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RESEARCH ADVANCE

# GRAVITY SURVEY OF THE MESOAMERICAN CUICUILCO ARCHAEOLOGICAL SITE, SOUTHERN BASIN OF MEXICO

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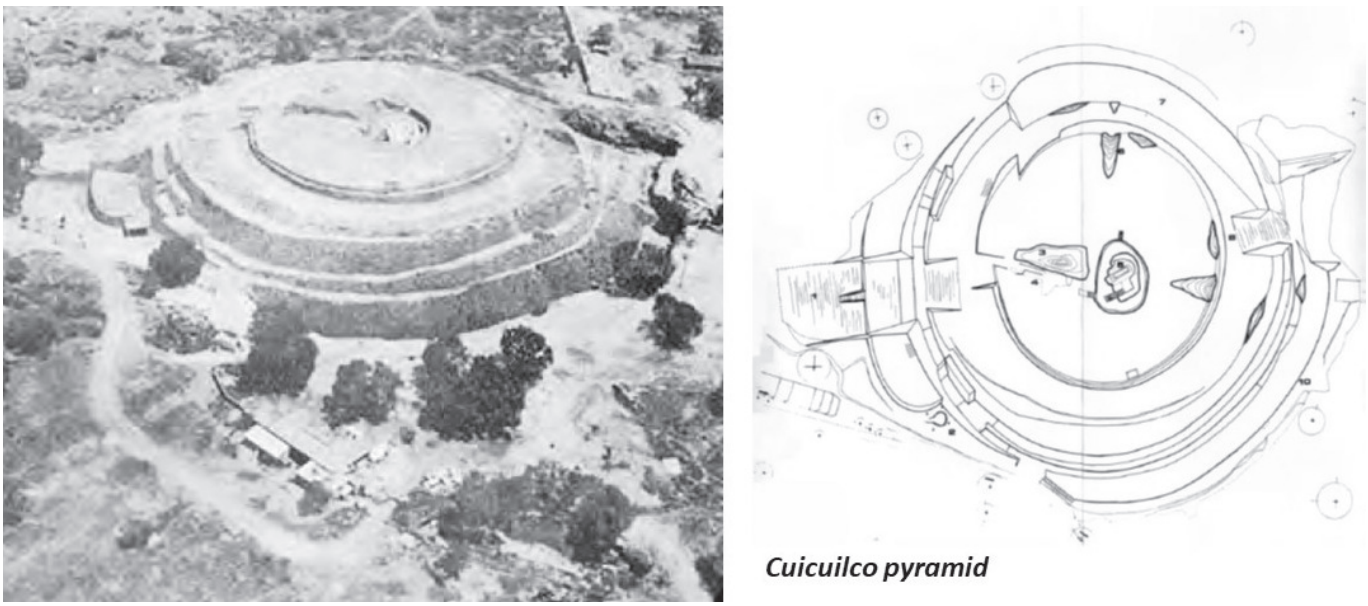


Figure 1. Cuicuilco archaeological site in the southern Basin of Mexico. Aerial view of the Cuicuilco pyramid taken in the 1950's (Compañía Mexicana Aerofoto). Map of the pyramid site drawn by Schávelzon (1980) using the INAH base map (1978) (adapted from Schávelzon, 1983).

***ABSTRACT****. The Cuicuilco archaeological site is an early Mesoamerican Preclassic ceremonial and urban center in the Basin of Mexico. The site is characterized by a round-section pyramid and several well-preserved stone structures that were covered by lava flows and tephras by the ~2000 yr old Xitle volcanic eruption. This article presents results from a gravity study to investigate the underground structure. Site gravity anomalies show a gradient trend from southeast to northwest related to the lava flow cover and underlying topographic relief. A semi-circular gravity anomaly high of around 6 to 8 mGals marks the circular main pyramid. The survey also detects two small amplitude anomalies on the eastern side of the pyramid, just north of the access ramp. The main access western ramp does not show any associated gravity anomaly. No other anomalies are observed around the pyramid structure in the surrounding excavated area. The gravity anomaly over the lava field masks any possible anomalies associated with other buried structures likely to be present in the site.*

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***KEYWORDS***. *Cuicuilco archaeological site; Basin of Mexico; gravity survey; Cuicuilco pyramid; Mesoamerica.*

***RESUMEN***. *El sitio arqueológico de Cuicuilco es un centro ceremonial y urbano del periodo Preclásico en Mesoamérica. Se localiza en el sur de la Cuenca de México y está caracterizado por una pirámide de sección circular que lo hace diferente de posteriores desarrollos en Mesoamérica. Cuicuilco fue cubierto por lavas y tefras de la erupción del volcán Xitle hace unos 2000 años. En el presente trabajo presentamos los resultados del estudio gravimétrico dirigido a investigar la estructura del sitio. Este se distingue por una anomalía con tendencia sureste-noroeste asociada a la cubierta de lavas y la topografía preexistente. La pirámide está caracterizada por una anomalía circular de alrededor de 6 a 8 mGals. En el estudio se detectan dos anomalías de baja amplitud en el sector oriental adyacente a la pirámide, al norte de la rampa de acceso. La rampa de acceso principal de mayores dimensiones no muestra anomalía gravimétrica asociada. No se observan otras anomalías en la zona excavada alrededor de la pirámide. La anomalía gravimétrica de la cubierta de lavas no permite detectar otras posibles estructuras en el sitio.*

***PALABRAS CLAVE***. *Sitio arqueológico Cuicuilco; Cuenca de México; exploración gravimétrica; pirámide de Cuicuilco; Mesoamérica.*

## INTRODUCTION

Cuicuilco is an early Mesoamerican ceremonial center located in the southern Basin of Mexico (Cummings 1926; Heizer and Bennyhoff 1957, 1972). It was explored in the late 1910's by Manuel Gamio, who recognized the importance of the site and organized the first excavation projects, which were carried out in association with Cummings and collaborators. Cuicuilco contains a large circular-section pyramid (Fig. 1). The site was partly covered by lava flows and tephras from the eruption of the Xitle volcano around ~2000 yr ago (Delgado *et al.* 1998; Urrutia-Fucugauchi *et al.* 2016).

The site has been divided into three major sectors, following studies in the excavated zones to the south and west. However, the extent of the occupied area is currently not well-defined, as surveys have been restricted by both urban development and lava flow cover. The main sector (A-sector) includes the Cuicuilco pyramid with its circular-cross section (Fig. 1). Later constructions of pyramids and ceremonial buildings by Mesoamerican cultures relied on different designs, mainly with square- and rectangular-cross sections. The pyramid has a truncated cone, four-terrace shape, and is ~137 m diameter at its base and ~20 m height. It was constructed in stages, with three main building phases. Relatively little is known of the underground structure of Cuicuilco. Here we present the initial results of a gravity survey at this site, focusing on the A-sector that includes the main pyramid. The survey investigates the structure and geophysical response of the Cuicuilco pyramid as well as the lava flow and possible presence of buried archaeological remains.

## THE CUICUILCO ARCHAEOLOGICAL SITE

The Cuicuilco ceremonial and urban center developed during the Preclassic Formative period (1500 BC–100 AD). The settlement extended over a wide area, which has only been partly explored. Today, the archaeological site is surrounded by construction related to urban expansion of the Mexico City metropolitan area, including the Olympic Villa and both commercial and residential centers. In addition, the site was covered by lava flows from the Xitle eruption, which led to the site's abandonment (Cummings 1926; Heizer and Bennyhoff 1958). The chronology of the Xitle eruption and its effect on the site have been intensely debated (e.g. Gonzalez *et al.* 2000). The timing of the eruption and its effects on the Cuicuilco population are important for understanding the development of settlements in central Mexico, particularly for the Teotihuacan ceremonial center (Nichols 2016). Studies have dated samples from soils and charcoal from outcrops and from archaeological excavations in different sectors of the lava field and in Cuicuilco itself. Radiocarbon dates for the site and the Xitle lava field cluster around 2100–1960 yr BP, showing multi-modal ~4000 to ~1500 yr BP wide range (Arnold and Libby 1952; Fergusson and Libby 1963; Cordova *et al.* 1994; Urrutia-Fucugauchi 1996; Gonzalez *et al.* 2000). Recent revised bootstrap analyses of calibrated radiocarbon and archaeomagnetic dates give mean dates and confidence intervals of 2041 and 1968–2041 cal yr BP and 2035 and 1968–2073 cal yr BP, respectively (Urrutia-Fucugauchi *et al.* 2016).

The Xitle volcano is a monogenetic cinder cone emplaced on the northern slope of the Ajusco volcanic

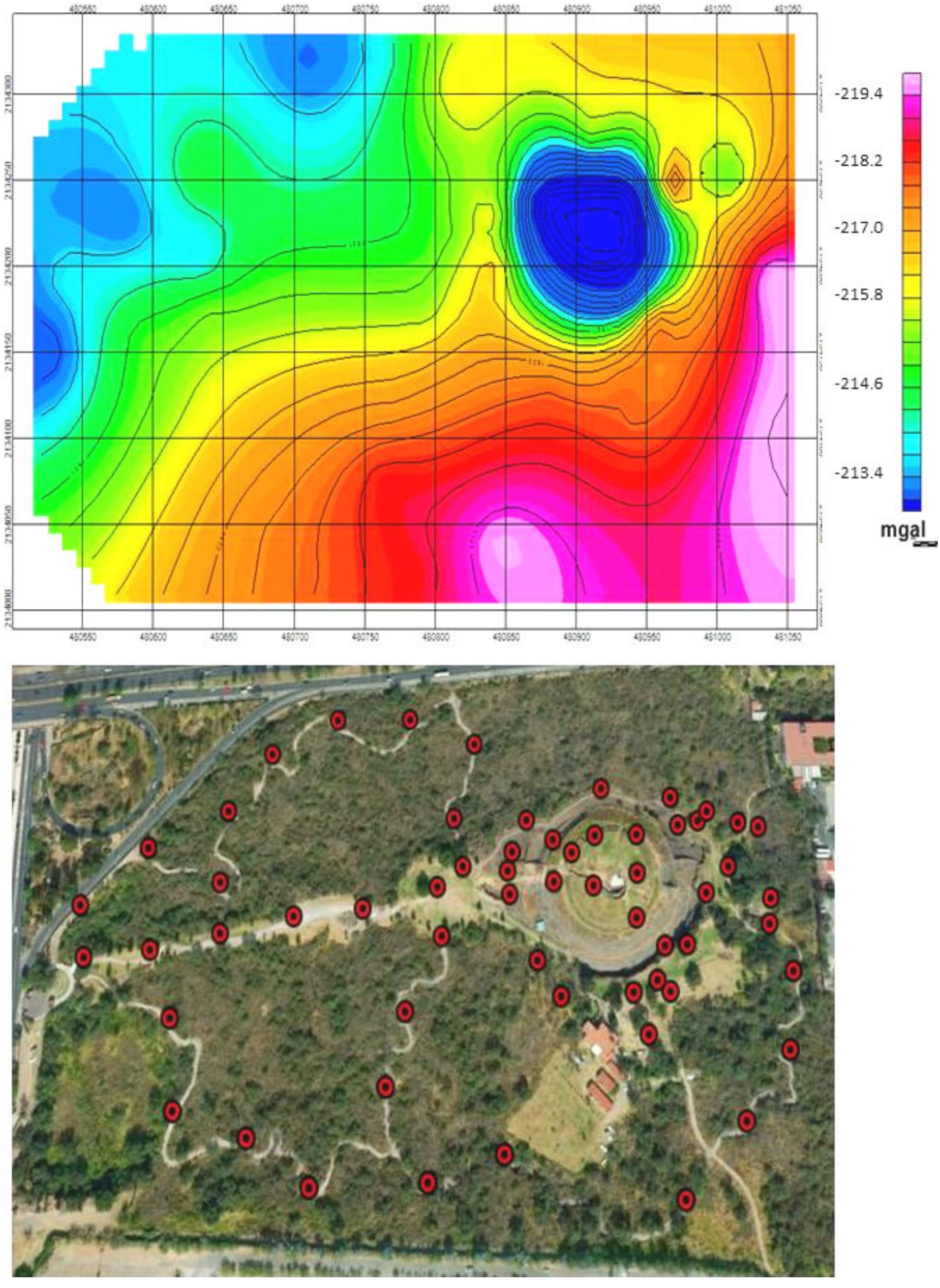


Figure 2. Bouguer gravity anomaly map of the Cuicuilco A-sector: (a) Contour plot of the gravity anomaly, the SE-NW gravity gradient and the semi-circular gravity high over the main pyramid; (b) Position and distribution of gravity stations in the Cuicuilco gravity survey zone.

complex. The lava field of the Xitle eruption extends along the Ajusco volcano slope into the southern Basin of Mexico, covering a large area, some >70 square km. The lava field is formed by several flow units, with their extension controlled by the slope, topographic relief and drainage. The lava cover has complicated and thus limited the excavation of the site. Despite this, archaeological surveys and excavation projects continued over several decades, up to the late 1960's when the Olympic Villa was constructed. This project revealed the extent of Cuicuilco and, unfortunately, damaged several pyramids and buildings. The urban expansion has affected the site in other ways as well, with several construction projects, including the ENAH National School of Anthropology and History, commercial and residential complexes and the peripheral ring Anillo Periférico road system (Gándara 2018; Ramírez 2018). Many details of the archaeological and urban development excavation projects remain unpublished (Schávelzon 1983).

## GRAVITY SURVEY

Gravity anomalies were measured with a LaCoste & Romberg Model-G gravimeter, which has reading accuracy of 0.01 mGal and drift rate of <1 mGal per month. Station coordinates and altitude were determined with Trimble GPS meters, referred to the site topographic map and Landsat image. About 60 gravity stations were measured for the initial survey. The gravity anomalies were corrected by instrumental drift, tides, altitude and density lateral effects to calculate the Bouguer anomaly (Hinze *et al.* 2005). The density for Bouguer correction was 2.67 kg/m$^3$. The Bouguer gravity measurements are interpolated and gridded using a minimum curvature algorithm. The relative positions of the gravity stations in the archaeological site were chosen following the access restrictions; the station distribution is shown, plotted on the Landsat satellite image. The contour plot for the gravity anomalies is shown in Figure 2.

The gravity response of the site shows a gradient from southeast to northwest, from –219 mGals to –212 mGals. The gravity anomaly trend is related to the lava flow cover and underlying topographic relief. The pyramid is characterized by a semi-circular anomaly high (Fig. 2). The main ramp and stair access on the western side does not show an anomaly associated, whereas there are two small amplitude anomalies at the eastern side, just north of the smaller eastern ramp and stair access.

The gravity anomaly high marking the pyramid is interpreted as arising from the density contrast with the surrounding lava flows. The pyramid, as well as the other structures, are constructed with volcanic rocks. Excavations show large up to 1–2 m lava boulders with the soil and clays. The circular pyramid and other smaller structures have only been partly excavated. Little is known of the structure and morphology of the site beneath the lava cover.

## DISCUSSION

The geophysical survey permits exploration of the geophysical response and underground structure of the site, lava cover and archaeological remains, including the inner structure of the pyramid.

The pyramid is marked by a semi-circular gravity high of about 6 to 8 mGals (Fig. 3). The horizontal gravity gradient and the second derivative field approximately correlate with the base of the structure and the basement. The main terraced access ramp on the western side does not show up in the anomaly configuration. Small amplitude anomalies are observed on the eastern side, located just north of the western ramp access and partly buried structures (Fig. 1). Additional gravity measurements confirm the presence of these small anomalies, which are targets for further investigation.

Forward modeling of the anomaly has been preliminary attempted using vertical prisms of various dimensions and density contrasts. Models show that using the geometry of the pyramid and strong density contrasts result in an anomaly that fits the shape, but with smaller amplitude of 2–3 mGals. Results suggest that the anomaly reflects the density contrasts between the lava flow cover and the underlying sedimentary relief. The amplitude of the circular anomaly is reduced using a first- or second-order regional trend that accounts for the lava units subtracted from the observed anomaly.

Around the pyramid, in the excavated area, the two small amplitude anomalies present on the eastern side are the only ones detected. No other anomalies are observed around the pyramid structures. It is likely that other structures were constructed in the site. Excavations in the other site sectors B and C have uncovered other pyramids and stone buildings, some of large dimensions (Gándara 2018; Ramírez 2018). However,

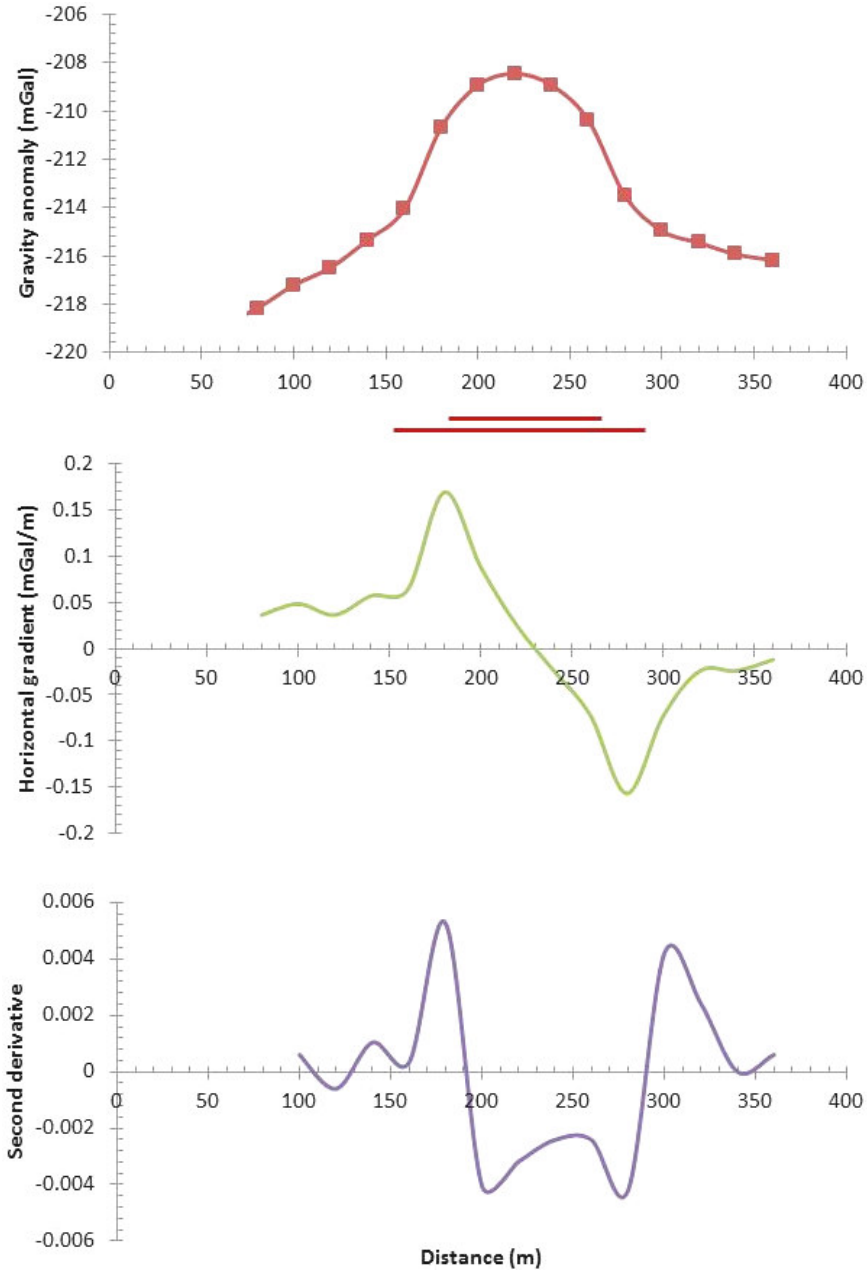


Figure 3. Gravity anomaly over the Cuicuilco pyramid: (a) S-N gravity profile, showing the Bouguer gravity anomaly over the lava field and the semi-circular pyramid; (b) Horizontal gravity gradient; (c) Second derivative. The horizontal red bars show the relative position of the pyramid structure along the gravity profile.

the gravity signal from the lava flows effectively masks any anomalies associated with buried structures.

The Cuicuilco center is located at the eastern edge of the Xitle lava field; the lava flows likely followed the topographic relief and drainage system. Seven lava units, with several sub-flows, have been identified in the Xitle eruption, which was characterized by low viscosity basaltic lavas and tephras (Delgado *et al.* 1998). The eruption may have lasted several years, giving time for the inhabitants to cope with the hazards. The Cuicuilco pyramid appears to have been covered, in an attempt to protect it from the eruptive products (Heizer and Bennyhoff 1958, 1972; Schávelzon 1983). The volume, extent and thickness of flow units varied, with thickness ranging from a couple up to several tens of meters. The largest flow unit of olivine basaltic composition extended farther south covering the National University campus area and reaching the Cuicuilco site. This flow unit shows a variable thickness, up to ~40 m thick. In the Cuicuilco site, the SE-NW gravity anomaly trend probably reflects the underlying relief and the lava cover and thickness variations.

Further extension of the gravity survey of the other archaeological B- and C-sector and surrounding zones

will provide additional information, as will detailed modeling of the gravity high that characterizes the circular-section pyramid. These studies will provide further insight into the pyramid and underlying site structure.

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