Heating-induced enhancement of ultrafine ferrimagnetic grains in soils

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Magnetic properties of soils indicate widespread presence of ultrafine ferrimagnetic minerals, formed *in situ* during pedogenesis[1,2]. It has generally been believed that the ultrafine magnetic grains are produced by biologically mediated processes (e.g. refs. 2, 3). Maher and Taylor[4] have recently shown that secondary ultrafine crystals of magnetite in soils may also be formed *in situ* by purely inorganic processes occurring during pedogenesis. We now present evidence that in soils where some amount of pedogenetically formed ultrafine ferrimagnetic grains already exist, heating results in further enhancement of their relative abundance, independent of the chemical environment.

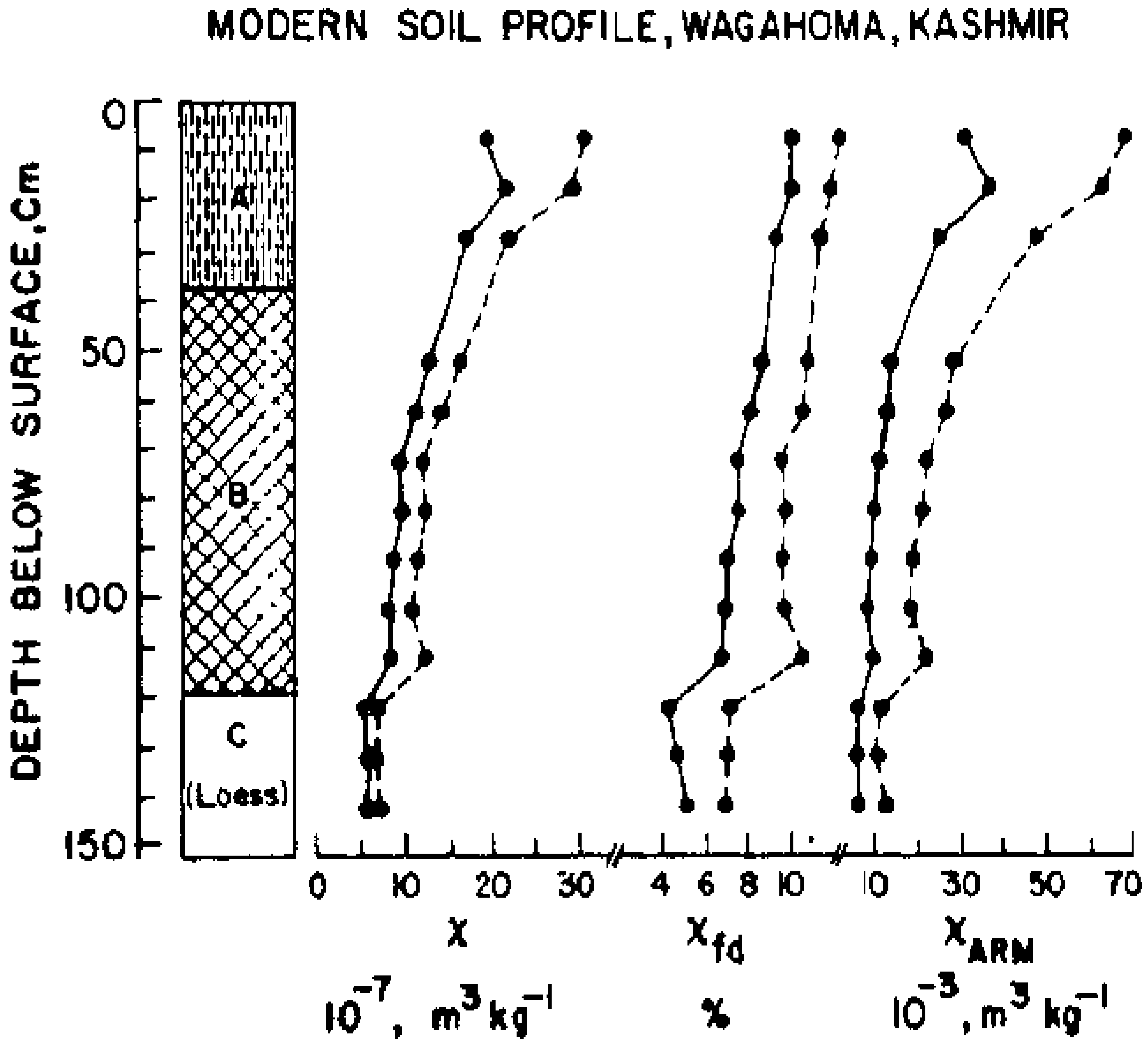

Figure 1. Parameters χ, χ_{fd} and χ_{ARM} for the Wagahoma modern soil profile. Continuous and dashed lines represent unheated and heated samples respectively.

THE enhancement of magnetic susceptibility (χ) in soils compared to their parent material/bedrock has received considerable attention in recent years[2,5,6]. The enhancement is associated with *in situ* conversion of iron oxides from an antiferromagnetic form, such as haematite (α Fe_2O_3) and goethite (α FeOOH), to the ferrimagnetic forms, magnetite (Fe_3O_4) and maghemite (γFe_2O_3). The parameter χ reflects the concentration of ferrimagnetic minerals in a sample and is nearly independent of the magnetic grain size, except for the superparamagnetic (SP) grains for which it is very high (ref. 2, fig. 4.7)

In this paper we show that heating of soils results not only in the expected enhancement of χ as noted by other workers (e.g. refs. 7,8) but also enhancement of the frequency-dependent component of magnetic susceptibility χ_{fd} as well as anhysteretic susceptibility χ_{ARM}. The parameter χ_{fd} is associated with the presence of ultrafine ferrimagnetic grains around the stable single domain (SSD)/SP boundary, whereas χ_{ARM} is associated with the presence of SSD grains[2,7].

We have conducted laboratory heating experiments similar to that of Tite and Lington[9] by heating soil samples in a furnace. Overnight heating of a few trial samples followed by cooling to room temperature was carried out at 200°, 450°, 600° and 800°C under different environments: (i) heating under N_2 atmosphere, cooling under N_2/air; (ii) heating under air, cooling under air; (iii) heating under vacuum (~10^{-3} torr), cooling under air.

The enhancement of mineral magnetic properties χ, χ_{fd} and χ_{ARM} was identical under these three chemical environments. The optimum enhancement was noted at 450°/600°C and therefore in the subsequent experiments overnight heating under N_2 atmosphere at 450°C followed by cooling under air was carried out.

Figure 1 shows the soil profile developed on loessic parent material at Wagahoma (33.8°N, 75.1°E) in Kashmir, India, having a well-developed humus-rich A-horizon, a fairly thick B-horizon, underlain by the loessic parent material (C-horizon). Thirteen samples, three each from A and C horizons and seven from B horizon, were taken, oven-dried at 60°C and tightly packed in fully filled 10 ml plastic vials. χ and χ_{fd} have been measured using the Bartington dual frequency a.c. susceptibility bridge (model MS1). χ_{fd} is obtained as a percentage from the difference in the susceptibility values at low frequency (1 kHz) and high frequency (10 kHz) relative to the χ at low frequency. χ_{ARM} was obtained by measuring the anhysteretic remanent magnetization (ARM) on a Schonstedt spinner magnetometer (model SSM-1) in an alternating magnetic field of 100 mT with a super-

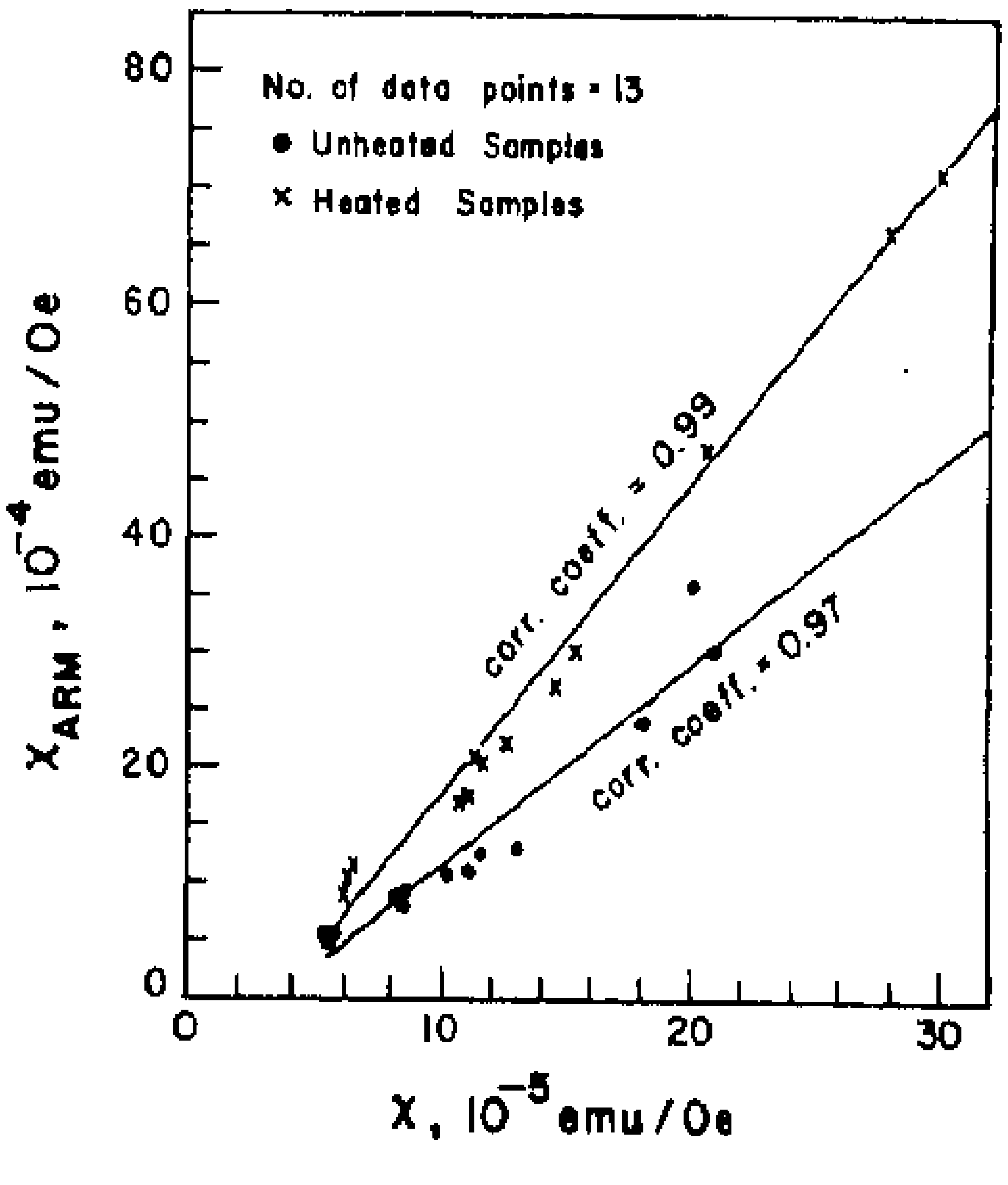

Figure 2: χ_{ARM} vs χ plot for the unheated (●) and heated (×) samples of Wagahoma modern soil profile.

imposed d.c. field of 0.05 mT.

Figure 1 also gives results of measurements of χ, χ_{fd} and χ_{ARM} parameters plotted against the soil profile. The figure shows not only heating-induced enhancement of χ as expected and observed by other workers but also significant enhancement of χ_{fd} and χ_{ARM}.

Banerjee *et al.*[10] have discussed the potential use of the χ_{ARM} vs χ plot for magnetic granulometry. King *et al.*[11] have constructed a simple phenomenological model (figure 1*b* of ref. 11) based on measurement of these parameters on magnetite powders of different grain sizes. This model shows that in magnetite, fining the magnetic grain size increases the slope of the straight-line plot of χ_{ARM} vs χ.

Following the model of King *et al.*[11] we have plotted χ_{ARM} vs χ for both unheated and heated soil samples (Figure 2). It can be seen that there is a marked increase of slope of the straight line for the heated samples. This is further evidence for the generation of secondary ultrafine ferrimagnetic grains in soils consequent upon heating.

In conclusion, we have shown evidence for the enhancement in the proportion of ultrafine ferrimagnetic grains during the process of heating of soils. The enhancement is independent of the chemical environment and thus appears to be due to breaking down of the domains during the process of heating.

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Estimation of cyclone heat potential over Bay of Bengal using satellite and ship data

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Monitoring of large-scale climate-related variability over the ocean from space using remote-sensing techniques allows the global coverage needed for climate studies. Using satellite-derived sea surface temperature (SST) and wind speed, cyclone heat potential (CHP_{28}) was estimated utilizing a regression analysis obtained from ship-derived CHP_{28}, wind speed and SST. CHP_{28} from satellite data has been compared with ship-derived CHP_{28} and found to be within ± 10% of the latter. Analysis of variation of CHP_{28} over western Bay of Bengal before and after a cyclonic storm shows that the storm heat potential increased towards the storm area, while after the storm it decreased.

STUDIES on the heat content of the surface mixed layer of the oceans have received considerable attention in recent years because of its importance in ocean–atmosphere energy exchanges. It is known that long-period weather fluctuations are related to the larger thermal memory of the oceans. Heat storage in the upper layer has a pronounced effect on the Indian monsoonal forcing. The annual heat content variations of this layer appear to be mainly due to vertical movement of the thermocline associated with the dynamics of seasonal winds[1]. Large-scale sea surface temperature (SST) changes have been found to affect cyclone tracks and related monsoon activity[2].

Cyclone heat potential of the ocean may be defined as the heat content from the surface to a particular isothermal depth, e.g. the 28°C isotherm[3] (CHP_{28}) or the 26°C isotherm[4]. Surface wind and SST are the key factors controlling CHP_{28}.

Cyclone heat potential over the Indian Ocean has earlier been estimated by conventional methods using vertical temperature profiles[3,4]. Some attempts have recently been made to estimate the heat content of the oceans using satellite data. Christensen and Mascarenhas[5] calculated the heat storage by attributing the density anomaly to temperature only. Miller[6] developed a one-dimensional model of the upper-ocean mixed layer and an algorithm that uses satellite-derived wind stress and SST to predict real-time changes in upper-ocean heat storage during cooling seasons. The present attempt is to estimate cyclone heat potential in the western Bay of Bengal