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Lightning strikes in archaeological magnetometry data. A case study from the High Bank Works site, Ohio, USA

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INTRODUCTION

Determining whether a magnetic anomaly detected at an archaeological site has a natural or a cultural source can be quite challenging in some regions of the world because of magnetic variability related to soil development and differing rock/parent material types. Though not consistently recognized, lightning is one major source of magnetic anomalies on archaeology sites that has been consistently overlooked and misinterpreted. A case study from the High Bank Works in south-central Ohio, USA shows the range of strike anomaly sizes, shapes, and intensities.

HISTORY AND GLOBAL OCCURRENCE

The effects of lightning strikes throughout the world are well known. Except for lightning-damaged trees, the most common visual evidence of strikes are fulgurites, which are fragile, tube-like geological features created by sand that has been fused by the strike's intense heat (Pye 1982; Appel *et al.* 2006). Fulgurites are only formed in sandy soils (Veimeister 1972); in other soils there might be no visual evidence of a strike event. Strikes can be apparent, however, in magnetometer data.

One of the first occurrences of lightning anomalies in archaeological data was detected in 1988 during a gradiometer survey in Wales (see Crew 2008). At the time, these anomalies were not interpreted as lightning strikes. Seven years later, a short article on lightning anomalies in magnetometer data was published by Bevan (1995), followed by an article about a probable lightning strike from an archaeological site in Japan (Sakai *et al.* 1998). Since the mid 1990s, other observations of lightning strikes have been published from, for example, the United States of America

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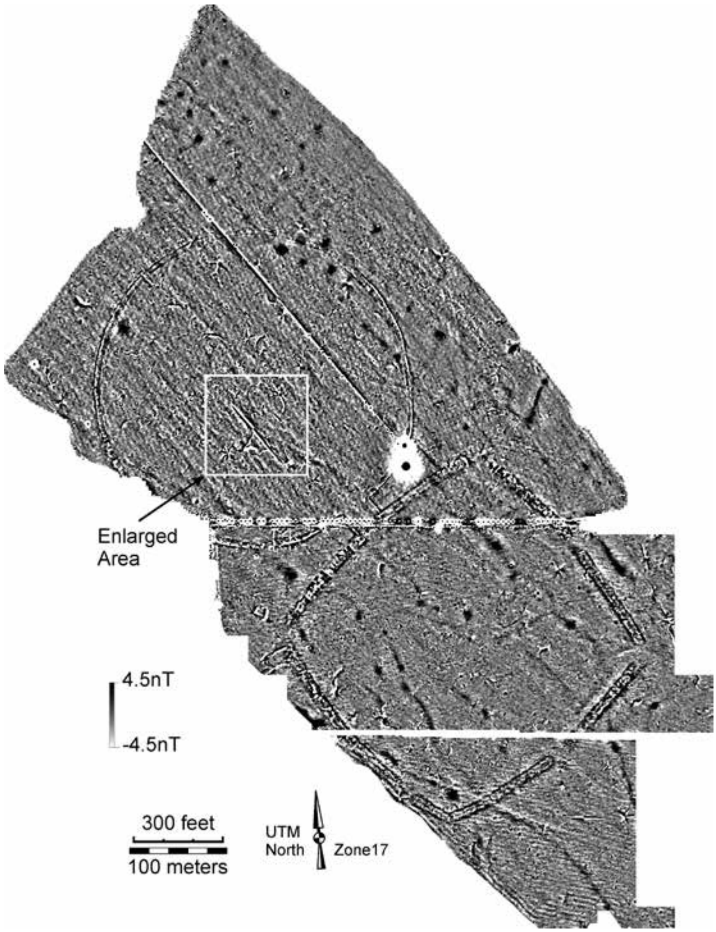

Fig. 1. Gradiometer results from the High Bank earthworks site, Ohio, USA: observed over 60 lightning anomalies in the magnetic data (data images provided by J. Burks)

(Jones and Maki 2005; Maki 2005; Beard *et al.* 2009; Cook and Burks 2010; Burks 2014), Sweden (Biwall *et al.* 2011; Trinks and Biwall 2011), Wales (Crew 2008; Bevan 2009), Austria (Walach *et al.* 2008), India (Bevan, personal communication) and Peru (Fassbinder and Górka 2009).

ATTRIBUTES

The most distinctive character of lightning strikes on magnetic maps are the positive and negative rays that extend out from a central point. The radiating arms are often about 10 m long (sometimes shorter), but examples from the United States show that they may extend for many dozens of meters. The amplitude of the magnetic anomaly decreases with distance from the strike point and

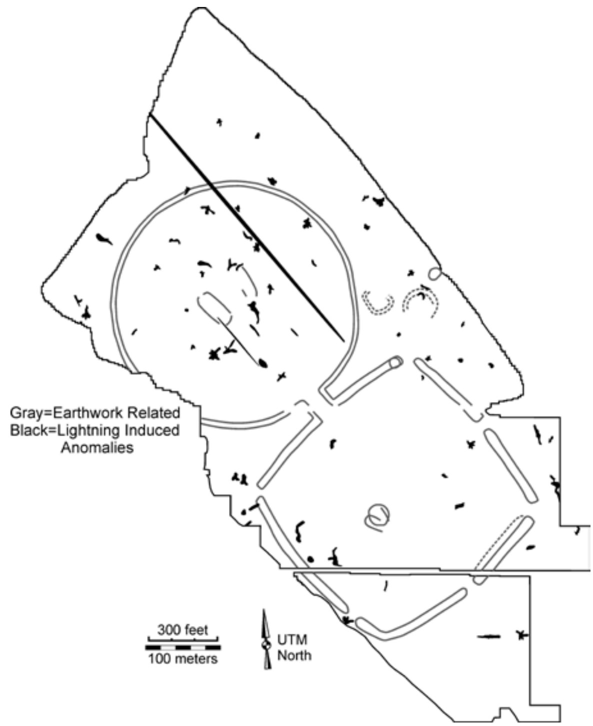

Fig. 2. Interpretation of gradiometer results

the anomalies may taper to indistinguishable at the end, rather than ending abruptly. Each radial arm is bipolar, with a magnetic low paralleling a magnetic high. The magnitude of the high will be about equal to the low, independent of the direction of the ray. This approximate equality will be true where the inclination of the Earth's magnetic field is rather steep, for example, 70 degrees or more. At locations where the strike is found closer to the Earth's equator, the magnetic high and low will become less equal, and the amplitudes of the rays will change much with direction (north–south rays will become invisible). Along each ray of a single lightning strike, the magnetic high will be clockwise from the magnetic low, relative to the strike point. Alternatively, along each of the rays, all of the magnetic highs will be counterclockwise from their matching lows. In the former case, with the magnetic highs clockwise from the lows, the magnetizing current (the strongest or final current) flowed outward from the strike point. Otherwise, with lows clockwise from highs, this current flowed inward toward the strike point (see Rakov and Uman 2007: 4 ff. for definition of different kinds of lightning discharges). The magnetic anomalies of lightning strikes will be found only where the current flow is primarily horizontal, at a shallow depth of perhaps less than 1 m. The horizontal flow of current probably requires that shallow soil has a greater conductivity than deeper soil. The low conductivity may result from an increased fraction of clay, silt, or other conductive materials at a shallow depth, compared to deeper underground.

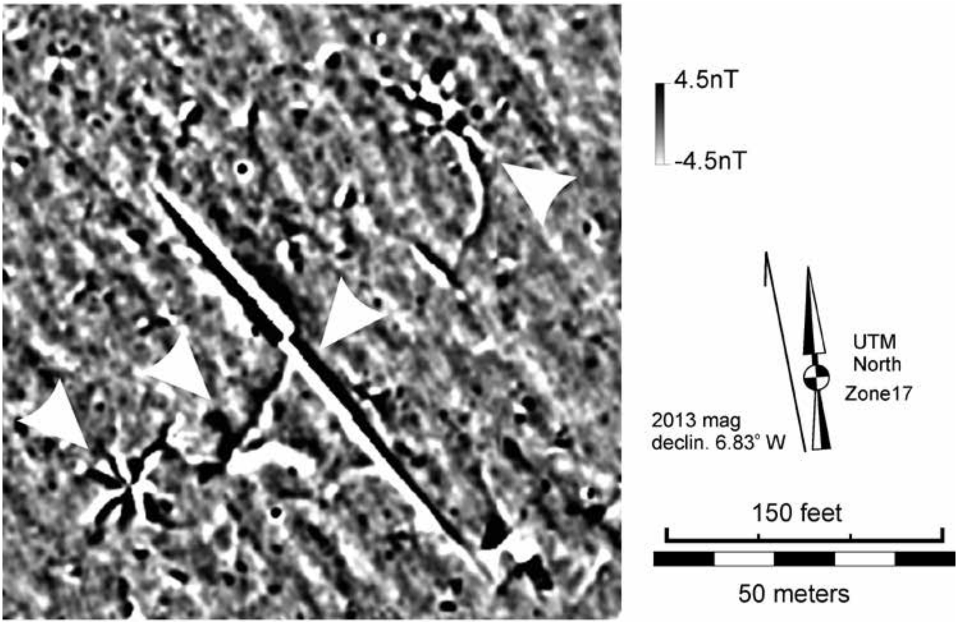

Fig. 3. Enlarged area showing a variety of lightning induced anomalies (indicated by white arrows)

THE OHIO CASE STUDY

Between 2011 and 2013, just over 30 ha was surveyed at the High Bank Works in Ross County, Ohio (USA) using a Foerster Instruments Ferex system (Burks 2013). High Bank is a large Hopewell earthwork complex constructed approximately 1700 years ago. The embankments, which are still slightly visible in the topography, where clearly detected in the magnetic survey (Fig. 1), as were dozens of lightning-induced bipolar anomalies (Fig. 2). It would appear that there are two kinds of strike anomalies at High Bank, those that are long and narrow with only two radiating arms, and those that are more amorphous, with more rays (Fig. 3). Many of the linear anomalies are parallel to plow marks, suggesting that these occur very close to or at the surface. While High Bank has not been plowed in perhaps a decade, over 150 years of plowing, prior to the site becoming a park, has left many fragments of lightning strikes that complicate attempts at interpreting the magnetic survey. However, the broader view provided by the large survey area makes it easier to identify definite and probable lightning-induced anomalies.

CONCLUSION

Lighting-related anomalies can be quite common in magnetic data. With large survey areas it is relatively easy to spot lightning anomalies. But in small surveys or thoroughly plowed ground, lighting anomalies may only appear as fragments of the more typical anomalies. As the

High Bank example shows, lightning anomalies can be abundant in magnetometer data. The correct identification of lightning strikes in magnetometry data is therefore an essential part of understanding magnetic maps and ensures the avoidance of unnecessary interpretational errors and misunderstandings.

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