UNIVERSIDADE FEDERAL DO PARÁ
INSTITUTO DE GEOCIÊNCIAS
CURSO DE PÓS-GRADUAÇÃO EM GEOFÍSICA

DISSERTAÇÃO DE MESTRADO

High Resolution GPR applied to the "Capela Pombo"

MANUEL ALEJANDRO JUNIOR ESPEJO ZEBALLOS

Belém
2016

MANUEL ALEJANDRO JUNIOR ESPEJO ZEBALLOS

High Resolution GPR applied to the "Capela Pombo"

Dissertação apresentada ao Programa de Pós-Graduação em Geofísica da Universidade Federal do Pará para obtenção do título de Mestre em Geofísica.

Área de Concentração: Métodos Eletromagnéticos

Orientador: Marcos Welby Correa Silva

Belém
2016

Dados Internacionais de Catalogação-na-Publicação (CIP)
Sistema de Bibliotecas da UFPA

Espejo Zeballos, Manuel Alejandro Junior, 1984-
High resolution gpr applied to the / Manuel Alejandro Junior Espejo Zeballos. - 2016.

Orientador: Marcos Welby Correa Silva.
Dissertação (Mestrado) - Universidade Federal do Pará, Instituto de Geociências, Programa de Pós-Graduação em Geofísica, Belém, 2016.

1. Geofísica na arqueologia - Belém (PA). 2. Radar de penetração no solo. 3. Arqueologia - Belém (PA). 4. Capela Pombo. I. Título.

CDD 22. ed. 930.10155

MANUEL ALEJANDRO JUNIOR ESPEJO ZEBALLOS

High Resolution GPR applied to the "Capela Pombo"

Dissertação apresentada ao Programa de Pós-Graduação em Geofísica da Universidade Federal do Pará para obtenção do título de Mestre em Geofísica.

Data de aprovação: 29 de fevereiro de 2016
Banca Examinadora:

Marcos Welby Correa Silva – Orientador.
Doutor em Geofísica.
Universidade Federal do Pará.

Diogo Menezes Costa
Doutor em Arqueologia.
Universidade Federal do Pará.

Victor Cezar Tocantins de Souza
Doutor em Geofísica.
Universidade Federal do Pará.

to my daughter, my "LEONCITA", CARPE DIEM

AGRADECIMENTOS

To my God for the health and strength to complete this big part of my life, overcoming the difficulties presented along the way.

To my daughter for by a constant source of strength and laughter, to give me the purpose to finish this journey.

To the professor Marcos Welby Correa Silva, for believe in my efforts and help me to make real this Work.

My friends and colleges, who were always supporting me, directly or indirectly, during this challenge; I thank in a special way to my friends Jarold Garcia Perez, Jorgue Antonio Teruya Monroe who contributed to this work.

To the professor Ellen Gomes and Cícero Roberto Teixeira Régis, by the confidence in our work and effort,

To the members of the Examining Committee, Prof. Dr. Diogo Menezes Costa and Prof. Dr. Victor Cezar Tocantis de Souza by the attention and patience provided in reading and correction of this work.

To the CPGf by confidence in the success of this project, providing facilities and resources for the development of this project.

to CNPq and INCT-Gp, whose financial support was instrumental in this work, through the stock incentive.

I would like to thanks to the Forum Landi UFPA by the help for the development of this work.

The dear secretaries of the graduate program in Geophysics, Benildes and Lucibela, competent professionals, always ready to solve any problem with a patient service, polite and affectionate.

My mother and all my family for all encouragement and support provided, as well as the trust placed in my plans.

RESUMO

Neste projeto foi aplicado o método eletromagnético (GPR), para a identificação de camadas superficiais, em um ambiente urbano específico. As medidas foram realizadas pra mapear camadas superficiais e artefatos que compõem a zona de estudo "*Capela de Nosso Senhor dos Passos - a Capela Pombo*", no Barrio da Campina-Belém. Esta capela conta com um trabalho prévio que resgata a importância y caraterísticas arquitetônicas que ela possui, conjuntamente com as evidência recoletadas pelo autor Domingos Sávio de Castro Oliveira, que assinalaram a importância histórica que tem, não só por ser a última capela privada na cidade de Belém, este Autor também reconhece la capela como uma possíble obra do arquiteto italiano Guissepi Antonio José Landi. Os perfis obtidos depois do correspondente processo de processamento, mostram que esta estutura apresenta provavelmente restos da estrutura do prédio, que anteriormente se encontrava nesse espaço. O estudo teve como objetivo principal identificar anomalias. O estudo teve como objetivo principal identificar anomalias estruturais, assim como possíveis soterramentos característicos da época quando foi ativamente utilizada. Os resultados das medidas de GPR foram encorajadores, pois o método apresentou resposta aproximadamente de 1.80 metros de profundidade, pode-se identificar anomalias de controle como as apresentadas pelos fundamentos da Capela, além de apresentar, possiveis anomalias ligadas a corpos estranhos estruturais.

Palavras-chaves: GPR. Arqueologia. Capela Pombo.

ABSTRACT

In this work was applied electromagnetic method (GPR), to identify surface layers in a specific urban environment. The measurements were performed to map the surface layers and artifacts that make up the study area " *Capela de Nosso Senhor dos Passos - a Capela Pombo*" in the Barrio of *Campina-Belém*. This chapel has a previous work that rescues the importance y architectural features that it has, together with the evidence recollected by the author Dominic Savio de Castro Oliveira, who noted the historical importance that has not only to be the last private chapel in the city of Belém, this author also acknowledges her design as an Italian architect's work possible Guissepi José Antonio Landi. The profiles obtained after corresponding processing procedure, show that this probably presences of structures, rest of the previous building structure, which previously was in this space. The study aimed to identify anomalies. The study aimed to identify structural abnormalities, as well as possible characteristic burials of the time when it was actively used. The results of the GPR measurements were encouraging, since the method presented response of approximately 1.80 meters deep, one can identify anomalies control for the reasons as presented Chapel, and present possible anomalies related to structural foreign bodies.

Keywords: GPR. Archeology. Chapel Pombo.

LIST OF FIGURES

CONTENTS

1 INTRODUCTION

The main purpose of this work is be show the use of the Ground Penetration Radar (GPR), in another task beside of the regular use. In the earth sciences it is used to study bedrock, soils, groundwater, and ice. It is of some utility in prospecting for gold *nuggets* and for diamonds in alluvial gravel beds, by finding natural traps in buried stream beds that have the potential for accumulating heavier particles. But is more frequently use as a non-destructive testing (NDT)device (ANA OSELLA, 2006).

In archaeology generally it is used for mapping archaeological features and cemeteries or in the investigation of archaeological areas like the work made by MARINA DA SILVEIRA in Engenho Murutucu. This research sought through geophysical methodology the indication of possible locations of buried remains of occupation and foundations of the old construction of a slave quarter in the Engenho Murutucu, a historical site that has importance and relevance for the history of Pará. Following a magnetic map constructed with data from a previous research, 26 GPR profiles. The analysis and correlation of the magnetic and GPR data allowed to reach the purpose of the research. The resulting geophysical indications will guide the future archaeological interventions in the site (MELO, 2007).

We also have the example of the work of HERSON OLIVEIRA. The survey at a site is located in the municipality of estuarine Penalva in the state of Maranhão. The methods used were Magnetometry and Ground Penetrating Radar (GPR). The magnetic measurements were used to indicate the locations for excavation. The GPR was used to confirm the anomalies generated by the magnetic method, providing fewer errors when the magnetic anomalies are not caused by archaeological features. Were 14 profiles performed GPR using an antenna 400 MHz and 1664 magnetic measurements using the magnetometer. During the archaeological survey conducted, based on the geophysical anomalies provided by the team led by archaeologists Deusdedit Carneiro Leite Filho and Luiz Fernando Tavares Marques made five excavations at the site, which allowed them to rescue several ceramic pieces. The results presented in this work allowed him to verify and evaluate the potential of geophysical prospecting method to assist in archaeological studies (ROCHA, 2012).

We can see another example in the work of SELMA RODRIGUES. In this case, GPR and electromagnetic induction (EM-38 instrument) method contributions in coastal *sambaqui* archaeological sites (Jabuticabeira II, Santa Marta IV, V, VII and VIII as well as Encantada III) are presented. These sites are placed in Jaguaruna, Santa Catarina center-south coast. They are characterized by accumulation of carbonate shells built by societies in pre-colonial period (7.5 to 1.3 thousand years BP). The studies were developed aimed at mapping archaeological artifacts and stratigraphic structures that help to understand

constructive and functional process of these sites. The interpretation of GPR results was supported by 2D GPR numerical modeling, 3D images and integrated with EM-38 surveys. They had as objectives to guide archaeological excavations. The results allowed finding archaeological targets and artifacts, reduced costs in exploratory process, and preserved historical heritage. Complementing integrated interpretation process, stratigraphic profiles and granulometric analysis of sediment from sounding drifts were important for defining the deposition environments where sambaquis (shell mounds) are settled, significantly supporting in developing research on Santa Catarina coast(RODRIGUES, 2009). Showing several results this work prove one more time the practicality of the GPR and the important of use more that one geophysical method.

In different type of environments or location the GPR present the same usefulness. We have the work made by CARLA QUEIROZ. This work was part of the Rescue Program for the Archaeological Site PA-ST-42: Santarem's Port located in Santarém/PA. Measurements were performed in Area 2 and Area 2A - Field 1, 2 and 3 using GPR as methodology. The GPR was applied in order to test the feasibility of the method in archaeological research, demonstrating its ability to identify structures and/or artifacts buried in the sites. The processing and analysis of the data allowed the observation of three anomalous patterns, which later were related to the presence and/or concentration of artifacts found under some profiles, according to the excavations(FURTADO, 2013). The urban environment of this work show the versatility and practicality for the use of this method.

Or in the inside of historical buildings like the example present by DANUSA DE SOUZA. This work was conducted in two areas. The first, located at the backyard of the Palacete Faciola,Belém/PA and, the second, named 4A, in the Archaeological Site PA-ST-42, located at the Port of Santarém/PA. The geophysical survey described in this work was undertaken in order to assist in archaeological prospecting, indicating places for future excavations in order to detect structures and/or artifacts buried on the sites. The radargrams acquired in both areas showed several anomalous features. Until the finish of this work in 2012, any excavation had been undertaken in Palacete Faciola. In 4A area, however, two trenches were opened revealing various archaeological fragments. (SOUZA, 2012), in this case is she use this method, trying to help in the recuperation and rebuild of this historical landmark building.

This work has been made in the "Capela de Nosso Senhor dos Passos" or mostly know as "Capela Pombo"a private chapel Designed possibly between 1754 - 1761, for the Italian architect Giuseppe Antonio Landi, and his construction was finish in 1790.

Aesthetically presents particular points, characteristic of the time in his was design, befitting of the European artistic movements of the XVIII century, mostly related with the Baroque movement.

Will use a multidisciplinary point of view to make the interpretation of the profiles

recorded in this work, using concepts apply in Geotchnical studies and projects in urban environment.

2 CAPELA POMBO

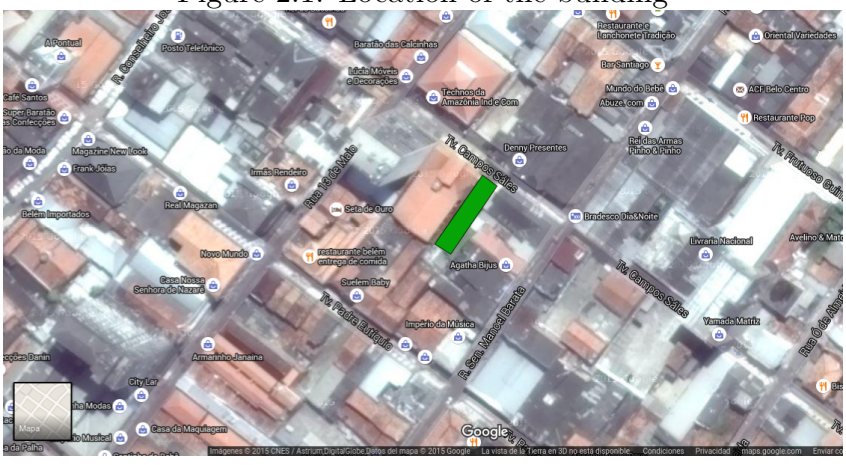
2.1 HISTORY AND LOCATION

The foundation of the city of Belem is considered since the arrival of the Portuguese sailors, around to the year of 1616. The start of the occupation begins surrounding the *Forte do Presépio* next of this military fortress was form the neighbourhood of *Bairro da Cidade*, call at the present time *Cidade Velha*, after that still in the XVII century, was expended to the area know this days fof the name of *Bairro da Campina*, been that two neighbourhoods separate waterlogged of the *Piri* (OLIVEIRA, 2008).

In the actual time this part of the city belongs to the denominated *Barrio Campina* a comercial area, and has the problem of overcrowding, noise pollution, visual contamination, and don't have tourist attractions, this take the potential tourist to other parts of the city.

The chapel *Capela do Senhor Bom Jesus dos Passos* and the adjoining mansion are ubicate in the *Travessa Campos Sales*, between the streets *13 de Maio* and *Senador Manoel Barata*, Figure 2.1.

Figure 2.1: Location of the building



Source:Google Earth 2016

The General Francisco Xavier de Mendonça Furtado, with the tittle of *Governador do Estado do Maranhão, Grão Pará e Rio Negro* commend a cartography work to Schwebel , this work made in the year of 1753 mention the existence of a building in that location. Otherwise in the extension of the same work in the year 1758, is made a mention of a enlargement of this building and the *existence of a chapel*.

All the history and registers of this time give us a confusing idea of this building, so we can't do reconstruct the time line of this historical landmark of the city. For example we have a three different denomination of this building, the first one, *Capela do Senhor dos Passos* (MEIRA FILHO, 1969) and the second one *Senhor Bom Jesus dos Passos* (TOCANTIS, 1987) and finally *Nosso Senhor dos Passos (IPHAN)*, but is much commonly know it like *Capela Pombo*.

The popular tradition tells us it was the *Coronel Ambrósio Henriques* was the person to entrusted the edification of this chapel, to be use by his family and friends. The end of its construction is indicated between the year 1790 (MEIRA FILHO, 1969) and 1793 (BARATA, 1914), and also the historical data give by OLIVEIRA (2008) tell us the possible author of this piece of art was *Antonio José Landi*, a architecture.

There are multiple of reference of this building, creating different version of the destine of this piece of art, in order to conserve the most accurate flow of information we take the most clear piece of information in this case will be provide by BARATA (1914).

> "Em 1841, já completamente arruinado o abandonado edifício, e constituído imminente perigo para os transeuntes mandouo demolir a câmara municipal"

In the decade of 1920 the property pass to the hands of the *Correa do Guamá*. In this period, the artistic elements of the inside they were looted, but the original totems of the saints were preserve until the year 1949, when the crowds and some figures were stolen. In the same year the chapel became deposit of papers, and keep closed. The chapel return to the hands of the Pombo family in the year of 1973,by means of a testament, donated to *José Augusto da Silva Pombo*. In the same year, a reform was carried out under the responsibility of Augusto Meira Filho (KETTLE, 2008).

The building was recognized like a historical heritage.

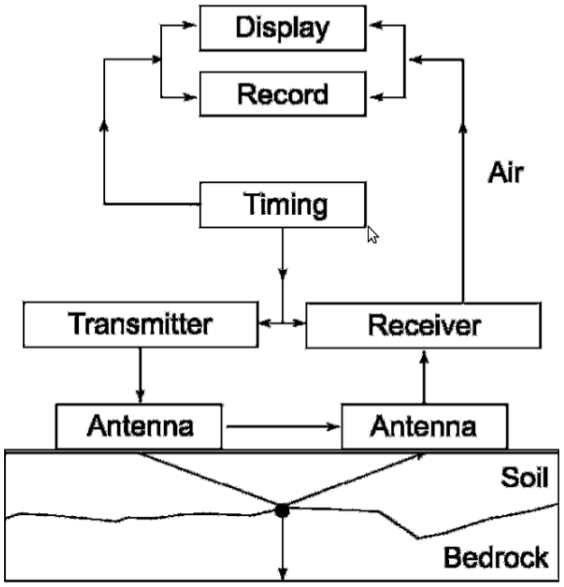
3 GPR METHOD

3.1 MEASURES WITH GROUND PENETRATING RADAR(GPR)

GPR is a geophysical method that can accurately map the spatial extent of near-surface objects and archaeological features or changes in soil media and ultimately produce images of those materials. Radar waves are propagated in distinct pulses from a surface antenna, reflected off buried objects, features, bedding contacts, or soil units, and detected back at the source by a receiving antenna. As radar pulses are transmitted through various materials on their way to the buried targets, their velocity changes depending on the physical and chemical properties of the material through which they travel (CONYERS, 2004; CONYERS; GOODMAN, 1997). The greater the contrast in electrical and to some extent magnetic properties between two materials at a subsurface interface, the greater the strength of the reflected signal and therefore the greater the amplitude of the reflected waves. When the travel times of energy pulses are measured and their velocity through the ground is known, distance (or depth in the ground) can be accurately measured to produce a three-dimensional data set (CONYERS; LUCIUS, 1997). Each time a radar pulse traverses a material with a different composition or water saturation, the velocity changes and a portion of the radar energy is reflected back to the surface to be recorded at the receiving antenna. The remaining energy continues to pass into the ground to be further reflected, until it finally spreads and dissipates with depth.

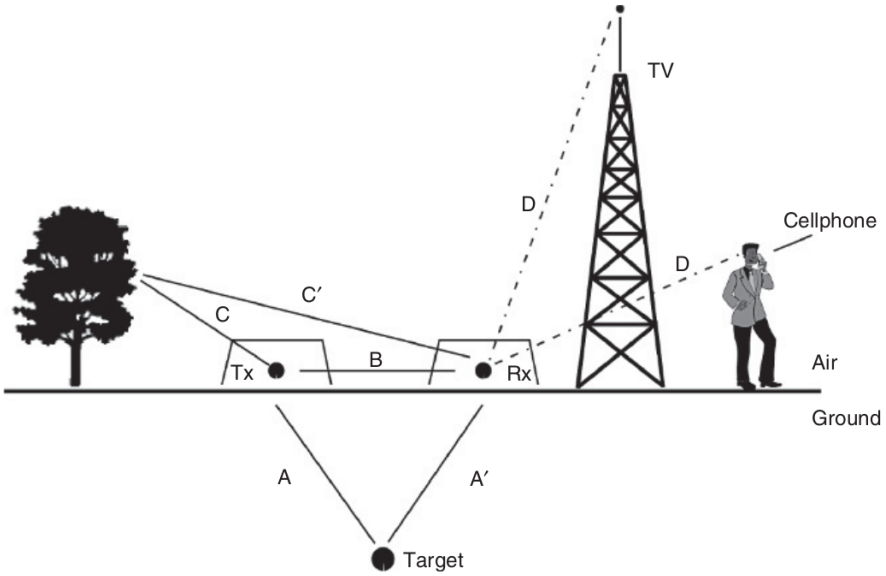
The GPR is a method of an artificial font. It consist in the irradiation of electromagnetic waves of high frequency, from a transmitting antenna(Tx) put close to the surface of the ground, the waves propagate through the materials of the surface, suffering reflection, refraction and diffraction. The waves returning to the surface are detected by the same antenna or in another reception antenna(Rx). The time of travelling between the instant of emission, irradiation, and the detection of the signal to return to the surface, is recorded, allowing them to estimate the depth of reflective interfaces, since it is known the velocity of the waves in the ground. The reflective interfaces are defined, whenever there variations in electromagnetic properties of the soil (electrical conductivity, permittivity and permeability and magnetic susceptibility).
The GPR has application to the archaeology for being a non-destructive method, being used for shallow depths (less than 3 m), giving the security in the demarcation of the areas of excavation and reducing the mistakes produced in this kind of activities. Another advantage of GPR is its contribution to the reduction in operating time, because the anomalous zones can be displayed during data collection.

Figure 3.1: Block diagram depicting main components of a ground penetrating radar (GPR)system.



Source: Ground Penetrating Radar Theory and Applications, 2008

Figure 3.2: A ground penetrating radar (GPR) system emits and detects radio wave signals. There are many possible signals and paths and the objective is to maximize the target response and minimize others.



Source: Ground Penetrating Radar Theory and Applications, 2008

Archaeological features in occupation of land, buried urns and pipelines, construction of foundations and tunnels produce patterns in very characteristic GPR records and can be distinguished from patterns associated with the course material deposited during geological processes.Among these patterns stand out from the side discontinuities in reflectors present in the records, usually caused by subsoil plowing during the burials, and

the hyperbolic forms, which can be caused by the presence of polls, pipelines and building foundations (JOL, 2009).
In this work, the GPR profiles were acquired with equipment GSSI(Geophysical Survey System) model 5103 and the antenna of 400Mrz. The measurements were performed by the time acquisition mode, the range use was 40 ηs and the sample per proflie was 512, with the distance control being done with the help of tape and inserting tags in the registry every 2 m. The lines were spaced measures of 50 cm.
Records obtained from the GPR were processed with the help of the Reflex-Win Version 7.5 program (Sandmeier Software). It was used only a basic processing to the following procedures to improve pictures:

a) Spatial redistribution of the sample to obtain uniform spacing between steps.

b) Establishment of zero record time, to obtain the zero level of depth (ground surface position).

c) Determination of the electromagnetic wave propagation velocity using the method of superposition hyperbolas.

d) Filter high-pass application (dewow).

e) Conversão da escala vertical de tempo em profundidade.

f) Gain application to compensate for the natural attenuation of signals.

g) applying bandpass filter with cut off frequencies of 50 MHz and 150 MHz.

h) Filter application removal background.

4 RESULTS AND CONCLUSIONS

We oriented the in-lines with the major walls, and the cross-lines are oriented in a perpendicular position to the in-lines, the distance between the in-lines was 50 centimetres approximately. The entrance of the building have a metallic internal structure, that it serves like a protection against intruders and support for the inner balcony, also has remains of the furniture in deteriorating conditions, caused for the strong humidity and the pass of time.
All the remains and furniture was carefully handle and placed in a proper position, to don't interrupt with the recording of the data.
We use a bi-static shielded antenna of 400 MHz, performing profiles ranging from 5m to 7m in length. This was the general setup with a Ground Penetration Radar (GPR) Model 5103, label Geophysical Survey Systems, the general setup was $4\eta s$ for the range factor, and the sample was 512.
Throughout this chapter will be shown profiles that identify these parameters for both inline and crosslines. We conduct 13 inline profiles in 2D and also 6 more crossline profiles, and a extra line in the back of the pulpit.

4.1 IN-LINES

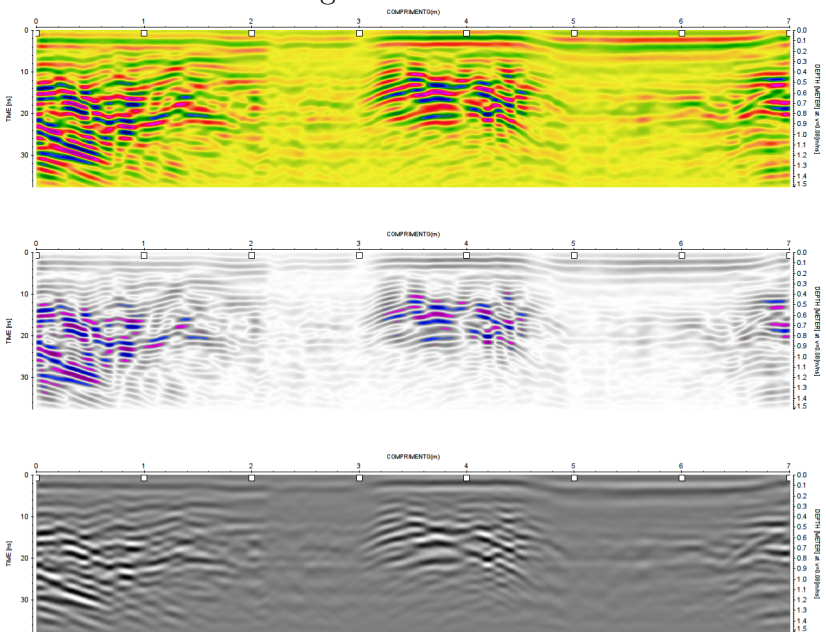
For the current profiles we can see, presence of anomalies, probably produced by the remains of the previous building located in that area. We have to consider the chapel was requested after the construction of the original building *Mansion dos Passos* and the anomalies that are gonna see with more interest are the ones to break the common behaviour of the excepted results, for example the anomalies produced for the support structures like pillars and walls. The anomalous signals are being take like a patron on behaviour. This will serve to a quick identification of the anomalies of interest, this method is used in the geotechnical project, like control of leaching pools, or the search for fails in tunnels. We need a control zone, to be compare to the rest of the data acquired.

4.1.1 Line A

We have 3 anomalies Fig. 4.3. The first one with length of 1.0 meters probably associated with the pillar and his foundations Fig. 4.1, presenting a constant behaviour in all other sections of 7 meters, this anomaly been seen as a control to ensure the continuity of other data.
The second anomaly starts approximately in 3.15 to 4.58 meters, and probably is also produced by the foundations of the building, and the two central pillars of the lateral wall

Nr^o 2 of the chapel, Fig. 4.2.
For our third anomaly, goes from 6.5 meters to the end of the line A, this one also is part of the foundations of the building, and coincide with the pillar of the lateral wall of the chapel (this hypothesis could be change at the end of the general analysis of all the IN-LINES).
Line A is a perfect example of the type of anomalies to has been founded in this work, and the quality of the signal, showing a constant thin layer at the beginning of the log. Representing the first layer of the floor (the only one original of that period). We witness this behaviour in all lines, close to front wall.

Figure 4.1: line A

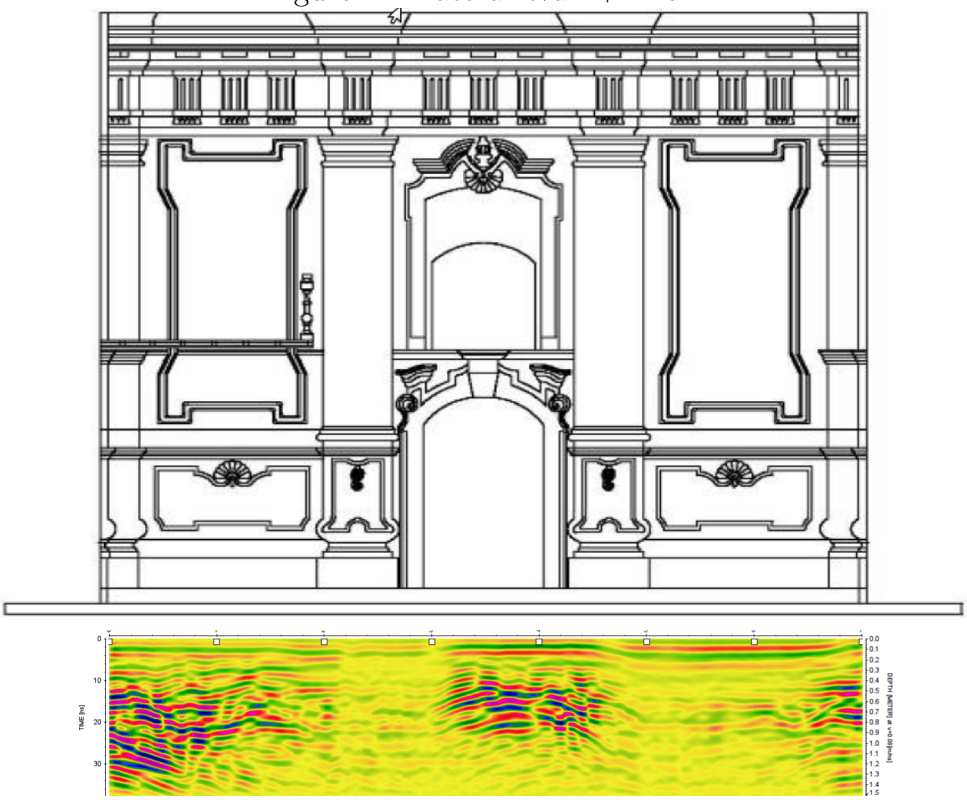


Source: The Author

4.1.2 Line B

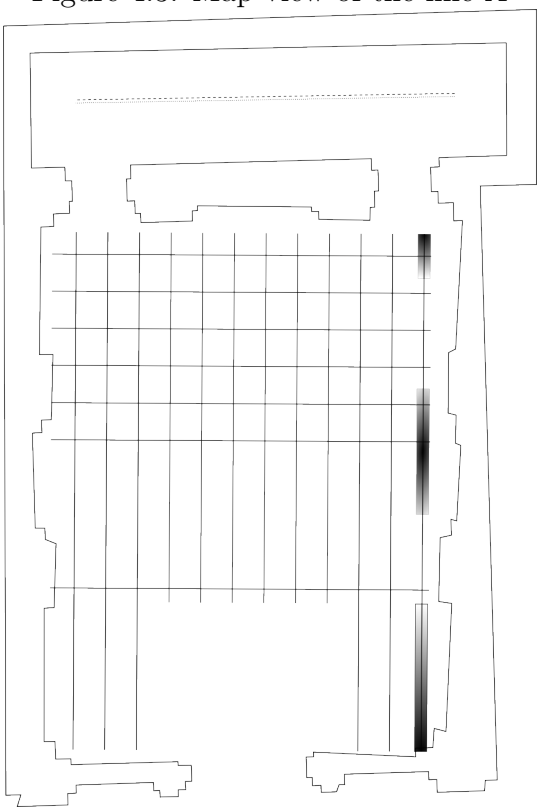
As can we see in the line A, the first anomaly is also present in this line, presenting almost the same characteristics of extension and the same possible depth, this is always see in the lines of 7 meters of length. In addition of this anomaly, is possible to see the deformation of the first layer, product of the own weight of the building, showing the most significant deformations close of the pillars.
For the second anomaly goes from 3.42 to 4.71 meters, like in the line A, this anomaly shows the same characteristics and almost the same length, and most important the same depth. We can assume the line A and B recorded the same anomaly and is in the same depth. The body that created this response is non metallic and probably share the same matrix of all the building.

Figure 4.2: lateral Wall + line A



Source: The Author

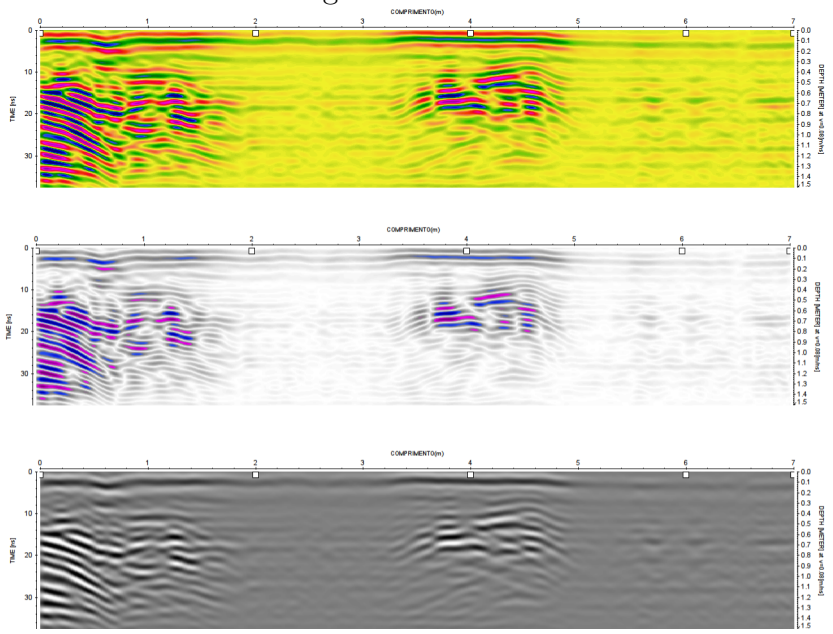
Figure 4.3: Map view of the line A



Source: The Author

The end of the line doesn't present any anomalous signal, because is relative far to the pillars, and close to the entrance of the sacristy. Is also consistent, with the absence of signs of deformation, in the surface layer. Except for a clear deformation in the distance off 6.5 meter, this has non explanation with out locking the line C

Figure 4.4: line B

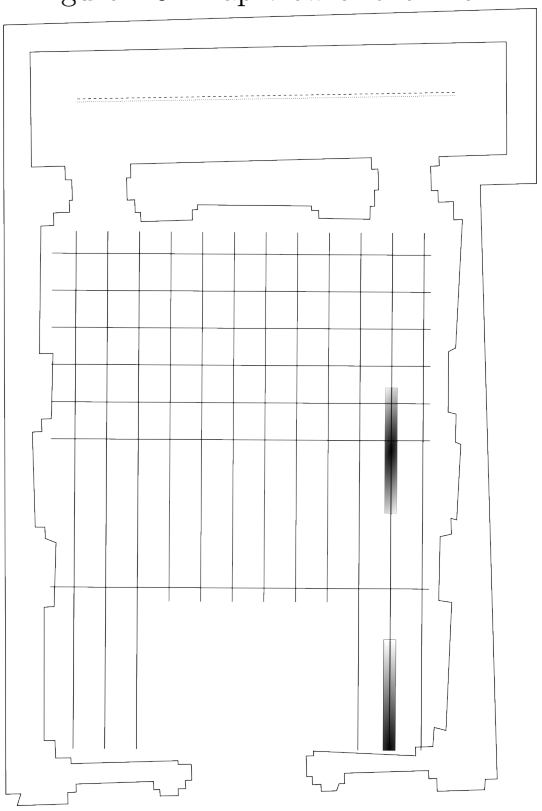


Source: The Author

4.1.3 Line C

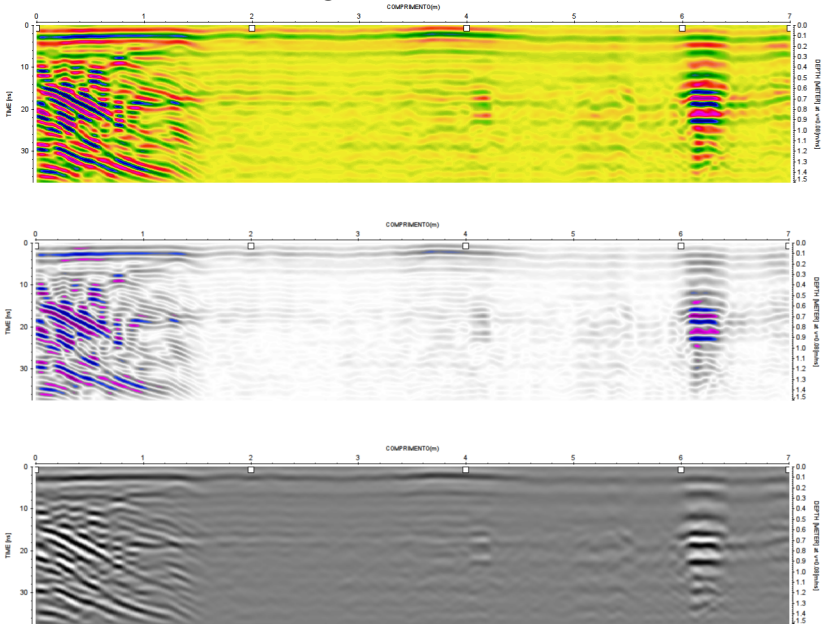
The initial anomaly is much stronger in this line, this could be happening for the nearness of the access door, and the metal reinforcement of the rooftop, this is a visually, much define and stronger signal, that generally is associated of a horizons whit a better consolidation or a much dense material.
Second anomaly goes from 3.35 to 4.28 meter, and present a very low respond, probably still part of the anomaly we see in the lines A and B, this could be the final segment of the area affected by the weight of the lateral wall Nr^o 2.
In the case of the third anomaly, goes from 5.94 to 6,94 meters approximately, but has a strong and clear signal. Goes from the time 0 until the end of the record, without showing a parabolic shape, this could be a pre-existed structure of the *Mansion dos Passos*, because this chapel was made after the construction of this Mansion, historical data tell us that this happened, so its a good assumption to think this maybe was part of the previous building.

Figure 4.5: Map view of the line B



Source: The Author

Figure 4.6: line C

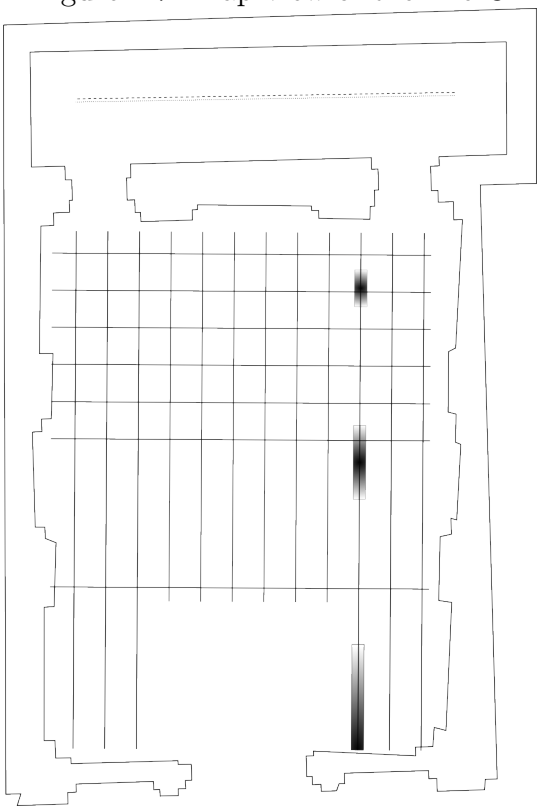


Source: The Author

4.1.4 Line D and E

Lines D and E doesn't present a clear anomaly, also is far away from the lateral wall, and from the pillars, but if we look carefully, we can see the constant variation to start in the

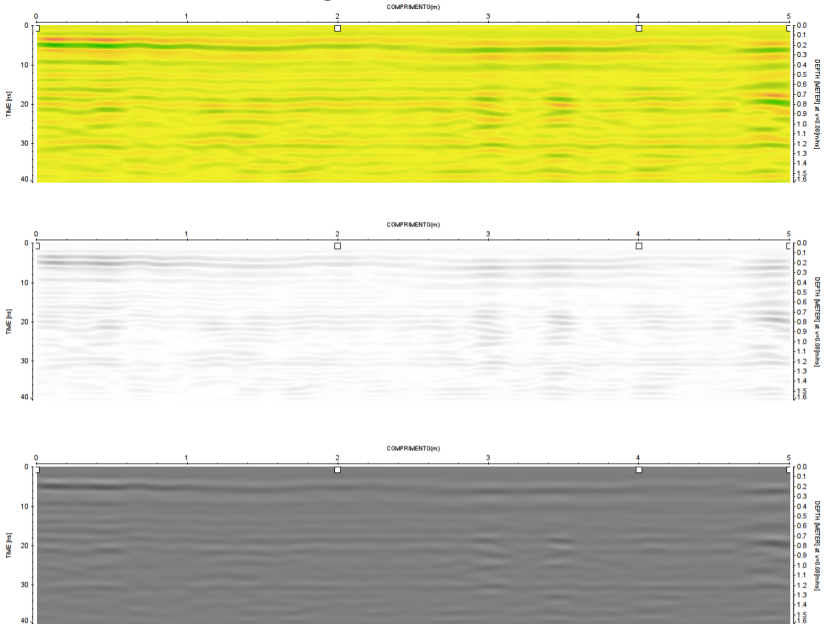
Figure 4.7: Map view of the line C



Source: The Author

16ηs approximately 0.5 meters, coinciding with the ground level of the street.

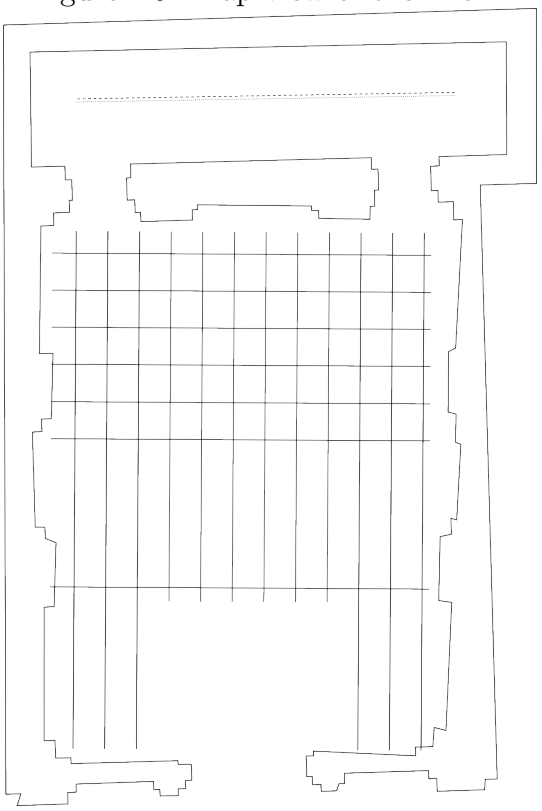
Figure 4.8: line D



Source: The Author

We see this in the line E, presenting the same behaviour and the same characteristics,

Figure 4.9: Map view of the line D



Source: The Author

and is much easier to see the possible difference between the ground level and the foundations of the building.
The length of this lines change of 7 to 5 meter, for the presence of a metal structure, that structure is used like a support of the balcony added to the entrance, besides to protect the building to be vandalise.

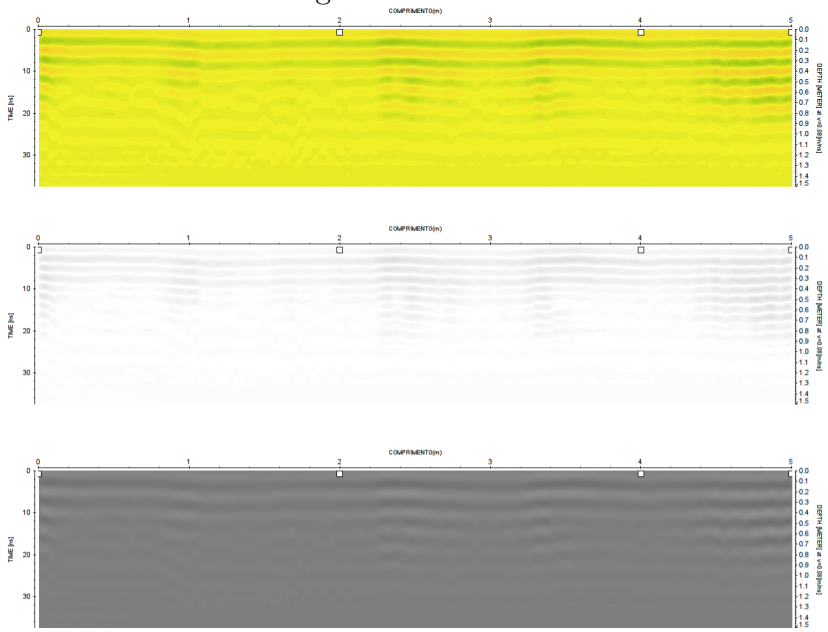
4.1.5 Line F

What we see in this line is a anomaly with a low response, because we are recording the beginning of the body to generated this responses. We can said this because the signal is much stronger in the *line G* and there both are align , the signal goes from 2.24 to 4,04 meters, probably a non-metallic body.

4.1.6 Line G

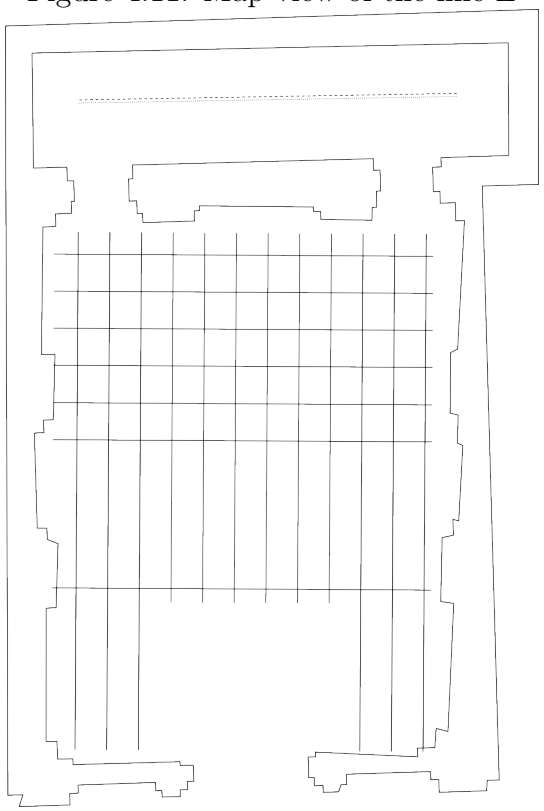
In this line is much clear to see the possible body or a variation of the density on the floor. The first anomaly goes from 1.15 to 1.63 and is has a low respond, but is also recorded in the next line, this prove the effectiveness of the GPR signal and the consistence of

Figure 4.10: line E



Source: The Author

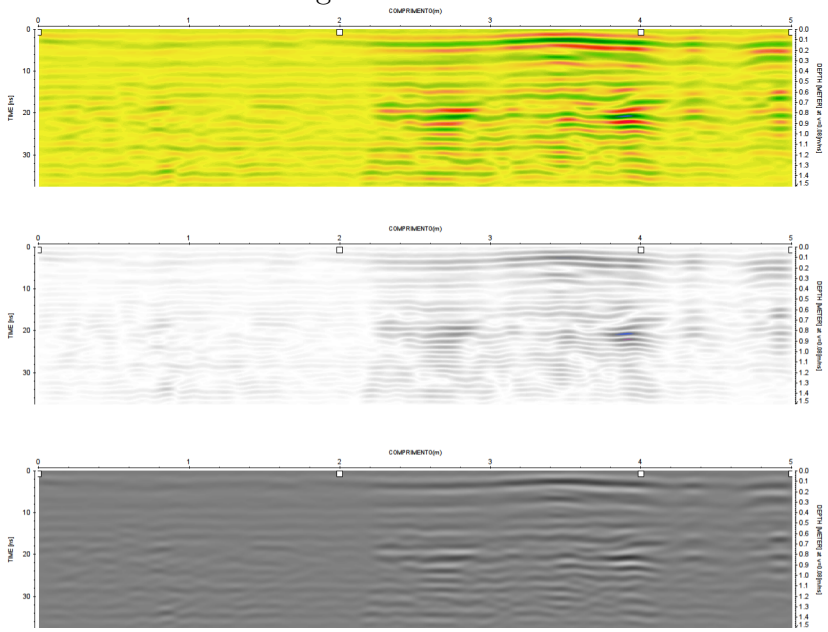
Figure 4.11: Map view of the line E



Source: The Author

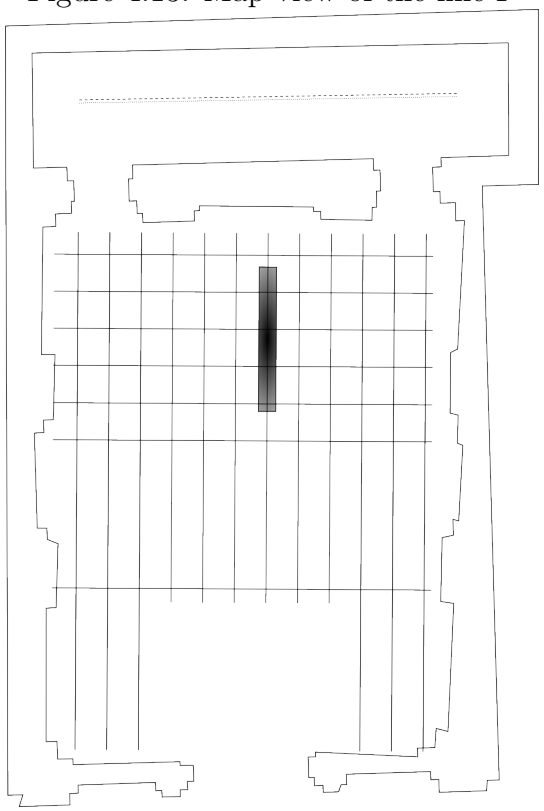
the data. By other hand this anomaly has a effect from the all the extension in time of the profile, and the extension is approximately of 50 centimetres that could tell us this is provably part of the previous building, because has the same form and behaviour of the

Figure 4.12: line F



Source: The Author

Figure 4.13: Map view of the line F



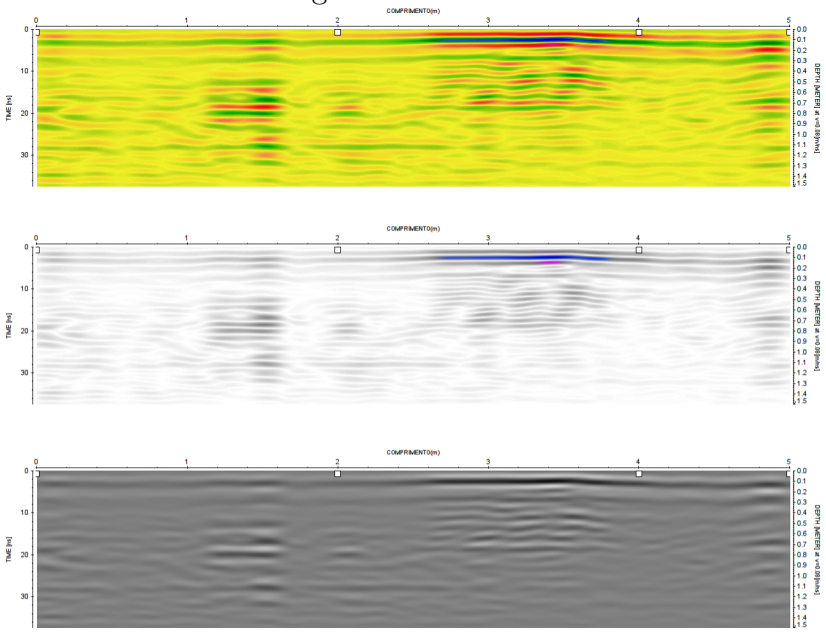
Source: The Author

anomaly show in the line C.

We can see this anomaly, present between the distances 2.56 to 3.78 meters and could be part of the anomaly recorded in the line F, and is also see in the line H, so shows a

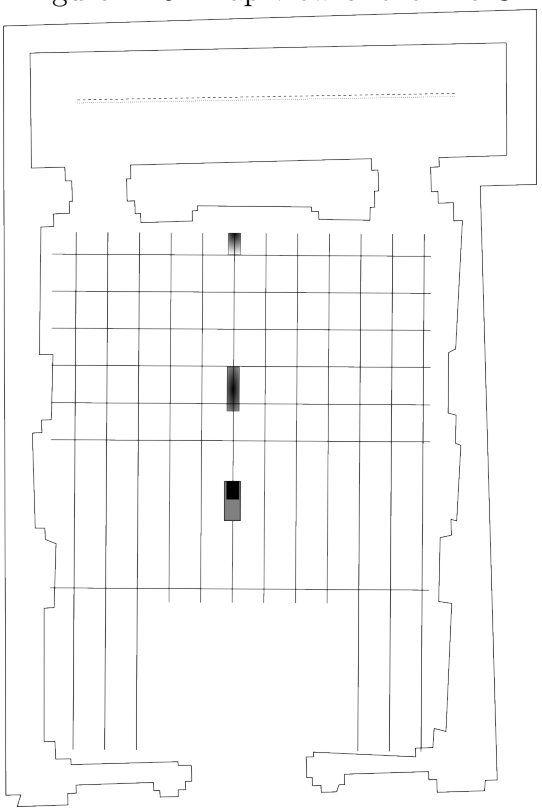
consistent behaviour and extension.

Figure 4.14: line G



Source: The Author

Figure 4.15: Map view of the line G

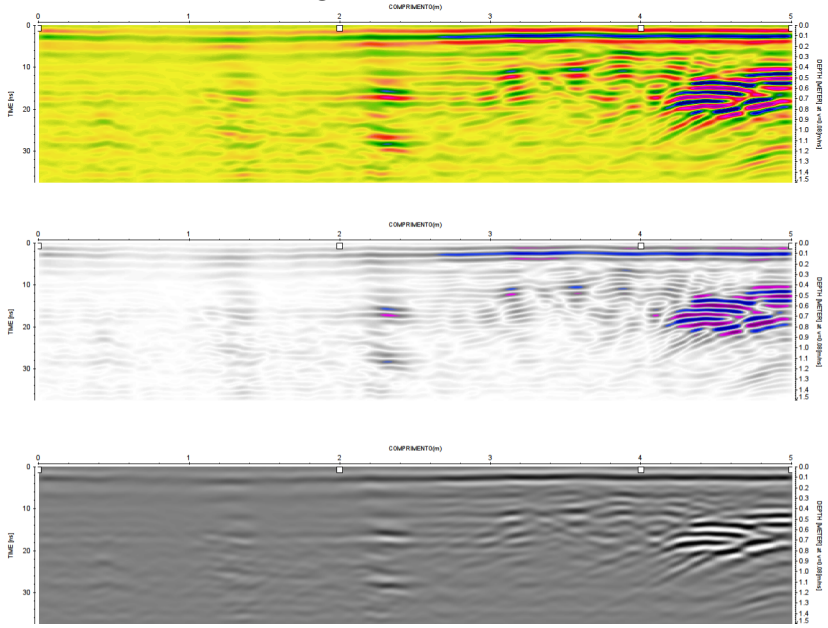


Source: The Author

4.1.7 Line H

In this line we have 3 anomalies, the first two are consistent with the to previous lines,(line F and line G).
The first anomaly start in 1.20 and goes to 1.44 meters, present the same behaviour, what can we see in the previous lines and almost the same length. Showing a consistent length in this type of anomalies and could confirm the theory of the presence of remains of the structure of the previous building.
Second anomaly goes from 2.17 to 2.48 and also present the characteristics of the possible remains of the previous building, this theory was take in consideration for two reasons, the first one is the absence of marks on the floor, to can show the presence of heavy object or furniture, in that points, and the second reason comes of the observation, of the construction methods of that period of time.
In the case of the last anomaly, can we see a clear anomaly with a strong response at the end of the line, also is recorded the anomaly of the previous lines. It could be caused, by the proximity of two different kind of anomalies, the part in the end of the line shows a parabolic shape characteristic of solid body, bigger granulometry, or a much dense material.

Figure 4.16: line H

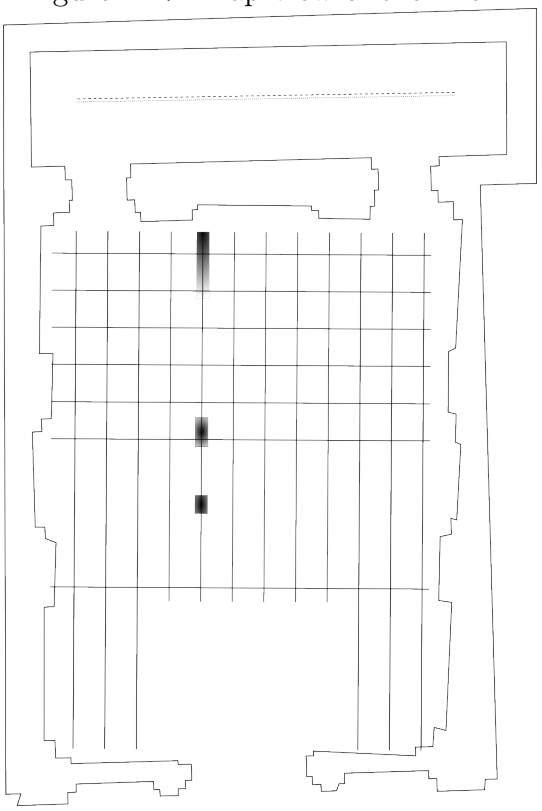


Source: The Author

4.1.8 Line I

We keep recording the anomalies seen in the previous lines, and we have a better view of the possible body at the end of the line, this also could be related with the pillar to

Figure 4.17: Map view of the line H



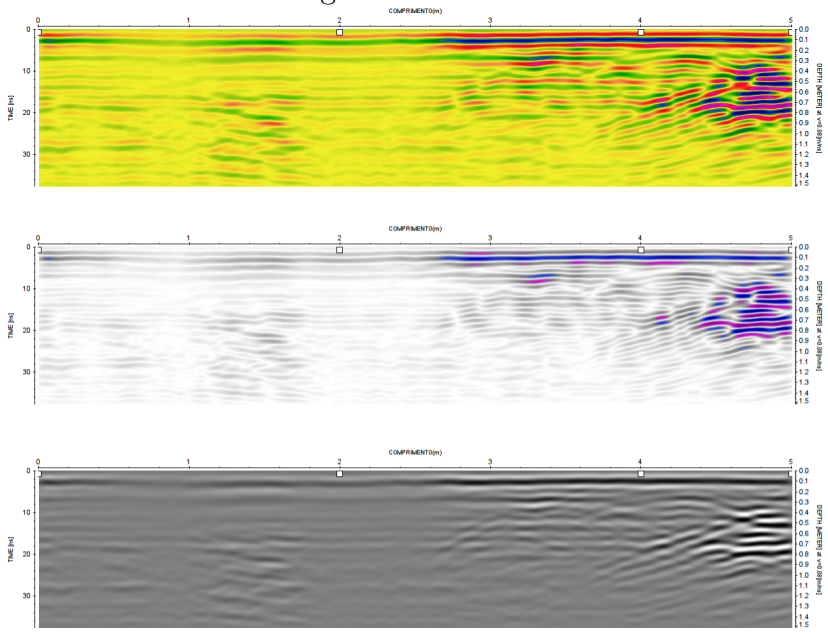
Source: The Author

is part of the altar of the chapel, and this similar characteristic are saw in the beginning of the line A, in this case only have this respond in this side of the altar, but why?, this could be caused for another body, different of the foundation of the pillars or remains of the previous building.
But how can we sure of this hypothesis?, in the GPR methodology used for this project, we choose a grid arraignment, having lines to goes to east to west that will be are main lines(INLINES), and lines that are goes north to south, this will be are transversal lines (CROSSLINES) and this lines will be used to confirm the behaviour and possible form of the body's detected in the chapel.

4.1.9 Line J

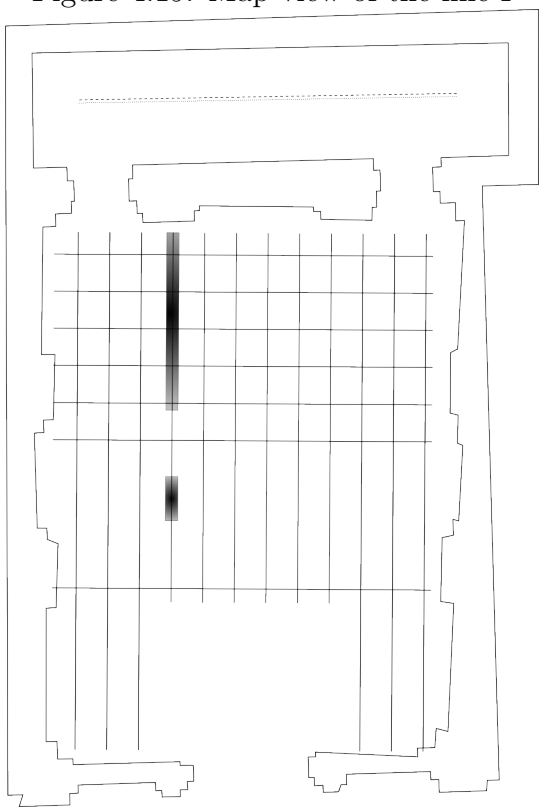
Line J, we have again a length of 7 meters, that help to clarified the hypothesis planted in analysis of the line I.
The first anomaly at the beginning of the line show the patron behaviour show in the lines A, B and C, this is clearly associate with pillars of the entrance and the foundations of this support structure, presenting the same characteristics and depth of the anomalies recorded in the lines A, B and C.
In other hand at the end of the line we have a anomaly with a different signal and close

Figure 4.18: line I



Source: The Author

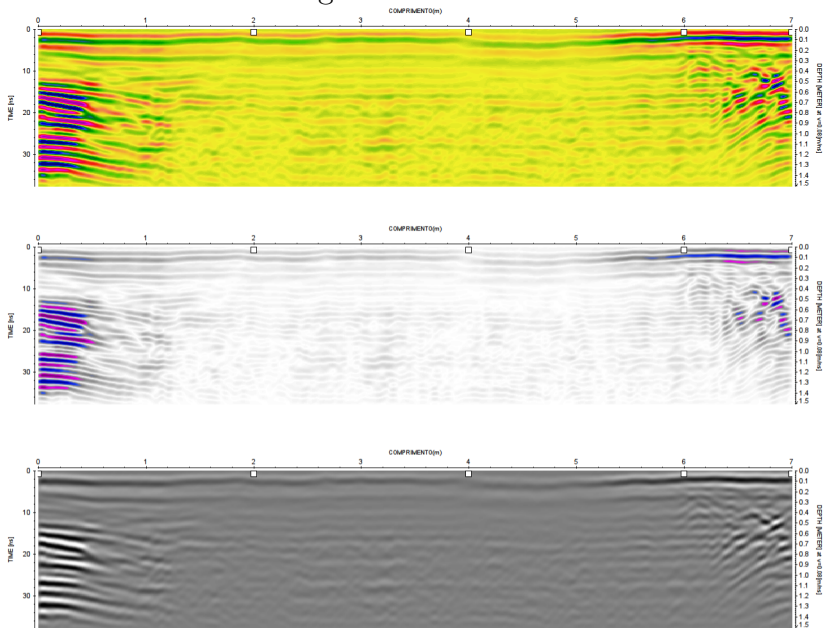
Figure 4.19: Map view of the line I



Source: The Author

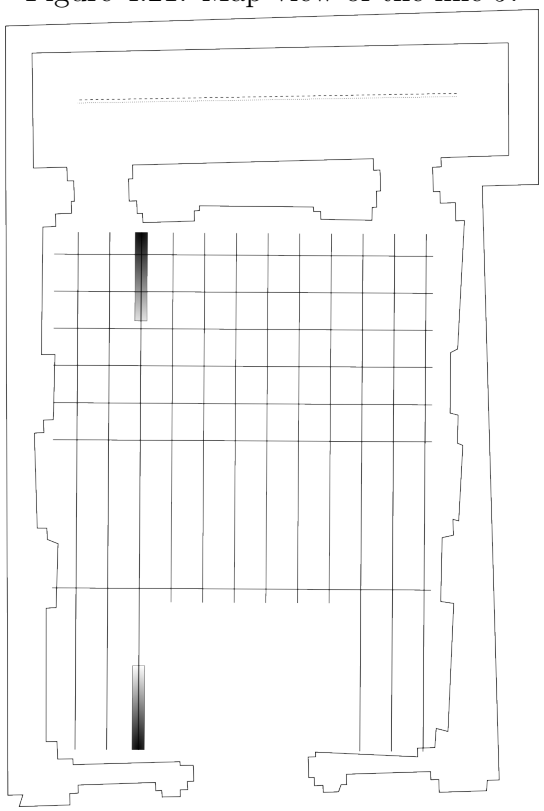
to a pillar, but we see a different behaviour and a presences of a parabola.

Figure 4.20: line J



Source: The Author

Figure 4.21: Map view of the line J.



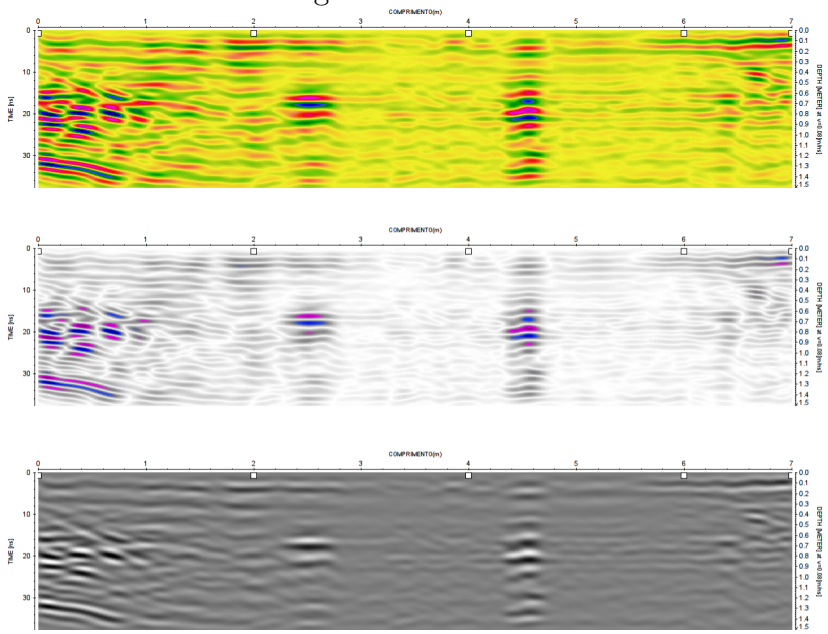
Source: The Author

4.1.10 Line K

line K shows a consistent behaviour, of the initial anomaly, starting in 0 and goes to 1.05 meters approximately, same characteristic in the signal and the same depth of the

anomaly.
The second anomaly goes from 2.30 to 2.75 meters approximately and show the characteristics that we propose be part of the remains of the previous building.
In the case of the case of the third anomaly that is located between the distances of 4.30 to 4.70 meters of this profile, again show us a correlation with the second anomaly, presenting similar dimensions and signal behaviour.
For the last anomaly of this line present in the end of the profile, we have a weak signal but with similar characteristic of the anomaly saw in the line J, at the same distance, this could be tell us that the influence of this possible body in ended, because we are recording outside of his zone of influence (main body).

Figure 4.22: line K



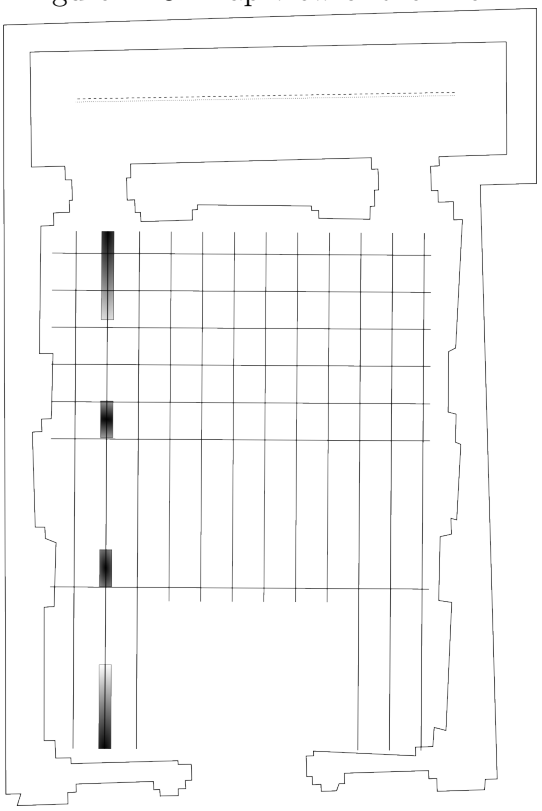
Source: The Author

4.1.11 Line L

Line L finally confirm the constant influence of the main entrances and his support pillars, this could by cause the weight and height of this particular wall is much bigger in comparative with the other walls to created this chapel, the amount of material is substantially different and the deformation in the subsoil is easily recorded for the GPR equipment.
In other hand, we don't have a similar profile to the line A, it was expected a similar behaviour along of of the profile in the line L, because line A and L are recorded close to the lateral walls, but in the line L, we don't have the anomaly in the middle and the end of the profile, but why?.

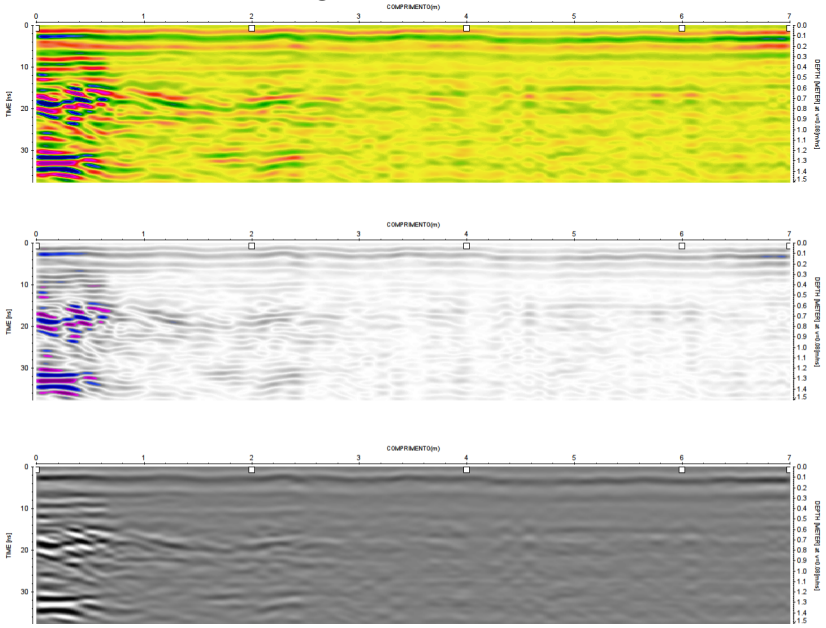
Another thing to is necessary to take note in this kind of project, is the surrounding

Figure 4.23: Map view of the line K



Source: The Author

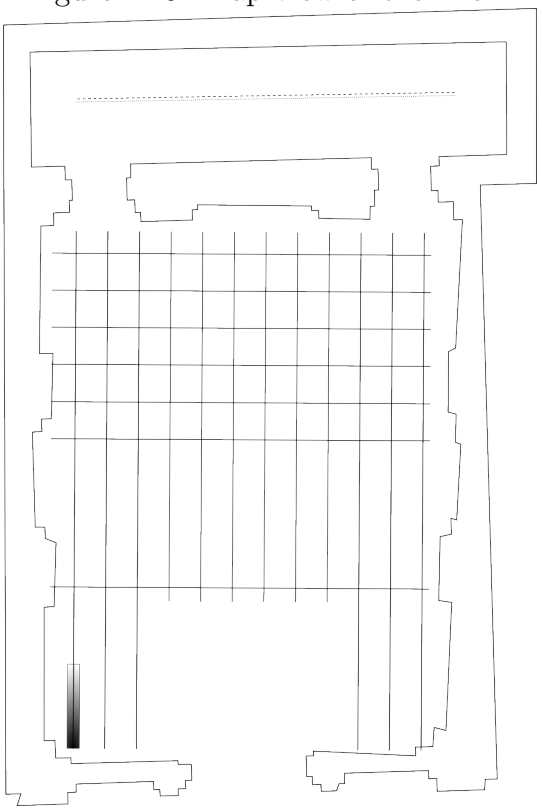
Figure 4.24: line L



Source: The Author

environment, in this case we have a building close to the lateral wall 1 (wall next to the line L), that almost present the same support structures of the original building, but with the differences of this building is now use like a commercial building, and the rooms and

Figure 4.25: Map view of the line L



Source: The Author

corridors, are been change or expanded, so we have less material in the inside, but the same support structure.

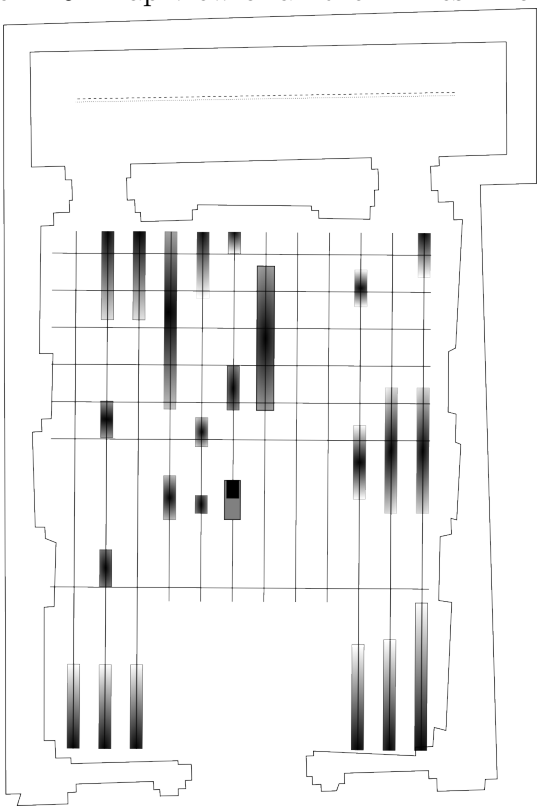
In the case of the line A, we don't have the same scenario, because the building next of this wall has suffer a mayor reconstruction and are been used modern materials in this process, like bricks and mortar, and support structure like pillar with steel reinforced construction, so the environment next to this wall has a big differences, and this change the initial hypothesis of the line A.

In the interpretation of GPR profiles for this work we don't only try to identify the possible bodies, we also apply are previous experience in the field of geotechnics and seismic, to give another view of this exciting field of the archeo-geophysics.

4.1.12 In-line Map

We can see in all the the In-lines profiles Fig. 4.26, are a tendency, close to the main door, the possible remains of the previous structure and a group of anomalies close to the Lateral wall Nr^o 1. Now its necessary do a confirmation of this possible bodies, using additional measurements (Cross-lines), using this method we can illustrate in a more clear way, the limits of anomalies (horizontal and vertical), and delimited the areas of interest for future works.

Figure 4.26: Map view of all the Inlines Anomalies



Source: The Author

4.2 CROSS-LINES

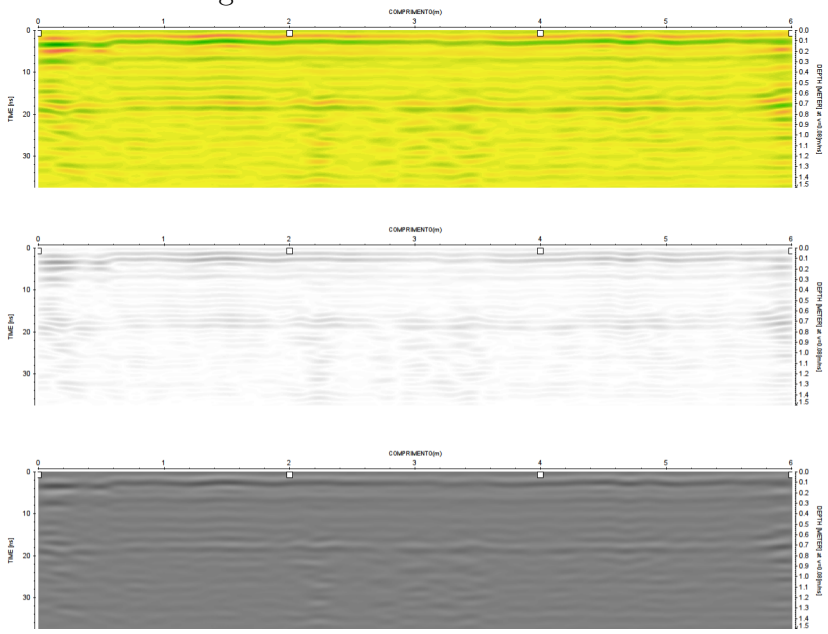
The necessity of this lines is to clarified with more accuracy the limits of are anomalies, and find new ones, this method also is used in geotechnical and seismic projects, other use of this arrangement is to make a global detections of are zones of interest, and delimited the areas of interest, after this global search, can we choose the best areas to make, a much detail acquisition of data, and improve our results, obtaining a better discrimination of the limits of the bodies and a better estimation of the depth in this profiles.

4.2.1 Transversal Line 2

For the transversal line 2 , we don't detect a clear anomaly, along the entire line, why this happen?, a possible answer of this question could be found if we see the data obtain with the equipment, like a real line in the floor, the antenna used in this work, It is designed to emit and record clearly, the signal between the transmission antenna (Tx), and the record antenna (Rx), this data represent a single point in space and time (sample), and the union of this points its what we call a GPR line.

So if the antenna is not directly above of the zone of influence (possible body or anomaly zone), the equipment doesn't gonna take any *significant data*, the exception of this point of view, are the metallic bodies, because this equipment is very sensible to this kind of material, metal generate strong radar reflections as a result of a significant change in radar-wave velocity. These features tend to produce reflection hyperbolas generated from a distinct "point feature" in the subsurface.

Figure 4.27: Transversal Line T2



Source: The Author

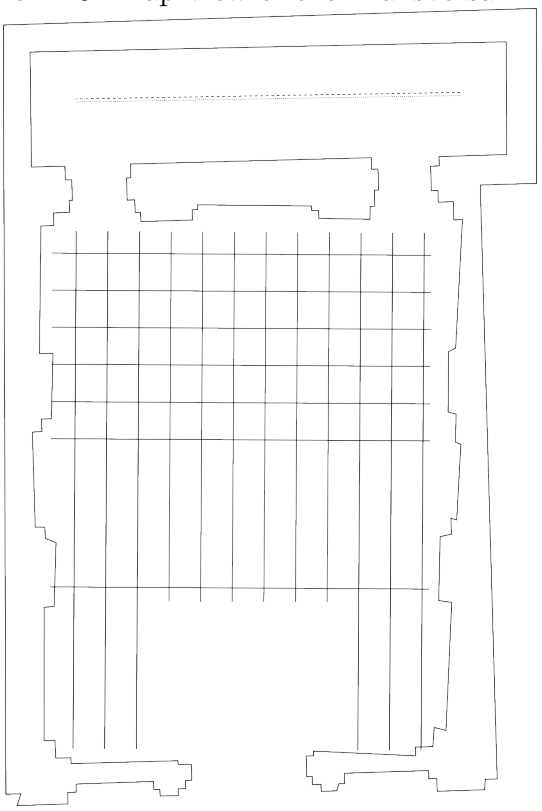
4.2.2 Transversal Line 3

In this case transversal Line 3, doesn't confirm the third anomaly in the line K, this could be happen because this line is just outside of this possible body, and the equipment is incapable to detect the influence of this possible body, the GPR equipment easily record the influence of metallics bodies(nearby the recording line), but is much difficult to record the presences of non-metallic bodies, in this case possibly the remains of a previous structure.

Transversal Line 3 has two anomalies, in this case the first anomaly, in this profile (Transversal 2),confirm the anomaly in the line H(the extension goes from 2.17 to 2.48 meters in that line), and the most intense section of this anomaly goes from 2.30 to 2.55 meters, and also show a better intensity in the data starting in the approximate depth of 0.5 meters up to the end of the profile.

The second anomaly in the transversal line 2, help us to define a limit of influence, of the anomaly located approximately in the middle of the lines A,B and C, shoeing a clear and

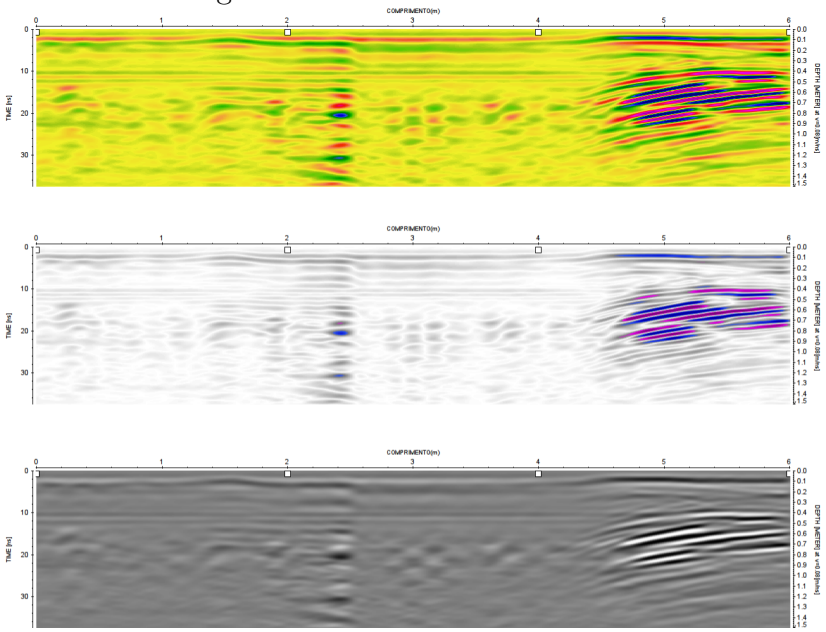
Figure 4.28: Map view of the Transversal line t2



Source: The Author

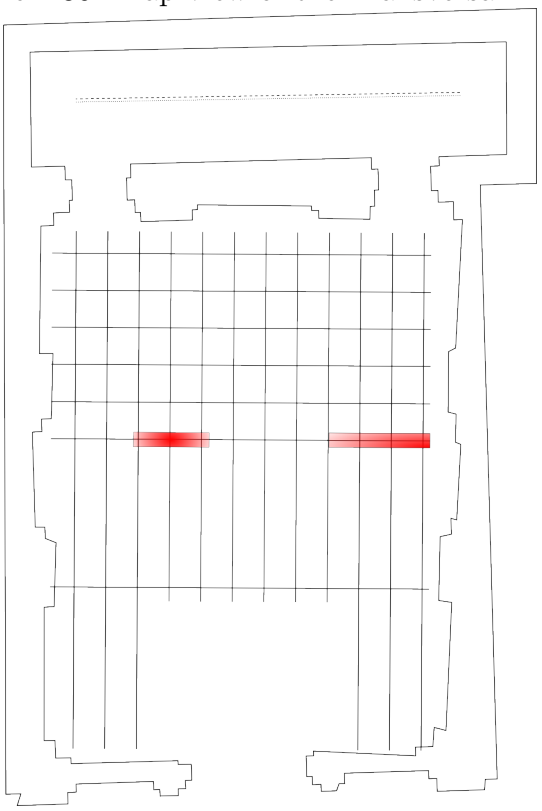
strong response of this possible body.

Figure 4.29: Transversal Line T3



Source: The Author

Figure 4.30: Map view of the Transversal line t3



Source: The Author

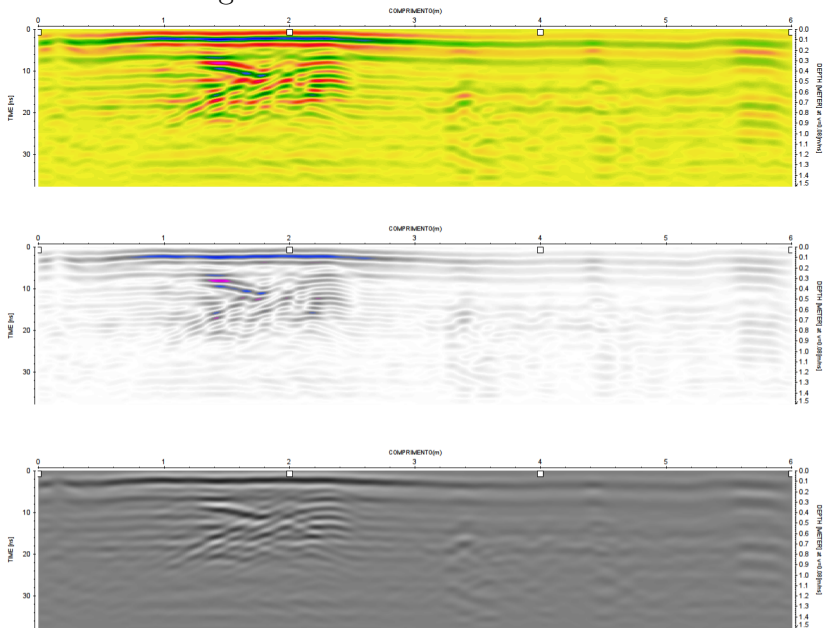
4.2.3 Transversal Line 4

For this line we have a match between the second anomaly detected in the *line i*, and the only anomaly in this transversal line. The anomaly present a strong signal and made a clear definition of the possible presence of a body, different to the remains of the previous building, but why we consider this anomaly be generated by a body?. This happen because like in the seismic data we use the pre-existed data to assume a possible interpretation, in this case the anomaly present a characteristic shape, commonly associate to bodies or areas whit a much high density, also is important to remember, this interpretation base in 1 field test, to have a better interpretation is necessary combine 2 or more geophysics methods.
But why we don't record any match between the *line F* and the transversal line 4?, that's not true, we poorly recorded the anomaly detected in the *line F* , this is a common mistake that constantly happen if we don't make a interpretation of *all the lines together*.

4.2.4 Transversal Line 5

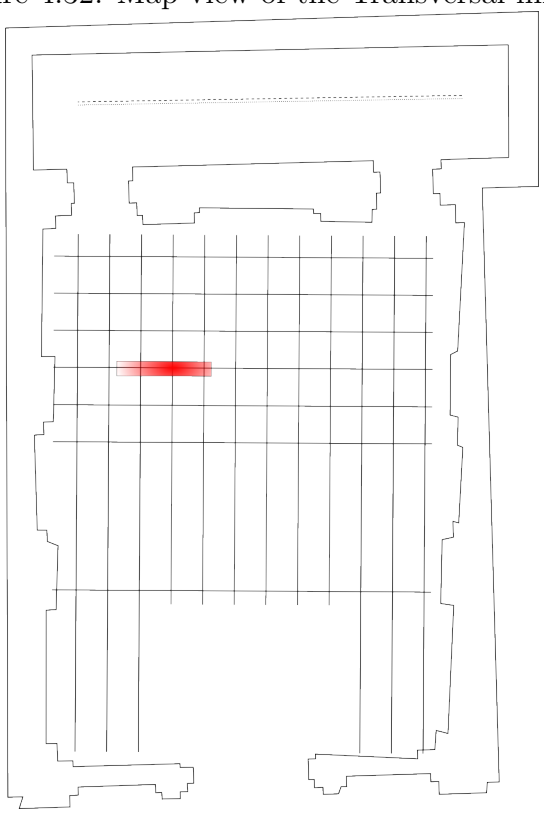
This is the transversal line to catch and match more *in-lines*, like the *line H*, *I*, *J* and *K*. Can we confirm the presence of a body?, the answer is no, because the presence of

Figure 4.31: Transversal Line T4



Source: The Author

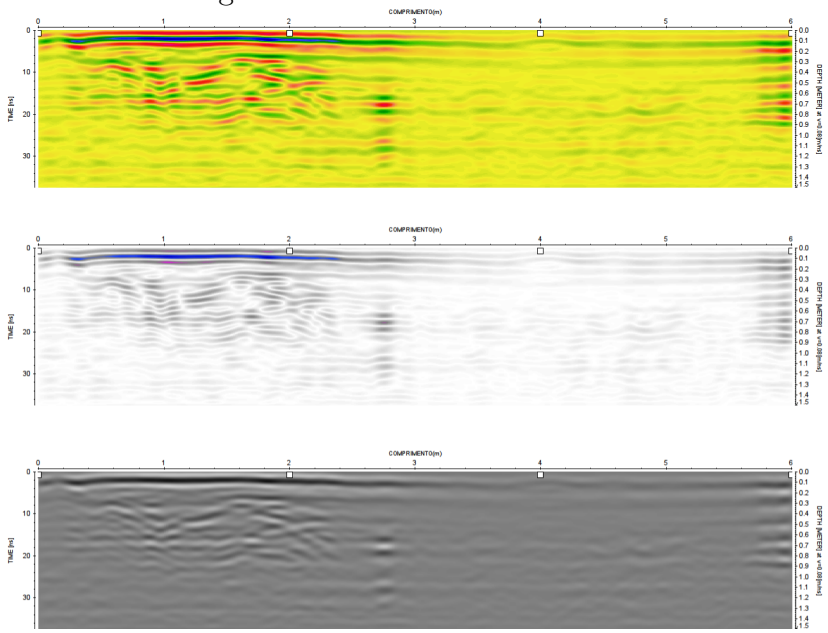
Figure 4.32: Map view of the Transversal line t4



Source: The Author

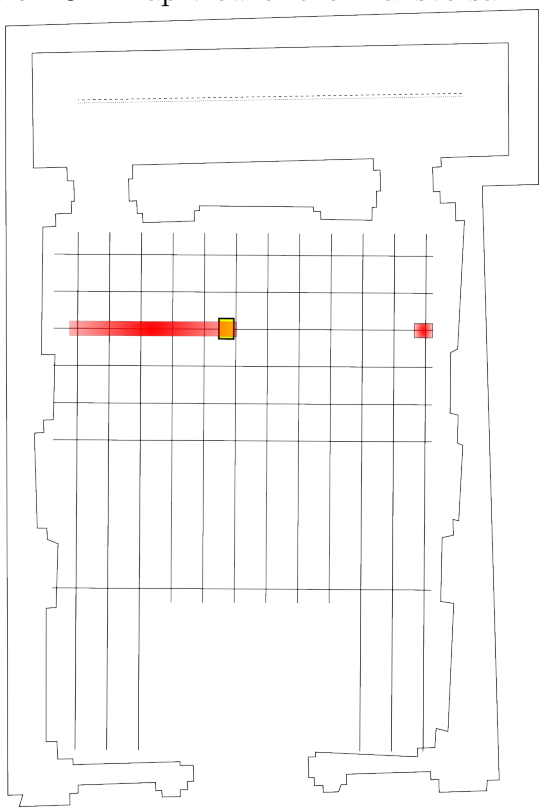
a anomaly never confirm the presence of a body. The reason of this is because this is a *non-intrusive method*, and use *non-intrusive data* to assume a possible interpretation, base in previous data, or anomalies recorded in a control area.

Figure 4.33: Transversal Line T5



Source: The Author

Figure 4.34: Map view of the Transversal line t5

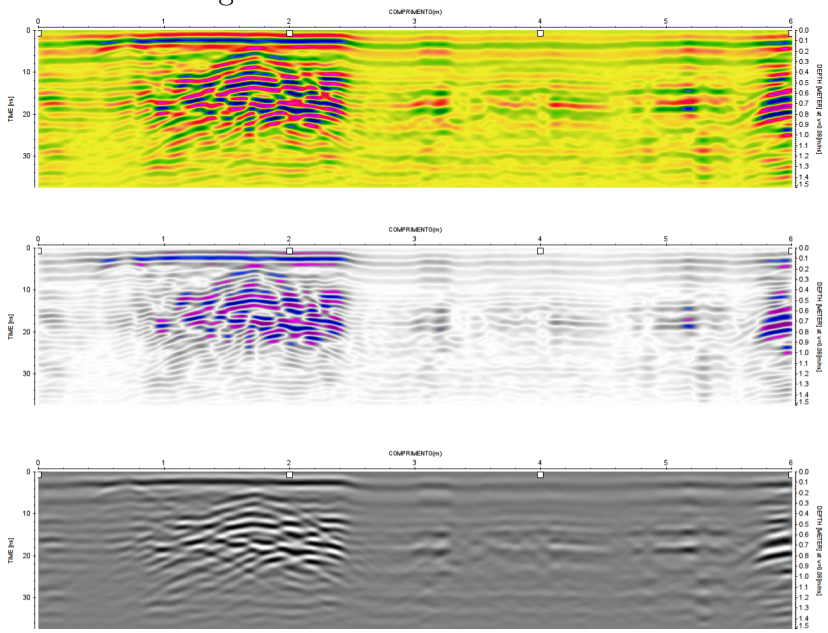


Source: The Author

4.2.5 Transversal Line 6

Transversal line 6 also catch and match with the *line H*, *I*, *J* and *K*. The difference between this line and the *transversal line 5*,is in our experience, this line present a better data to improve the interpretation, this is because, can we saw a stronger data and the presence of a top and bottom of this possible body.

Figure 4.35: Transversal Line T6



Source: The Author

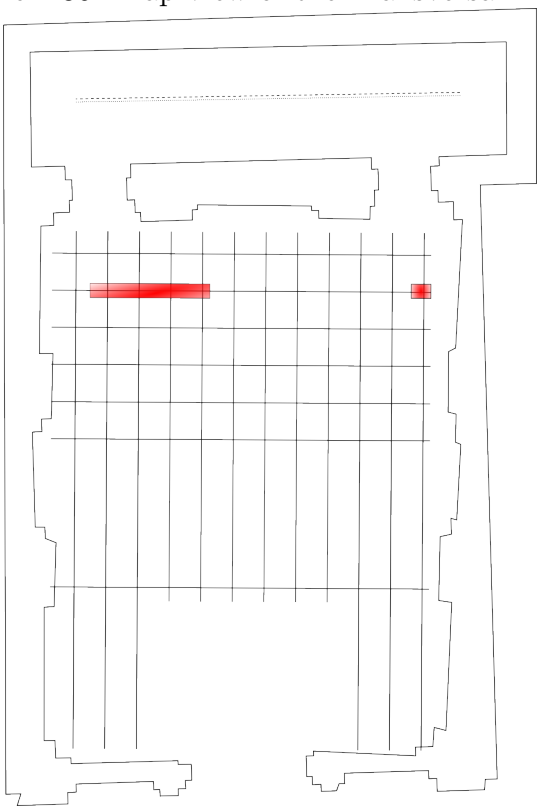
4.2.6 Transversal Line 7

Transversal Line 7 and the *Transversal Line 6* are the more significant lines in this area of the chapel, the reason is the presences of clear and strong data, without mention of the consistent distances in the anomalies detected in this lines.

4.2.7 Sacristy Line

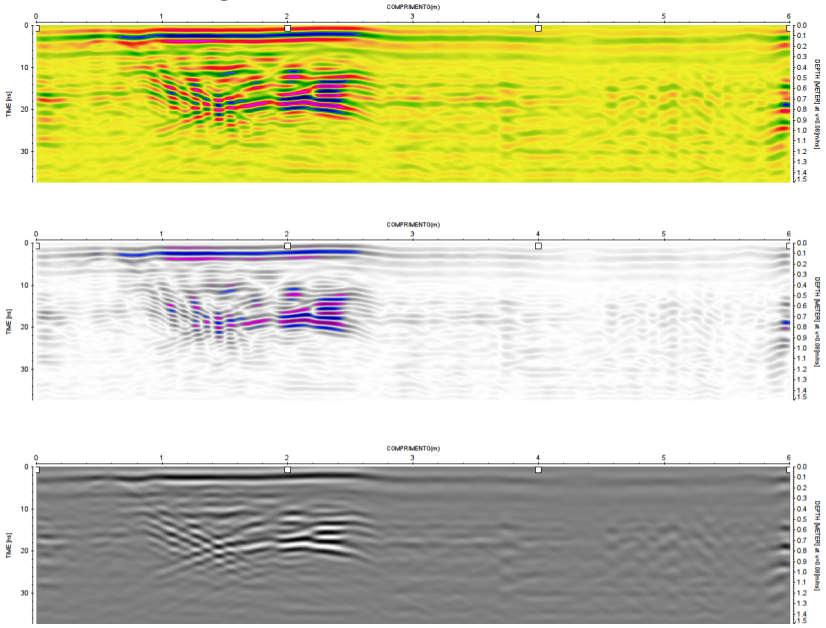
What we can see in this line is the most unusual data of this work, this line is located in the area of the Sacristy, and present a very particular type of signal, generally associated with empty spaces or the recording of air, this data is easily saw after the applied of the FK Filter, showing the characteristic pattern of a empty space.
we can said this is a empty space? the answer is highly probable, the reason to suggest this probably reside in to punctual pieces of information, first the GPR data recorded in this work, secondly the mention to *indicates a moat and a niche in the old area sac-*

Figure 4.36: Map view of the Transversal line t6



Source: The Author

Figure 4.37: Transversal Line T7



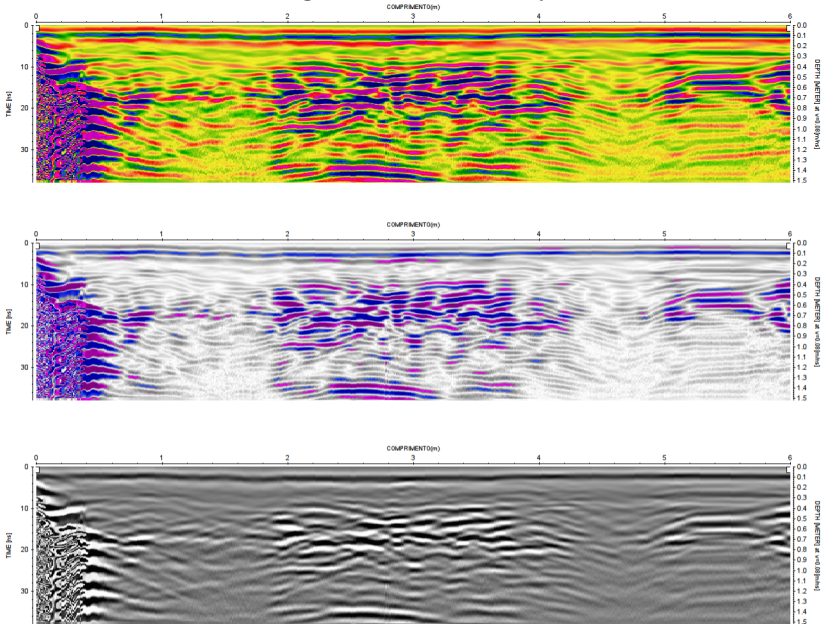
Source: The Author

risty (dissertation, Architecture in Belem in the XVIII century: the works of Antonio Landi,Ana Cristina Braga Lopes (1998, p. 85))is not clear, because the number of data and the working space is very limited.

Figure 4.38: Map view of the Transversal line t7

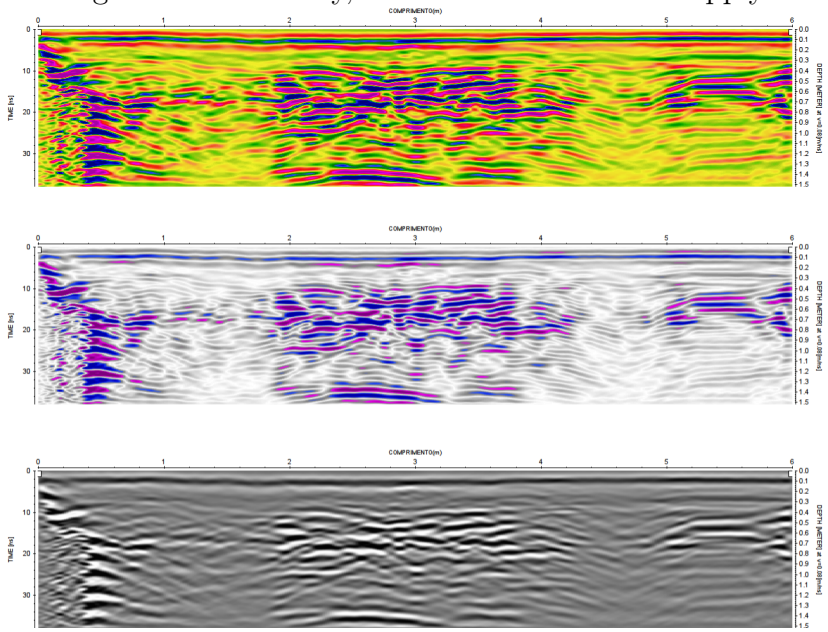
Source: The Author

Figure 4.39: Sacristy



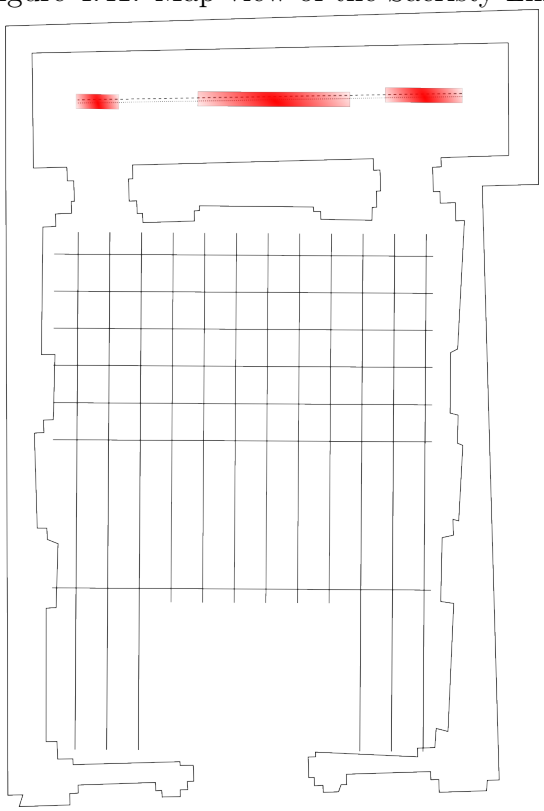
Source: The Author

Figure 4.40: Sacristy, data with the FK filter apply



Source: The Author

Figure 4.41: Map view of the Sacristy Line



Source: The Author

4.2.8 Cross-line Map

In the case of the Cross-lines we confirm the presences of a possible massive anomaly close to the Lateral wall Nr^o 1 Fig. 4.42, and the possible influence of the overweight presences

next to the Lateral wall Nr^o 2, produce by the new building close to this wall.

Figure 4.42: Map view of all the Cross-lines Anomalies

Source: The Author

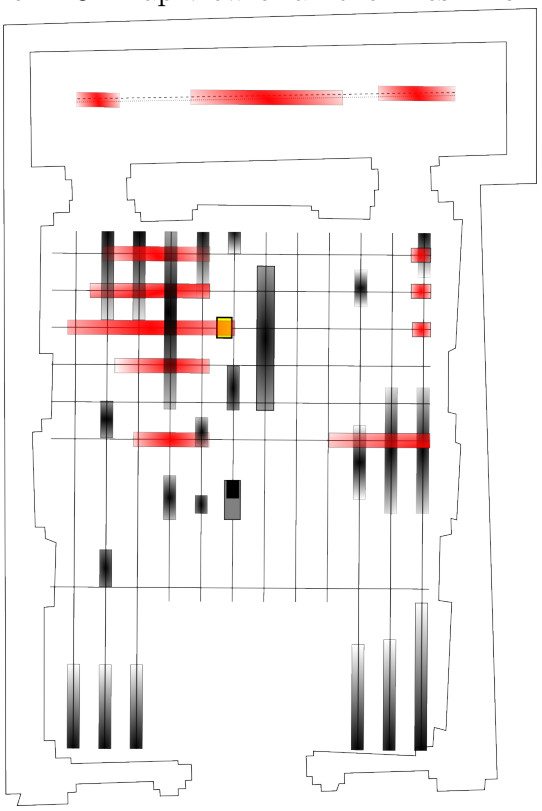
4.3 CONCLUSIONS AND RECOMMENDATIONS

The present work record different type of anomalies, and show the possible presences of body that generated that response.

The anomalies show at the begin of the lines A,B,C and J,K,L are consistent with the presence of the pillar and the foundation of the building, this type of signal can be used like a pattern to confirm the theory that this chapel It was actually designed by Antonio Landi, making a comparison with the signal produce by other buildings that are avowed to be part of Antonio Landi work. This is a common practice in the control geotechnical projects.

The anomaly detected at the end of the lines G, H, I, J, K and the end beginning of the cross-lines T4, T5, T6 and T7 is the most important anomaly of this area, for his size and the intensity of his response, making this probable body, a object of a possible future study, using a more dense grid and a variety of antennas.
We also detected a very particular signal in the area of the sacristy, commonly associate with empty spaces, this is another interesting anomaly that need to be explore with more

Figure 4.43: Map view of all the lines Anomalies



Source: The Author

detail in future projects.

The use of seismic refraction is suggested, to difference the signal produce by a body or its a signal produced by the infiltration of water in the ground, increasing the density of that area,or really is a body different of the matrix of the ground.

Is not recommend the use of Magnetic Methods in future studies, because we have the presences of high voltage cables, close to the building.

In the current situation the chapel is in a state of vulnerability and progrecibo deterioration, which has compromised its upper structure (beams and ceilings).

It is suggested to make a more extensive study of the work area using a triaxial geophone, adding walls and columns as study objectives, to have a quantification of the actual state of conservation found in the chapel.

REFERENCES

ANA OSELLA, J.L.L. **Arqueogeofísica**: una metodología interdisciplinaria para explorar el pasado. [S.l.]: Universidad Maimonides, 2006.

BARATA, M.D.M.C. **O passinho. folha do norte. Fastos Paraenses**, 1, 1914.

CONYERS, L.B. **Ground-Penetrating Radar for archaeology**. [S.l.]: AltaMira Press, 2004.

CONYERS, L.B.; GOODMAN, D. **Ground-Penetrating Radar**: an introduction for archaeologists. [S.l.]: AltaMira Press, 1997.

CONYERS, L.B.; LUCIUS J. Velocity analysis in archaeological ground-penetrating radar
studies. **Archaeological Prospection,** v. 3, n. 1, p. 25-38, 1996.

FURTADO, C.P.Q. **O método GPR aplicado à arqueologia no Sítio PA-ST-42**: porto de Santarém, Pará. 2013. Dissertação (mestrado em Geofísica) – Instituto de Geociências, Universidade Federal do Pará, Belém, 2013.

JOL, H.M. **Ground Penetrating Radar Theory and applications**, Elsevier Science, vol. 1, 2008.

KETTLE, W.O. **CAPELA VIVA DO SENHOR MORTO**:usos do oratório público no Grão-Pará do Século XVIII. 2008. , Universidade Federal do Pará, Belém, 2008.

MEIRA FILHO, A. **A capela do senhor dos passos**. A Província do Pará, 4(1), 1, 1969.

MELO, M.D.S.E. **Geofísica aplicada à arqueologia**: investigação no Sítio Histórico Engenho Murutucu, em Belém, Pará. 2007. Dissertação (mestrado em Geofísica) – Instituto de Geociências, Universidade Federal do Pará, Belém, 2007.

OLIVEIRA, D.S.D.C. **Capela Pombo, Belém/PA**: interpretação e perspectivas. 2008. Dissertação (mestrado em Geofísica) – Instituto de Geociências, Universidade Federal do Pará, Belém, 2008.

ROCHA, H.O.D. **Gradiometria magnética e GPR aplicados à arqueologia em sítio estuarino em Penalva-MA**. 2012. Dissertação (mestrado em Geofísica) – Instituto de Geociências, Universidade Federal do Pará, Belém, 2012.

RODRIGUES, S.I. **Contribuições dos métodos GPR e eletromagnético indutivo em estudos de sítios arqueológicos de sambaquis costeiros no estado de Santa Catarina**. 2009. Tese (doutorado) - Universidade de São Paulo, São Paulo, 2009.

SOUZA, D.M.D. **GPR aplicado à arqueologia nas áreas do porto da Cargill (Santarém/PA) e no Palacete Faciola (Belém/PA)**. 2012. Dissertação (mestrado em Geofísica) – Instituto de Geociências, Universidade Federal do Pará, Belém, 2012.

TOCANTIS, L. **Santa Maria de Belém do Grao Pará: instantes de Evocacoes da Cidade**, Belo Horizonte: Itatiaia, 1987