The location and the used notation are shown in figure 1. From each location we sliced 2.2 cm sub-samples, which were packed into 10 ml cylindrical plastic holder. The magnetic susceptibility of the samples was measured using the Bartington magnetic susceptibility meter (MS2B).

![Figure 1. The sample core locations. The input rivers, the Konto and the Kwayangan, are marked by TP and TK, respectively. The output river, the Pinjal, is denoted by DKT. The sedimentation sites is marked by TT, at the center position of the reservoir. (Source: google map with some modification)](image)

At low frequency, the susceptibility ($\chi_{lf}$) was measured using AMS in 13 directions following the so-called Borradile method [18]. From this data the values of maximum-, minimum- and the intermediate-susceptibility can be determined. These values are the Eigen values of the magnetic susceptibility, regarding the AMS ellipsoid axes. We denote these values as $K_{\text{max}}$, $K_{\text{min}}$, and $K_{\text{int}}$, respectively. The analysis of every data is based on these AMS parameters, derived to additional parameters, namely, the average of magnetic susceptibility ($K_{\text{ave}}$), the lineation ($L=K_{\text{max}}/K_{\text{int}}$), the foliation ($F=K_{\text{int}}/K_{\text{min}}$), the degree of anisotropy ($P=K_{\text{max}}/K_{\text{min}}$), and the shape parameter ($T=[\ln F - \ln L]/[\ln F + \ln L]$). In rocks and sediments the anisotropic behavior commonly originates from the magneto-crystalline anisotropy, where the principal axes are related to the crystallographic axes of the mineral grain, and the shape anisotropy, where the elongated mineral grain is due to the self-demagnetizing factor in a specific direction [8].
3. Results and Discussion
The magnetic susceptibility of samples from two water inputs has a different property, where the value of TK is higher compared to that of TP, hence from the data, the origin of the magnetic minerals can be easily distinguished. This finding is also supported by the result of scanning electron microscopy and the dispersive spectroscopy (SEM/EDAX) analysis of the corresponding samples of the sediment reservoir. The EDAX analysis shows that the magnetic constituent is dominated by titanomagnetite, due to the existence of Fe-Ti-O elements (c.f. table 1). This fact is also verified by the morphology from electron micrograph shown in figure 2. In case of titanomagnetite minerals the anisotropic behavior in AMS is caused by the shape effect, since this mineral is crystallographically isotropic [8]. The SEM images also demonstrates the variation of grain size of the samples taken from TK and TP sites, which determines two categories of sizes, which have one order of magnitude difference as shown in figure 3.

Table 1. Elements dissolved in representative sample of sediment. Fe is a major element.

| Element | Wt% | At% |
|---------|-----|-----|
| OK      | 28.74 | 52.72 |
| MgK     | 02.13 | 02.57 |
| AlK     | 09.10 | 09.89 |
| SiK     | 05.61 | 05.86 |
| TiK     | 04.13 | 02.53 |
| FeK     | 50.30 | 26.43 |
| Matrix  | Correction | ZAF |

Figure 2. The electron micrograph of Titanomagnetite mineral with defect in one side, shown by the red rectangle. The sub-sample was extracted from TT7 location.

Figure 3 shows the variation of AMS parameters along the vertical section of the core taken from TP1, represents the initial sediment samples, and core TT, that represents the sediment yield. We found no specific pattern of AMS parameter for both cores, in the vertical direction. However, we found the variation of the shape factor, which shows a wide range at the bottom and narrow range at the middle and the top. The value of foliation and lineation oscillates along the samples, which indicates the oblate and prolate grains, induced by the transport process. The maximum lineation indicates that the prolate grain and the sedimentation is dominantly affected by the transport process. Otherwise, the minimum value indicates the oblate grain, created by the compaction process.
Assuming that the dissolved minerals were transported from the input river to the output, we mapped the horizontal section to study the layer-by-layer sedimentation. For this purpose we fit the three AMS parameters; $K_{ave}$, the lineation and the foliation. We found two horizontal patterns, shown in figure 4. The plots show a consistent pattern along vertical section (shown in figure 5), which reveal the change in flow dynamics. This finding can also interpreted as the size difference of the grain originated from the Kwayangan River and the Konto River. The first transfers larger grains that mix in the center location of the reservoir. These grains become smaller at the output (Pinjal River).

**Figure 3.** The SEM imaging of magnetic minerals extracted from sub samples (a) TK2.7, (b) TP1 and (c) TT7, using 200x magnification. The figure sequence shows clearly the grain size gradation of magnetic mineral from the sample points.

**Figure 4.** The variation of the average Eigen value, $K_{ave}$, as a function of a distance of magnetic mineral transport from the source in horizontal section (from TKI or TK2 to TT and ends at DKT, c.f. Fig. 1.)
Figure 5. The profile of AMS parameters along vertical section of core sediment from the origin of the Konto River (TP1 and TP2) and the sediment at the center of reservoir (TT).
5. Conclusion
Based on the average of magnetic susceptibility of each core, we can distinguish the origin of sediment input. This result is in agreement with SEM images that show the grain size of magnetic mineral from the two cores taken from the Kwayangan and the Konto River as an input of water and sediment. The difference is about one order of magnitude. The average of the layer-by-layer magnetic susceptibility in horizontal section is consistent, represents consistency of the surrounding process along vertical section. Our result shows that foliation and lineation was developed alternately along the core, however this does not demonstrate a specific pattern.

Acknowledgements
The authors would like to thanks to Husni Cahyadi Kurniawan, Agus Riyanto, Shelia Sindaratna, Rizka Amirul Hikma, Lutfia Tri Wahyuni, Yuni Chairun Nisa and Susanti Mayangsari for grate help on the sampling process. Thanks also to PEDISGI2015 committee for immeasurable help of publishing this paper.

References:
[1] Loizeau J-L, Roze S, Peytreman C, Monna F, Dominik J 2003 Mapping Sediment Accumulation Rate by Using Volume Magnetic Susceptibility Correlation in contaminated Bay (Lake Geneva, Switzerland) Eclogae geol. Helv 96 Supplement 1, S73-S79.
[2] Tamuntuan G, Bijaksana S, Gaffar E, Russel J, Safiuddin L O, and Huliselan E 2010 The Magnetic Properties of Indonesian Lake Sediment: A Case Stidy of a Tectonic Lake in South Sulawesi and Maar Lakes in East Java ITB J. Sci. V.42 No. 1 31- 48.
[3] Baltrunas, V., Seirien, V., Molodkov, A., Zinkut, R., Katinas, B., Kisielien, D., Petrosius, R., Taraskevicius, R., Piliciauskas, G., Schmölcke, U., and Heinrich, D., 2013, Depositional environment and climate changes during the late Pleistocene as recorded by the Netiesos section in southern Lithuania, Quarternary International, V.292, 136-149.
[4] Campos C, Beck C, Crouzet C, Carrillo E, Welden AV, and Tripsanas E 2013 Late Quaternary paleoseismic sedimentary archive from deep central Gulf of Corinth: time distribution of inferred earthquake-induced layers Annals of Geophysics 56 6
[5] Murdock K J, Wilkie K, and Brown L L 2013 Rock magnetic properties, magnetic susceptibility, and organic geochemistry comparison in core LZ1029-7 Lake El’gygytgyn Russia Far East Climate of The Past 9 467-479.
[6] Pozza M R, Boyce J I, and Morris W A 2004 Lake-based magnetic mapping of contaminated sediment distribution, Hamilton Harbour, Lake Otario, Canada Journal of Applied Geophysics 57 23-41
[7] Hailwood H G, and Maher B A 2009 Fingerprinting Upland Sediment Sources: particle size-specific magnetic linkages between soils, lake sediments and suspended sediments, Earth Surface Process and Lanforms
[8] Hailwood E A and Sayre W O 1983 Sediment Transport Mechanisms at NE Atlantic Margins: Evidence from the Magnetic Anisotropy of Ipod Cores, Structure and Development of the Greenland-Scotland Ridge Nato Conference Series Volume 8 pp 479-493
[9] Bungkang Y and Soemarno 2014, Sentani Watershed Erosion Potential Study and Suspeded Solid Distribution In Connection With Lake Silting, Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), V.8
[10] Paris R, Wassmer P, Lavigne F, Belousov A, Belousova M, Iskandarsyah Y, Benbakkar M, Ontowirjo B, and Mazzoni N 2014 Coupling eruption and tsunami records: the Krakatau 1883 case study, Indonesia, Bull Volcano 76 814
[11] Horton B, MacInnes B, Gonzalez F, Hemphill-- Haley E, Switzer A, Witter R, Tanioka Y, and Pilarczyk J, ----, Long-Term Records of Tsunamis (and Storms) with Insights from Recent Events
[12] Veerasingam S, Venkatachalapathy R, Basavaiah N, Ramkumar T, Venkatramanan S, and Deenadayalan K 2014 Identification and characterization of tsunami deposits off southeast coast of India from the 2004 Indian Ocean tsunami: Rock magnetic and geochemical approach J. Earth Syst. Sci. 123 pp. 905–921

[13] Pares J M 2015 Sixty years anisotropy of magnetic Susceptibility in deformed sedimentary rock Review Article Frontiers in Earth Science

[14] Zhang R, Kravchinsky V A, Zhu R, Yue L 2010 Paleomonsoon route reconstruction along a W–E transect in the Chinese Loess Plateau using the anisotropy of magnetic susceptibility: Summer monsoon model Earth and Planetary Science Letters 299 236-246.

[15] Pronovost A L, St-Onge G, Gogorza C, Jouve G, Francus P, and Zolitschka B 2014 Rock-magnetic signature of precipitation and extreme runoff events in south-eastern Patagonia since 51, 200 cal BP from the sediments of Laguna Potrok Aike Quaternary Science Reviews 98 110-125

[16] Sangren P and Snowball I 2001 Application of Mineral Magnetic Techniques to Paleolimnology in Tracking Environmental Change Using Lake Sediments Physical and Chemical Technique V.2 Kluwer Academic Publisher Dordrocht, The Netherlands

[17] Shouyun H U Chenglong D Appel E and Verosub K L 2002 Environmental Magnetic Studies of Lacustrine Sediment Chinese Science Bulletin V.47 No 7

[18] Borradaile G J 1995 Anisotropy of Magnetic Susceptibility: Measurement Schemes Geophysical Research Letter 22