Proceedings of the 8th Symposium on Geo-Environments and Geo-Technics, 1998, Pages 235-240

Magnetic Properties of Suspended Particulate Matter (SPM) in Atmosphere

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Abstract: Identifying different dust populations, *Suspended Particulate Matter* (SPM), in the atmosphere is important in a variety of environmental research contexts. Ultrafine-grained magnetic particles in the populations can be used to assess an air pollution by anthropogenic pollutants and also to identify their source area. Magnetic properties of SPM samples collected from the near-surface air of industrial and residential areas among various cities in Pakistan have been defined using initial magnetic susceptibility and isothermal remanent magnetization (IRM) measurements. Sampling was made by a non-magnetic adhesive tape that was exposed in the atmosphere 72 hours. The saturation IRM (SIRM) marks generally larger intensities in highly populated or industrial areas such as Karachi and Peshawar cities. The SIRM value normally varies as a simple function of concentration of ferromagnetic materials in sample, thus the intensity probably represent a grade of air pollution by metallic (ferromagnetic) materials. The initial magnetic susceptibility also gives similar tendency to the SIRM values in spatial variation. A deviation of S-ratio, a quantitative measure of the degree of saturation of IRM acquisition curves, shows a clear difference in composition of magnetic particulate, where ferrimagnetic magnetite (β-Fe_3O_4) and/or maghemite (γ-Fe_2O_3) are predominant in the SPM collected from industrial areas whereas hematite (α-Fe_2O_3) and/or goethite (FeOOH) are relatively rich in those from non-industrial areas. The result implies that the composition of magnetic materials in SPM indicates the source of pollutants. The effect of air pollutants on health is major concern in urban or industrial areas. The present magnetic approach to characterizing variations in SPM will be applicable to a wide range of temporal and spatial air pollution and also capable of providing information for studies of atmospheric environment.

1. Introduction

Various rock and mineral magnetic methods have been developed for determining the nature of the magnetic properties of rocks and sediments last three decades. These methods are now able to employ not only for paleomagnetic studies in geological sciences, paleomagnetism, but also for environmental purposes, environmental magnetism (Thompson et al., 1980; Thompson and Oldfield, 1986; Oldfield, 1991; Verosub and Roberts, 1995), where the transport, deposition, or transformation of magnetic minerals is governed by environmental processes in the atmosphere, hydrosphere, lithosphere, and biosphere (Figure 1). An important advantage of magnetic methods is that its techniques are relatively quick, simple, non-destructive, and inexpensive.

Magnetic measurements have provided a basis for qualifying and differentiating atmospheric particulate. Air pollutants are trace components of the atmosphere which exhibit some detrimental effect, whereas it is rather difficult to discriminate the pollutants by anthropogenic emissions from natural pollutants (Brimblecombe, 1996). The magnetic method probably contributes to distinguish between natural and anthropogenic pollutants.

An aerosol magnetism observation project was undertaken in Pakistan, 1995-96, where environmental contrast between industrial and non-industrial area is distinct (The Aerosol Magnetism Research Team, 1996). In this paper, we summarize the results of the observation and examine the possibility of magnetic *site-characterization* of air pollution.

2. Magnetic Parameters

Before describing our results of magnetic measurement, we briefly define the rock and mineral magnetic parameters employed in this study.

(1) Initial Magnetic Susceptibility: One of the most commonly used mineral magnetic parameters is the initial magnetic susceptibility (k) which is the ratio of induced magnetization (M) acquired by a sample in the presence of a weak magnetic field, to the applied field (H) itself, as following equation: $M = kH$.

Keywords: *Environmental magnetism, SPM, Magnetic susceptibility, IRM, Air pollution*

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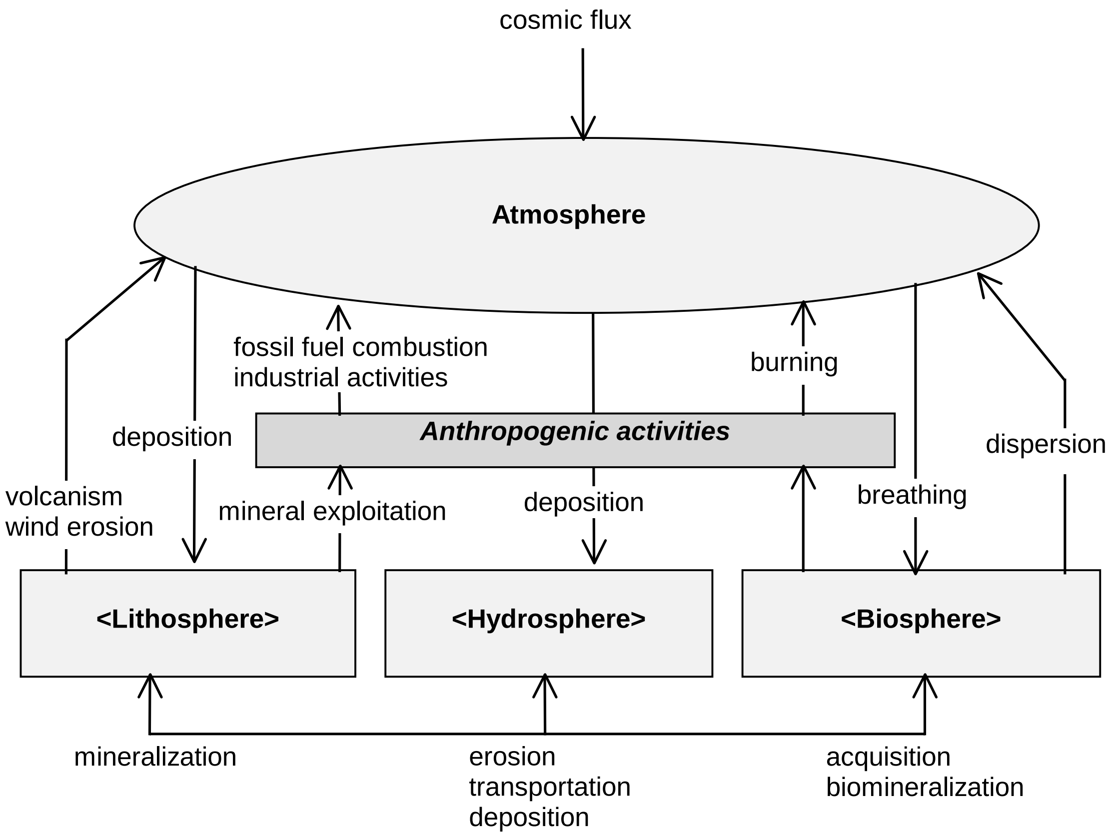

Figure 1: Simplified model of the movements of magnetic material between the atmosphere, lithosphere, hydrosphere, and biosphere, with interference of anthropogenic activities.

Initial magnetic susceptibility is usually measured with coil bridge that produces weak alternating fields (<1 mT) of high frequency (~10 kHz). Initial magnetic susceptibility is directly proportional to the quantity and grain size of ferromagnetic or ferrimagnetic materials in a sample.

(2) Isothermal Remanent Magnetization: Isothermal remanent magnetization (IRM) is measured on a sensitive magnetometer after placing a sample in a strong, uniform, dc. magnetic field in laboratory. As the intensity of the applied dc. magnetic field increases, the acquired IRM intensity increases until the sample becomes as magnetized as its mineralogy. At this point, the remanent magnetization is called as saturation IRM (SIRM).

Ferrimagnetic minerals, such as magnetite (β-Fe_3O_4) and maghemite (γ-Fe_2O_3), fully saturate in applied fields of the order of 300 mT, while canted-antiferromagnetic hematite (α-Fe_2O_3) and ferromagnetic goethite (FeOOH), require fields around 3~5 T for acquisition of SIRM (Lowrie and Heller, 1982). The presence or absence of saturation at these applied field is easily observed on the IRM acquisition curve, which is used to differentiate magnetic mineralogy within given sample. For convenience, the SIRM is usually represented by the intensity of IRM acquired in a field around 1 T, while it is here represented by that acquired in 2.6 T. The parameter S or S-ratio, a quantitative measure of the degree of saturation of IRM acquisition curves, which is considered to be a parameter of presence of ferrimagnetic magnetite, is the absolute value of the IRM remaining after exposure to a back-field of 300 mT[1] divided by forward SIRM (King and Channell, 1991; Blomendal et al., 1992).

$$S = -IRM_{-300mT}/SIRM_{1T}$$

The parameter S' or S'-ratio is also given by the following formula, where the SIRM is determined by the intensity of IRM acquired under the applied field of 2.6 T.

$$S' = -IRM_{-300mT}/SIRM_{2.6T}$$

Values of S or S' of about 1.0 indicate a high proportion of low coercive magnetite, whereas lower values indicate an increasing proportion of high coercive hematite and/or goethite. Another parameter hard IRM (HIRM) is given by the following formula[2] (King and Channell, 1991):

[1] Robinson (1986) adopted -100 mT for the back-field in stead of -300 mT.
[2] Robinson (1986) called HIRM as the difference between IRM_{-300mT} and SIRM.

$$HIRM = (IRM_{-300mT} + SIRM)/2$$

The parameter HIRM is a measure of the concentration of high coercivity minerals such as hematite and goethite in the sample. Values of HIRM appear 1.0 in the absence of magnetite. Other IRM related parameter is Bcr of which field strength completely cancel the $SIRM_{2.6T}$.

3. Sampling

The SPM samples under examination in this study were obtained at several locations in industrial and non-industrial areas of Pakistan by the Aerosol Magnetism Research Team (Figure 2). The sampling was made in March and April, 1995 before the summer monsoon season set on. The samples were all collected from the near-surface atmosphere, approx. 1.5 m above the ground surface. A non-magnetic adhesive tape was utilized for SPM sample collection. A constant size (38 mm × 87 mm) of adhesive tape was exposed in the atmosphere 72 hours, which continuously made atmospheric very fine particulate adhere to its surface. This sampling technique is appropriate for magnetic measurement of SPM, because ordinary filter sampler is highly dependent on particle size, which can not effectively collect very fine particulate less than a few microns.

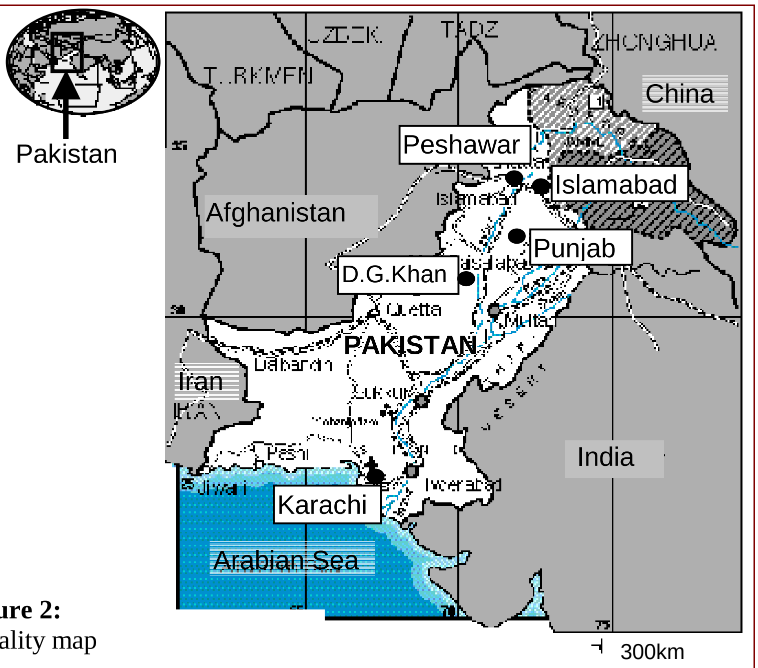

Figure 2:
Locality map

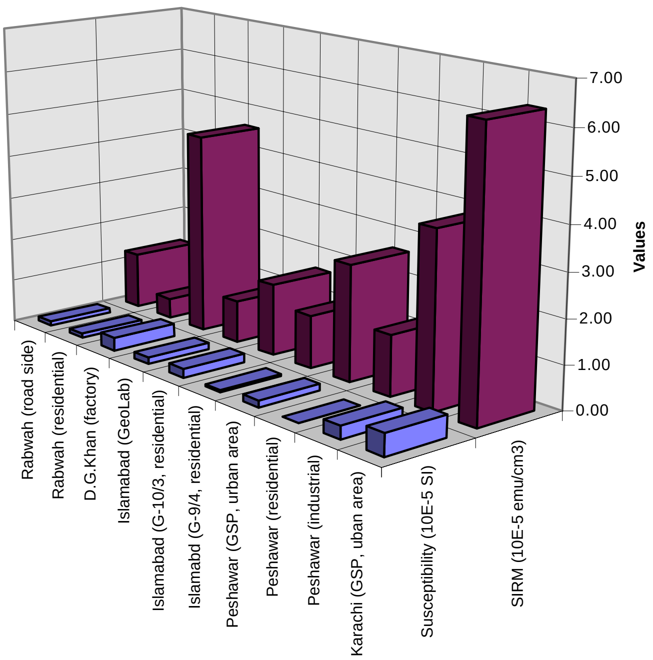

Figure 3: Variation of magnetic susceptibility and SIRM.

4. Measurements

Each sample collected was folded and packed in individual 10 cm^3 poly-carbonate container and routinely underwent the following mineral magnetic measurements:

Initial magnetic susceptibility was measured at a dual frequency (0.47 Hz and 4.7 Hz) Bartington model MS/2 susceptibility meter. It is hard to measure the mass and volume of the particulate, but we used the bulk reading in volume basis given by above-mentioned 10 cm^3 container sample for the 'initial magnetic susceptibility' value in convenience.

Samples were given IRM in a succession of fields of increasing strength from 0 to ca.2.6 mT using a 100 m.sec. pulse magnetizer MMPM9. Then the sample acquired 2.6 T IRM was subjected to reverse fields (back-field) of increasing strength until the IRM was completely cancelled.

5. Results and Interpretation

Magnetic mineralogy of the SPM population in given samples can be analyzed by IRM acquisition and demagnetization properties. The IRM acquisition curves always show a coexistence of both saturated and unsaturated components at 0.3 T applied field. However the grade of saturation is rather different between those from industrial or highly populated areas and residential or rural areas. The former samples tend to show almost saturated performance at 0.3 T with a negligible under-saturated component whereas the latter ones depict partly saturated at 0.3 T with large under-saturated component. It means the SPM population is a mixture of ferrimagnetic minerals such as magnetite (β-Fe_3O_4) of which saturation field is around 0.3 T, and canted-antiferromagnetic hematite (α-Fe_2O_3) or ferromagnetic goethite (FeOOH) of which saturation are above 0.3 T.

Initial magnetic susceptibility (k) shows from 2×10^{-6} to 5×10^{-5} (SI), which always larger values in highly populated or industrial area such as Karachi and Peshawar (Figure 3, see Appendix). It is a measure of the magnetizability of a sample and mainly reflects the concentration of magnetic minerals, in particular ferrimagnetic minerals such as magnetite, in it. However, k is not a precise expression of the content of magnetic (ferrimagnetic) minerals since it is affected by the grain size and shape of the magnetic particles. The main k-contributing component is probably magnetic spherules having an anthropogenic origin (Doyle et al., 1976).

The saturation IRM (SIRM) also marks generally larger intensities in highly populated or industrial areas such as Karachi and Peshawar cities (Figure 3). The SIRM value normally varies as a simple function of concentration of ferrimagnetic mineral in sample, thus the intensity probably represent a degree of concentration of ferrimagnetic mineral.

The spatial variation pattern of initial magnetic susceptibility is quite similar to that of SIRM intensity (Figure 4). Both values are distinctly larger in highly populated or industrial areas but smaller in rural or non-industrial areas.

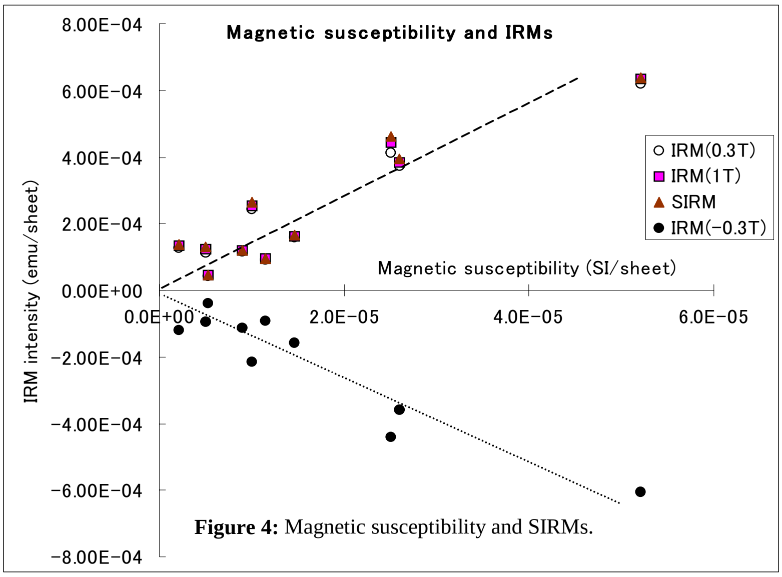

Figure 4: Magnetic susceptibility and SIRMs.

The S-ratio and S'-ratio vs. SIRM, and S-rato and S'-ratio vs. magnetic susceptibility are shown in Figures 5 and 6. These diagrams demonstrate that the samples having high SIRM intensity or high susceptibility always give high S-ratio and S'-ratio (≈1.0). The deviation of the S-ratio and S'-ratio caused by a variation in composition of magnetic particulate as either magnetite (β-Fe_3O_4) rich or hematite (α-Fe_2O_3)-goethite (FeOOH) rich. Thus the increase of magnetic susceptibility and SIRM intensity at highly populated or industrial areas is probably contributed by and increase of concentration of ferrimagnetic particulate such as magnetite in SPM population. Similar deviation is observed in the relationship of S-ratio and S'-ratio vs. Bcr (Figure 7).

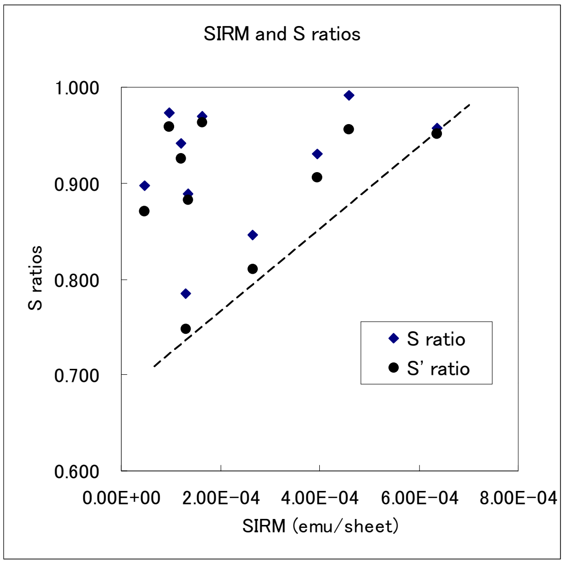

Figure 5: Relationship between SIRM and S ratios.

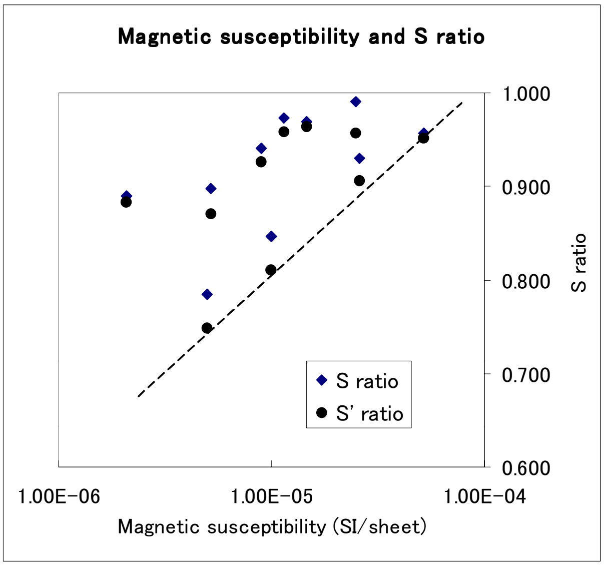

Figure 6: Relation ship between susceptibility and S ratios.

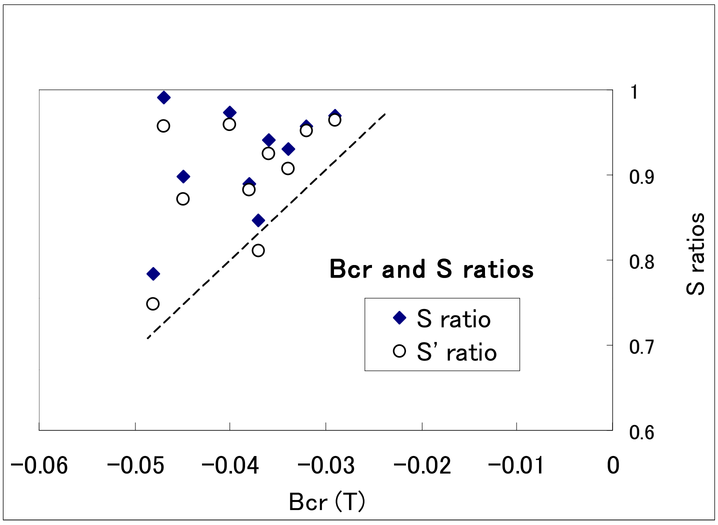

Figure 7: Relationship between Bcr and S ratios.

Thompson et al. (1980) first systematically argued some possibilities of application of magnetic methods to atmospheric dust studies. In this work, Thompson and his colleagues documented a result of magnetic measurements of peat at several locations in western Europe, and they related the variation of atmospheric magnetite input to history of industrial activities. Chester et al. (1984) found that the ferrimagnetic mineral content of the aerosol in the Mediterranean Sea and surrounding region was controlled by the extent to which the non-soil material was mixed with, and diluted by, crustal components (Al), and there was a general inverse linear trend between the initial magnetic susceptibility values and the Al concentration. Oldfield et al. (1985) and Hunt (1986) also reported detailed magnetic properties of atmospheric fine particulate directly collected from air, and they concluded that magnetic parameters could be of considerable value in characterizing atmospheric dusts and aerosols derived from different sources, whether the differentiation results from seasonal variations at single collection site or large-scale spatial variations.

These results are consistent with our results, which implies that the composition of magnetic SPM in atmospheric SPM indicates the source of pollutants, *i.e.* ferrimagnetic minerals attributes anthropogenic origin.

Acknowledgements: Thanks are due to Mujeeb Ahmad, Nayyer Iqbal, Mujeeb-ur-Rahman, Muhammad Sadin, and Safdar Sultan, for helping us in field sampling, 1995. Special thanks are due to S. Hasan Gauhar, Muhammad Sakhawat, Junkichi Yajima, Yoshiya Ikeda, and Teruo Shirahase, Geoscience Laboratory Project. This collaboration has been carried out as a part of technical cooperation project between Geological Survey of Pakistan (GSP) and Japan International Cooperation Agency (JICA).

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Appendix: Results of magnetic measurements of 72hr-exposed sampling tapes

Location	Sample ID	Mag.sus.	IRM(0.3T)	IRM(1T)	SIRM	IRM(−0.3T)	Bcr(T)
Punjab(highway side)	E−1A	5.00E−06	1.14E−04	1.23E−04	1.29E−04	−9.65E−05	−0.048
Punjab(agricultural area)	E−1B	5.21E−06	4.29E−05	4.50E−05	4.64E−05	−4.04E−05	−0.045
D.G.Khan(industrial area)	E−2	2.50E−05	4.11E−04	4.44E−04	4.60E−04	−4.40E−04	−0.047
Islamabad(Shahzad Town, Geolab)	E−3	1.15E−05	9.29E−05	9.51E−05	9.65E−05	−9.25E−05	−0.040
Islamabad(F10/3residential area)	E−4	1.46E−05	1.59E−04	1.63E−04	1.64E−04	−1.58E−04	−0.029
Islamabad(G9/4residential area)	E−5	9.00E−06	1.15E−04	1.19E−04	1.21E−04	−1.12E−04	−0.036
Peshawar(urban area)	E−6	1.00E−05	2.44E−04	2.53E−04	2.64E−04	−2.14E−04	−0.037
Peshawar(residential area)	E−7	2.08E−06	1.27E−04	1.35E−04	1.36E−04	−1.20E−04	−0.038
Peshawar(industrial area)	E−8	2.60E−05	3.74E−04	3.85E−04	3.95E−04	−3.58E−04	−0.034
Karachi(urban area)	E−9	5.21E−05	6.22E−04	6.33E−04	6.37E−04	−6.06E−04	−0.032