# Geophysical tests applied to the archaeological research of the Sacred City of Caral

## Des essais geophisiques appliqués aux recherches archeologiques dans la ville sacrée de Caral

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ABSTRACT:
The investigation was carried out in the Sacred City of Caral considered as the oldest civilization of America, with 5000 BC, located in Supe to the north of Lima. The objective is to contribute to the archaeological investigations using non-destructive techniques applying Geophysical methods of Geo Radar, Seismic Refraction and Multichannel Analysis of Surface Waves (MASW). It was made a comparison between the P wave velocity (Vp), S wave velocity (Vs) and dielectric constant (k) of the three geophysical tests that were also used to obtain greater precision. The work has been done in two zones: Zone 01: "Dune" and Zone 02: "Possible cemetery". It has been determined that shear wave velocity varies from 180 m/s to 340 m/s. In the zone 01 has been found an Aeolian material that has a thickness of 2.0 m to 8.8 m; Beneath this cover was found a more rigid material that could be a natural barrier that protected the city from the floods that occurred in the rainy season. In the zone 02, an anomaly in the form of a parabola was visualized, reason why an excavation was decided, finding a funerary context of an adult mummy and of an infant.

RÉSUMÉ :
La recherche a été développée dans la ville sacrée de Caral considérée comme la civilisation la plus ancienne d'Amérique, 5000 av J.C. Elle est située au nord de la capital Lima .L'objectif est de contribuer aux recherches archéologiques en utilisant des techniques non destructives et en appliquant les méthodes géophysiques Geo-radar, réfraction sismique et MASW.
Afin d'obtenir une meilleure précision dans nos explorations nous avons effectué une comparaison de la vitesse d'onde P (Vp), vitesse d'onde S (Vs) et le constant diélectrique (k) des 3 essais géophysiques. Les recherches ont été réalisées sur les Zone 01 "Dune" et Zone 02 " possible cimetière ». Il a été déterminé que la vitesse de coupe varie de 180 m/s à 340m/s. Sur la zone 01, il a été trouvé un matériel éolien d'une puissance de 2.0m à 8.0m. En dessous de cette couverture nous avons trouvé un matériel plus rigide qui pourrait être une barrière naturelle protégeant la ville contre les alluvions qui ont eu lieu pendant la saison des pluies.
Dans la zone 02, on a visualisé une anomalie sous la forme d'une parabole. C'est pour cette raison que nous avons décidé de réaliser des excavations. Nous y avons trouvé un contexte funéraire d'une momie adulte avec un enfant.

KEYWORDS: Geophysics test, shear wave velocity, radargrams.

## 1.0 INTRODUCTION

The Sacred City of Caral is the urban establishment of the oldest civilization in America, approximately 5000 years old. It is located on the left bank of the river Supe, at an altitude of 350 meters above sea level, on the central coast of Peru, Supe district, Barranca province and Lima department. This civilization would have been occupied between 500 and 660 years (Carlotto et al., 2001) [1], so it is inferred the existence of a cemetery that to date has not been possible to find. It is also worth mentioning that there is a hypothesis about the extinction of the Caral population that was hit by two major events of nature, a major earthquake, and a major event, similar to the *El Niño* phenomenon, followed by a drought. A jumping aspect is the presence of a dune located transversally to the Chupacigarro ravine, south of the sacred city of Caral. Figure N ° 01

The present study aims to contribute to archaeological research using geophysical tests.


Figura N° 01: Sacred City of Caral, satelital image

## 2.0 GEOPHYSICAL TESTS CARRIED OUT

The geophysical research was carried out in two stages during the months of October 2015 and November 2016. The work has been done in two zones: zone 01 "Dune" and zone 02 "Possible cemetery" (Figure N ° 02), through the following Tests: Ten lines of Seismic Refraction with a total length of 756 meters, two 1D MASW test points and one 2D MASW test line, determining the compressional and shearing wave velocities (P waves and S waves) and 115 lines with Georadar (GPR) in a total length of 3912 meters. Table No. 01. Summarizes the tests performed.

Table N ° 01. Summary of tests performed

| Areas | Stages | Seismic Refraction | | Masw | | Georadar (gpr) | |
|---|---|---|---|---|---|---|---|
| | | Nº of lines | Length (m) | Nº of points | Length (m) | Nº of lines | Length (m) |
| Dune | 1ra | 3 | 204 | 1 | 54.5 | 4 | 210.8 |
| | 2da | 2 | 192 | 2 | 100 | 31 | 728 |
| Cemetery | 1ra | 5 | 360 | - | - | 80 | 2974 |
| Total | | **10** | **756** | **3** | **154.5** | **115** | **3912.8** |

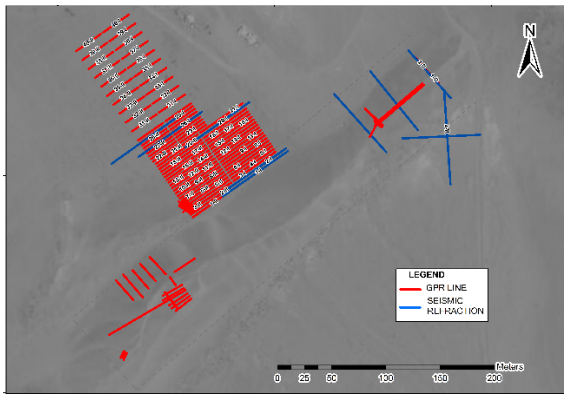


Figure N° 02: View of location of done geophysical test

## 2.0 ANALYSIS AND INTERPRETATION

In Zone 01, a group of radargrams was analyzed through which the presence of Aeolian sand having a thickness varying between 4 m and 6.5 m was located. According to the seismic profiles, the minimum and maximum depth of investigation has been 13.0 m and 21.0 m respectively. Vp speeds range from 300 m/s to 600 m/s. The Shear velocity profile determined that the minimum shearing velocity is 180 m/s and the maximum value is 340 m/s, so the material type has a loose compactness, moderately dense and dense. See Tables N° 02 and 03, Figures from N°03 to N°05. At 8.0 m below this cover it is assumed that there is a more rigid material, disposed as a natural barrier that protected the city from alluviums that occurred in the rainy season.

**Table No. 02. Values of Vs (m/s)**

| **Zone 01** | **Vs (m/s)** | **Thickness (m)** | **Description** |
|---|---|---|---|
| Dune High | <180 | 2.00 -3.00 | Aeolian sand of loose compactness. |
| | 180 ≤ Vs ≤ 260 | 3.00-5.00 | Loose, medium to dense compact Aeolian sand |
| | 260 ≤ Vs ≤ 340 | 2.00-8.00 | Compact alluvial material |
| Dune Small | <180 | - | Aeolian sand of loose compactness. |
| | 180 ≤ Vs ≤ 260 | 2.50-3.50 | Loose, medium to dense compact Aeolian sand |
| | 260 ≤ Vs ≤ 340 | 1.00-1.50 | Compact alluvial material |

Table N ° 03. Values of Vp (m/s)

| Zone 01 | Vp (m/s) | Thickness (m) | Description |
|---|---|---|---|
| Dune – High | 300 | 4.00 -6.00 | Aeolian sand |
| | 400 | 4.00 -6.00 | Sand with gravel |
| | 500 | 3.00 -6.00 | Alluvial material |
| | 600 | 2.00-3.00 | Alluvial material |
| Dune - Small | 300 | 2.50-3.50 | Aeolian sand |
| | 400 | 1.00-1.50 | Sand with gravel |
| | 500 | 1.00 | Alluvial material |
| | 600 | 0.50-1.00 | Alluvial material |

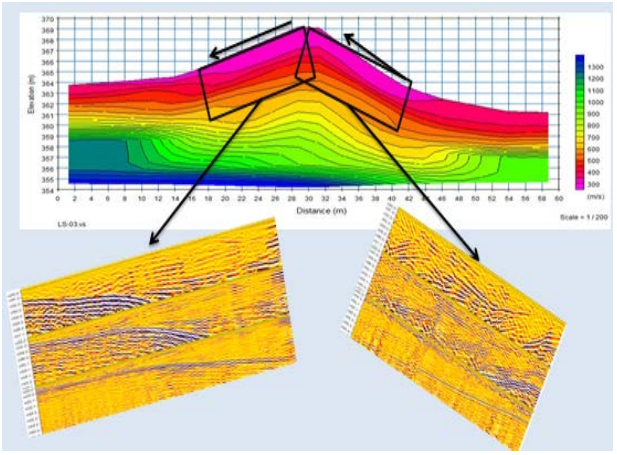


Figure N° 03. Evaluation of thickness of the aeolian sand of the dune by compare the seismic profile and radargram

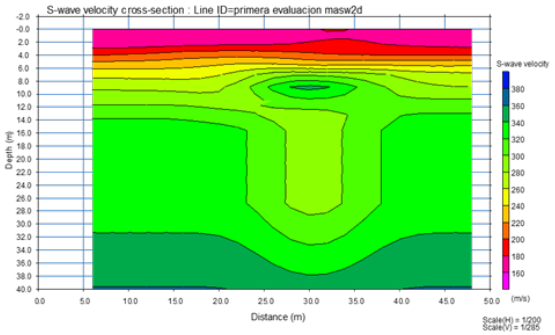


Figure N° 04. S-wave velocity seismic profile of MASW test

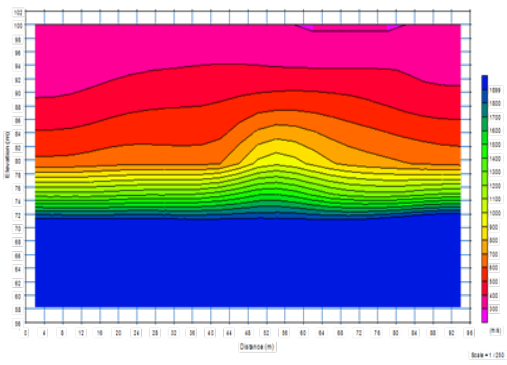

Figure N° 05. P-wave velocity seismic profile of seismic refraction test

In Zone 02 the results of the radargrams were analyzed, being possible to identify three types of soils: sand with silt, gravel with fragments of rock and silty sand with presence of gravel. In a radargram, an anomaly in the form of a parabola was visualized at a distance of 33 m and a depth of 1.4 m, whereby an excavation was made with the responsible archaeologist, finding a funerary context of two mummies one adult and one infant with different elements, such as knitting sword, needles, fragment of textile, ceramic vase among others (Bezares M, 2016) [2] as is shown in Figure N°06 and Photograph N°01.

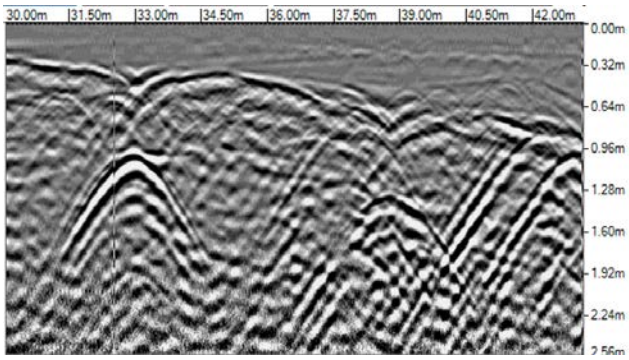


Figure N° 06.The radargram shows the anomaly is in form of parabola

Photograph N° 01. View of mummy, the anomaly of the radargram

## 4.0 COMPARISON OF GEOPHYSICAL TESTS

A comparison of seismic refraction, MASW and GPR results in zone 01 was performed in the same alignment. With respect to the Georadar it is known that the relative dielectric constant (k) not only varies according to the type of soil, it varies according to the density, humidity, temperature and frequency. In sands the value of k varies in function of humidity and density, the frequency of the antenna has little influence (Cihlar and Ulaby, 1974) [3]. For the case of the sands, Cihlar and Ulaby (1974) [3] propose curves that relate the dielectric constant of the real part (k1) and imaginary part (k2) as a function of humidity (w), considering the humidity less than 40%, by means of the following relation (See equations Nº 1 y Nº 2):

$$k1=3+0.5w, \quad 0.3GHz < f < 1.5GHz \qquad (1)$$

$$k2=0.26w, \quad 0.3GHz < f < 1.5GHz \qquad (2)$$

The obtained parameters of Vp, Vs and k were compared. First, we compared the values of P wave velocity and S wave velocity, estimating that the sand extends to 8.8m depth (Alva et al, 2015) [4], and the Vp / Vs ratio and Poisson Value, as shown in Table No. 04. It is observed that at the depth of 0.0 to 8.8 m the values of the Poisson quotient are between 0.24 and 0.31 corresponding to fine-grained sands of medium and dense compactness, respectively, according to Alva 2005 [5].

The relative dielectric constant (k) was also evaluated as a function of humidity (w%), considering that the frequ encies of the Georadar antenna used are 250MHz, 500MH z and 1000MHZ. Equations 1 and 2 were used to obtain t he value of k, to be compared with the values of Vs and Vp, the comparison of these values is shown in Table No. 04. This comparison is shown in Figure N°07 at the respec tive depth. When the value of k versus Vs and Vp is com pared it is observed that for the low dune Vs and Vp hav e a linear behavior, whereas for the high dune the values of Vs and Vp have a bilinear behavior being this change or break to the depth of 3.7 m due to the change in dens ity of the material as is shown in Figure No. 08

By the result of the radargram the soil type can be identified and therefore the dielectric constant of the soil type can be known, considering that for the case of the Aeolian sand of the Caral dune the behavior is bilineal so it is possible to estimate the velocities of P wave and S wave, with the following equations Nº 3 y Nº 4:

**for 0<k<=3.7**

$$Vs = 9\,0.4k - 92.8 \qquad (3)$$

$$Vp = 161.2k - 162.8 \qquad (4)$$

Table No. 04. (Vp, Vs), Humidity (%), dielectric constant (K)

| Description | Depth (m) | Vp/Vs | Poisson Value | k2/k1 | K |
|---|---|---|---|---|---|
| Dune high | 0.0 | 1.76 | 0.26 | 0.00 | 3.00 |
| | 0.8 | 1.81 | 0.28 | 0.01 | 3.05 |
| | 1.7 | 1.85 | 0.29 | 0.02 | 3.10 |
| | 2.6 | 1.84 | 0.29 | 0.04 | 3.25 |
| | 3.7 | 1.82 | 0.28 | 0.07 | 3.51 |
| | 4.8 | 1.79 | 0.27 | 0.09 | 3.61 |
| | 6.1 | 1.74 | 0.25 | 0.09 | 3.64 |
| | 7.4 | 1.72 | 0.24 | 0.09 | 3.67 |
| | 8.8 | 1.82 | 0.28 | 0.10 | 3.69 |
| Dune small | 0.0 | 1.78 | 0.27 | 0.00 | 3.00 |
| | 0.8 | 1.74 | 0.25 | 0.01 | 3.05 |
| | 1.7 | 1.80 | 0.28 | 0.02 | 3.10 |
| | 2.6 | 1.79 | 0.27 | 0.04 | 3.25 |
| | 3.7 | 1.90 | 0.31 | 0.07 | 3.51 |

## 5.0 CONCLUSIONS

- The subsoil of the Sacred City of Caral has been evaluated by geophysical tests, identifying the stratigraphy, dynamic properties of the soil and some anomalies in zone 01 "Dune" and zone 02 " Possible cemetery" contributing to the archaeological investigations.
- From the seismic profiles, the stratigraphy of zone 01 has been determined, with the presence of Aeolian sand up to 8.8 m. Below this cover it is assumed that there is a more rigid material, disposed as a natural barrier that protected the city from alluviums that occurred in times of rain.
- An anomaly in the form of a parabola at a distance of 33 m and a depth of 1.4 m was visualized in a radargram of zone 02, whereby an excavation was carried out with the responsible archaeologist, finding a funeral context of two mummies of one adult and one infant with different elements, such as knitting sword, needles, fragment of textile, pottery vase among others.
- By the result of the radargram the soil type can be identified and therefore the dielectric constant of the soil type can be known, considering that for the Aeolian sand of the Caral dune the behavior is bilinear it is possible to estimate the velocities of P waves and S waves, with the following equations Nº 3 y Nº 4:

**for 0<k<=3.7**

$$Vs = 9\ 0.4k - 92.8 \quad (3)$$

$$Vp = 161.2k - 162.8 \quad (4)$$

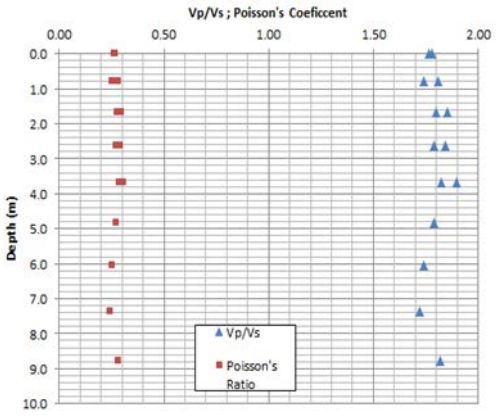


Figure N°07 Vp/Vs Ratio and Poisson's ratio with the depth

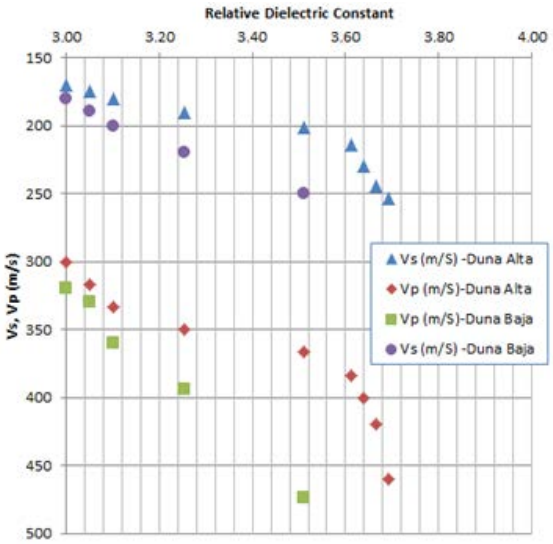


Figure N°08 Relatisonship of k y Vp, k y Vs

## 6.0 ACKNOWLEDGMENTS

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