Archeomagnetic intensity variations in India from 500 BC to 1000 AD: A preliminary report

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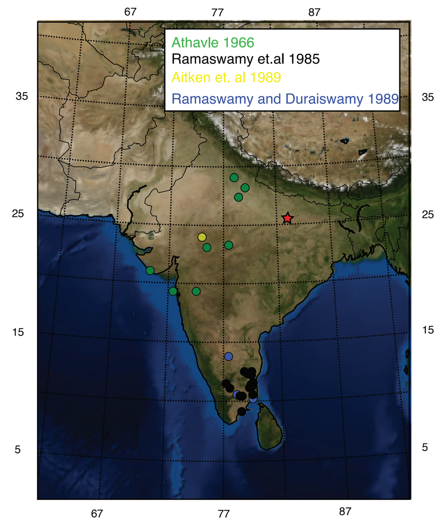
Archeointensity records from India are few and far between, with only 45 published intensity estimates. Most do not meet the rigorous experimental checks required of present day paleointensity experiments viz., check for alteration or multidomain grains and correcting for cooling rate discrepancies or anisotropy. The richness of Indian archeology offers immense possibilities to obtain high resolution archeointensity records. This is a preliminary study targeted to build a high quality comprehensive archeointensity reference curve for the region. The samples were part of a collection of one of the authors. 15 samples from 13 different sites were analyzed. The samples were mostly iron slags (7) and pot sherds (7) and one furnace clay. 4 sites gave reliable paleointensity estimates. All the iron slags failed due mostly to alteration even at low temperatures. We observe a ~48% drop in intensity in the second half 1st millenium BC, which is at the higher end of the range estimated from existing datasets.

Location

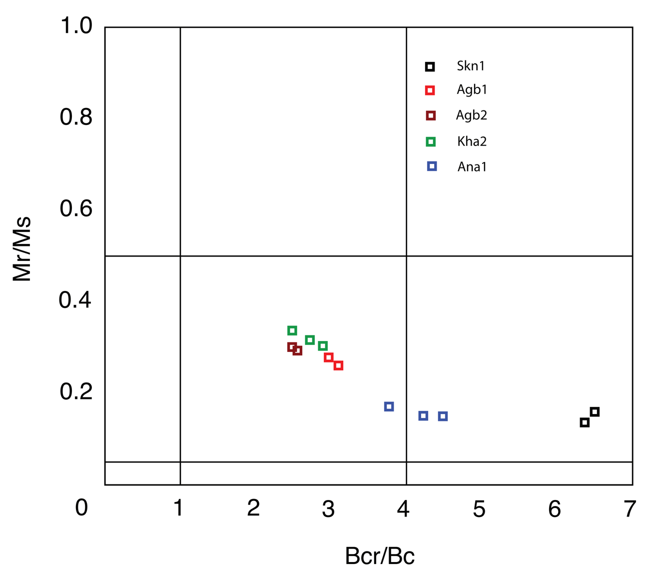


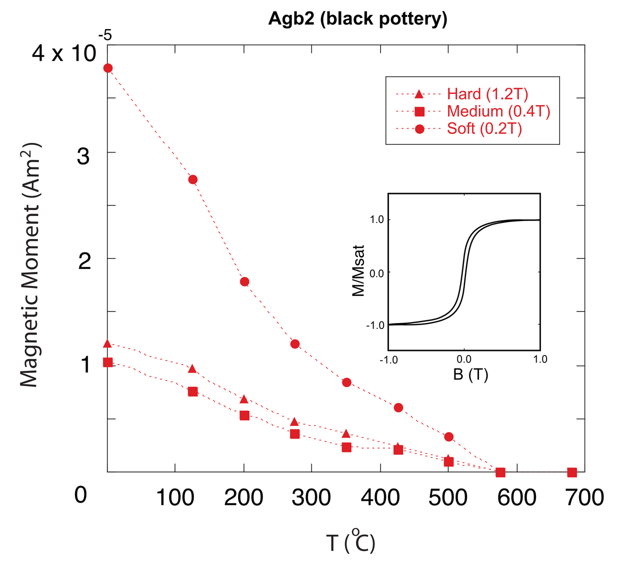
All sites were located within a 100 miles radius of the ancient city of Varanasi, 25.45°N, 82.85°E (red star). Locations of previous studies [1-4] are color coded.

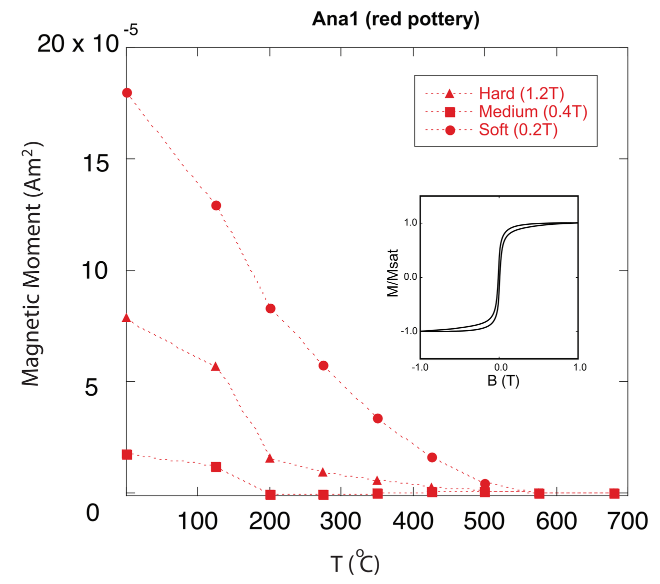
Archeological Sampling

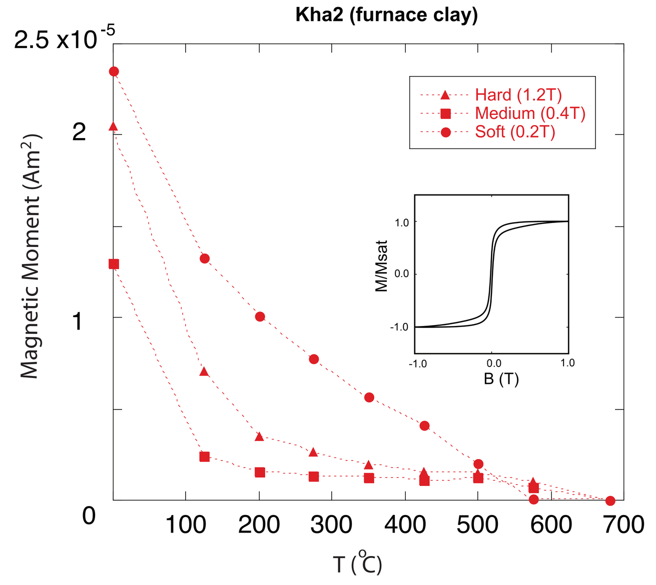
Site	Sample Description	Age	Dating Method	No. of samples
Khairadih, Balia (Kha)	Furnace clay associated with slag	150 ± 50 BC	Coins and inscriptions	1 (Kha2)
Anai, Varanasi (Ana)	Red pot sherd	500 ± 100 BC	Relative dating between carbon dated horizons of the Northern Black Polished Ware (NBPW) period (1000 to 200 BC)	1 (Ana1)
Agiabir, Mirzapur (Agb)	Red and black pot sherds	550 ± 50 BC	Same as Ana	2 (Agb1,Agb2)
Sikandarpur, Chandauli (Skn)	Red pottery	900 ± 300 AD	Pottery style	1 (Skn1)

Magnetic Mineralogy





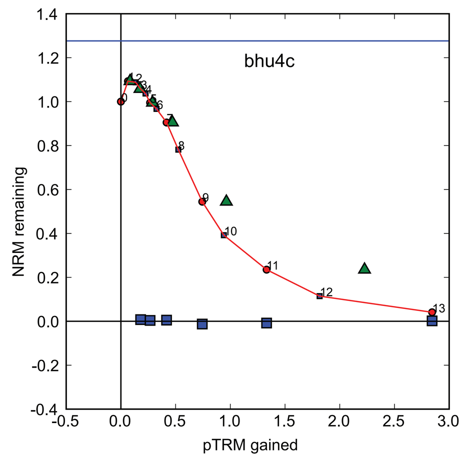




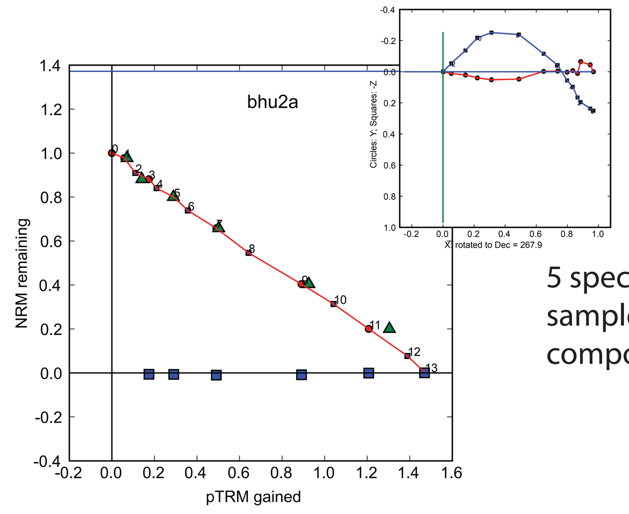
Hysteresis parameters were measured at 1T maximum field. Three axis IRM demagnetization experiments [5] at 1.2 T, 0.4T and 0.2 T were conducted to understand the underlying magnetic mineralogy. All the samples were magnetically homogenous and showed PSD hysteresis behavior with some falling in an undefined quadrant. The hysteresis loops showed low to high wasp waisting indicating presence of low to high proportion of higher coercivity minerals. In the IRM demagnetization experiments all the pot sherds showed a dominant soft component which monotonically unblocked upto 580°C showing predominance of magnetite (or titanomagnetite). A minor contribution from higher coercivity minerals sometimes displayed strong unblocking at 200°C (eg., Ana1). This could be due to low unblocking temperature phases of hematite which have been reported to be common in pot-teries [6]. The furnace clay besides showing monotonic demagnetization of the soft component upto 580°C, showed strong unblocking at 125°C for all components indicating significant goethite contribution with a wide range of coercivities. The hard and the medium fraction also unblocked up to 680°C showing an additional hematite phase.

Paleointensity Experiments

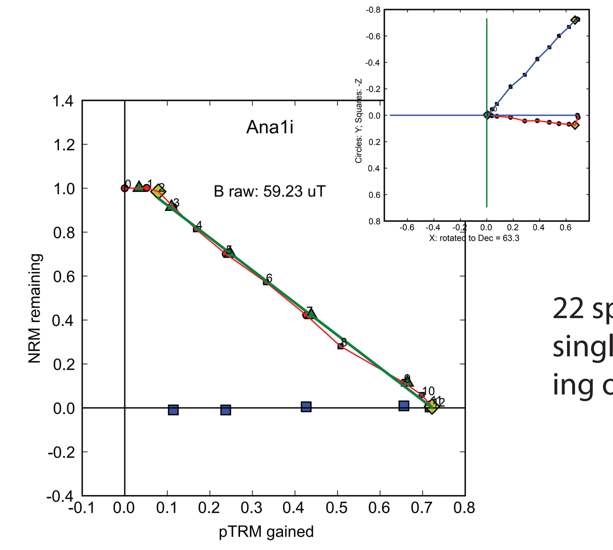
Raw paleointensity estimates were obtained using the IZZI protocol [7]. In this method the in-field (I) and zero-field(Z) heating steps are alternated at each temperature steps. Additionaly pTRM checks and pTRM tail checks have been introduced at every alternate step to detect for alteration and equivalence of blocking and unblocking temperatures, which are necessary preconditions for a successful paleointensity experiment. 13 double heating steps between 100°C and 600°C was used for the experiments with steps of 50°C between 100°C and 500°C and steps of 25°C between 500°C and 600°C.



84 out of 111 specimens were rejected because of alteration and/or multidomain behavior. All the slag specimens which comprized more than 50% of the specimens suffered from extensive alteration even at low temperatures.

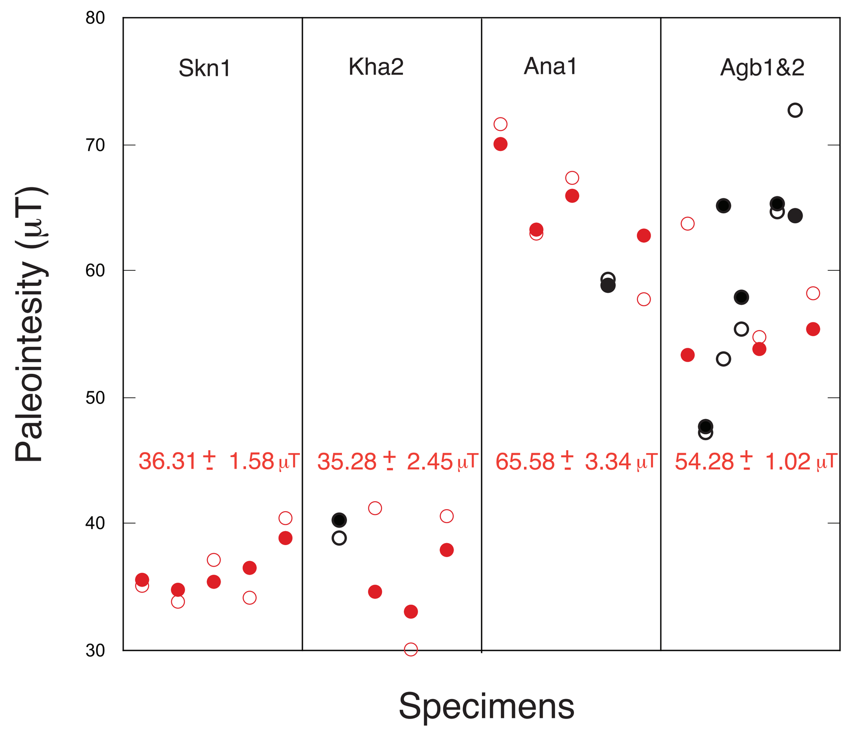


5 specimens all belonging to a single sample were discarded due to multicomponent remanance.

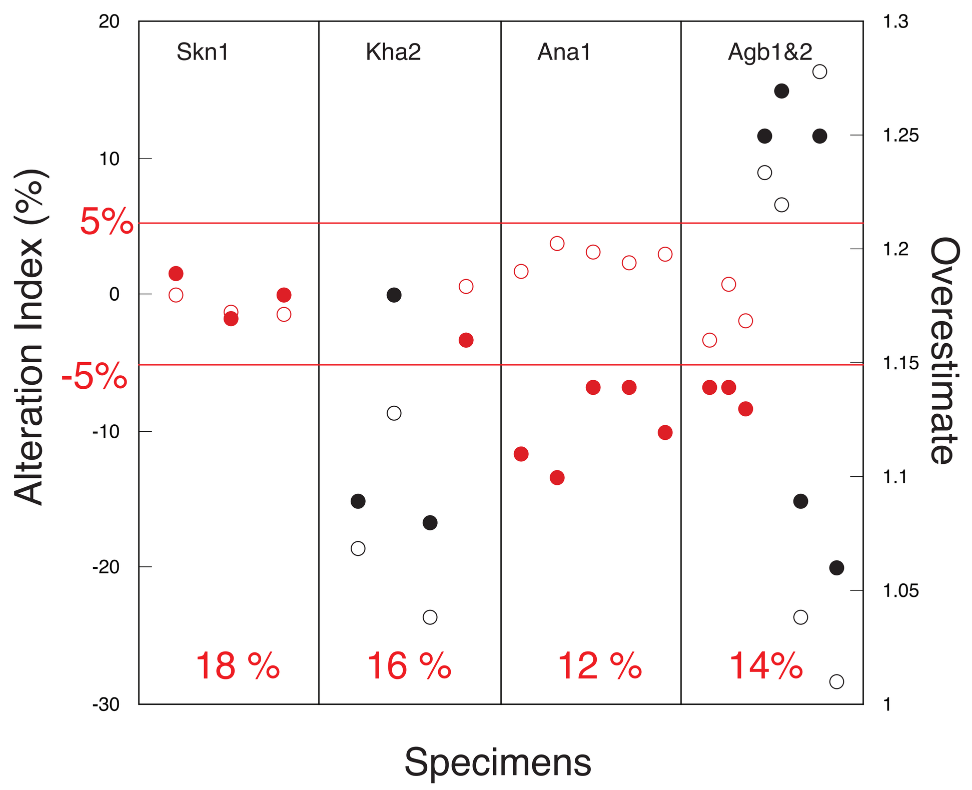


22 specimens showed no alteration and single component remanance besides meeting other standard quality criteria.

Corrections

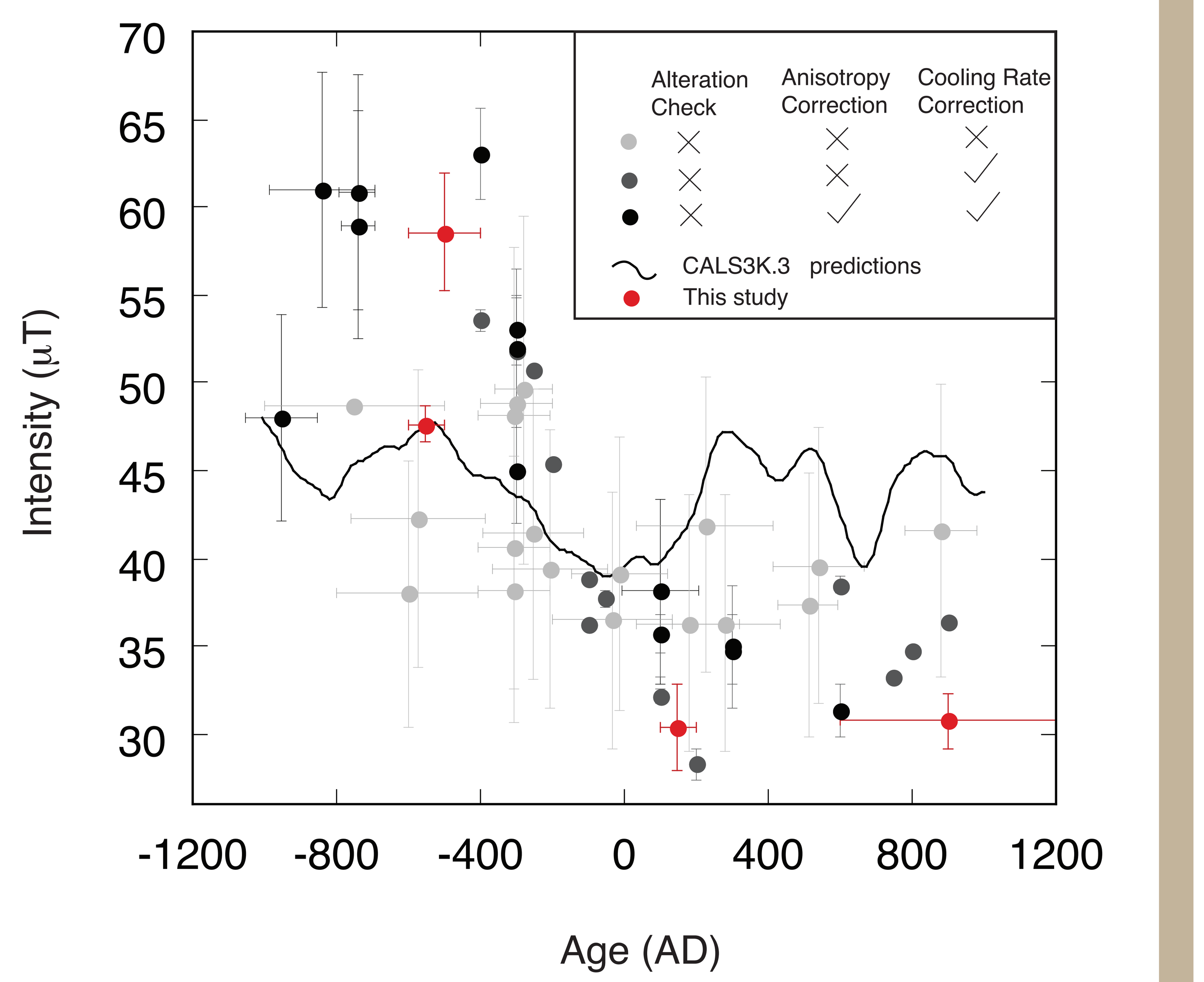


Pottery samples are often anisotropic to TRM acquisition because of manufacturing processes. To correct for this we have used anisotropy of anhysteric remanance (AARM) [8]. Each of the 22 specimens were subjected to ARM acquisition in 15 different orientations and the correcting tensor was calculated. 7 specimens (black circles) were discarded in this step because the corrected TRM direction was found to be more than 5° off from the laboratory field direction. Raw intensity values (open circles), AARM corrected values (solid circles) and corrected site averages are shown.



TRM acquisition is a function of the cooling rate [9]. Slow cooled samples tend to overestimate the field. To correct for this we assumed an ancient cooling rate of 10 hrs. A cooling rate experiment was conducted on all the 22 specimens. The experiment consisted of three successive total TRM (600°C to room temperature) acquisitions; $TRM_{30\,mins}$, $TRM_{10\,hrs}$ and $TRM_{30\,mins}$, where the subscript indicates total cooling time. Difference between the two $TRM_{30\,mins}$ show alteration (open circles) while the ratio of $TRM_{10\,hrs}$ to $TRM_{30\,mins}$ show the overestimate (solid circles). The site level average of the overestimate for specimens which showed no alteration (<5%) (red open circles) was used to correct site level intensity estimates.

The Big Picture



We provide 4 paleointensity estimates from India with the most stringent quality control.

There is a 48% drop in intensity in the last 500 yrs of the 1st millenium BC.

There is a possibility of a big intensity spike around 500 BC as evident from the 23% jump in intensity around that time.

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