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Magnetometer Evidence of a Structure within the La Venta Pyramid

Abstract. *The pyramid at La Venta, Tabasco, Mexico, was surveyed in May 1969 with a high-sensitivity difference magnetometer. The general pattern of the magnetic map is one of low (10-gamma) radial anomalies, which reflect the ridge and gully topography of the pyramid, with a larger magnetic high area (+30 gammas) centered 25 meters south and 10 meters east of the center of the pyramid. The anomalous region near the top has been interpreted with the aid of computer-calculated anomalies from three-dimensional rectangular blocks. The major high is probably associated with a basalt structure that rises to within 1 to 2 meters of the surface. A possible form for this structure was found to be a 10-meter-square horizontal platform with walls along its northern and eastern margin.*

The La Venta pyramid (Fig. 1), although the largest single structure at the important Olmec ceremonial center in lowland Tabasco, has until recently received scant attention from researchers at the site. Investigations there by M. W. Stirling and P. Drucker in 1940–42 centered around the unique art style embodied in the large carved stone monuments and the problems of ceramic stratigraphy (*1*). The large-scale explorations of Drucker and Heizer in 1955 concentrated on the unexpected complexities of complex A (*2*). Although the entire site was mapped, the pyramid (also referred to as complex C) was covered with a dense growth of jungle cover and was incorrectly reported by the party surveyor to be a somewhat elongated rectangle. Drucker and Heizer found in 1967 that the pyramid was actually a fluted cone or, more technically, a conoidal frustum (*3, 4*). Ten alternating valleys and ridges were seen to run up and down the structure's 100-foot elevation, spaced at roughly equal intervals around its circular basal plan. In 1968 a University of California field party completed a detailed topographic map of the entire pyramid structure that constitutes complex C (*5, 6*).

This new information, as well as providing new facts and fresh insights into the history of Olmec culture (*4, 6*), has generated a certain interest in the unique structure itself (*7, 8*). Much of this interest, of course, revolves around the possible function of the great mound and the question of what it might contain. The 1969 magnetometer survey was conceived in the hope of providing partial answers to these questions. It was known that most of the large Olmec carved monuments, as well as the natural basalt columns that were used to border the plaza or "ceremonial court" and the "tomb" in complex A, were of a highly magnetic basalt secured from the Tuxtla Mountains, some 100 km to the west (*9*). Samples of clays from the site were tested and found to be effectively nonmagnetic. Thus it was felt that, had the Olmecs buried any large stone monuments or built any structures of basalt within the pyramid, they could be detected by a sensitive magnetometer. This hope was encouraged by the successful magnetometer survey in 1968 at San Lorenzo, about 31 km from the La Venta site (*7*).

Test calculations before the survey indicated that the increased sensitivity of a difference magnetometer would be required to detect significant basalt monuments within the pyramid. The principles of operation of such a magnetometer, which employs two Varian alkali vapor sensors, have been described (*10*). For the La Venta survey we borrowed a cesium sensor and leased a rubidium sensor from Varian Associates. The sensitivity of the magnetometer for the system used at La Venta was $\pm 0.0325\ \gamma$. (The earth's total magnetic field at La Venta is approximately 43,000 γ.)

To facilitate carrying the roving sensor with its dragging cable, the pyramid was cleared of the dense plant growth. Survey lines were then laid out radially with heavy white string that was marked off in 3-m intervals. Readings were taken at each 3 m out on one line, the line was then swung approximately 6 m in chord distance at the 60-m radius, and the line was surveyed again. Intermediate values between lines at large radii were filled in by estimating position.

Azimuth readings were taken periodically, and topographic features were noted on the survey lines so that the data could later be fitted accurately to the plan map of the pyramid.

The values at each station were recorded directly on radially scaled graph paper, a procedure that allowed preliminary contouring of data in the field. All the data were later digitized, the mean was removed, and the values were accurately machine-contoured in levels of 5 γ. The final magnetic contour map is presented in Fig. 2.

The large magnetic anomaly to the south of the center of the pyramid, contained within the inner rectangle of Fig. 2, is the feature of main interest in the survey. The pattern of this anomaly is complex, although it may conveniently be broken into two parts. The first is the broad high contained within the 10-γ contour, with an associated belt of lows roughly outlined by the zero contour, which runs from the southeast across the top of the pyramid and off to the northwest. Superimposed on this general high-low pattern is a further region of high values confined within the 20-γ contour. The very high gradient along the northern and eastern margin of the broad high suggests an origin near the surface, whereas the ex-

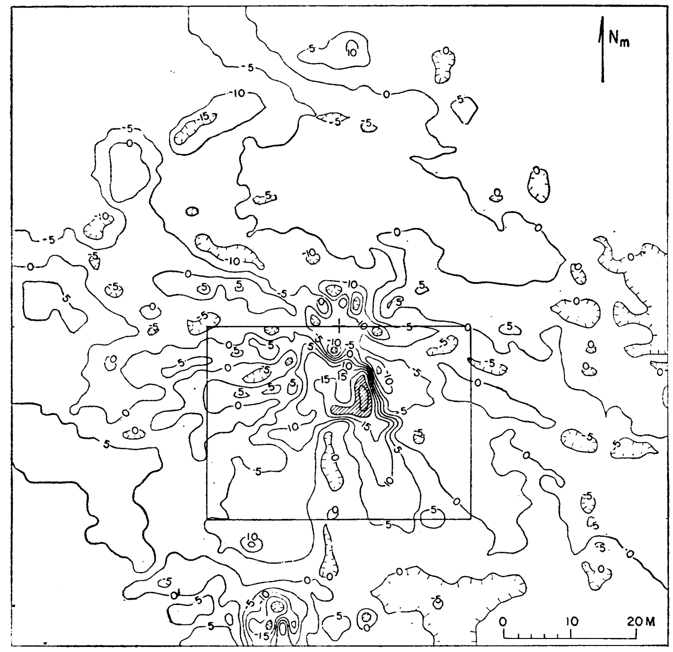

Fig. 1 (left). View from the southeast of the La Venta pyramid (when cleared of vegetation in 1968). Fig. 2 (right). Contour map of total magnetic intensity. N_m indicates magnetic north. The contour interval is 5 γ; the mean is removed. The inner rectangle contains the principal anomaly.

tent and slope to the west and south suggest that the high is caused by a relatively large body at greater depth.

The general pattern on the remainder of the magnetic map is one of strong radial anomalies on the southern half of the pyramid's surface, turning into gentle broad circumferential anomalies on the northern half. Near the top and to the south is a striking magnetic high, which falls off sharply to the north into a tight, arc-shaped, low area.

The area at the top of the pyramid was not surveyed, owing to the presence of several concrete blocks with embedded iron bolts. Some readings taken within 4 m of the center showed steep gradients with anomalies as high as 100 γ. It is unlikely, however, that the iron bolts are responsible for the magnetic low encountered about 6 m due south of the center, and it is evident that the accentuation of the low at this point is due to very shallow magnetic objects, possibly buried iron pipe.

The large magnetic low in the northwest is caused by roofing metal and probably by other iron objects associated with the nearest of the houses that encroach on the site.

The radial pattern is produced by the radial ridge-and-gully topography of the pyramid. The earth's magnetic field in the La Venta area has an inclination of approximately 45°, so that on the north side of the pyramid the field is parallel, and inclined at only 15°, to the ridge and gully pattern. At such low inclination very little secondary field is to be expected. On the remainder of the pyramid, we might assume that the ridges were represented by long cylinders with a component of the field perpendicular to them, giving rise to typical high-low anomalies. The actual combination of multiple ridge effects will not yield a simple pattern, but the radial nature of the anomalies should be most pronounced on these flanks. This general pattern is so well demonstrated in the magnetic map that there is little doubt that these features are due to a magnetic soil layer mantling the topography.

The magnetic low area just off the center line at the extreme south of the area surveyed coincides with a bulldozed excavation; thus it probably results from the removal of the magnetic soil layer. A "hole" in magnetic material produces a reversed anomaly—that is, a low over the hole surrounded by smaller highs.

The apparent high susceptibility of the soils was not anticipated, since soil samples collected in 1968 from the La Venta site had been tested prior to the survey and found to be essentially nonmagnetic. A crude test of soil susceptibility on the pyramid yielded a susceptibility of 7×10^{-5} electromagnetic unit. The uncertainty in this test is of the order of 5×10^{-5} electromagnetic unit.

Soil susceptibilities of this order are not uncommon. Many highly organic soils have volume susceptibilities of 5×10^{-4} electromagnetic unit, owing to the in situ formation of the mineral maghemite (*11*). However, as Le Borgne has pointed out, in areas of high humidity where the drainage is sufficient, the iron is usually leached out. Why soil of the La Venta pyramid should remain so magnetic is not known.

The effect of this surface layer of magnetic material is to mask anomalies from subsurface bodies with a "noise" level of 5 to 10 γ. Fortunately, in our survey the main anomaly, just south of center, is sufficiently above the topographic noise level so that no corrections were necessary.

To effect a quantitative interpretation of this anomaly, we have designed a program to compute the anomaly due to any three-dimensional rectangular block as measured on the surface of an approximately equivalent cone (30 m in height, 80 m in radius at base). This program could equally well compute the anomaly on the actual surface, but such a computation would require that the topographic map be digitized, a step considered unnecessary for the present interpretation. The method of computation is outlined by Bhattacharyya (*12*).

In this interpretation a value of 10^{-3} electromagnetic unit has been assigned for the susceptibility of the model material in order to represent an average basalt. In their study of the rock types used in Olmec monuments, Williams and Heizer describe most of the stone used at the La Venta site as olivine basalt with scattered magnetite grains (*9*), a description that would certainly not classify them as iron-deficient. As-

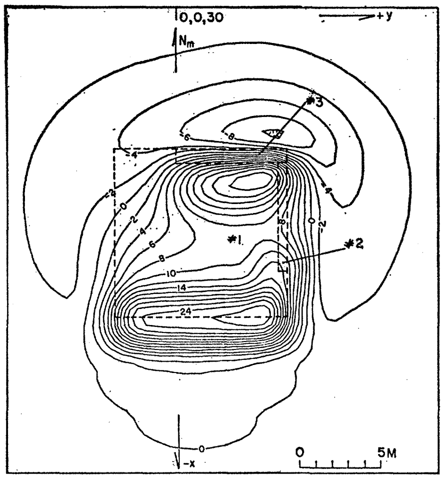

Fig. 3. Plan view (computer-drawn) of the basalt platform with two walls, with superimposed magnetic anomaly contours (in gammas). Blocks 1, 2, and 3 come to within 1.0, 1.0, and 1.5 m of the pyramid's surface, respectively. Block 1: $Z = 20.75$; $\Delta z = 0.25$. Block 2: $Z = 21.50$; $\Delta z = 0.50$. Block 3: $Z = 22.50$; $\Delta z = 1.50$. The point 0,0,30 is located at the center of the pyramid and 30 m above its base.

suming a "normal basalt," it is evident that the choice of 10^{-3} is probably conservative. It has also been assumed that the magnetization is uniform and is in the direction of the earth's field.

The values of the model anomaly have been calculated for points on the surface of an equivalent cone; these project in plan to an equidimensional grid. These points are then contoured within the computer program, and the resulting anomaly is plotted by a Calcomp plotter and compared with the field data.

Tests of models representing discontinuities in the soil layer (that is, pits) indicated that the anomaly could also be produced by some slablike body at least 4 m thick with a susceptibility of approximately 10^{-4}. There are several possible forms that this structure could take. One would be a pit filled with highly organic soil. Another would be a pit filled with some stone other than basalt. It is difficult to imagine that a pit of this composition and dimension would show no erosional expression and no surface geological expression. Should the pit contain a less susceptible stone than basalt (for instance, serpentine), then a significant archeological structure would still be indicated.

The fitting of "standard" buried block models is a matter of trial and error procedures. This process is extremely tedious and is quite costly in computer time; therefore, the present analysis has not been continued beyond a model that provides a basic fit. The final multiple block model that was found to provide a good basic fit to the data consists of a thin 10- by 10-m platform with peripheral walls on the northern and eastern sides (see dotted outline in Fig. 3). The horizontal location to the center of mass of the block is given in this plan drawing, with the vertical coordinate (Z) to its center and the half-height (Δz) given in the figure legend. The x coordinate is positive north, y is positive east, and z is positive up, all with respect to the base and center of the pyramid. The enclosing margin of the model location plot and the resulting model anomaly (Fig. 3) correspond to the inner rectangle of Fig. 2.

The calculated anomaly (Fig. 3) fits the field data surprisingly well, except that the background level of these theoretical data must be raised over a broad area and its western side must be stretched out. It appears that an even deeper structure is responsible for this broadening in the field data. The effects of topography and the generally disturbed area within 4 m of the top all combine to complicate the interpretation. However, it may be safely concluded from this model work that the basalt structure comes within 1 to 2 m of the surface and is of the general form suggested by the slab-plus-walls model.

FRANK MORRISON
JOSÉ BENAVENTE
Department of Materials Science and Engineering, University of California, Berkeley 94720
C. W. CLEWLOW, JR.
R. F. HEIZER
Department of Anthropology, University of California

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Mariner 6: Origin of Mars Ionized Carbon Dioxide Ultraviolet Spectrum

Abstract. *The predicted intensities of the ionized carbon dioxide ($CO_2{}^+$) emission feature at 2890 angstroms and the Fox-Duffendack-Barker bands are 5.2 and 19.9 kilorayleighs, respectively, for a vertical column. Direct photoionization of carbon dioxide by solar radiation contributes 3.5 and 4.1 kilorayleighs, respectively, and fluorescent scattering by $CO_2{}^+$, 1.6 and 15.3 kilorayleighs, respectively. Photoelectron impacts are less important.*

Studies by Barth *et al.* of Mariner 6 spectra (*1*) have established that the Fox-Duffendack-Barker bands and the $CO_2{}^+$ ultraviolet doublet bands are important components of the dayglow of Mars. Barth *et al.* (*1*) noted that the Mars spectrum they observed is similar to that produced in the laboratory by the bombardment of CO_2 by 20-ev electrons, and they pointed out that the excitation mechanisms that occur on Mars may or may not be electron-impact processes. Our calculations show that most of the excitations arise from photo-ionization of CO_2 and fluorescent scattering by $CO_2{}^+$ and that comparatively few excitations arise from electron impacts.

The Fox-Duffendack-Barker band system corresponds to the transition from the $\tilde{A}^2\Pi_u$ state to the $\tilde{X}^2\Pi_g$ state that emits over a broad region between 3000 and 4500 Å, and the $CO_2{}^+$ ultraviolet doublet band system corresponds to the transition from the $\tilde{B}^2\Sigma^+{}_u$ state to the $\tilde{X}^2\Pi_g$ state that emits over a narrow region near 2890 Å. The excited $\tilde{A}^2\Pi_u$ and $\tilde{B}^2\Sigma^+{}_u$ levels of $CO_2{}^+$ can be populated (i) by direct photo-ionization of CO_2 by solar radiation

$$CO_2 + h\nu \longrightarrow CO_2{}^+(\tilde{A}^2\Pi_u, \tilde{B}^2\Sigma^+{}_u) + e \quad (1)$$