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Prospecting in the southwestern Amazon forest (Bolivia): Magnetometry near the geomagnetic Equator

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Highlights: New discovered large pre-Hispanic settlements in the southwestern Amazonia, Archaeo-geophysical prospecting in the densely wooded Amazon forest, Magnetometry close to the geomagnetic equator

Keywords: prospecting in the forest, magnetometry, ERT, magnetic susceptibility, Bolivia

Introduction

The Casarabe culture developed between 500 and 1400 AD in the Southern Amazonian forest on Alisols with advantageous agricultural properties (Brito *et al.*, 2024) and had its greatest flourishing around 1000 AD. Very little is known about the organization of their settlements and the architecture of residential buildings, temples, and public buildings.

Recent Lidar remote-sensing and field-reconnaissance analyses have revealed the presence of a multitude of large prehistoric monumental sites (locally known as 'Lomas') and smaller sites, including canals and causeways which connect the sites (Prümers *et al.*, 2022). With one of the largest proto-urban settlements, this culture covers an area of approximately 4,500 km². LIDAR, mainly provides information on the topography of archaeological sites. It is the geophysical prospection that will reveal more and further details about the features hidden in the ground. The site chosen for this pilot study is El Cerrito ("little hill"). It is located a 10 km distance east of the town of Casarabe, which is currently a reserve of the municipality of the same name. Cerrito is one of the central places in Casarabe Culture. The architectural elements of the Cerrito site comprise platform buildings, a polygonal enclosure, and straight causeways radiating from the central platform of the core site (Fig. 1).

An almost quadrangular-shaped base platform located on the right bank of a paleo-river rises 6 m high and covers about 6 ha. The core area of the Cerrito site dominates a set of civic-ceremonial structures covering an area of almost one hectare. Although the Lidar image does not allow us to determine the precise perimeter of these structures, there are remains of what may have been four structures: a rectangular building to the south ~46 x 23 x 12 m high, two buildings to the west ~18 x 20 x 8 m high and another ~37 x 20 x 8

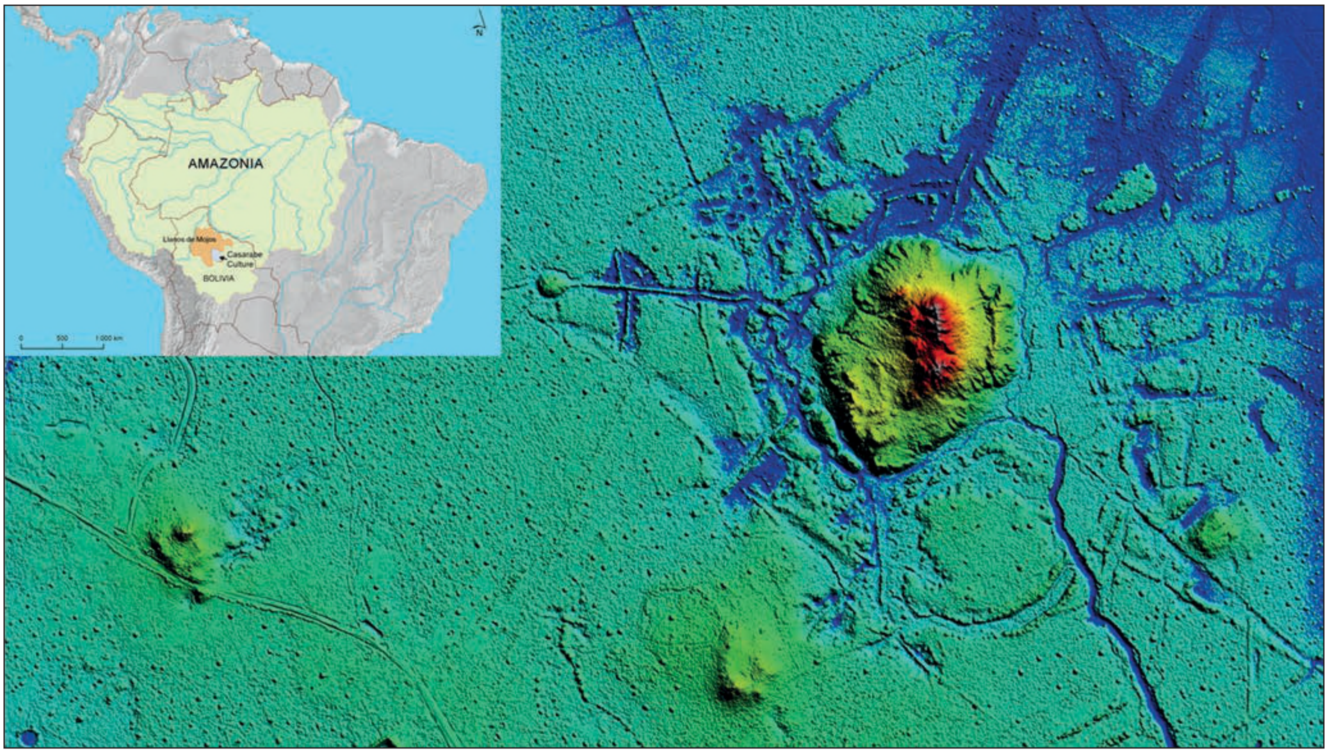

Figure 1: Location of Amazonia. DTM image of the study site Cerrito, southwestern Bolivia.

R. Torrico.

m high, and a rectangular structure to the east ~63 x 29 x 10 m high. Opposite the northwest corner of the central architectural complex is a 30 x 13 m structure. A system of at least four causeways radiates from the inner precinct in different directions, crossing the limits of an enclosed area of approximately 41 ha. A causeway in a north-easterly direction crosses an intersecting platform. There are remnants of a second enclosure to the south of the site that delimited a much larger area but whose limits to the north are impossible to observe. In addition to its monumental architectural features, Cerrito is interconnected by a complex network of canals and causeways with at least eight other second and third-tier sites.

Geophysical prospecting in the Amazon forest

Geophysical prospection on Alisols developed in forests and under crops is a challenge. Due to the high soil moisture, loamy and high clay mineral content and a dense root system beneath the forest, radar prospecting will likely not be successful. Although the measuring areas were mainly cleared of low vegetation for prospecting, larger trees and particularly valuable cocoa plants were spared from the clearing. No area of the survey area was free of vegetation, so prospecting in a precise decimetre grid was impossible. Detecting a precise GPS point under the forest takes 3-4 hours. For measurements under these conditions, grid-based magnetometer prospecting, magnetic susceptibility and electrical resistivity tomography are probably the most suitable methods. However, the flat inclination of the magnetic field makes magnetometer measurements even more difficult. Gradiometer measurements with commercially available devices will fail since they measure only the difference in the Z-component of the Earth's magnetic field. In order to achieve high sensitivity at high measuring speed despite these difficulties, we carried the Geometrics G-858 magnetometer system on a plastic frame ~ 30 cm above the ground as a total field magnetometer in a so-called "duo-sensor" configuration. All areas remain covered with many trees, so we had to neglect the associated inaccuracies in spatial resolution. Although in the measurement period, 09/2024, the solar activity and the daily variations induced by the solar wind were comparatively high (see: http://www.ips.gov.au/Space_Weather), we were able to approximate the diurnal variations to the mean value of all data of each 40 m × 40 m grid without visible disturbances in the magnetogram. Due to the flat inclination, a stripe pattern running parallel to the

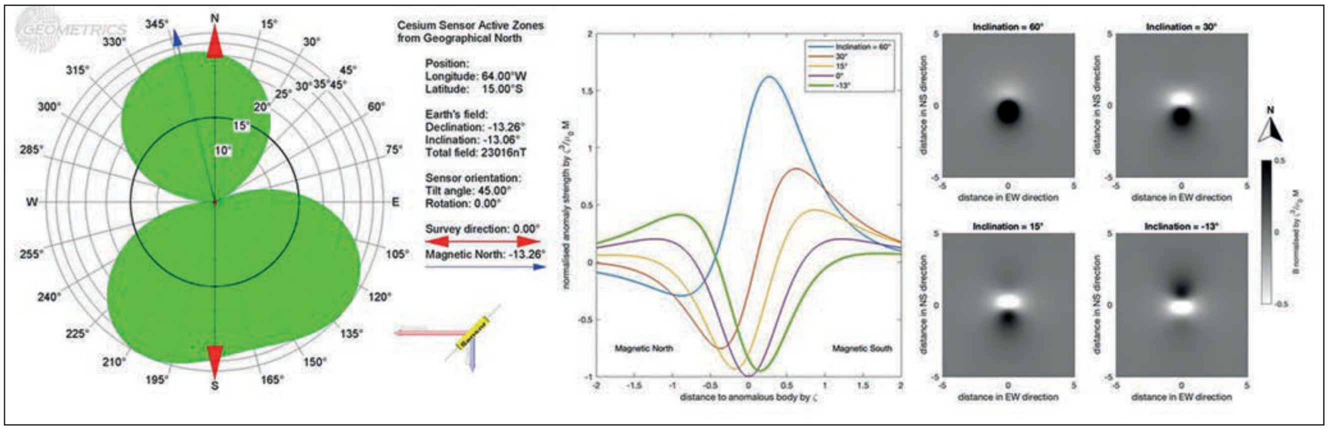

Figure 2: Cerrito. From left to right: Actual magnetic field data for the location, provided by the Geometrics App, the 2D shape of magnetic anomalies decreases with decreasing inclinations; on the right, the variation of the shape of magnetic anomalies. Note: It flips from positive to negative in the southern hemisphere.

Hahn, 2024.

profile direction are due to the heading error of the caesium magnetometer applied in bumpy terrain. Correcting these is impossible without creating unwanted artefacts.

For the ERT measurements, we used the "4point light hp 10W" manufactured by Erich Lippmann, the company's software "GeoTest," and the commercial program Res2Dinv for inverting the data. We measured each profile in Dipole-Dipole, Wenner, and Schlumberger configuration using 40 electrodes and a 1m electrode distance. The resistivity values in the settlement area ranged from 10 to 150 Ω m. Due to the high soil moisture, the trees had no disruptive influence on the measurement results.

Results and conclusions

Using magnetometer measurements, we covered ca. 3 hectares in five areas (left side Fig. 3). The magnetometer results correspond to the typical characteristics of the theoretically anticipated magnetic anomalies near the geomagnetic equator with an inclination of ca. -13° (see Fig. 2) (Tite, 1966; Fassbinder & Gorka, 2011; Fassbinder, 2015; Ostner *et al.,* 2019).

The magnetograms confirmed a dense settlement pattern with traces of wooden (round?) houses, large adobe mud-brick features, pits and fireplaces in all surveyed areas. The area Cer2024b (Fig. 3 right) is divided and bordered by a 6 m wide and 2 m deep ditch (see ERT profile 6, Fig. 3). This ditch was no longer visible in the topography or the Lidar image. In situ measurements of the topsoil magnetic susceptibility inside (2.9 - 7.3 x 10^{-3} SI units) and outside (1.2 - 2.0 x 10^{-3} SI units) the settled area by a handheld Kappa meter SM30 also indicate evident differences in the topsoil and intensive settlement activity inside the enclosure. We extracted living south-seeking magnetotactic bacteria from wet and flooded soil samples similar to those we found in Bavaria (Fassbinder et al., 1990). Fossils of these bacteria probably contribute to the magnetically highly enriched top soils of the Alisols (Brito *et al.*, 2024) and to the highly contrasting magnetic anomalies of the pits and ditches.

ERT profiles that we aligned perpendicular to the suspected channels show rectangular U-shaped profiles 20 m wide and 4.5 m deep, which are typical features of artificially created channels and confirms the hypothesis of Prümers and James Betancourt *et al.*, 2022.

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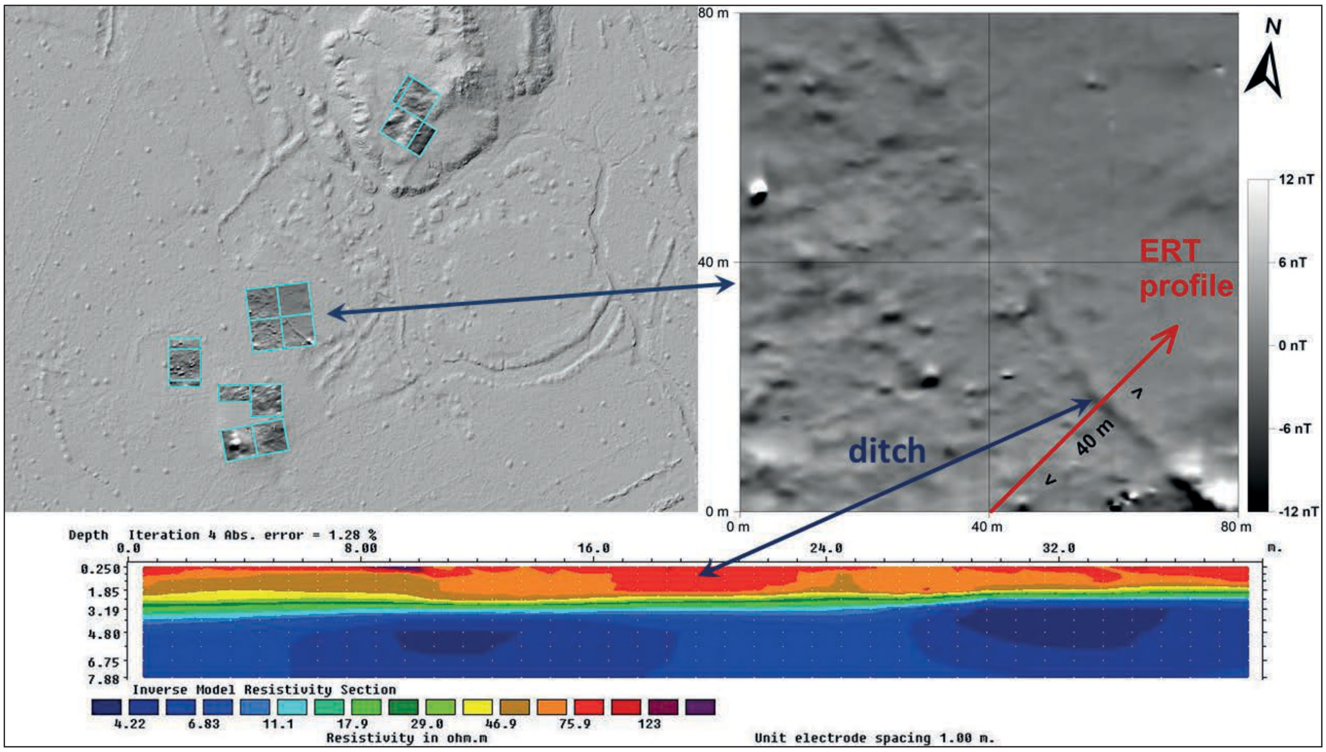

Figure 3: Cerrito. Digital Terrain Model of the area overlaid with magnetogram images on selected sites around the central mound of the site (left). On the right, the magnetogram reveals a densely settled area enclosed by a ditch—the results of the ERT-profile (Schlumberger configuration) across the ditch (bottom). The intensity of the Earth's magnetic was ca. 22.900,00 ±50 nT.

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