GPR
RESEARCH PROJECT
FOR
THE GREAT PYRAMID (“CHEOPS PYRAMID”)
IN GIZA, EGYPT

Adam Szynkiewicz, PhD.

Poland, Wrocław, 2023

STAGES OF RESEARCH

STAGE I. GPR EXAMINATION ON THE OUTER WALLS
OF THE GREAT PYRAMID ("CHEOPS PYRAMID") IN GIZA, EGYPT

STAGE II. GPR EXAMINATIONS INSIDE THE "KING'S CHAMBER"
IN THE GREAT PYRAMID ("CHEOPS PYRAMID") IN GIZA

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STAGE IV. GPR TESTS OF THE GROUND SURFACE
AROUND THE GREAT PYRAMID ("CHEOPS" PYRAMID) IN GIZA

REFERENCE

1. MALA GeoScience (GuidelineGeo AB)
2. Geophysical Survey System, Inc.
3. SUMO SURVICES, Upton Upon Severn, Worcestershire, England
4. www.eurogpr.org
5. www.kart-geo.eu

STAGE I.

PROJECT
OF THE GPR RESEARCH ON WALL SURFACES
OF THE GREAT PYRAMID ("CHEOPS PYRAMID"),
GIZA, EGYPT

Author:

Adam Szynkiewicz, PhD. (Poland)

Cooperation:

Reda Abdelhaleem Mohamed Khalifa, PhD. (Egypt)
Andrzej Kapłanek, MSc.Eng. (Poland)
Magdalena Udyrysz – Kraweć, MA. (England)

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1.0. THE GREAT PYRAMID ("CHEOPS PYRAMID") IN GIZA, EGYPT

In Egypt, on the Giza plateau, in a complex of three pyramids (and several small ones), there is the Great Pyramid, also called the "Cheops Pyramid" (Fig.1, 2, 3). The Giza Plateau (ca 50-120 m above sea level), is located on the western side of the Nile River Valley (bottom of valley is ca 18-20 m above sea level) and is located west of the center of Cairo. The plateau is built of limestone of the Eocene age.

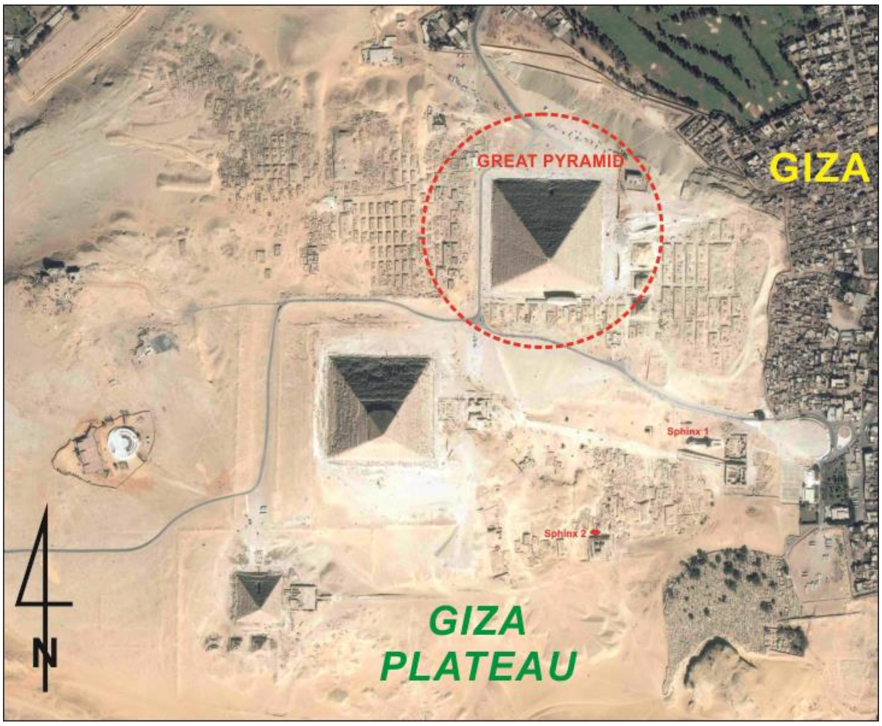


Fig. 1. Egypt, Giza Plateau. Pyramids on the Giza Plateau.
(Google Earth)

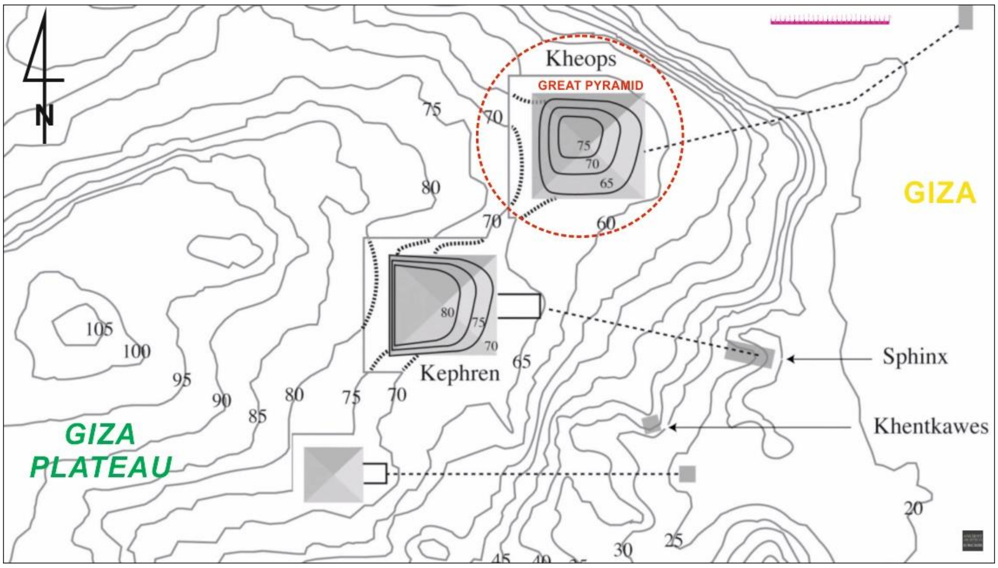


Fig. 2. Egypt. Topography of the Giza Plateau. Location of the Great Pyramid ("The Pyramid of Cheops")
according to internet data

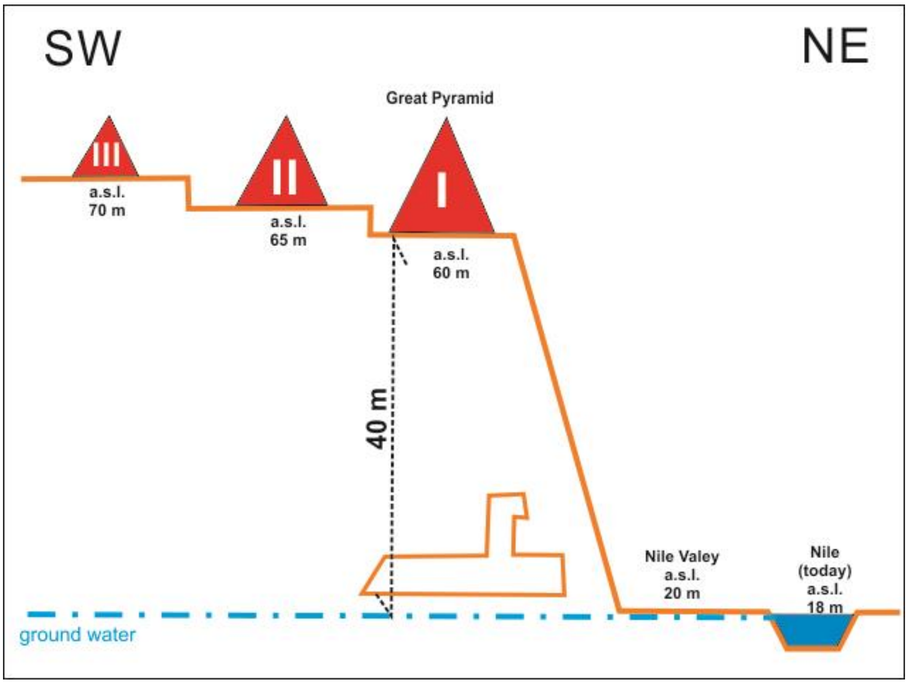


Fig. 3. Egypt, Giza Plateau. Location of the Great Pyramid ("The Pyramid of Cheops") above the Nile Valley. Schematic SW-NE section.

The Great Pyramid (“The Pyramid of Cheops”), is located at an altitude of 60 m above sea level (Fig. 2, 3). Currently, the pyramid has a height of about 146.59 m (Fig. 4). The surface of the walls of the pyramid are blocks of Eocene limestone, arranged in steps (the limestone blocks are about 1m x 1m x 1m). The base of the pyramid has the shape of a square with a side length of about 230.5 m. The general inclination of the pyramid's walls is about 51˚52'. Inside the pyramid there are corridors and chambers. The largest of them is the so-called "King's Chamber". Below the "King's Chamber" is the "Queen's Chamber" (Fig. 4).

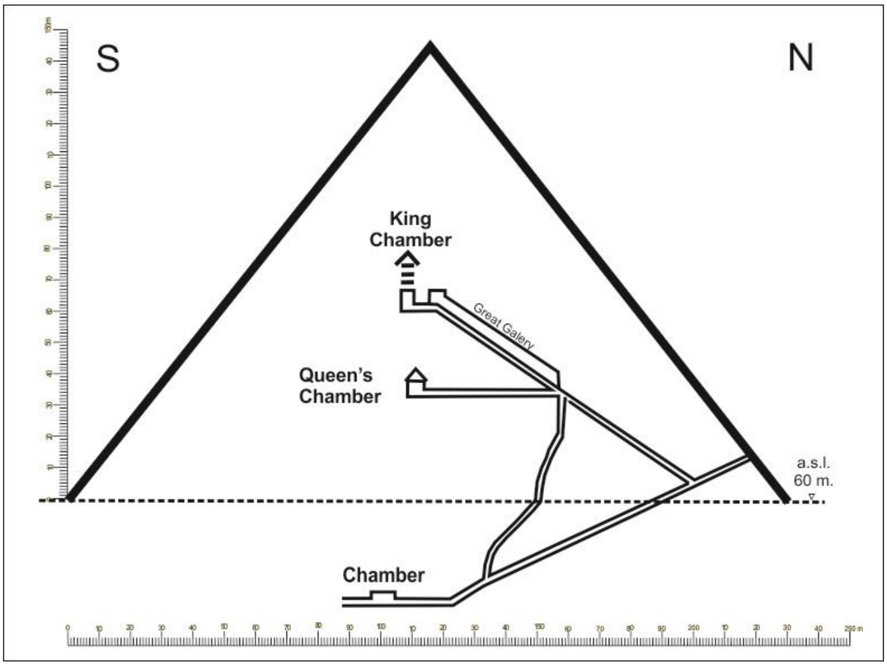


Fig. 4. Egypt, Giza Plateau. The Great Pyramid ("The Pyramid of Cheops"). Schematic S-N section

In the central part of the Great Pyramid, at an altitude of about 120 m above sea level, i.e. about 60 m above the surface surrounding the pyramid (60 m above sea level), there is a chamber with dimensions: 10.65 m (W-E) and 5.23 m (S-N) and 5.81 m high, called the "King's Chamber" (Fig.4). The longer axis of the Chamber is oriented in the W-E direction. The walls, ceiling and floor of the Chamber are made of large granite blocks (1-5 m long). The entrance to the Chamber (approximately 1 m x 1 m) is at the base of the north wall, in the south-eastern corner of this wall. In the northern wall and in the southern wall, at a height of about 1 m from the floor of the Chamber, there are openings for small corridors (about 20 cm x 20 cm).

Under the "King's Chamber", at an altitude of about 90 m above sea level, i.e. about 30 m above the surface surrounding the pyramid (60 m above sea level), there is a chamber with dimensions: 5.75 m (length E-W), 5.23 m (width S-N) and a height of max. 6.13 m (at the highest point), commonly known as the "Queen's Chamber" (Fig. 4). In the northern wall and in the southern wall, at a height of about 1 m from the floor of the Chamber, there are openings for small corridors (about 20 cm x 20 cm). It is believed that the Chamber is hollowed out in solid Eocene limestone.

The base of the eastern pyramid face is S-N. The outer walls of the pyramid are bipartite (Fig. 5, 6). As the satellite images show, each of the faces is divided into two equal parts (from the top to the base), with a slight indentation to the inside of the pyramid. The top of the pyramid is devoid of a pyramidon and has the shape of a square, with side dimensions of about 9 m. The photograph shows a flat surface made of limestone blocks (Photos 6, 7).

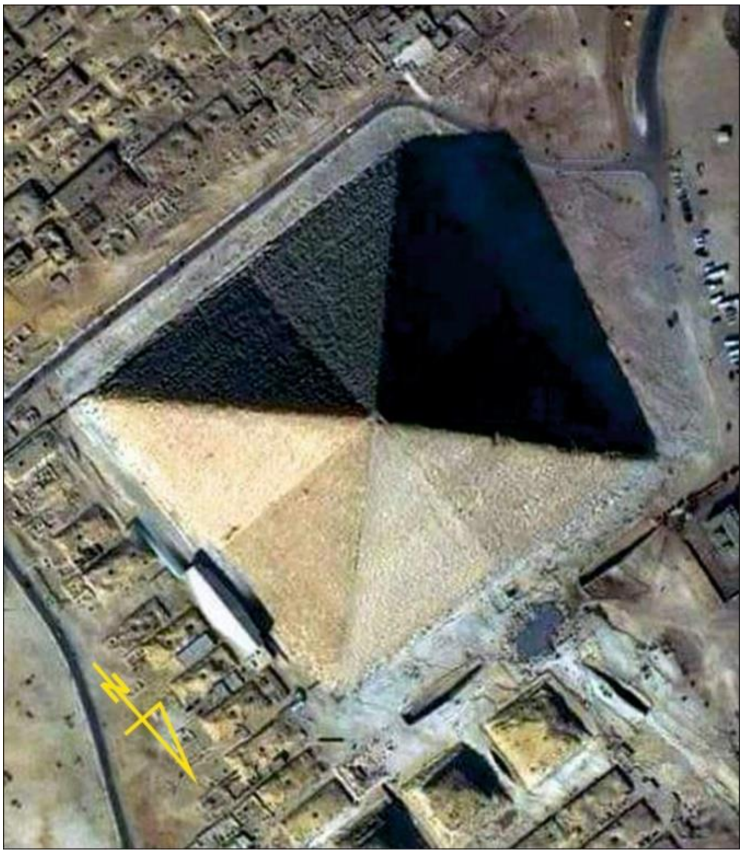


Fig. 5. The Great Pyramid of Giza ("The Pyramid of Cheops").
The aerial photograph shows the pyramid from above from the NE side
(www.Google Earth)

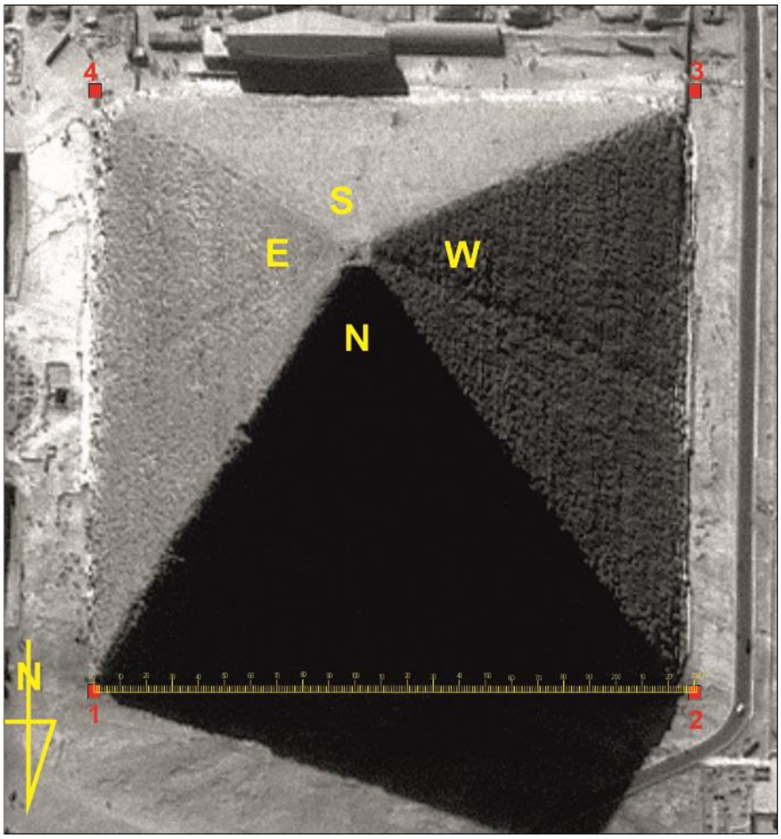


Fig. 6. The Great Pyramid of Giza ("The Pyramid of Cheops"). The aerial photograph shows the pyramid from above, from the N side (N, W, S, E - pyramid walls;
red square 1, 2, 3, 4 - control points)

Fig. 7. The Great Pyramid of Giza ("The Pyramid of Cheops").
Aerial photography shows the top of the pyramid from above
(www.internet)

In the north wall of the pyramid there are two entrances to the pyramid, marked "a." and "b." (Fig. 9, 10). The entrance marked "a." is presumably the original entrance to the pyramid, now blocked. It is located east of the axis dividing this pyramid face (about 110-115 m west of the north-eastern corner of the pyramid), at a height of about 20 m from the base of the pyramid. The entrance is inside a niche cut in limestone blocks. The niche is about 5 m wide and about 15 m high. The second, artificial entrance "b." is cut in limestone blocks, to the west of the axis dividing the pyramid's wall. The entrance "b." is located about 6 m above the base of the pyramid, in a niche carved in limestone blocks, about 117-120 m west of the north-eastern corner of the pyramid.

Fig. 8. The Great Pyramid of Giza ("The Pyramid of Cheops"). North wall and east wall of the pyramid.
(according to The Ark of the Covenant & The Great Pyramid of Egypt / Ancient Architects / youtube)

Fig. 9. The Great Pyramid of Giza ("The Pyramid of Cheops"). North wall and east wall of the pyramid.
(according to The Ark of the Covenant & The Great Pyramid of Egypt / Ancient Architects / youtube)

Fig. 10. The Great Pyramid of Giza ("The Pyramid of Cheops"). North wall of the pyramid: a, b - entrances to the pyramid.
(according to The Ark of the Covenant & The Great Pyramid of Egypt / Ancient Architects / youtube)

In the southern axis of the pyramid's wall there is a niche, marked "n.", cut in limestone blocks (Fig. 11, 12). This niche is at a height of about 20-21 m above the level of the base of the pyramid and has the following dimensions: width about 5-6 m, height about 15 m.

Fig. 11. The Great Pyramid of Giza ("The Pyramid of Cheops"). The western and southern wall faces of the pyramid. View from the SW side.

Fig. 12. The Great Pyramid of Giza ("The Pyramid of Cheops"). South wall face of the pyramid. ("n." - niche)

There are no niches in the western and eastern walls of the pyramid.

Fig. 13. The Great Pyramid of Giza ("The Pyramid of Cheops"). Western wall face of the pyramid.

There are assumptions that the "Queen's chamber" is cut in solid limestone (Fig. 14). There are also suggestions that solid limestones extend to the "King's Chamber" (Fig. 15).

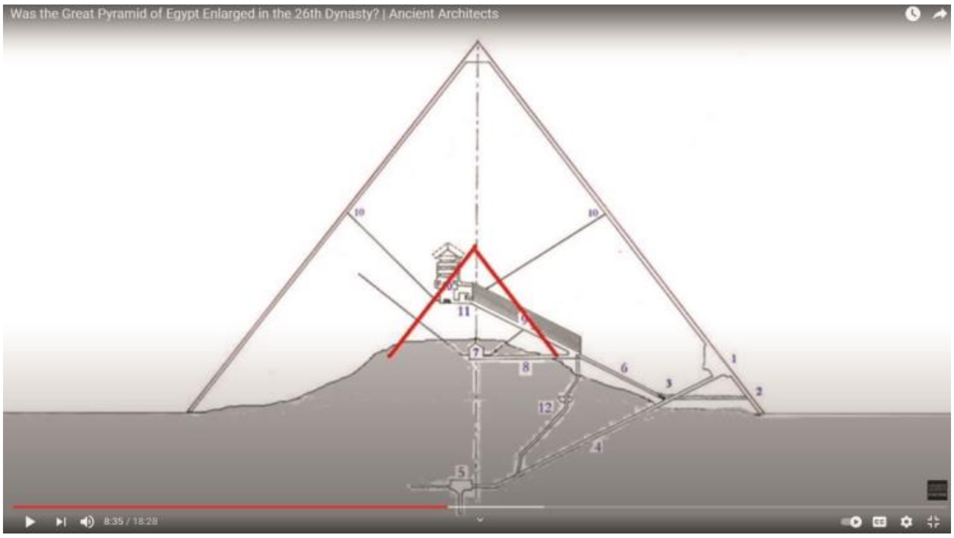


Fig. 14. The Great Pyramid of Giza ("The Pyramid of Cheops"). Schematic S-N section.
(Was the Great Pyramid of Egypt Enlarged in the 26th Dynasty? / Ancient Architects/ youtybe)

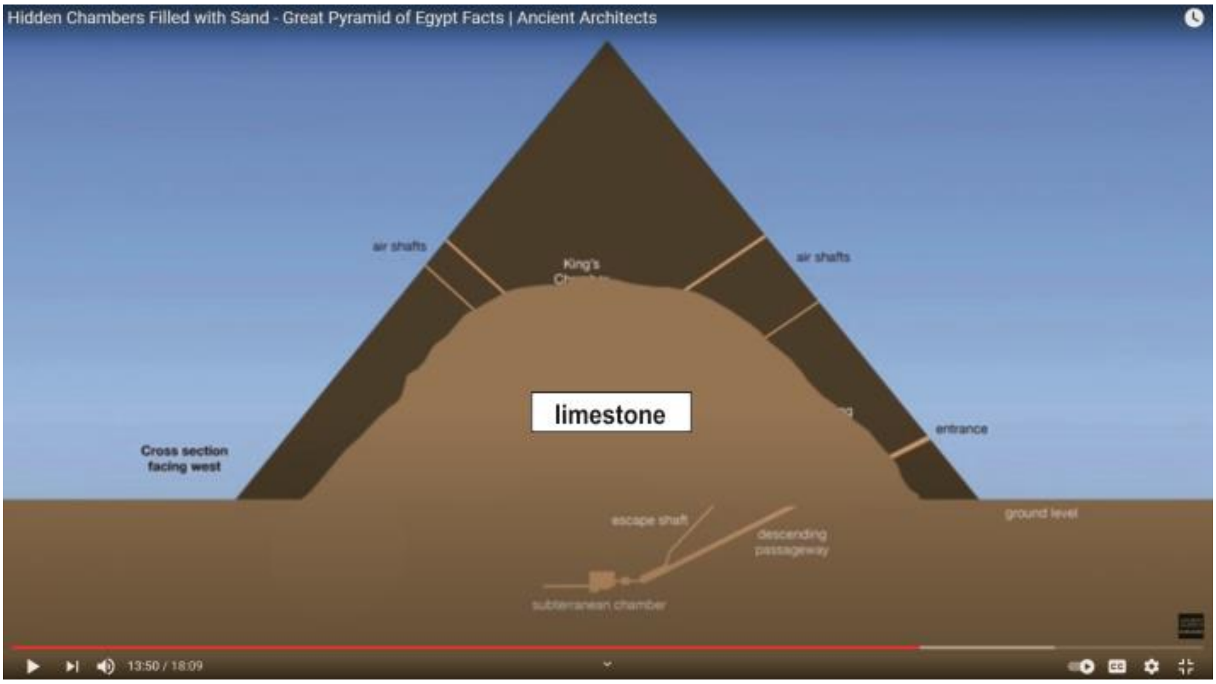


Fig. 15. The Great Pyramid of Giza ("The Pyramid of Cheops"). Schematic S-N section.
(Hidden Chambers Filled with Sand - Great Pyramid of Egypt Facts / Ancient Architects/ youtybe)

2.0. GPR RESEARCH SO FAR IN THE AREA OF THE GREAT PYRAMID ("CHEOPS PYRAMID") IN GIZA

In the area of the Great Pyramid of Giza, geophysical surveys were carried out using various methods. On the northern and eastern sides of the pyramid, several cross-sectional lines were made using the seismic method (Fig. 16). On the northern side of the pyramid, numerous GPR cross-sectional lines were made. On the southern and eastern sides of the pyramid, several cross-sectional lines were made using the georadar method (Fig. 17, 18). GPR surveys were not conducted on the surfaces of the walls of the pyramid.

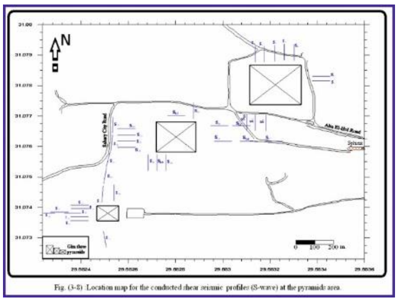


Fig. 16. Egypt, Giza Plateau. Seismic surveys in the area of the Great Pyramid ("Cheops Pyramid").
(according to the Institute of Geophysics in Cairo)

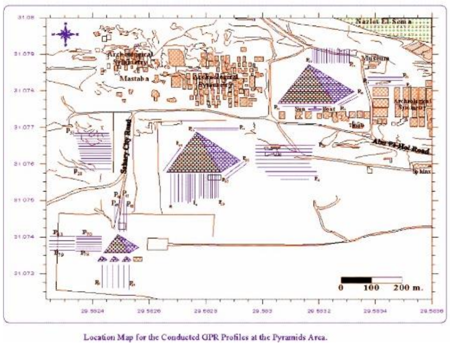


Fig. 17. Egypt, Giza Plateau. GPR research in the area of the Great Pyramid ("Cheops Pyramid").
(according to the Institute of Geophysics in Cairo)

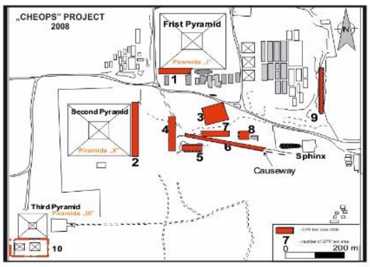


Fig. 18. Egypt, Giza Plateau. GPR research in the area of the Great Pyramid ("Chaops Pyramid") made in 2008
(according to the Institute of Geophysics in Cairo, Egypt and Wroclaw University, Poland)

3.0. PURPOSE AND SCOPE OF GPR TESTS ON THE OUTER WALLS OF THE GREAT PYRAMID (CHEOPS PYRAMID) IN GIZA

The purpose of non-destructive testing on the outer walls of the Great Pyramid (the so-called "Chaops Pyramid") in Giza is to check with the GPR method:

1. Location of the roof surface of the natural limestones under the pyramid.

2. Is the "King's Chamber" on natural limestone or limestone blocks.

3. Is the "Queen's Chamber" carved in natural limestone rocks, or is it arranged on limestone blocks (Fig. 19).

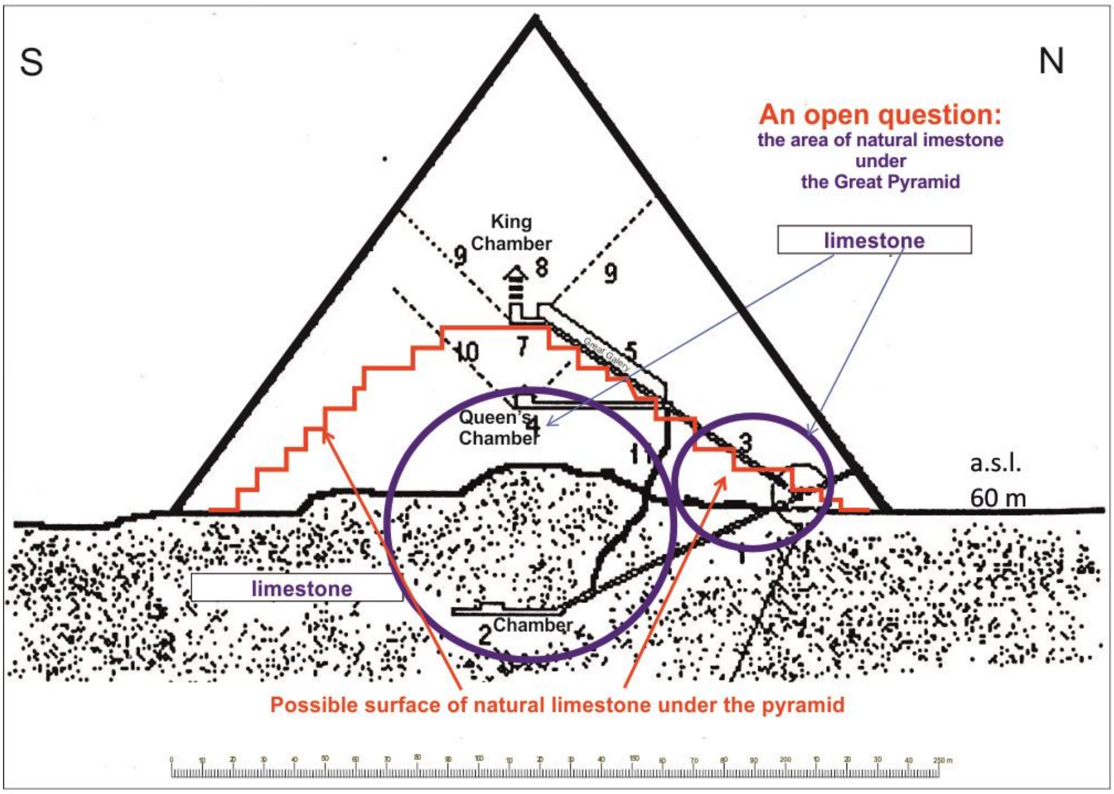


Fig. 19. Egypt, Giza, the Great Pyramid ("The Pyramid of Cheops"). Schematic S-N section through the pyramid.
blue circles - places where solid limestone rocks were found,
red stairs - projected area of solid limestone under the "King's Chamber"

On the surface of the walls of the Great Pyramid ("The Pyramid of Cheops") in Giza, it is proposed to perform detailed GPR surveys: MALA GeoDrone 80 and GPR MALA TRA with 30 MHz antennas - to a depth of about 60-100 m. (or/and MALA RTA with 100 MHz antennas - to a depth of 15-25 m). GPR data analysis will be performed in 2D and 3D.

4.0. GPR METHOD

4.1. Ground Penetrating Radar (GPR)

Georadar (Ground Penetrating Radar - GPR) is an electronic equipment for geophysical ground research. The GPR consists of: a transmitting antenna and a receiving antenna, which are connected by optical fibers (or WiFi) to the Central Unit. The device works on the principle of counting the return delays of electromagnetic pulses of very high frequency (10 - 3000 MHz). The EM waves are sent by the transmitting antenna and are reflected from different lithological boundaries of the ground. The received echo of EM waves by the receiving antenna are transmitted to the central unit in order to count the time of return delays of the wave. The boundaries reflecting the radar signal should be understood as the boundaries between the media differing in the value of the dielectric constant. Rocks have different dielectric constant values. The impulses sent by the transmitting antenna into the center return with a delay to the receiving antenna and through optical fibers go to the central unit controlling the system, and then they are processed and sent to the recorder (e.g. a portable computer hard drive or XV monitor). In the field, these impulses are observed by the operator on the monitor in the form of an echogram/time waveform (i.e. linear, vertical, cross-section) of soil parameters variability. Such a chart can then be converted, for example, into metric units, it can be printed in colors (so-called filtration - a separate color for different wave speeds). The obtained image can be compared with model images of various objects hidden in the ground or with model images of geological structures or with cartographic documentation of uncovers, as well as with data obtained from geological drillings. Compared to other geophysical methods, the radar method (GPR) allows non-invasive, linear tracking of the geological structure in the field, i.e. tracking the variability of lithology and shallow geological structures. The use of interchangeable antennas (with different frequencies, e.g. from 10 MHz to 3 GHz) depends on the task and the assumed depth of ground monitoring. The lower the central frequency of the antennas, the greater the depth range of the profiling. For shallow archaeological and geotechnical research, antennas with a higher central frequency are used, enclosed in a specially shielded container (shielded antennas).

For non-invasive georadar surveys (GPR) on the surface of the outer walls of the Great Pyramid (the so-called "Pyramid of Cheops") in Giza, it is proposed to use the following measuring equipment:

A) MALA GeoDrone 80 - a GPR with 80 MHz antennas placed on a DRON flying system (Fig. 20, 21), which allows tracking of geological structures, e.g. behind the pyramid wall, to a depth of about 10-30 m, from the surface of the pyramid wall.

B) MALA ProEX (or RAMAC/GPR) system apparatus with antennas: MALA RTA 30 MHz - to a depth of about 30 -100 m or/and MALA RTA 100 MHz - to a depth of 15-30 m (Fig. 22, 23) together with MALA XV Monitor (or laptop).

GPR data analysis will be performed in 2D and 3D.

4.2. GPR measuring equipment

- **MALA GeoDrone 80**

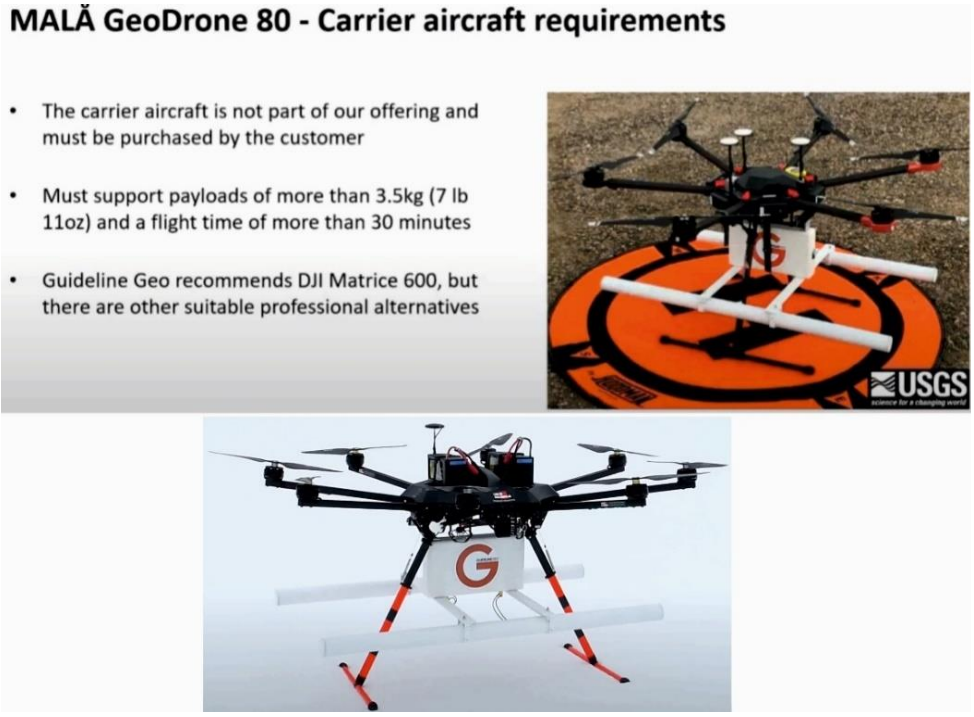


Fig. 20. MALA GEODrone 80 system - with GPR 80 MHz antennas placed on a drone-type flying system

Fig. 21. System MALA GeoDrone 80.

➢ MALA ProEX + RTA antenna

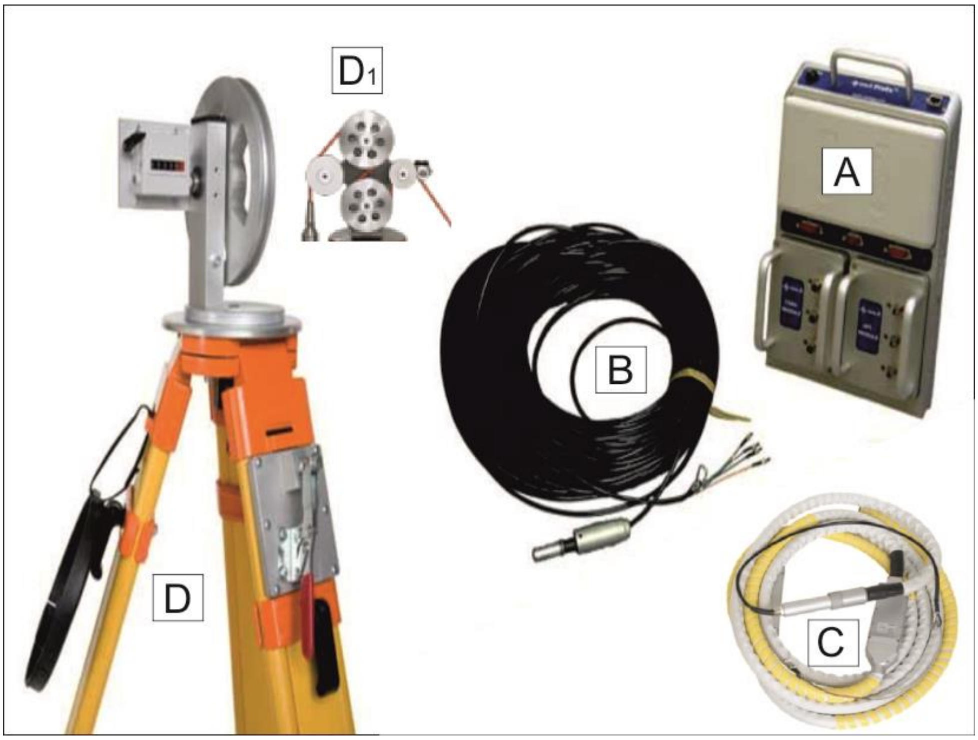


Fig. 22. Kit for performing non-invasive GPR examinations on the outer surface of the walls of the Great Pyramid ("The Pyramid of Cheops") in Giza, Egypt:
A - MALA ProEX control unit, B - optic fiber (between central unit and antenna), C - MALA Rough Terrain Antenna (RTA), D - tripod stand for distance measuring wheel; D1 - modified distance measuring wheel

Fig. 23. MALA Rough Terrain Antenna (RTA) 100 MHz

4.3. Possibilities of transporting GPR antennas over the walls of the pyramid

Method I.

Method (I) - involves the use of the MALA GeoDrone 80 system. The antennas are suspended on the DRON apparatus. A drone with GPR antennas moves from the base of the pyramid to its top, along lines such as: 2 m, 5 m, 10 m. The antennas do not touch the walls of the pyramid.

Method II. – Elevator/winch with carring rope/lifting rope and turning station at the top

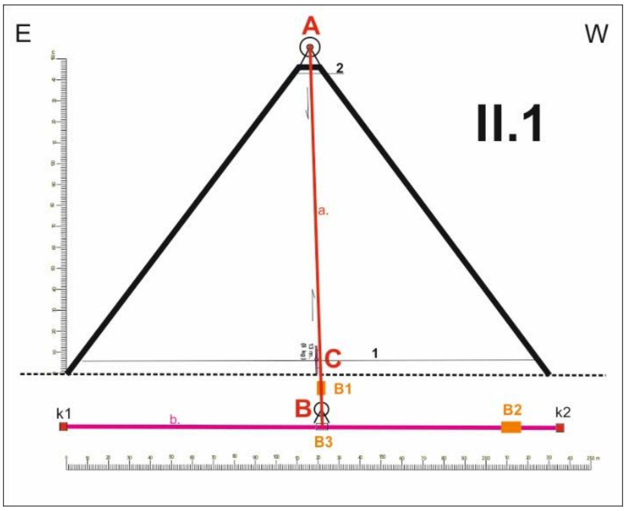


Fig. 24. Method II.1 - moving the RTA antennas on the surface of the pyramid walls.
Elevator/winch: Module A - turning station with a pulley at the top of the pyramid, Module B - winch with a pulley at the base of the pyramid, B1, B2 - tensioning device, “a.” – carrying rope/lifting rope, B3 - sleeve guiding the working rope,
k1, k2 - fastening wedges or weights
C - MALA RTA 30 antennas suspended from the suspension line "a." stretched between the modules of the B-A elevator;
1-2 – distance of GPR profiling section

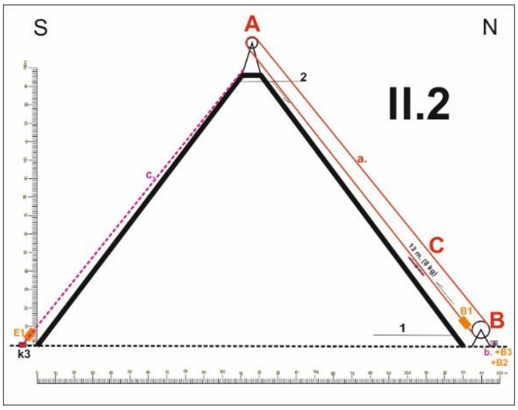


Fig. 25. Method II.2 - moving the RTA antennas on the surface of the pyramid walls, version with a guy rope on the opposite side of the pyramid.
Elevator/winch: Module A - turning station with a pulley at the top of the pyramid, Module B - winch with a pulley at the base of the pyramid, B1, B2, E1 - rope tensioning devices, B3 - sleeve guiding the working rope "b", “a.” – carrying rope/lifting rope, “c.” - tension rope on the other side of the pyramid, k3 - fastening wedge or weights,
C - MALA RTA 30 antennas suspended from the rope "a." between elevator modules B-A;
1-2 – distance of GPR profiling section

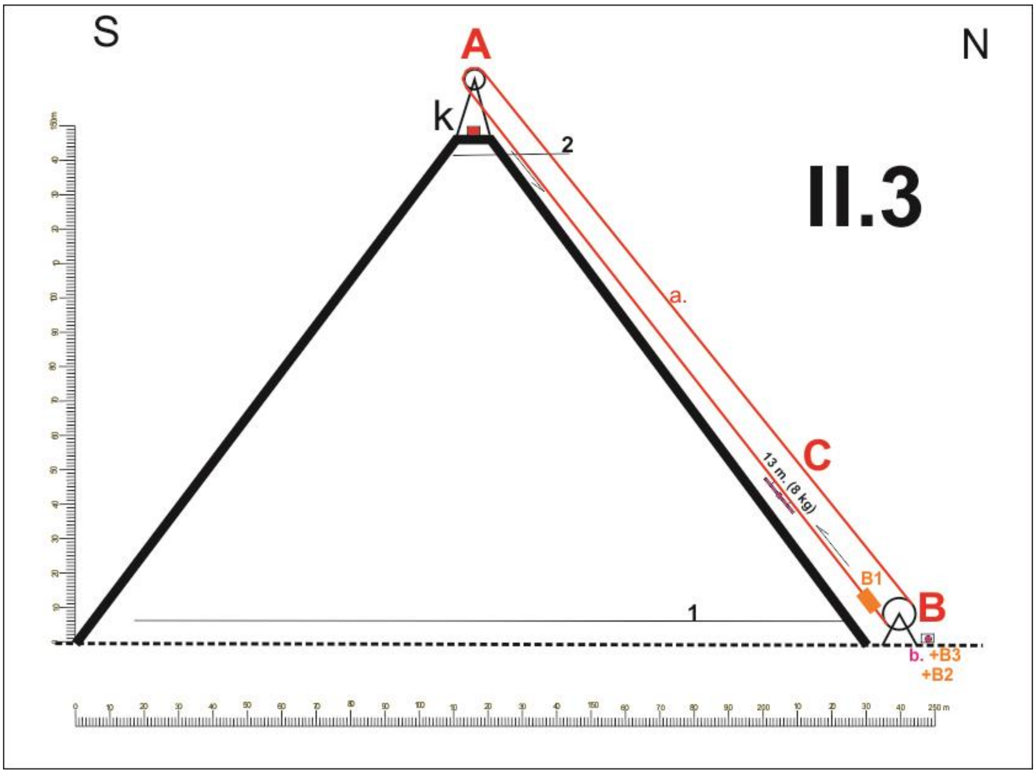


Fig. 26. Method II.3 - moving the RTA antennas on the surface of the pyramid walls, version with anchoring of module A (return station) at the top of the pyramid.
Elevator/winch: Module A - turning station with a pulley at the top of the pyramid, Module B - winch with a pulley at the base of the pyramid, B1, B2 - rope tensioning devices, B3 - sleeve guiding the working rope "b", a. – carrying rope/lifting rope,
k - fastening wedges or weights at the top of the pyramid,
C - MALA RTA 30 antennas suspended from the rope "a." between elevator modules B-A;
1-2 – distance of GPR profiling section

Method II - consists in using the MALA ProEX system with RTA 30 MHz antennas (about 13 m long and weighing about 8 kg), which are suspended from the suspension rope "a." (Fig. 24, 25, 26). The antennas do not touch the walls of the pyramid. Lift/winch rope "a." it runs from module B (at the base of the tested pyramid wall) and through module A - the turning station at the top of the pyramid back to module B at the base of the tested pyramid wall (Fig. 24, 25, 26). GPR data collection will take place over a distance, a section of the pyramid wall between points 1-2.

Two variants of stabilizing module A at the top of the pyramid should be considered.

Variant II.2 - provides for the installation of a tension rope on the opposite side of the pyramid (Fig. 25).

Variant II.3 - provides for the possibility of anchoring module A (return station) at the top of the pyramid (Fig. 26). Module B (turnstile) should be able to be moved along the working rope "b" (Fig. 24) - a fixed baseline at the base of the tested pyramid wall. The working rope "b" should be anchored at the corners of the tested pyramid wall (k1, k2 in Fig. 24). On the ropes: "a." (carrying rope), "b." (working rope), "c" (tension rope) - tensioning devices for these ropes should be installed (B1, B2 and E1 in Fig. 24, 25, 26). The guide sleeve (B3 in Fig. 24, 25, 25) through which the working rope passes serves to stabilize the suspension rope during measurements with the antennas along the pyramid wall.

4.4. Necessary auxiliary equipment to perform GPR tests with RTA antennas

To perform GPR surveys using the method of linear profiling on the surface of the walls of the Great Pyramid ("The Pyramid of Cheops"), using MALA Rough Terrain Antenna (RTA), auxiliary equipment in the form of a makeshift elevator will be necessary (Fig. 22, 23, 24, 25, 26, 27, 28, 29).

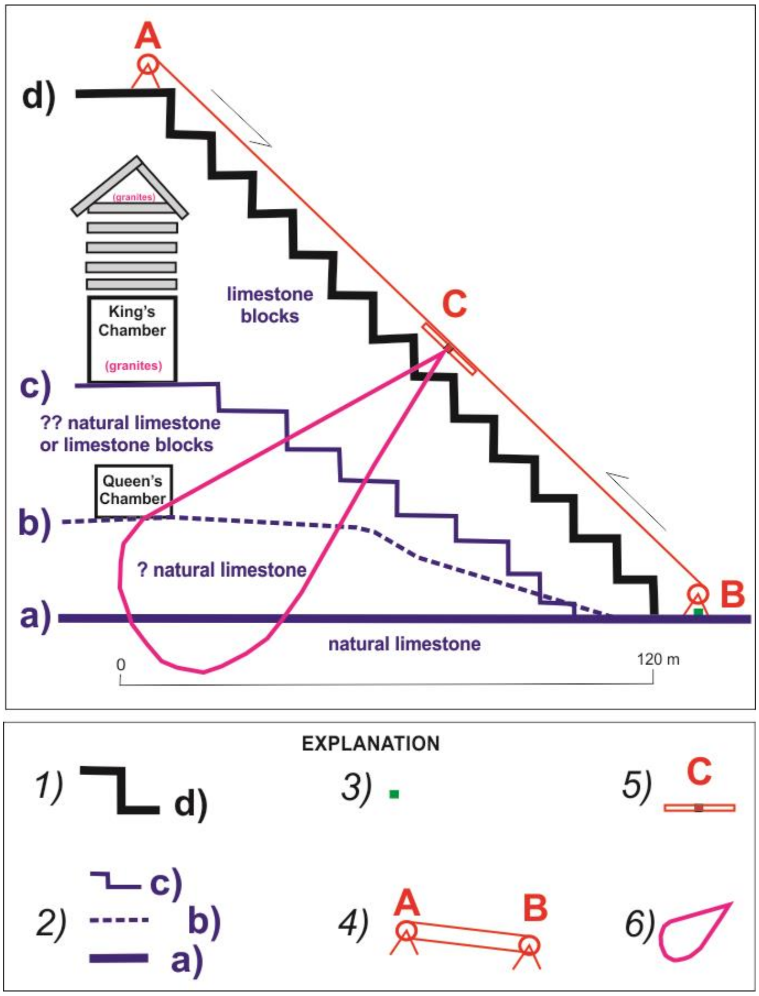


Fig. 27. Scheme of the GPR test method on the outer surface of the pyramid walls:
1) the theoretical surface of the pyramid wall; 2) possible natural solid limestone surfaces: a - under the base of the pyramid, b - under the "Queen's Chamber", c - under the "King's Chamber"; 3) baseline of GPR measurements; 4) elevator/winch for moving the GPR antennas above the surface of the pyramid walls (Module A - return station set with a pulley at the top of the pyramid, Module B - tripod with a pulley and a turnstile at the base of the pyramid); 5) MALA RTA antennas (Module C), suspended from the rope lifts (A-B); 6) theoretical range of the cone of EM waves sent by the RTA antenna.

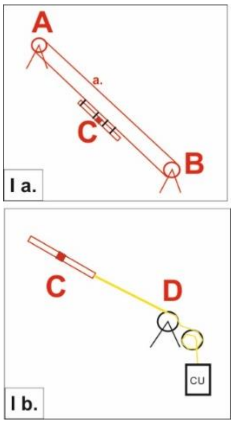


Fig. 28. Scheme of the elevator/winch necessary for GPR research with RTA antenna on the outer surface of the pyramid walls.
Ia – elevator/winch: Module A – tripod with a pulley at the top of the pyramid, Module B – tripod with a pulley and a winch at the base of the pyramid, Module C – MALA RTA antennas suspended to the suspension rope; "a." - lifting rope
Ib – GPR measurement set with RTA antennas: C - MALA RTA 30 MHz antennas; D - tripod stand for distance measuring wheel, CU - central unit

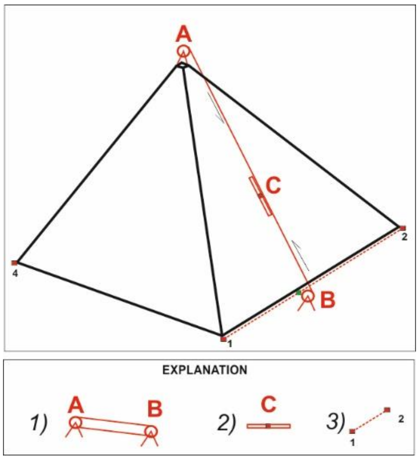


Fig. 29. Scheme of making one cross-sectional GPR line on the outer surface of the pyramid wall.
1) elevator/winch, 2) GPR antennas, 3) control points and baseline 1-2

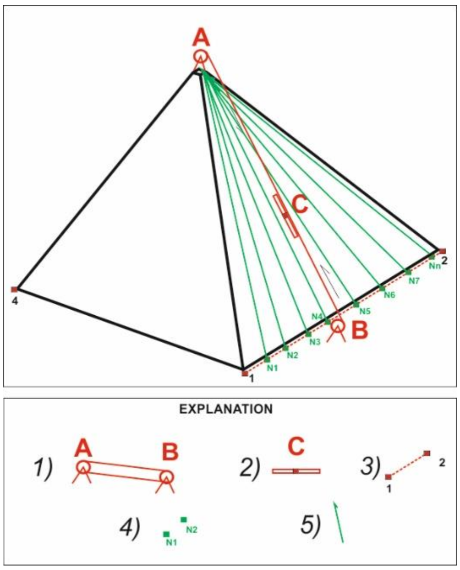


Fig. 30. Scheme of making GPR cross-sectional lines on the outer surface of the pyramid wall.
1) elevator/winch, 2) GPR antennas, 3) control points and baseline, 4) beginning of the section line, 5) GPR section line

ELEVATOR / WINCH (A – B on Fig. 24, 25, 26, 27, 28, 29, 30).

Module **A** - turning station. A frame (or tripod) with a pulley to be placed on top of the pyramid. A carrying rope ("a" in Fig. 28. Ia) will be passed through the pulley, running from module B through module A (at the top of the pyramid) back to module **B** (a tripod with a pulley and a winch at the base of the pyramid). Module **A**, at the top of the pyramid, should have a load and the ability to move towards the individual walls of the pyramid. Module **B**, should be loaded but moveable. The lift/elevator/winch should have a manual drive (a winch with a crank) or a mechanical drive (motor). Consideration should be given to the option of installing a "c" guy line. and the extraction module, on the opposite side of the pyramid (see Fig. 25). This seems to be a good solution.

The MALA RTA antennas (Fig. 22, 23 and C in Fig. 24, 25, 26, 27, 28, 29, 30) should be suspended from the carrying rope/lifting rope of the lift/elevator/winch **A-B**.

At the base of the pyramid, next to module **B**, there should be module **D** - a tripod stand for distance measuring wheel (Fig. 22 and Fig. 28 Ib), and a GPR operator with a central unit (CU) and a control computer (or with an XV monitor).

At the base of the pyramid, along the base lines: 1-2, 2-3, 3-4, 4-1, modules B and D will be moved/moved, as well as a USAR operator with a central unit (CU) and a computer or monitor XV. Module B will be moved by a fixed distance interval (e.g. every 1 m, every 2 m, every 5 m or every 10 m; e.g. N1, N2…. Nn in Fig. 29).

Note: lift/elevator/winch (Modules A and B) - Requires detailed technical projects

5.0. METHODOLOGY OF GPR FIELD WORKS

GPR field works on the surfaces of the walls of the Great Pyramid ("Cheops' Pyramid") will be carried out:

I. MALA GeoDrone system 80 m (shallow depths: 20-30 m from the surface of the pyramid walls).

The drone with antennas will be guided about 1 m above the surfaces of the pyramid walls, in a linear system: from the base of the pyramid to the top of the pyramid (at intervals of measurement lines, e.g. 2 m, 5 m).

II. Portable ground penetrating radar (GPR): MALA ProEX (or RAMAC/GPR), powered by 12V batteries, with RTA antennas 30 MHz (or/and 100 MHz). The antennas will be attached to the carrying rope/lifting rope (lift/winch) and will be moved about 1 m above the surface of the pyramid walls, from the base of the pyramid to its top. The tests will be performed using the linear profiling method (Fig. 31, 32, 33, 34), to a depth of about 30-60 m. Trace interval: i = 0.05 m or 0.1 m (this will be determined after preliminary field tests). Distances will be measured with a measuring wheel (Modules D, D1 in Fig. 22 and D in Fig. 28 Ib). The EM pulses will be sent from the center of the antenna and therefore the so-called blind spots: at the start and at the end of the measurement (see levels: 1 - 2 in Fig. 24, 25, 26).

The GPR research project of the pyramid walls was divided into tasks:

Task 1 - north wall (N) of the pyramid (Fig. 31).

Task 2 - western wall (W) of the pyramid” (Fig. 32).

Task 3 - south wall (S) of the pyramid (Fig. 33).

Task 4 - eastern wall (E) of the pyramid (Fig. 34).

Task 1 - north wall (N) of the pyramid.

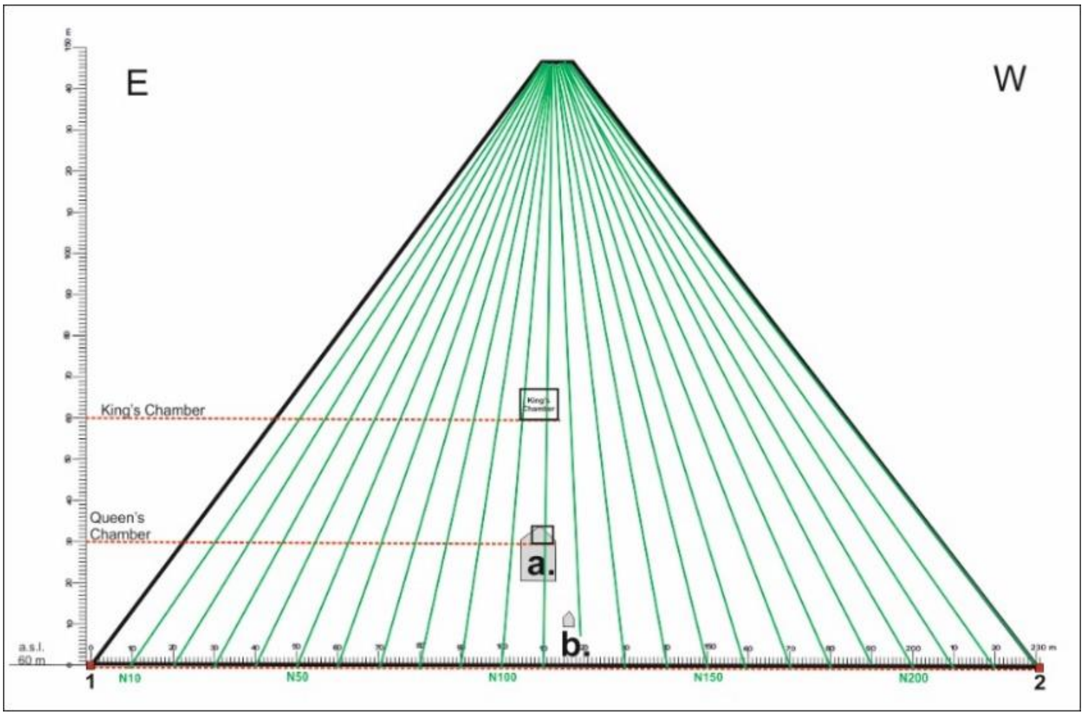


Fig. 31. The Great Pyramid ("The Pyramid of Cheops") in Giza. Diagram of GPR cross-sectional lines along the northern wall (N) of the pyramid.
a. b. - niches in the wall with entrances to the pyramid
The theoretical height of the "King's Chamber" and "Queen's Chamber" are marked

A tape measure will be laid along the base of the pyramid, from control point 1 to control point 2 (baseline 1-2). Modules: **B** and **D** will be moved along this line in intervals, e.g. every 1 m, every 2 m, every 5 m or every 10 m (N1, N2…N230 in Fig. 31). Also along this baseline, the georadar operator will move along with the central unit (CU) and computer (or monitor XV). The RTA antennas (module **C**) will be moved from the base of the pyramid to its top using a winch. The initial location of the measurement start points: N1…Nn is shown in Fig. 31.

Version 1. With the spacing between the cross-sectional lines every 1 m - it is planned to make 230 cross-sectional lines, each about 180 m long (41 400 m in total).

Version 2. With spacing between cross-sectional lines every 2 m - it is planned to make 115 cross-sectional lines, each about 180 m long (20 700 m in total).

Version 3. With spacing between the cross-sectional lines every 5 m - it is planned to build 46 cross-sectional lines, approximately 180 m long each (8 280 m in total).

Task 2 - western wall (N) of the pyramid.

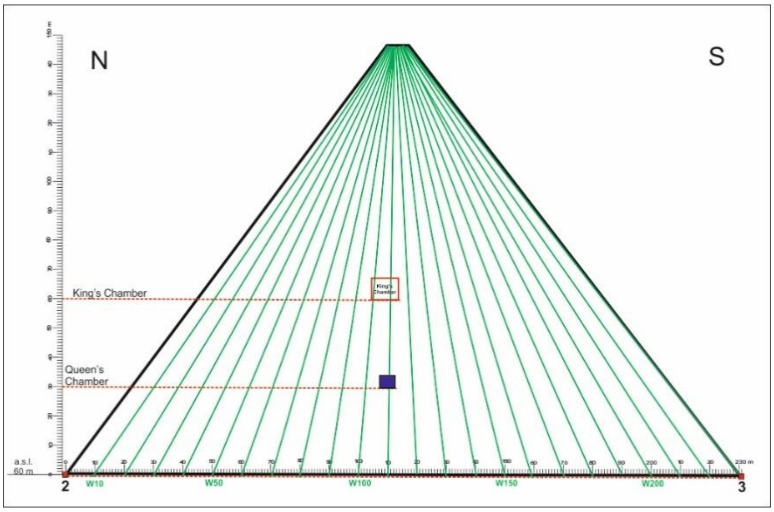


Fig. 32. The Great Pyramid ("The Pyramid of Cheops" in Giza. Diagram of GPR cross-sectional lines along the western wall (W) of the pyramid.
The theoretical height of the "King's Chamber" and "Queen's Chamber" are marked

A tape measure will be laid along the base of the pyramid, from control point 2 to control point 3 (baseline 2-3). Modules: **B** and **D** will be moved along this line in intervals, e.g. every 1 m, every 2 m, every 5 m or every 10 m (W1, W2…W230 in Fig. 32). Also along this baseline, the georadar operator will move along with the central unit (CU) and computer (or monitor XV). The RTA antennas (module **C**) will be moved from the base of the pyramid to its top using a winch. The initial location of the measurement start points: W1…Wn is shown in Fig. 32.

<u>Version 1.</u> With the spacing between the cross-sectional lines every 1 m - it is planned to make 230 cross-sectional lines, each about 180 m long (41 400 m in total).

<u>Version 2.</u> With spacing between cross-sectional lines every 2 m - it is planned to make 115 cross-sectional lines, each about 180 m long (20 700 m in total).

<u>Version 3.</u> With spacing between the cross-sectional lines every 5 m - it is planned to build 46 cross-sectional lines, approximately 180 m long each (8 280 m in total).

Task 3 – south wall (S) of the pyramid.

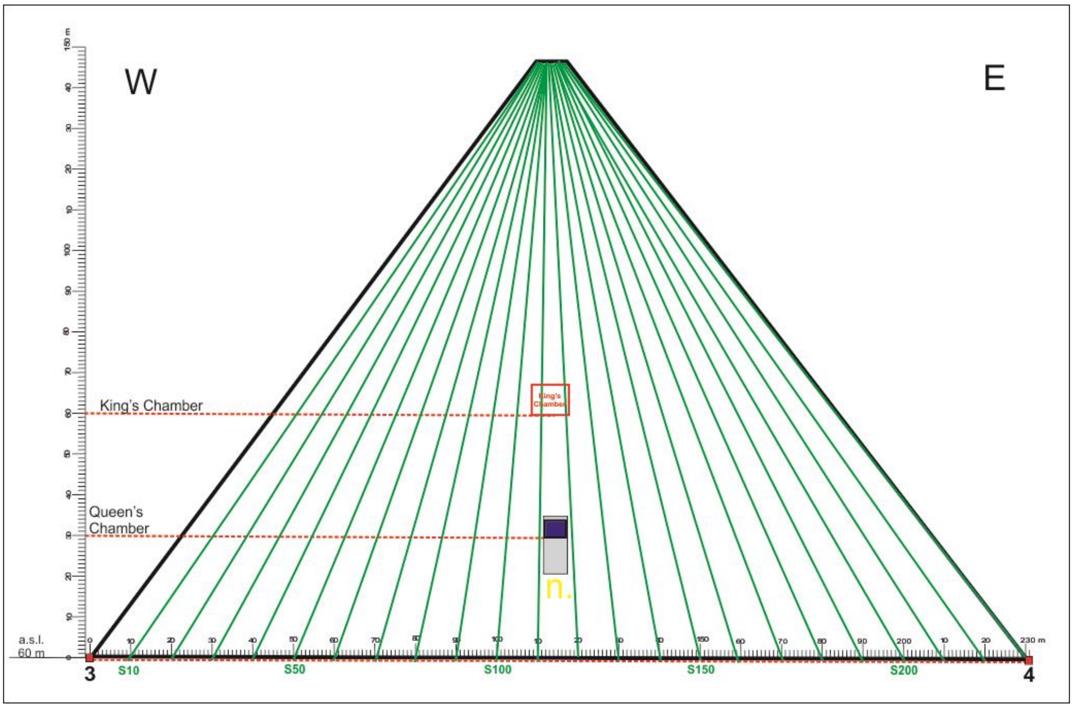


Fig. 33. The Great Pyramid ("The Pyramid of Cheops") in Giza. Diagram of GPR cross-sectional lines along the south wall (S) of the pyramid.
n. - niche in the wall of the pyramid
The theoretical height of the "King's Chamber" and "Queen's Chamber" are marked

A tape measure will be laid along the base of the pyramid, from control point 3 to control point 4 (baseline 3-4). Modules: **B** and **D** will be moved along this line in intervals, e.g. every 1 m, every 2 m, every 5 m or every 10 m (S1, S2…S230 in Fig. 33). Also along this baseline, the georadar operator will move along with the central unit (CU) and computer (or monitor XV). The RTA antennas (module **C**) will be moved from the base of the pyramid to its top using a winch. The initial location of the measurement start points: S1…Sn is shown in Fig. 33.

<u>Version 1.</u> With the spacing between the cross-sectional lines every 1 m - it is planned to make 230 cross-sectional lines, each about 180 m long (41 400 m in total).

<u>Version 2.</u> With spacing between cross-sectional lines every 2 m - it is planned to make 115 cross-sectional lines, each about 180 m long (20 700 m in total).

<u>Version 3.</u> With spacing between the cross-sectional lines every 5 m - it is planned to build 46 cross-sectional lines, approximately 180 m long each (8 280 m in total).

Task 4 - Eastern wall (E) of the pyramid.

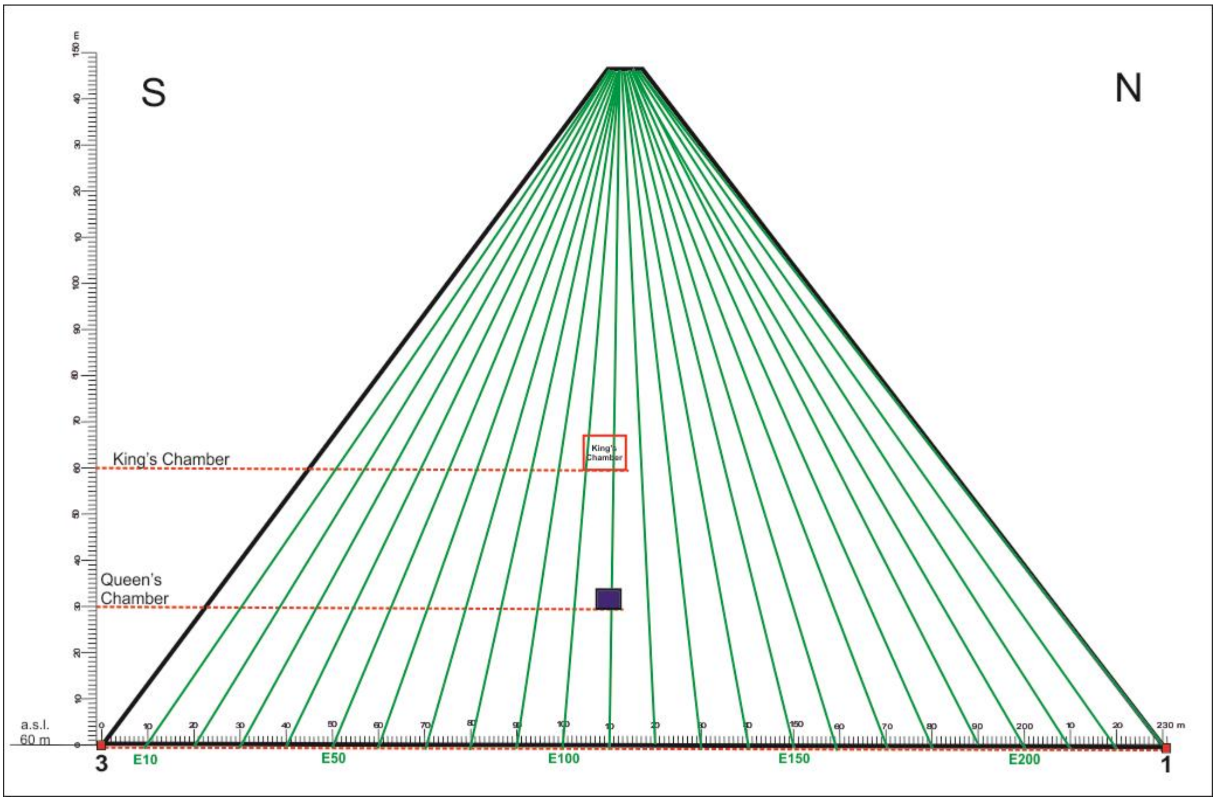


Fig. 34. The Great Pyramid ("The Pyramid of Cheops" in Giza. Diagram of GPR cross-sectional lines along the eastern wall (E) of the pyramid.
The theoretical height of the "King's Chamber" and "Queen's Chamber" are marked

A tape measure will be laid along the base of the pyramid, from control point 4 to control point 1 (baseline 4-1). Modules: **B** and **D** will be moved along this line in intervals, e.g. every 1 m, every 2 m, every 5 m or every 10 m (E1, E2…E230 in Fig. 34). Also along this baseline, the georadar operator will move along with the central unit (CU) and computer (or monitor XV). The RTA antennas (module **C**) will be moved from the base of the pyramid to its top using a winch. The initial location of the measurement start points: E1…En is shown in Fig. 34.

<u>Version 1.</u> With the spacing between the cross-sectional lines every 1 m - it is planned to make 230 cross-sectional lines, each about 180 m long (41 400 m in total).

<u>Version 2.</u> With spacing between cross-sectional lines every 2 m - it is planned to make 115 cross-sectional lines, each about 180 m long (20 700 m in total).

<u>Version 3.</u> With spacing between the cross-sectional lines every 5 m - it is planned to build 46 cross-sectional lines, approximately 180 long each (8 280 m in total).

Summary.

The project of GPR research on the outer walls of the Great Pyramid ("The Pyramid of Cheops") provides for the possibility of performing for each of the walls of the pyramid:

I. Research using the MALA GeoDRONE 80 system: 115 GPR cross-sectional lines at intervals, e.g. every 2 m, a total length of about 20 700 m.

II. Research using the MALA ProEX system with 30 MHz antennas:

Version 1. With the spacing between the cross-sectional lines every 1 m - it is planned to make 230 cross-sectional lines, each about 180 m long (41 400 m in total).

Version 2. With spacing between cross-sectional lines every 2 m - it is planned to make 115 cross-sectional lines, each about 180 m long (20 700 m in total).

Version 3. With spacing between the cross-sectional lines every 5 m - it is planned to build 46 cross-sectional lines, approximately 180 m long each (8 280 m in total).

TABELA 1. Proposal to perform GPR tests for the pyramid

		Version					
METHOD	Task	Cross-sectional lines [every 1 m]		Cross-sectional lines [every 2 m]		Cross-sectional lines [every 5 m]	
		Numer of lines	[m]	Numer of lines	[m]	Numer of lines	[m]
A. (DRON)	1.wall N	230	41 400	115	20 700	46	8 280
	2.wall W	230	41 400	115	20 700	46	8 280
	3.wall S	230	41 400	115	20 700	46	8 280
	4.wall E	230	41 400	115	20 700	46	8 280
Together	**1+2+3+4**	**920**	**165 600**	**460**	**82 800**	**184**	**33 120**
B. Antenna RTA	1.wall N	230	41 400	115	20 700	46	8 280
	2.wall W	230	41 400	115	20 700	46	8 280
	3.wall S	230	41 400	115	20 700	46	8 280
	4.wall E	230	41 400	115	20 700	46	8 280
Together	**1+2+3+4**	**920**	**165 600**	**460**	**82 00**	**184**	**33 120**
Total: A.+ B.	**all sides of the pyramid**	**1 840**	**331 200**	**920**	**165 600**	**368**	**66 240**

6.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 2D SYSTEM

The echograms (EM wave echoes) obtained from individual cross-sectional lines will be converted by the GPR central unit and saved on the hard disk of the computer or XV monitor (each profiling line is a separate result file .rd3). In the laboratory, the data files will be transferred to a stationary computing computer and filtered in the GroundVision and ReflexW programs. Different color palettes and different combinations of filters will be used when analyzing the data.

Calibration of the depth scale will be performed on the basis of the assumed average value of electromagnetic waves passing through limestone and granite. The depth scale error on 2D sections can be 50%. This may be due to: A) - changes in the color of the FM phase during filtration (the principle of EM wave amplitude, positive phase and negative phase; B) - the assumed speed of propagation of EM waves in the examined rocks (granite, limestone).

After selecting the color scale, filters, filtering and obtaining the optimal image for interpreting the GPR data and answering the questions, as well as after calibrating the depth scale, the echograms (2D images) will be transferred to CorelDraw for interpretation and marking of anomalies.

Echograms, i.e. 2D images of electromagnetic waves (EM), obtained as a result of filtration, will be compared with model images and with images obtained during experimental GPR surveys. Attention will be paid to: a) GPR anomalies in EM field images, and b) characteristic refractions of wave images in anomalous zones.

Echograms (2D images) in CorelDraw will show detected GPR anomalies. These anomalies will be respectively transferred to the maps of the surface of the pyramid walls, with an accuracy of ±1 m. Sets of anomalies from several lines will make it possible to interpret whether there are any hitherto unknown: voids, corridors, chambers, etc. behind the surface of the pyramid walls, and at what distance from the surface of the pyramid walls can be located.

Comments:

1) *in the paper version of the documentation (WORD), the drawings will be difficult to read, therefore a CD (or USB flash drive) has been attached to the documentation, where all figures will be in JPG (or PDF) version, which can be enlarged.*
2) *on the 2D cross-sections the distance scale will not equal the depth scale.*

7.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 3D SYSTEM

GPR data, obtained from cross-sectional lines, will also be processed in the 3D Slices system. On horizontal time slices images (e.g. every 0.5 m or 0.2 m), EM fields will be analyzed. Detected GPR anomalies will be marked (e.g. with a purple rectangle) and numbered. The analysis of EM fields will be carried out on horizontal time slices from the surface of the wall to a depth of about 20 m or 100 m, depending on the antennas used. EM field anomalies detected at individual horizontal time slices will also be shown in collective drawings (for selected depths, e.g. 0-10 m, 10-20 m, 20-30 m, etc.).

In the horizontal time slices images, the "warm" colors - light blue, yellow to red - will indicate the locations of EM field anomalies (GPR anomalies). Maps of detected GPR anomalies behind the individual faces of the pyramid will be drawn. Three-dimensional 3D image of detected GPR anomalies and images of GPR anomalies on vertical time slices will be made.

A comparison of the test results obtained in the 3D system with the results obtained from the analysis of GPR data in the 2D system will be performed.

8.0. PERSONNEL NECESSARY FOR THE PROJECT

a) persons operating the MALA GeoDrone 80 apparatus:

- One person or 2 people from Sweden - operating the DRON eqiupment;
- Adam Szynkiewicz, PhD. – operating Monitor XV and data collection

b) persons operating GPR equipment with RTA antennas:

- Adam Szynkiewicz, PhD. - a GPR operator, operating Monitor XV
- Andrzej Kapłanek, MSc. Eng. - control of the "elevator/winch" service;

c) persons supporting field research:

- Supervisor of the Ministry of Antiquities in Cairo;
- Reda Abdelhaleem Mohamed Khalifa, PhD - supervision of research by the Egyptian side
- Two technicians to help with the assembly of the elevator/winch and to move the antennas along the walls of the base of the pyramid;
- Person controlling the work of the "elevator/winch" at the top of the pyramid
- Security guards (2 persons).

d) persons interpreting USAR data and preparing documentation:

- Adam Szynkiewicz, PhD. - data analysis in the 2D system of documentation
- Magdalena Udyrysz-Kraweć, MA. - analysis of GPR data in the 3D system
- Andrzej Kapłanek, MSc. Eng.- cooperation in the preparation of documentation

9.0. TIME REQUIRED TO COMPLETE THE PROJECT

I. The following working time is required to perform the GPR field tests:

A. DRON method - 4-5 days of work, about 5-6 hours a day;

B. Method with RTA antennas - depending on the version:

version 1 (every 1 m) - about 8-10 working days (5-6 hours a day);

version 2 (every 2 m) - about 6-8 working days (about 5-6 hours a day);

version 3 (every 10 m) - about 4-6 working days, about 5-6 hours a day).

II. For the analysis of the obtained GPR data and preparing of documentation need:

A. DRON method - 30 days of work, about 6 hours a day (data analysis in the 2D system and in the 3D system).

B. Method with RTA antennas - 90 days of work, about 6 hours a day (data analysis in the 2D system and in the 3D system).

STAGE II.

GREAT PYRAMID IN GIZA (EGYPT)
"KING'S CHAMBER"
PROJECT OF THE GPR RESEARCH

Author:

Adam Szynkiewicz, PhD. (Poland)

Cooperation:

Reda Abdelhaleem Mohamed Khalifa, PhD. (Egypt)
Magdalena Udyrysz–Kraweć, MA. (England)

Poland, Wrocław, 2023

CONTENTS

1.0. THE GREAT PYRAMID ("CHEOPS PYRAMID") IN GIZA (EGYPT)

In Northern Egypt, on the Giza plateau, in a complex of three pyramids (and a few small ones), there is the Great Pyramid, also called the "Cheops Pyramid". The Giza Plateau (105-120 m above sea level), is located on the western side of the Nile River Valley (18-20 m above sea level) and is west of the center of Cairo. The plateau is built of limestone of the Eocene age.

Fig. 1. Great Pyramid in Giza Plateau. View from the SE side

Fig. 2. Great Pyramid in Giza Plateau. View from above

The Great Pyramid ("The Pyramid of Cheops"), is located at an altitude of 60 m above sea level. Currently, the pyramid has a height of about 146.59 m (Fig. 1). The surface of the walls of the pyramid are blocks of Eocene limestone, arranged in steps (the limestone blocks are about 1m x 1m x 1m). Currently, the length of the northern, eastern, western and southern bases of the pyramid's walls is approximately 230.5 m (Fig. 2). The general inclination of the pyramid's walls is about 51˚52'. Inside the pyramid there are corridors and chambers. The largest of them is the so-called "King's Chamber".

2.0. THE „KING'S CHAMBER" IN THE GREAT PYRAMID

In the central part of the Great Pyramid, at an altitude of about 120 m above sea level, i.e. about 60 m the surface surrounding the pyramid (60 m above sea level), there is a chamber measuring 10.65 m (W-E) and 5.23 m (S-N) and high 5.81 m, called the "King's Chamber". The longer axis of the Chamber is oriented in the W-E direction. The walls, ceiling and floor of the Chamber are made of large granite blocks (1-5 m long). The entrance to the Chamber (approximately 1 m x 1 m) is at the base of the north wall, in the south-eastern corner of this wall. In the eastern wall and in the southern wall, at a height of about 1 m from the floor of the Chamber, there are openings for small corridors (about 20 cm x 20 cm). In the western part of the Chamber, there is an open "coffer/chest", with dimensions: length of about 2.4 m, width of about 1.1 m and height of about 1 m, called the "sarcophagus". This coffer/chest ("sarcophagus") is cut out of a single block of granite. The longer axis of the "coffer" has a direction similar to S-N, with a slight deviation towards NW. This structure is located approximately 1.5 m from the northern wall of the Chamber and approximately 1.5 m from the western wall of the "King's Chamber" (Fig. 3).

At the northern wall of the "King's Chamber" and under the "coffer/chest" ("sarcophagus"), a trench was made, about 2-3 m in size and 4.5 m deep (pit in Fig. 3). The documentation of the excavation shows that under the "King's Chamber" there are solid limestone rocks, and the granite blocks of the floor and walls of the Chamber are laid on solid limestone.

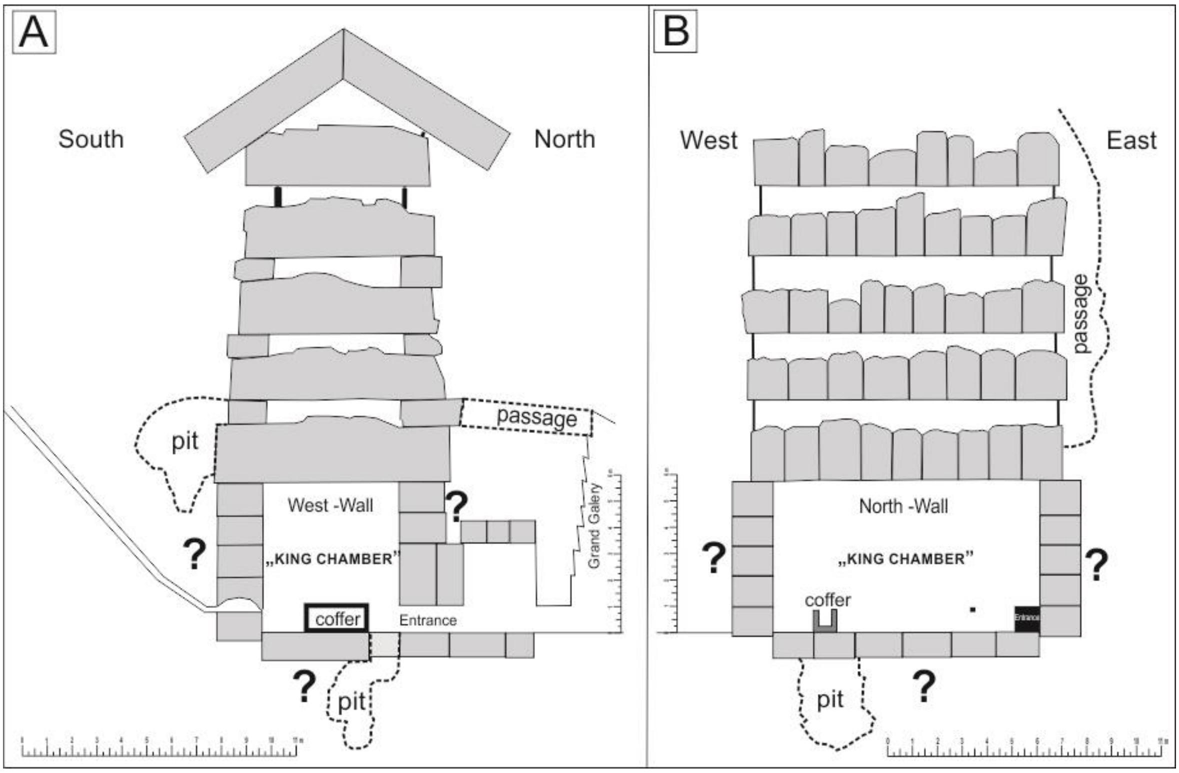


Fig. 3. Egypt, Giza, the Great Pyramid. Schematic cross-sections through the "King's Chamber": A - S-N cross-section; B – section W-E

In the so-called The "King's Chamber" geophysical research was performed. See: Studies in Egyptian Culture, No. 8: "Non-Destructive Pyramid Investigation (2)", WASEDA University, Tokyo-Japan, 1988 (see: "Inside the Pit beneath the floor of the Great Pyramid Kings Chamber - the Facts. Ancient Architects" on YouTube, https://youtu.be/GsioIsvtfMw and: "Scientific Evidence for a Secret Door in the Kings Chamber of the Great Pyramid/ Ancient Architects" on YouTube, https://youtu.be/7Rbi6_SMT5w). The result of these studies are, among others, images of geophysical anomalies occurring under the floor of the "King's Chamber" (Fig. 4).

Fig. 4. The Great Pyramid ("The Pyramid of Cheops"). Geophysical anomalies under the floor of the "King's Chamber". Top view
(according to "Scientific Evidence for a Secret Door in the Kings Chamber of the Great Pyramid/ Ancient Architects" on YouTube https://youtu.be/7Rbi6_SMT5w)

3.0. PURPOSE AND SCOPE OF THE RESEARCH

The purpose of non-invasive research, inside the so-called "King's Chamber" in the Great Pyramid in Giza, is to check geophysical anomalies under the floor of the Chamber, detected by the Japanese team, with the geophysical method, as well as to clarify whether the "King's Chamber" is located on limestone blocks or on a natural limestone rock (? in Fig. 3 and Fig. 5). GPR studies with antennas facing the walls of the Chamber should clarify: are there any corridors or other chambers behind the granite walls of the Chamber (? in Fig. 3). Detailed GPR tests will be performed in 2D and 3D system. It is assumed that the research will be carried out to a depth of about 5-10 m.

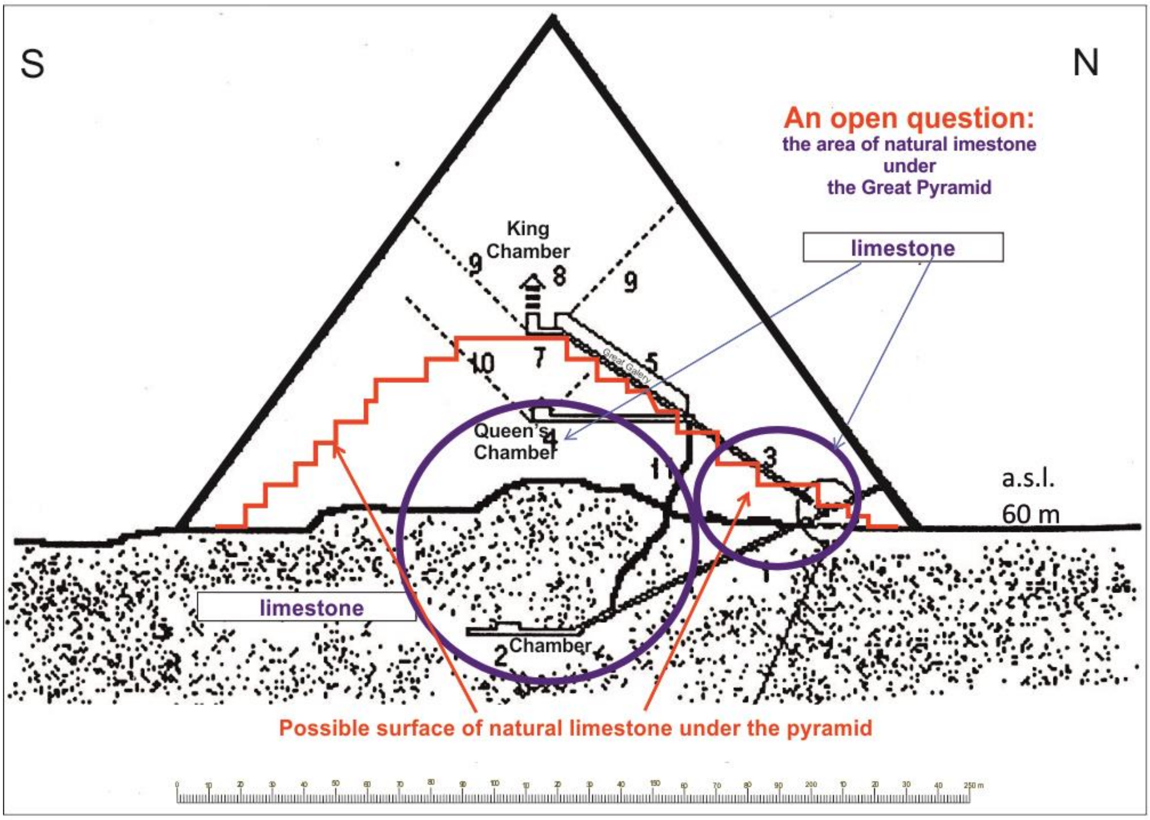


Fig. 5. Egypt, Giza, Great Pyramid. Schematic S-N section through the pyramid.
(blue circles - places where solid limestone rocks were found,
red stairs - prognose area of solid limestone under the "King's Chamber")

4.0. GPR METHOD

4.1. Ground Penetration Radar (GPR).

Georadar (Ground Penetrating Radar - GPR) is an electronic apparatus for geophysical ground research. The GPR consists of: a transmitting antenna and a receiving antenna (in a shielded box), which are connected by optical fibers (or WiFi) to the central unit. The device works on the principle of counting the return delays of electromagnetic pulses of very high frequency, sent by the transmitting antenna, which are reflected from various lithological boundaries of the ground, various types of rocks (dielectrics), and are received by the receiving antenna and are transmitted to the unit central to count the time of wave return delays. The boundaries reflecting the radar signal should be understood as the boundaries between the media differing in the value of the dielectric constant. Rocks have different dielectric constant values. The impulses sent by the transmitting antenna into the center, return with a delay to the receiving antenna and through optical fibers go to the central unit controlling the system, and then they are processed and sent to the recorder (e.g. a portable computer hard drive or XV monitor). In the field, these impulses are observed by the operator on the monitor in the form of an echogram/time waveform (i.e. linear, vertical, cross-section) of ground/rocks parameters variability. Such a chart can then be converted, for example, into metric units, it can be printed in colors (so-called filtration - a separate color for different wave speeds). The obtained image can be compared with model images of various objects hidden in the ground or with model images of geological structures or with cartographic documentation of uncovers, as well as with data obtained from geological drillings. Compared to other geophysical methods, the radar method (GPR) allows **non-invasive**, linear tracking of the geological structure in the field, i.e. tracking the variability of lithology and shallow geological structures. The use of interchangeable antennas (with different frequencies, e.g. from 10 MHz to 2 GHz) depends on the task and the assumed depth of ground monitoring. The lower the central frequency of the antennas, the greater the depth range of the profiling. For shallow archaeological and geotechnical research, antennas with a higher central frequency are used, enclosed in a specially shielded container (**shielded antennas**).

For non-invasive georadar surveys (GPR), in the so-called the "King's Chamber" it is proposed to use the RAMAC/GPR apparatus with 250 MHz shielded antennas or the MALA Ground Explorer apparatus with GX160, GX450 shielded antennas. The possibility of renting such apparatus on site in Egypt should be considered, or such apparatus may be rented and brought by the project contractor (loan from MALA in Sweden).

4.2. Additional essential equipment

Additional equipment will be needed for the GPR research in the "King's Chamber":

1. Laser, indicating horizontal and vertical lines,
2. Measuring tapes (4 x 10 m).

The height of the walls in the "King's Chamber" is 5.81 m. Therefore, in order to make vertical sections (from the floor to the ceiling of the Chamber) and horizontal sections along the walls of the Chamber, you will need (Fig. 5, 6):

3. Two folding ladders (up to 5 m),
4. Foldable scaffolding,
5. A block (bricklayer's block for lifting GPR on a rope),
6. Rope 10 m long.

To make horizontal cross-sections (GPR), you will need scaffolding up to 4.5 m high (with the possibility of moving it on wheels), on which GPR antennas will be moved along the walls, facing the Chamber wall. Or it could be a fixed scaffold over which they will walk (along the chamber wall): the GPR operator with control unit and computer and an assistant moving the antenna facing the chamber wall and holding the measuring wheel to roll along the wall. Due to the strenuous work, two helpers will be needed.

Fig. 6. The Great Pyramid. GPR research project in the "King's Chamber".
Folding ladder (up to 4 m) for making vertical GPR section lines

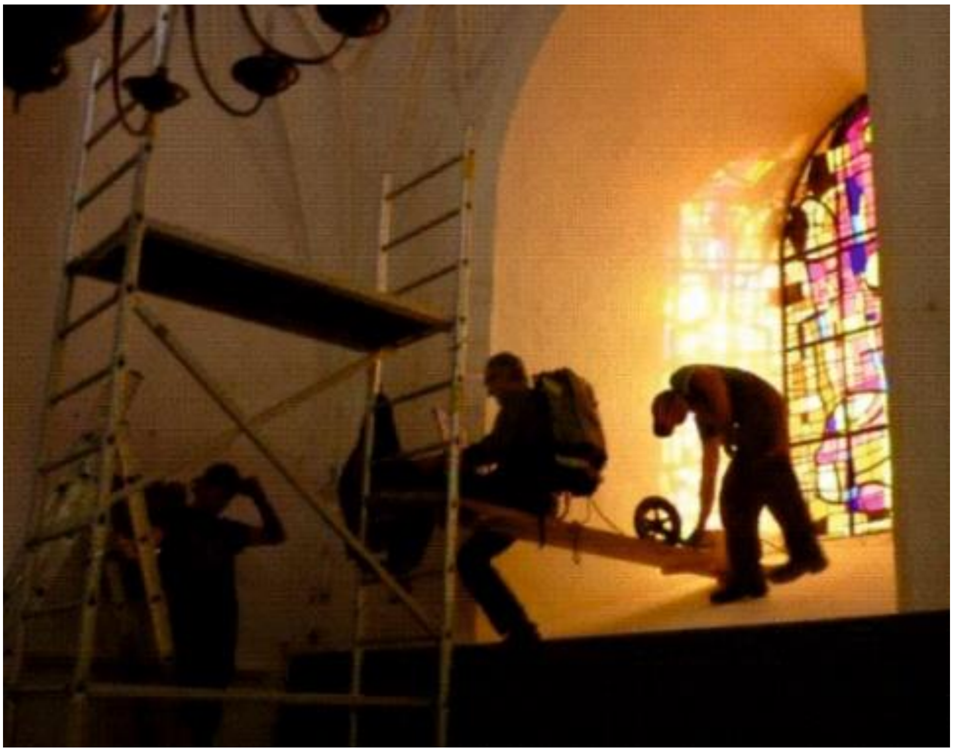


Fig. 7. The Great Pyramid. GPR research project in the "King's Chamber".
Folding portable scaffolding for making horizontal cross-sectional GPR lines.

5.0. METHODOLOGY OF GPR FIELD WORKS INSIDE CHAMBER

Ground-penetrating radar (GPR) field work inside the "King's Chamber" will be carried out with a portable ground penetrating radar: RAMAC/GPR (made by the Swedish company MALA), powered by 12V batteries, with shielded antennas with a central frequency of 250 MHz, or radar: MALA Ground Explorer, with antennas shielded GX160, GX450. The antennas will be moved along the surface of the Chamber floor or directed towards the surface of the walls of the Chamber. The tests will be performed using the linear profiling method (Fig. 8, 9, 10, 11, 12), to a depth of about 5-10 m. Trace interval: i = 0.02 m. Distances will be measured with a measuring wheel (Fig. 6). EM pulses are sent from the center of the antenna, and for this reason there are so-called blind spots: at the start (from the center to the rear of the antenna and measuring circle) and at the end of the measurement (from the center to the front of the antenna), ± 0.5 m.

The GPR research project in the "King's Chamber" was divided into the following tasks:

ask 1 - floor in the "King's Chamber" (Fig. 8).

Task 2 - the western wall in the "King's Chamber" (Fig. 9).

Task 3 - eastern wall in the "King's Chamber" (Fig. 10).

Task 4 - southern wall in the "King's Chamber" (Fig. 11).

Task 5 - northern wall in the "King's Chamber" (Fig. 12).

Task 1 - The floor in the "King's Chamber" (Fig. 8).

Measuring tapes will be placed on the floor of the chamber along the walls. Baseline X will run along the east wall and baseline X1 will run along the west wall accordingly. Line Y will run along the south wall and, accordingly, baseline Y1 will run along the north wall. The starting point of the measurements (X0, Y0) will be located in the south-eastern corner of the Chamber. GPR cross-sectional lines will be run parallel (at 0.25 m intervals): from the southern wall to the northern wall (S-N) and from the eastern wall to the western wall (E-W). The course of the line on the floor will be marked by a line of laser light. The place of the granite coffer ("sarcophagus") will be a blind spot for research.

61 GPR cross-sectional lines will be made, with a total length of about 405 m (Fig. 8).

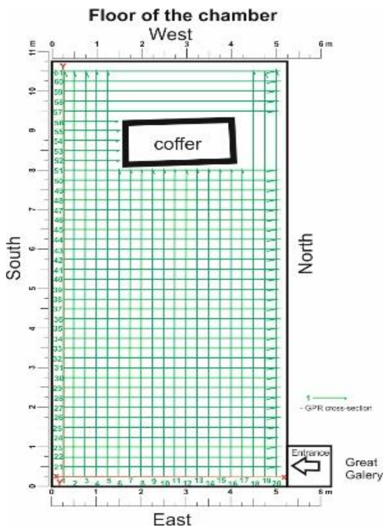


Fig. 8. The Great Pyramid.
Proposal GPR cross-sectional lines on the floor surface in the “King's Chamber”.

Task 2 - Western wall in the "King's Chamber" (Fig. 9).

A measuring tape will be placed on the chamber floor along the west wall (base line X). There will be baseline Y at the corner of the west and south walls. The starting point of the measurements (X0, Y0) will be at the south-west corner of the Chamber. GPR cross-sectional lines will be run parallel (at 0.25 m intervals): from the floor to the ceiling of the Chamber and from the southern wall to the northern wall (S-N). The course of the line on the wall will be determined by the lines of laser light (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope for lifting the antennas from the floor to the ceiling of the Chamber will be passed. A second ladder will be needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5m (or 3m). In order to conduct horizontal GPR cross-sectional lines (S-N), a foldable scaffolding is necessary to enable the helper (or helpers) to move the antennas parallel to the chamber floor and for the GPR operator to follow the antennas.

40 GPR cross-sectional lines will be made, with a total length of about 200 m (Fig.9).

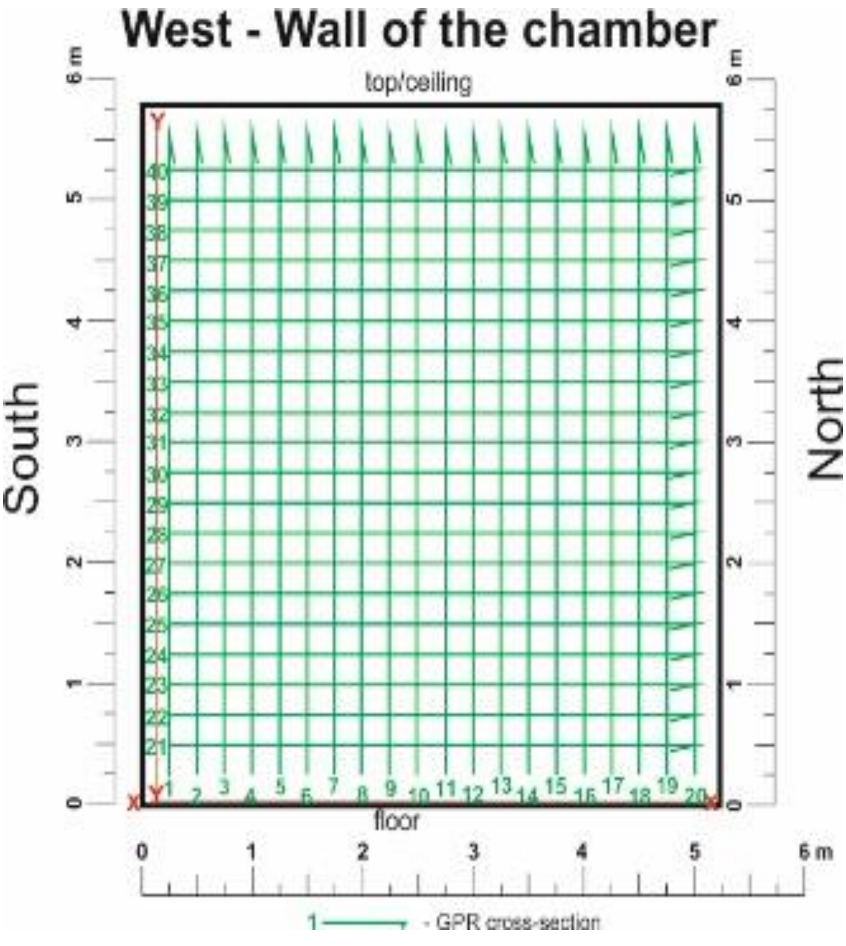


Fig. 9. The Great Pyramid.
Proposal of GPR cross-sectional lines on the surface of the western wall in the "King's Chamber".

Task 3 - Eastern wall in the "King's Chamber" (Fig. 10).

A measuring tape will be laid on the chamber floor along the east wall (base line X). There will be baseline Y at the corner of the east and north walls. The starting point of the measurements (X0, Y0) will be at the northeast corner of the Chamber. GPR cross-sectional lines will be run parallel (at intervals of 0.25 m): from the floor to the ceiling of the Chamber and from the north wall to the south wall (N-S). The course of the line on the wall will be determined by the lines of laser light (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope to pull up the antennas will be put, from the floor to the ceiling of the Chamber. A second ladder will be needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5m (or 3m). In order to conduct horizontal GPR cross-sectional lines (S-N), a foldable scaffolding is necessary to enable the helper (or helpers) to move the antennas parallel to the chamber floor and for the GPR operator to follow the antennas.

40 GPR cross-sectional lines will be made, with a total length of about 200 m (Fig. 10).

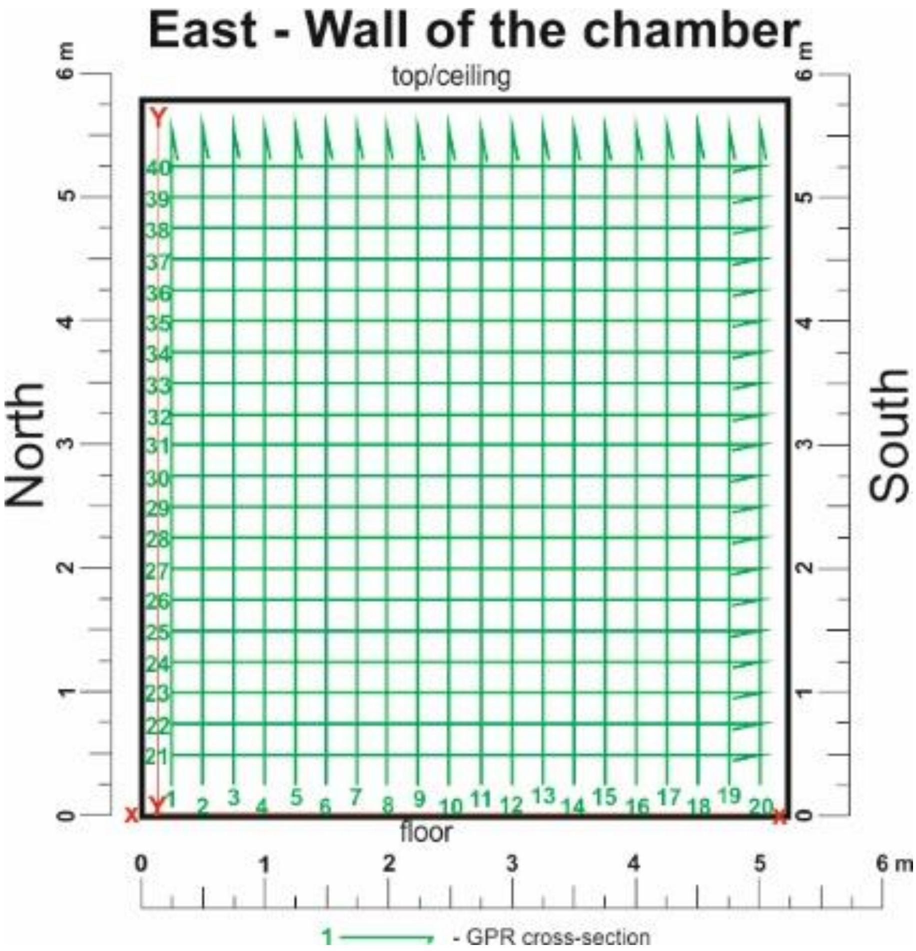


Fig. 10. The Great Pyramid.
Proposal of GPR cross-sectional lines on the surface of the eastern wall in the "King's Chamber".

Task 4 - Southern wall in the "King's Chamber" (Fig. 11).

A measuring tape will be laid on the floor of the Chamber along the southern wall (base line X). There will be a baseline Y at the corner of the south and east walls. The starting point of the measurements (X0, Y0) will be at the southeast corner of the Chamber. GPR cross-sectional lines will be run parallel, at 0.25 m intervals: from the floor to the ceiling of the Chamber and from the eastern wall to the western wall (E-W). The course of the line on the wall will be determined by the lines of laser light (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope for lifting the antennas from the floor to the ceiling of the Chamber will be passed. A second ladder is needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5m (or 3m). In order to conduct horizontal GPR cross-sectional lines (E-W), a foldable scaffold is required to enable the helper (or helpers) to move the antennas parallel to the chamber floor and the GPR operator to follow the antennas.

61 GPR cross-sectional lines will be made, with a total length of about 410 m (Fig. 11).

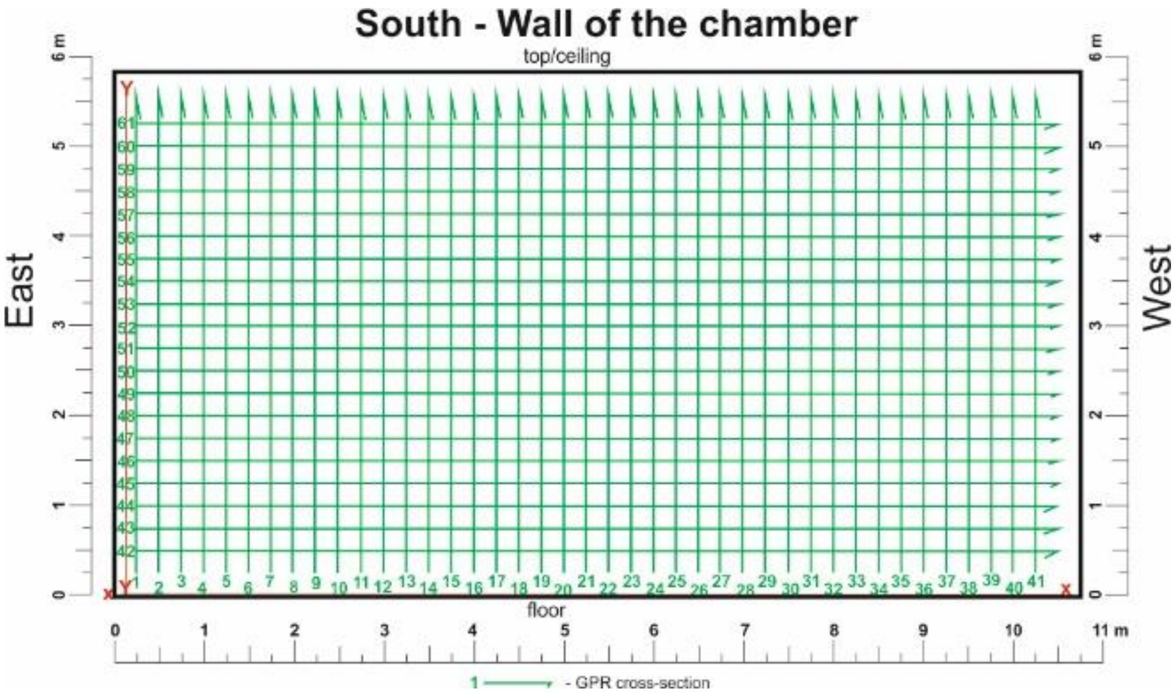


Fig. 11. The Great Pyramid.
Design of GPR cross-sectional lines on the surface of the southern wall in the "King's Chamber".

Task 5 - Northern wall in the "King's Chamber" (Fig. 12).

A measuring tape will be laid on the chamber floor along the northern wall (base line X). There will be baseline Y at the corner of the north and west walls. The starting point of the measurements (X0, Y0) will be at the north-west corner of the Chamber. GPR cross-sectional lines will be run parallel (at 0.25 m intervals): from the floor to the ceiling of the Chamber and from the western wall to the eastern wall (W-E). The course of the GPR cross-sectional lines on the wall will be marked by laser light lines (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope for lifting the antennas from the floor to the ceiling of the Chamber will be passed. A second ladder will be needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5m (or 3m). In order to conduct horizontal GPR cross-sectional lines (W-E), a foldable scaffold is required to enable the helper (or helpers) to move the antennas parallel to the chamber floor and the GPR operator to follow the antennas. The blind spot for GPR research is the entrance to the Chamber, located in the north-eastern corner of the Chamber.

61 GPR cross-sectional lines will be made, with a total length of about 400 m (Fig. 12).

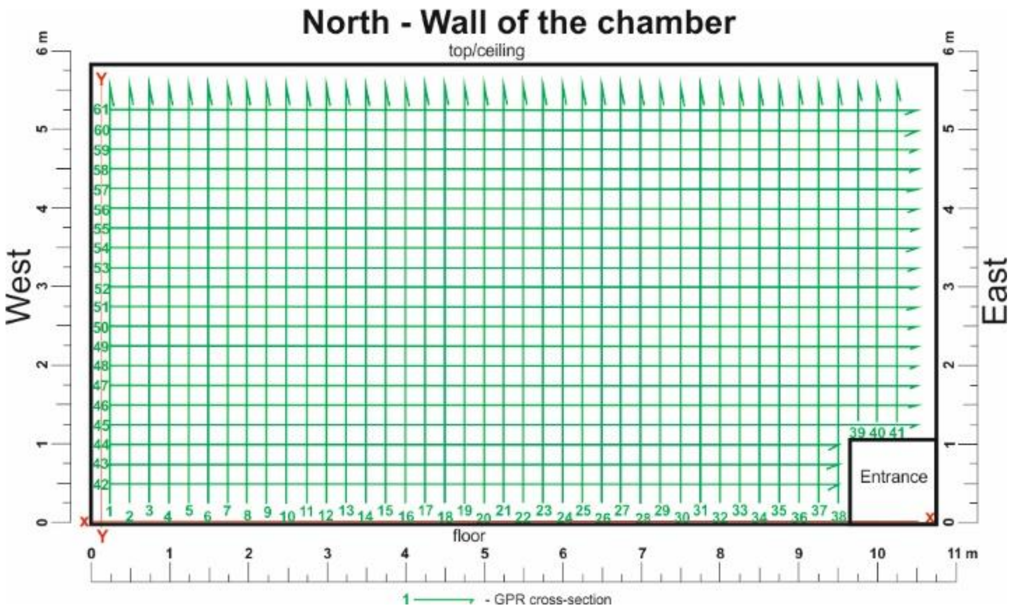


Fig. 12. The Great Pyramid.
Design of GPR cross-sectional lines on the surface of the northern wall in the "King's Chamber".

To sum up.

The GPR research project in the "King's Chamber" provides for the construction of a total of 263 GPR cross-sectional lines, with a total length of about 1625 m.

6.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 2D SYSTEM

The echograms (EM wave echoes) obtained from individual cross-sectional lines will be converted by the GPR central unit and saved on the hard disk of the computer or XV monitor (each profiling line is a separate result file .rd3). In the laboratory, the data files will be transferred to a stationary computing computer and filtered in the GroundVision and ReflexW programs. Different color palettes and different combinations of filters will be used when analyzing the data.

Calibration of the depth scale will be performed on the basis of the assumed average value of electromagnetic waves passing through the granite. The error of the depth scale in 2D sections may be +0.1 m. This may be due to: A) - change in the color of the FM phase during filtration (the EM wave amplitude principle, positive phase and negative phase; B) - the assumed speed of propagation of EM waves in the studied rocks (granite, limestone).

After selecting the color scale, filters, filtering and obtaining the optimal image for interpreting the GPR data and answering the questions, as well as after calibrating the depth scale, the waveforms / echograms will be transferred to CorelDraw for interpretation and marking of anomalies.

Echograms, i.e. images of electromagnetic waves (EM), obtained as a result of filtration, will be compared with model images and with images obtained during experimental GPR surveys. Attention will be paid to: a) GPR anomalies in EM field images, and b) characteristic refractions of wave images in anomalous zones.

On echograms (drawings in 2D), in CorelDraw, detected anomalies will be marked. These anomalies will be transferred to the maps of the Chamber floor and walls of the Chamber, respectively, with an accuracy of ± 0.1 m.

Comments:

1) *in the paper version of the documentation (WORD) the drawings will be difficult to read, therefore a CD will be attached to the documentation, where all the figures will be in JPG (or PDF) version, which can be enlarged.*
2) *the 2D sections will be surpassed (the distance scale will not equal the depth scale).*

7.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 3D SYSTEM

GPR data obtained from section lines will also be processed in the 3D Slices system. On the images of horizontal time cuts (e.g. every 0.03 m), GPR anomalies will be analyzed. The analysis will be carried out from the surface of the floor or wall to a depth of about 5 or 10 m (depending on the antennas used). Anomalies detected on individual horizontal time slices will also be shown on collective drawings (for selected depths, e.g. 0-1 m, 1-2 m, 2-3 m, etc.). In the horizontal time slices images, the "warm" colors - light blue, yellow to red - will indicate the places of GPR anomalies. Maps of GPR anomalies will be made for the floor of the Chamber and for individual walls of the Chamber.

A comparison of the test results in the 3D system with the results obtained from the analysis of the GPR data in the 2D system will be performed.

8.0. PERSONNEL NECESSARY FOR THE PROJECT

1. Persons operating the GPR equipment:

    Adam Szynkiewicz, PhD. - GPR operator;

2. Representative of the Egyptian Ministry of Antiquity;

3. Persons supporting field research:

    a) Reda Abdelhaleem Mohamed Khalifa, PhD. - supervision of research by the Ministry of Antiquities in Cairo;

    b) two technicians to assist in erecting the scaffolding needed to move the antennas along the walls of the Chamber and over the floor of the Chamber;

    c) two security guards

4. Persons interpreting GPR data and documentation:

    a) Adam Szynkiewicz, PhD. - analysis of GPR data in the 2D system

    b) Magdalena Udyrysz-Kraweć, MA. - analysis of GPR data in the 3D system

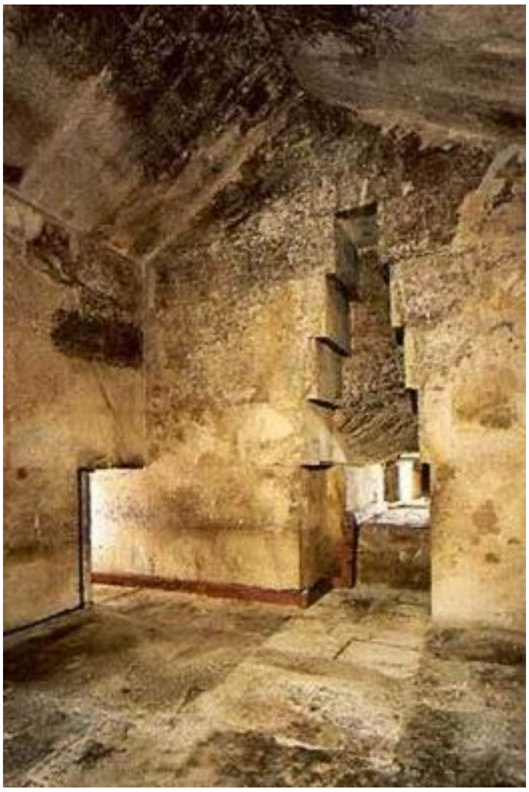
9.0. TIME REQUIRED TO COMPLETE THE PROJECT

4-5 days of work are needed to perform the GPR field tests in the "King's Chamber", approximately 6-8 hours a day (depending on the battery discharge time). Fieldwork can be carried out after the tourists leave the "King's Chamber".

It takes 30 days from the end of the field work to perform the analysis of the obtained GPR data and to prepare the documentation.

STAGE III

GEORADAR RESEARCH PROJECT (GPR)
IN "QUEEN’S CHAMBER"
GREAT PYRAMID (“CHEOPS PYRAMID”),
GIZA, EGYPT



Author:

Adam Szynkiewicz, PhD. (Poland)

Cooperation:

Reda Abdelhaleem Mohamed Khalifa, PhD. (Egypt)
Magdalena Udyrysz – Kraweć, MA. (England)

Poland, Wrocław, 2023

CONTENTS

1.0. THE GREAT PYRAMID ("CHEOPS' PYRAMID") IN GIZA

In Northern Egypt, on the Giza plateau, in a complex of three pyramids (and a few small ones), there is the Great Pyramid, also called the "Cheops Pyramid". The Giza Plateau (50-115 m above sea level), is located on the western side of the Nile River Valley (18-20 m above sea level) and is located west of the center of Cairo. The plateau is built of limestone of the age of Eocene.

Fig. 1. Three pyramids on the Giza Plateau. View of the Great Pyramid ("The Pyramid of Cheops") from the NE side (during the flooding of the Nile when there was no Aswan dam)

Fig. 2. Great Pyramid in Giza Plateau. View from above

The Great Pyramid ("The Pyramid of Cheops"), located at an altitude of 60 m above sea level. Currently, the pyramid has a height of about 146.59 m (Fig. 1). The surface of the walls of the pyramid are blocks of Eocene limestone, arranged in steps (the limestone blocks are about 1 m x 1 m x 1 m). Currently, the length of the northern, eastern, western and southern bases of the pyramid's walls is approximately 230.5 m (Fig. 2). The general inclination of the pyramid's walls is about 51˚52'. Inside the pyramid there are corridors and chambers. The largest of them is the so-called "King's Chamber". Below the "King's Chamber" is the "Queen's Chamber" (Fig. 3).

2.0. THE "QUEEN'S CHAMBER" IN THE GREAT PYRAMID ("CHEOPS PYRAMID")

In the central part of the Great Pyramid, under the "King's Chamber", at an altitude of about 90 m above sea level, i.e. about 30 m above the surface surrounding the pyramid (60 m above sea level), there is a chamber with dimensions: 5.75 m (length E-W), 5 .23 m (width S-N) and a height of max. 6.13 m (at the highest point), commonly known as the "Queen's Chamber" (Fig. 2 and Fig. 3). Perhaps, the chamber is hollowed out in solid Eocene limestone.

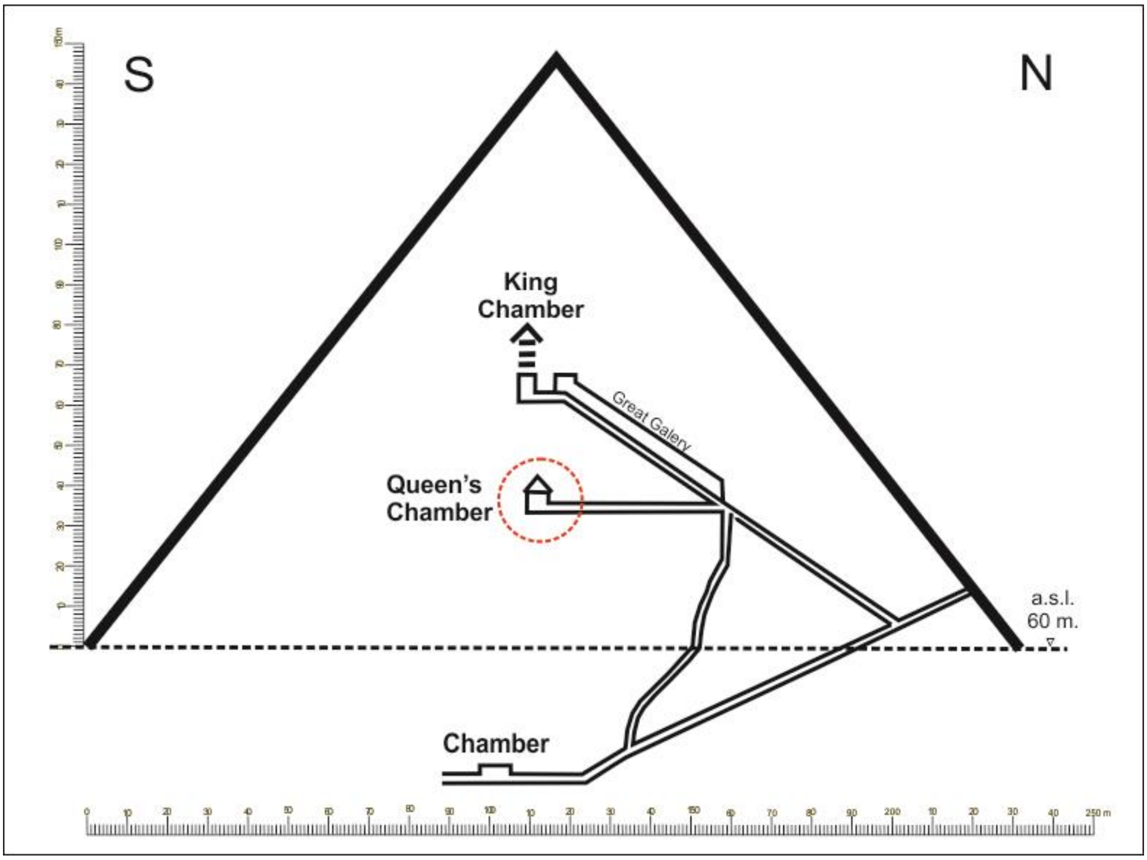


Fig. 3 . The Great Pyramid of Giza ("The Pyramid of Cheops"). Schematic S-N section. Location of the Queen's Chamber"

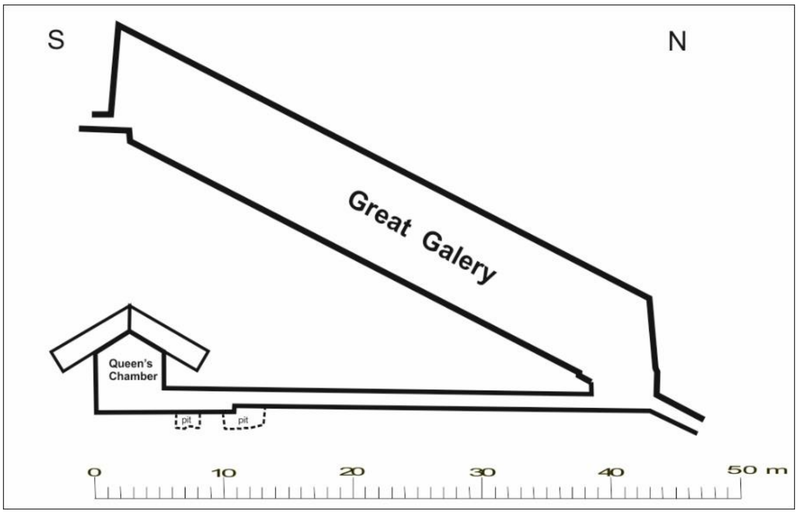


Fig. 4 . The Great Pyramid of Giza ("The Pyramid of Cheops").
Schematic S-N section through the Great Gallery and the "Queen's Chamber"

The "Queen's Chamber" is entered from a horizontal corridor whose opening, approximately 1.7 m high, is located at the base of the northern wall of the Chamber, in the north-eastern corner of this wall (Fig. 3, 4, 5).

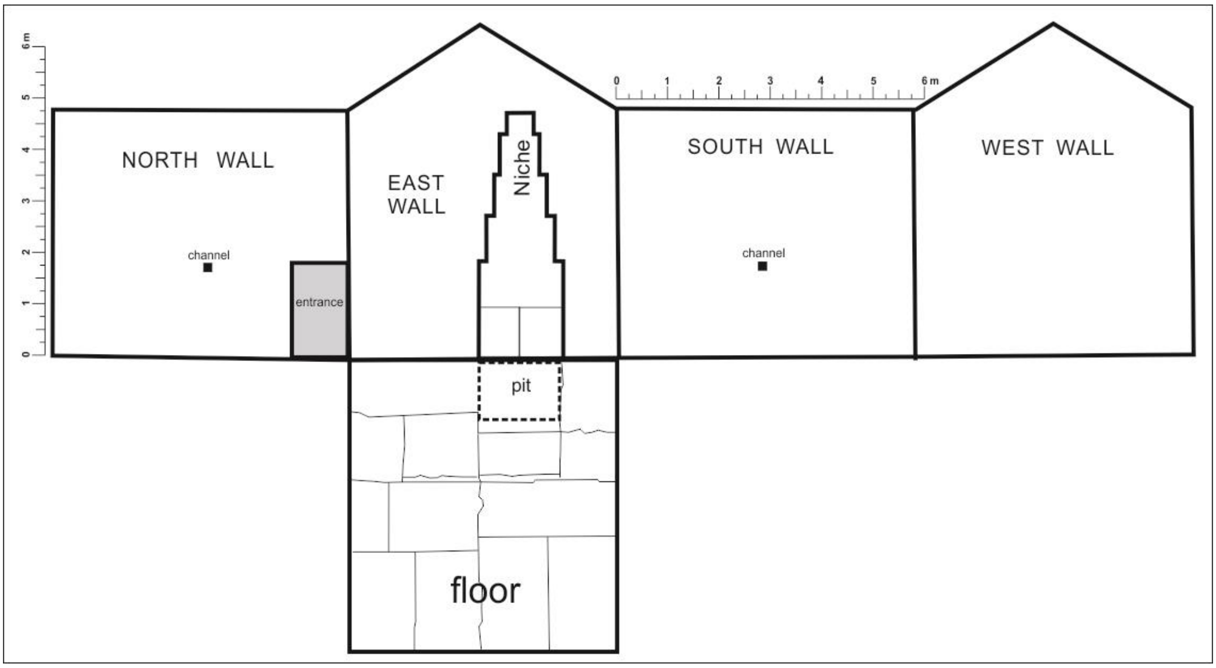


Fig. 5 . The Great Pyramid of Giza ("The Pyramid of Cheops").
"Queen's Chamber" - schematic drawing of the floor and walls

The longer axis of the Chamber is oriented in the W-E direction. The walls, ceiling and floor of the chamber are made of large blocks of limestone. In the eastern wall there is a niche carved in limestone (?), from which a corridor runs northwards (Fig. 5, 6, 7, 8, 9).

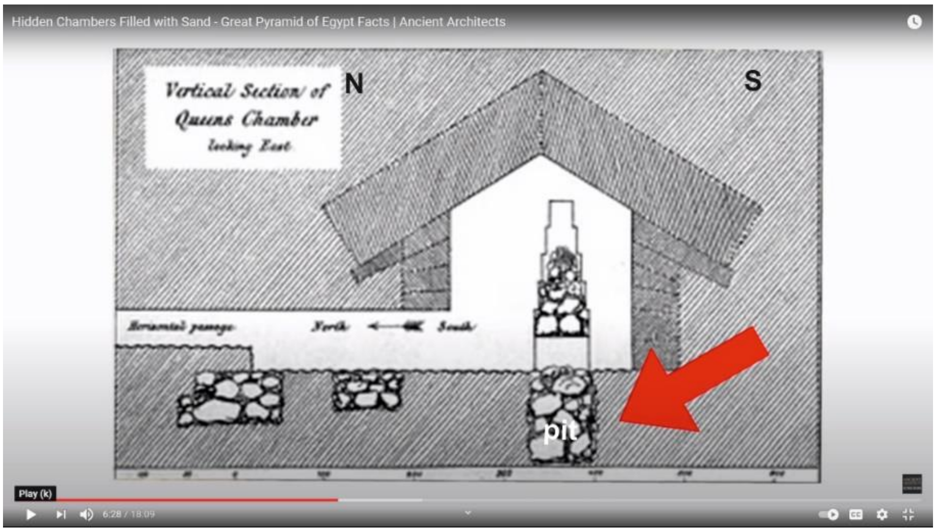


Fig. 6 . The Great Pyramid of Giza ("The Pyramid of Cheops").
"Queen's Chamber" - a schematic N-S section
("Hidden Chambers Filled with Sand – Great Pyramid of Egypt. Facts"/Ancient Architects- youtube)

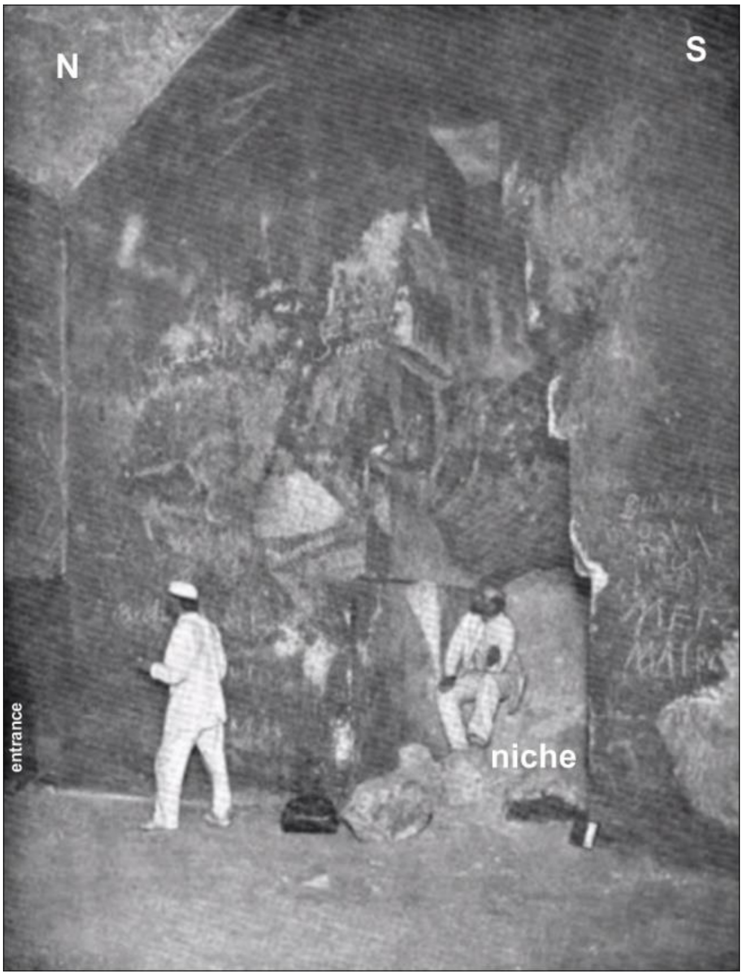


Fig. 7. The Great Pyramid of Giza ("The Pyramid of Cheops").
Old photograph of a niche in the eastern wall of the "Queen's Chamber"
("Hidden Chambers Filled with Sand – Great Pyramid of Egypt. Facts"/Ancient Architects- youtube)

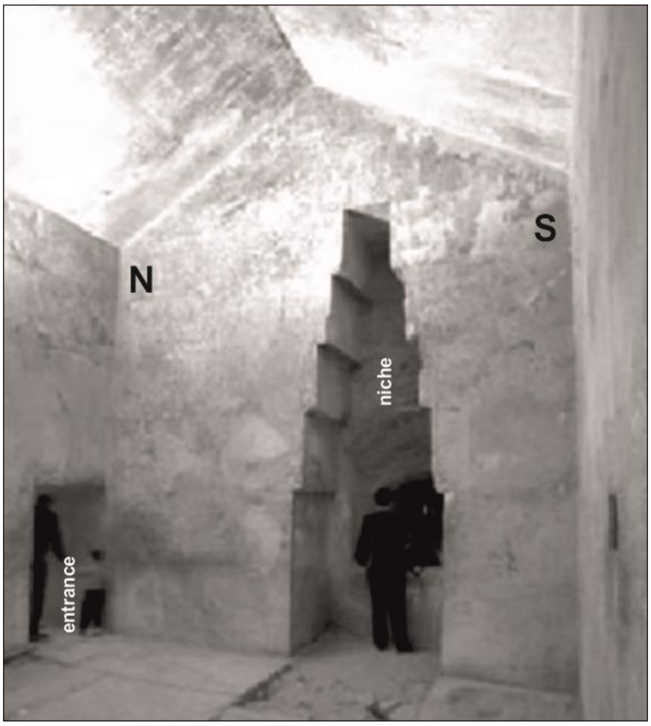


Fig. 8. The Great Pyramid of Giza ("The Pyramid of Cheops").
Current photograph of the niche in the eastern wall of the "Queen's Chamber"
(“Hidden Chambers Filled with Sand – Great Pyramid of Egypt. Facts”/Ancient Architects- youtube)

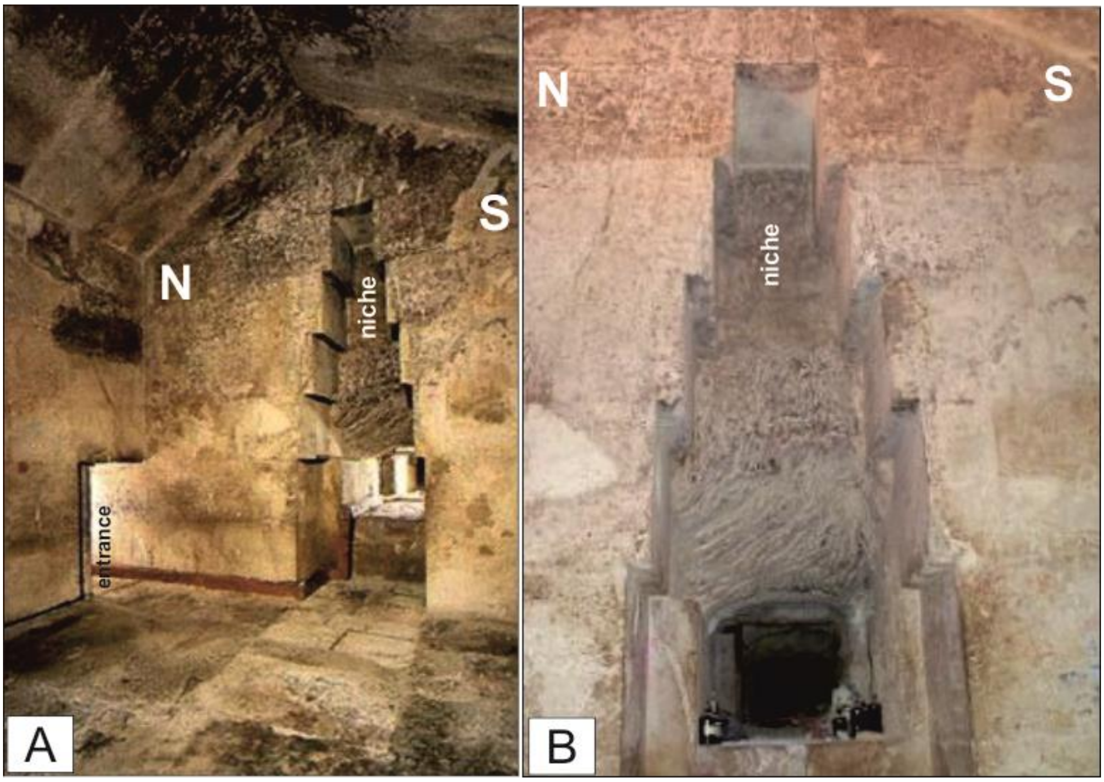


Fig. 9. The Great Pyramid of Giza ("The Pyramid of Cheops").
Eastern wall of the "Queen's Chamber" - entrance to the corridor in the niche

Fig. 10. The Great Pyramid of Giza ("The Pyramid of Cheops").
Canal in the north wall of the "Queen's Chamber"
(“Hidden Chambers Filled with Sand – Great Pyramid of Egypt. Facts”/Ancient Architects- youtube)

In the floor of the Chamber, below the niche, there was an archaeological excavation with dimensions: length N-S about 1.5 m, width E-W about 1.25 m and depth 2.25 m (Fig. 5, 6, 14, 16). In the eastern wall and in the southern wall, there are openings for small corridors (about 15 cm x 15 cm). These corridors are at a height of about 1 m from the floor of the Chamber.

3.0. PURPOSE AND SCOPE OF GPR TESTS IN THE "QUEEN'S CHAMBER"

The purpose of non-destructive testing, inside the so-called The "Queen's Chamber" in the Great Pyramid of Giza is to be checked with the GPR method: whether the "Queen's Chamber" is carved in natural limestone rocks, or maybe it is arranged on limestone blocks (Fig. 11). GPR surveys with antennas pointed towards the walls of the Chamber should also clarify whether there are any corridors or other chambers behind the limestone blocks of the walls of the Chamber, as there are suggestions that there is an unknown channel behind the north wall of the chamber, in its southwestern corner. Detailed GPR tests will be performed in 2D and 3D. It is assumed that the research will be carried out to a depth of about 5-10 m.

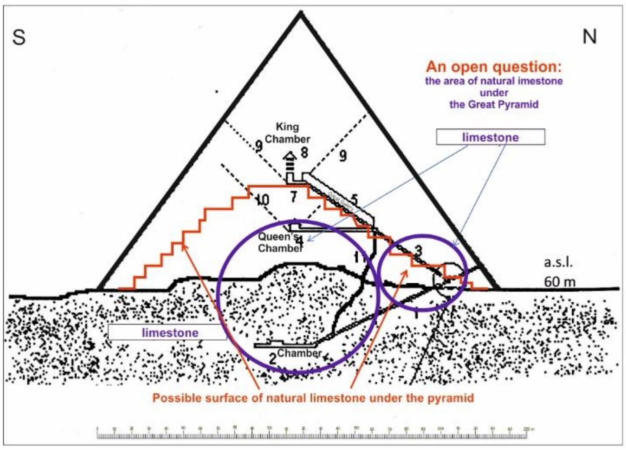


Fig. 11. Egypt, Giza, the Great Pyramid ("The Pyramid of Cheops").
Schematic S-N section through the pyramid.
(blue circles - places where solid limestone rocks were found, red stairs - projected area of solid limestone under the "King's Chamber")

4.0. GPR EQUIPMENT

4.1. Ground Penetrating Radar(GPR).

Ground Penetrating Radar (GPR)/ Wall Probing Radar, is an electronic equipment/apparatus for geophysical ground research. The GPR apparatus consists of: a transmitting antenna and a receiving antenna (in a shielded container), which are connected by optical fibers (or WiFi) to the central unit. The device works on the principle of counting the return delays of electromagnetic pulses of very high frequency (10 - 1000 MHz), sent by the transmitting antenna, which are reflected from various lithological boundaries of the ground, various types of rocks (dielectrics), are received by the receiving antenna and transmitted to the unit central to count the time of wave return delays. The boundaries reflecting the radar signal should be understood as the boundaries between the media differing in the value of the dielectric constant. Rocks have different dielectric constant values. The impulses sent by the transmitting antenna into the center, return with a delay to the receiving antenna and through optical fibers go to the central unit controlling the system, and then they are processed and sent to the recorder (e.g. a portable computer hard drive or XV monitor). In the field, these impulses are observed by the operator on the monitor in the form of an echogram/time waveform (i.e. linear, vertical, cross-section) of soil parameters variability. Such a chart can then be converted, for example, into metric units, it can be printed in colors (so-called filtration - a separate color for different wave speeds). The obtained image can be compared with model images of various objects hidden in the ground or with model images of geological structures or with cartographic documentation of uncovers, as well as with data obtained from geological drillings. Compared to other geophysical methods, the radar method (GPR) allows **non-invasive**, linear tracking of the geological structure in the field, i.e. tracking the variability of lithology and shallow geological structures. The use of interchangeable antennas (with different frequencies, e.g. from 10 MHz to 2 GHz) depends on the task and the assumed depth of ground monitoring. The lower the central frequency of the antennas, the greater the depth range of the profiling. For shallow archaeological and geotechnical research, antennas with a higher central frequency are used, enclosed in a specially shielded container (**shielded antennas**).

For non-invasive georadar surveys (GPR), in the so-called the "Queen’s Chamber" it is proposed to use the RAMAC/GPR equipment with 250 MHz shielded antennas or the MALA Ground ProEx with GX160, GX450 shielded antennas. The possibility of renting such equipment on site in Egypt should be considered, or such equipment may be rented and brought by the project contractor (loan from MALA in Sweden).

4.2. Essential equipment

Additional equipment will be needed for the GPR research in the "Queen’s Chamber":

1. Laser, indicating horizontal and vertical lines,
2. Measuring tapes (4 x 10 m).

The height of the walls in the "Queen’s Chamber" is 5.81 m. Therefore, in order to make vertical sections (from the floor to the ceiling of the Chamber) and horizontal sections along the walls of the Chamber, you will need (Fig. 12, 13):

3. Two folding ladders (up to 5 m),
4. Foldable scaffolding,
5. A block,
6. Rope 10 m long.

To make horizontal sections (GPR), you will need scaffolding up to 4.5 m high (with the possibility of moving it on wheels), on which GPR antennas will be moved along the walls, facing the Chamber wall. Or it could be a fixed scaffold over which they will walk (along the chamber wall): the GPR operator with control unit and computer and an assistant moving the antenna facing the chamber wall and holding the measuring wheel to roll along the wall. Due to the strenuous work, two helpers will be needed.

Fig. 12. The Great Pyramid. The "Queen’s Chamber" - GPR research project.
Folding ladder (up to 4 m) for making vertical GPR section lines

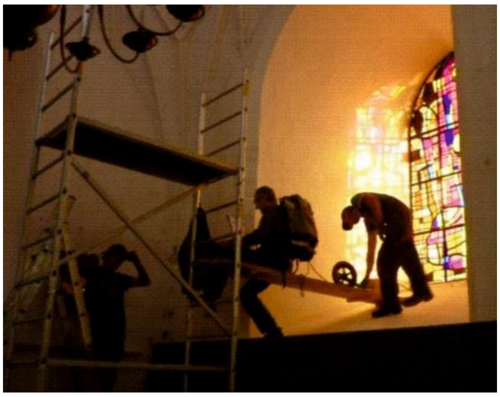


Fig. 13. The Great Pyramid. The "Queen’s Chamber" - GPR research project.
Folding portable scaffolding for making horizontal cross-sectional GPR lines.

5.0. METHODOLOGY OF THE GPR FIELD WORKS

Ground-penetrating radar (GPR) field work inside the "Queen's Chamber" will be carried out with a portable ground penetrating radar (GPR), powered by 12V batteries, with a central frequency 250 MHz shielded antennas, or radar: MALA Ground Explorer (ProEx), with GX160, GX450 shielded antennas. The antennas will be moved along the surface of the Chamber floor or directed towards the surface of the walls of the Chamber. The tests will be performed using the linear profiling method (Fig. 14, 15, 16, 17, 18), to a depth of about 5-10 m. Trace interval: i = 0.02 m. Distances will be measured with a wheel measuring wheel (Fig. 13). EM pulses are sent from the center of the antenna, and for this reason there are so-called blind spots ($\pm$ 0.3 m): at the start (from the center to the rear of the antenna and measuring wheel) and at the end of the measurement, from the center to the front of the antenna).

The GPR research project in the "Queen's Chamber" was divided into the following tasks:

Task 1 - floor in the "Queen's Chamber" (Fig. 14).

Task 2 - the western wall in the "Queen's Chamber" (Fig. 15).

Task 3 - eastern wall in the "Queen's Chamber" (Fig. 16).

Task 4 - southern wall in the "Queen's Chamber" (Fig. 17).

Task 5 - northern wall in the "Queen's Chamber" (Fig. 18).

Task 1 - The floor in the "Queen's Chamber" (Fig. 14).

Measuring tapes will be placed on the floor of the chamber along the walls. Baseline X will run along the south wall (and accordingly, baseline X1 will run along the north wall). Line Y will run along the west wall (and, accordingly, baseline Y1 will run along the east wall). The starting point of the measurements (X0, Y0) will be located in the south-western corner of the Chamber. GPR cross-sectional lines will be run parallel, at 0.25 m intervals: from the southern wall to the northern wall (S-N) and from the western wall to the western wall (W-E). The course of the line on the floor will be marked by a line of laser light. 42 GPR cross-sectional lines will be made, with a total length of about 200 m (Fig. 14).

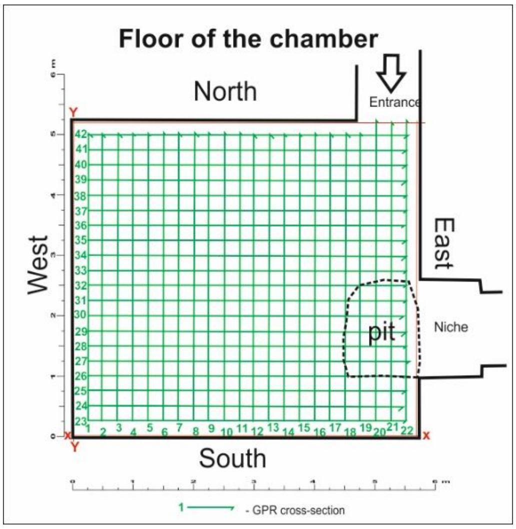


Fig. 14. The Great Pyramid, "Queen's Chamber".
Proposal of GPR cross-sectional lines on the floor surface in the "Queen's Chamber".

Task 2 - Western wall in the "Queen’s Chamber" (Fig. 15).

A measuring tape will be placed on the chamber floor along the west wall (base line X). There will be baseline Y at the corner of the west and south walls. The starting point of the measurements (X0, Y0) will be at the south-west corner of the Chamber. GPR cross-sectional lines will be run parallel, at 0.25 m intervals: from the floor to the ceiling of the Chamber and from the southern wall to the northern wall (S-N). The course of the line on the wall will be determined by the lines of laser light (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope for lifting the antennas from the floor to the ceiling of the Chamber will be passed. A second ladder will be needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5 m (or 3 m). In order to conduct horizontal GPR cross-sectional lines (S-N), a foldable scaffolding is necessary to enable the helper (or helpers) to move the antennas parallel to the chamber floor and the GPR operator to follow the antennas. 42 GPR cross-sectional lines will be made, with a total length of about 200 m (Fig. 15).

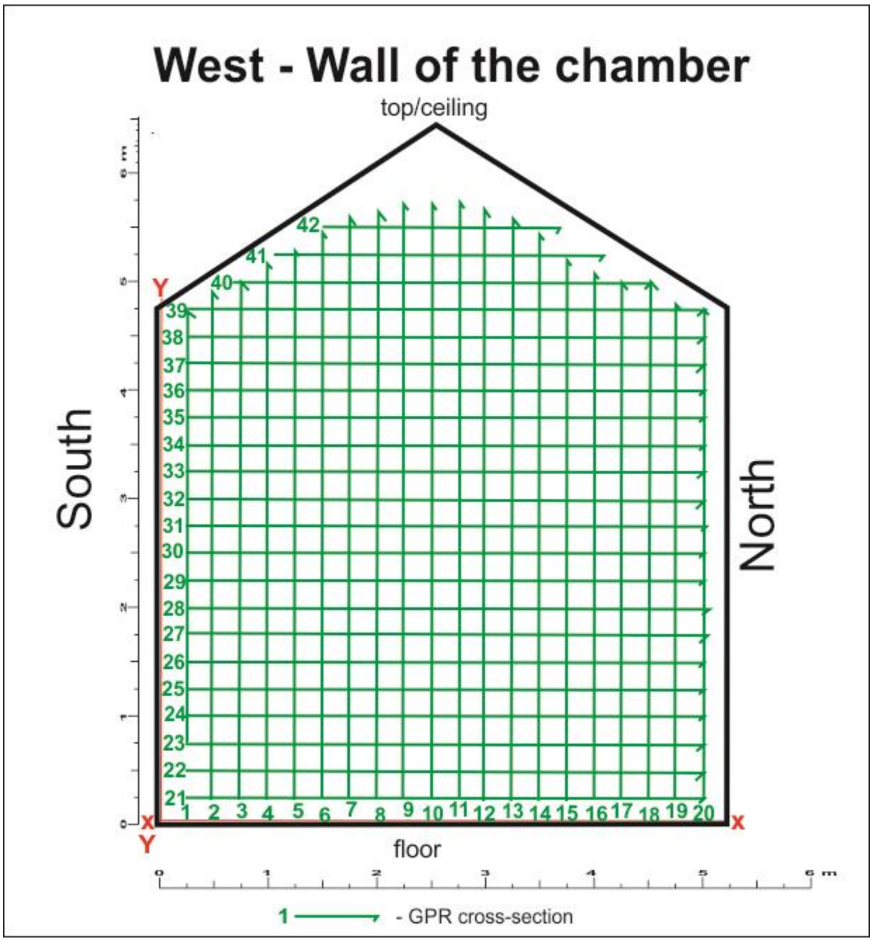


Fig. 15. The Great Pyramid, “Queen’s Chamber”.
Proposal of GPR cross-sectional lines on the surface of the western wall in the "Queen’s Chamber".

Task 3 - Eastern wall in the "King's Chamber" (Fig. 16).

A measuring tape will be laid on the chamber floor along the east wall (base line X). There will be baseline Y at the corner of the east and north walls. The starting point of the measurements (X0, Y0) will be at the northeast corner of the Chamber. GPR cross-sectional lines will be run parallel, at intervals of 0.25 m: from the floor to the ceiling of the Chamber and from the north wall to the south wall (N-S). The course of the line on the wall will be determined by the lines of laser light (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope to pull up the antennas will be put, from the floor to the ceiling of the Chamber. A second ladder will be needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5m (or 3m). In order to conduct horizontal GPR cross-sectional lines (S-N), a foldable scaffolding is necessary to enable the helper (or helpers) to move the antennas parallel to the chamber floor and the GPR operator to follow the antennas. It is planned to build 38 cross-sectional GPR lines, with a total length of about 115 m (Fig. 16). Tests in the niche and horizontal lines between the niche and the southern wall will not be performed.

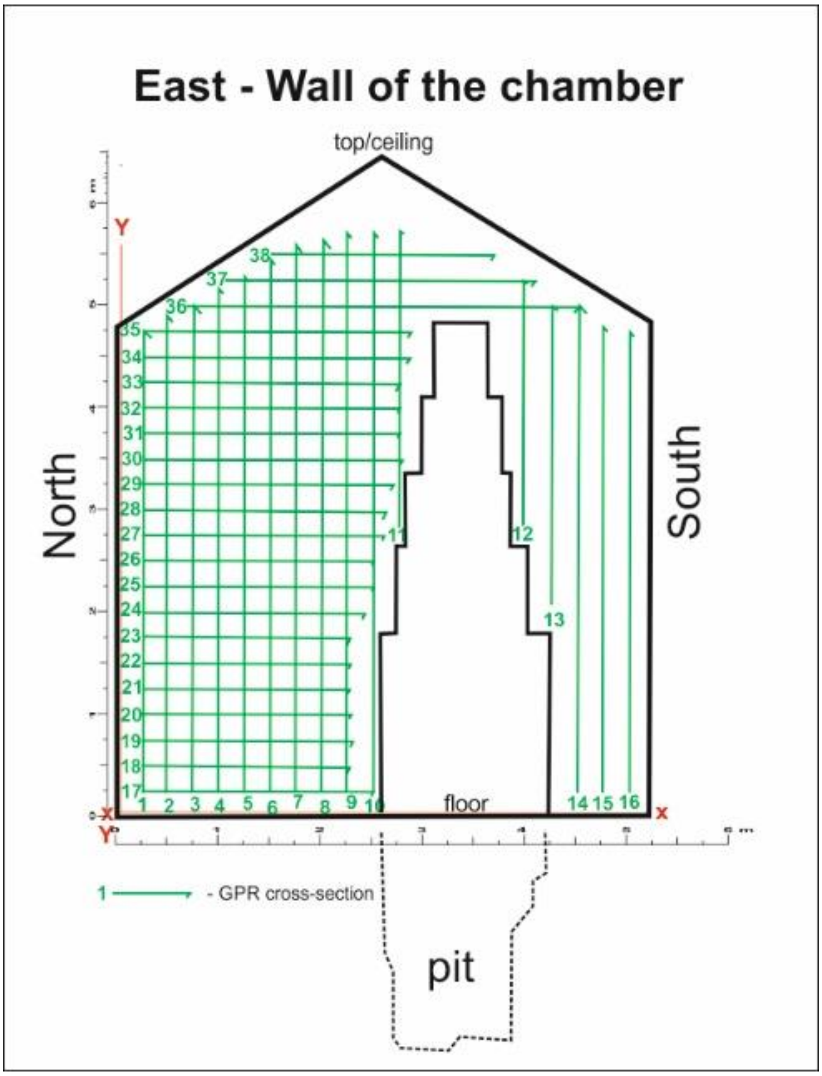


Fig. 16. The Great Pyramid, "Queen's Chamber".
Proposal of GPR cross-sectional lines on the surface of the eastern wall in the "Queen's Chamber"

Task 4 - Southern wall in the "Queen's Chamber" (Fig. 17).

A measuring tape will be laid on the floor of the Chamber along the southern wall (base line X). There will be a baseline Y at the corner of the south and east walls. The starting point of the measurements (X0, Y0) will be at the southeast corner of the Chamber. GPR cross-sectional lines will be run parallel, at 0.25 m intervals: from the floor to the ceiling of the Chamber and from the eastern wall to the western wall (E-W). The course of the line on the wall will be determined by the lines of laser light (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope for lifting the antennas from the floor to the ceiling of the Chamber will be passed. A second ladder is needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5m (or 3m). In order to conduct horizontal GPR cross-sectional lines (E-W), a foldable scaffold is required to enable the helper (or helpers) to move the antennas parallel to the chamber floor and the GPR operator to follow the antennas. 42 GPR cross-sectional lines will be made, with a total length of about 200 m (Fig. 17).

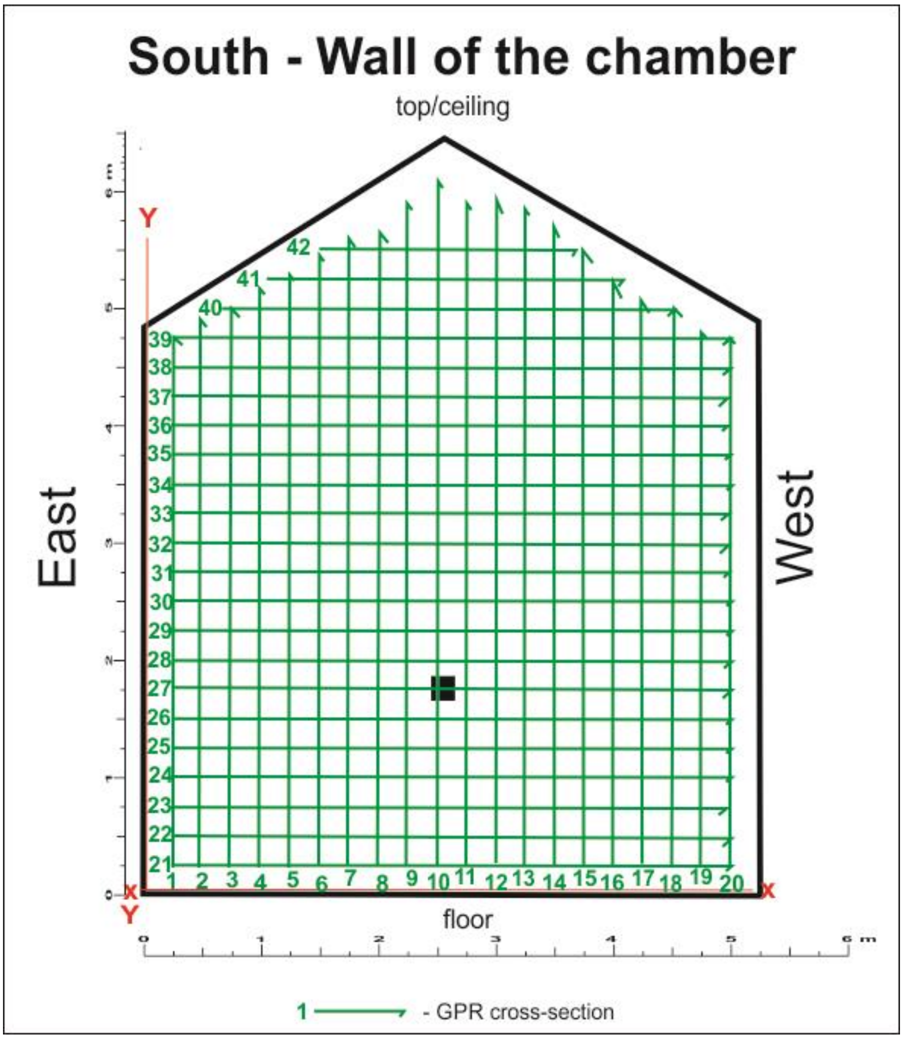


Fig. 17. The Great Pyramid, "Queen's Chamber".
Proposal of GPR cross-sectional lines on the surface of the southern wall in the "Queen's Chamber"

Task 5 - Northern wall in the "Queen's Chamber" (Fig. 18).

A measuring tape will be laid on the chamber floor along the east wall (base line X). There will be baseline Y at the corner of the north and west walls. The starting point of the measurements (X0, Y0) will be at the north-west corner of the Chamber. GPR cross-sectional lines will be run parallel, at 0.25 m intervals: from the floor to the ceiling of the Chamber and from the western wall to the eastern wall (W-E). The course of the GPR cross-sectional lines on the wall will be marked by laser light lines (vertical and horizontal). Two folding ladders (5 m) will be needed to run the vertical section lines (GPR). One with a pulley through which the rope for lifting the antennas from the floor to the ceiling of the Chamber will be passed. A second ladder will be needed for the operator as the cables connecting the antennas to the central unit on the operator's back are 1.5m (or 3m). In order to conduct horizontal GPR cross-sectional lines (W-E), a foldable scaffold is required to enable the helper (or helpers) to move the antennas parallel to the chamber floor and the GPR operator to follow the antennas. The blind spot for USAR research is the entrance to the Chamber, located in the north-eastern corner of the Chamber.

61 GPR cross-sectional lines will be made, with a total length of about 400 m (Fig. 18).

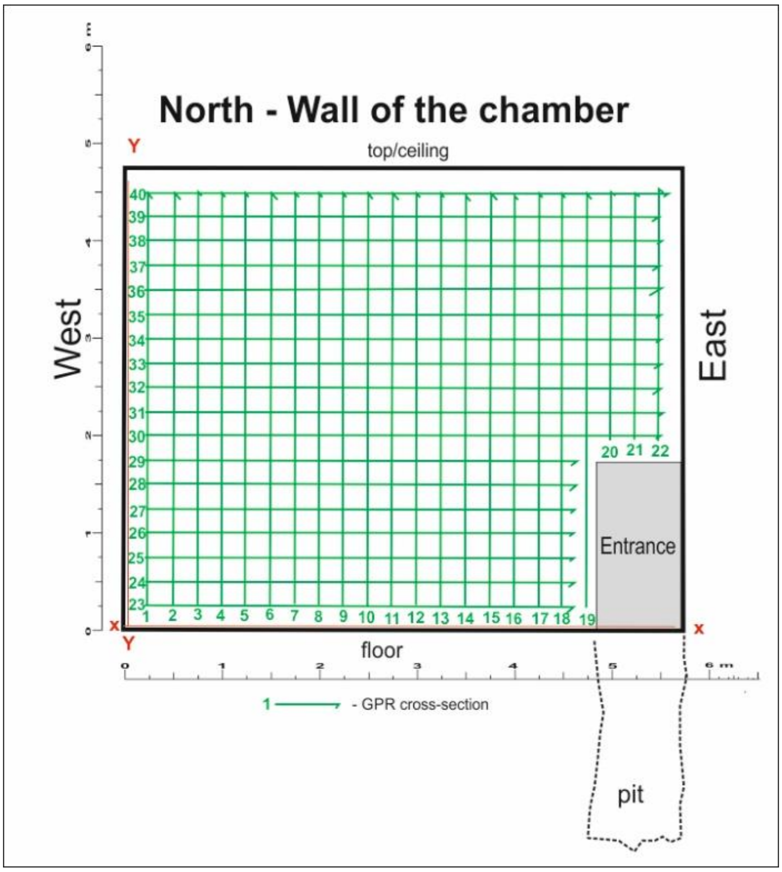


Fig. 18. The Great Pyramid, "Queen's Chamber"
Proposal of GPR cross-sectional lines on the surface of the northern wall in the "Queen's Chamber".

To sum up.

The GPR research project in the "Queen's Chamber" provides for the construction of a total of 204 GPR cross-sectional lines, with a total length of about 900 m.

6.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 2D SYSTEM

The echograms (EM wave echoes) obtained from individual cross-sectional lines will be converted by the GPR central unit and saved on the hard disk of the computer or XV monitor (each profiling line is a separate result file .rd3). In the laboratory, the data files will be transferred to a stationary computing computer and filtered in the GroundVision and ReflexW programs. Different color palettes and different combinations of filters will be used when analyzing the data.

Calibration of the depth scale will be performed on the basis of the assumed average value of electromagnetic waves passing through the granite. The error of the depth scale in 2D sections may be +0.1 m. This may be due to: A) - change in the color of the FM phase during filtration (the EM wave amplitude principle, positive phase and negative phase; B) - the assumed speed of propagation of EM waves in the studied rocks (granite, limestone).

After selecting the color scale, filters, filtering and obtaining the optimal image for interpreting the GPR data and answering the questions, as well as after calibrating the depth scale, the waveforms / echograms will be transferred to CorelDraw for interpretation and marking of anomalies.

Echograms, i.e. images of electromagnetic waves (EM), obtained as a result of filtration, will be compared with model images and with images obtained during experimental GPR surveys. Attention will be paid to: a) GPR anomalies in EM field images, and b) characteristic refractions of wave images in anomalous zones.

On echograms (drawings in 2D), in CorelDraw, detected anomalies will be marked. These anomalies will be transferred to the maps of the Chamber floor and walls of the Chamber, respectively, with an accuracy of ± 0.1 m.

Comments:

1) *in the paper version of the documentation (WORD) the drawings will be difficult to read, therefore a CD has been attached to the documentation, where all the figures will be in JPG (or PDF) version, which can be enlarged.*
2) *the 2D sections will be surpassed (the distance scale will not equal the depth scale).*

7.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 3D SYSTEM

GPR data obtained from section lines will also be processed in the 3D Slices system. On the images of horizontal time cuts (e.g. every 0.03 m), GPR anomalies will be analyzed. The analysis will be carried out from the surface of the floor or wall to a depth of about 5 or 10 m (depending on the antennas used). Anomalies detected on individual horizontal time cuts will also be shown on collective drawings (for selected depths, e.g. 0-1 m, 1-2 m, 2-3 m, etc.). In the horizontal time cut images, the "warm" colors - light blue, yellow to red - will indicate the places of GPR anomalies. Maps of GPR anomalies will be made for the floor of the Chamber and for individual walls of the Chamber.

A comparison of the test results in the 3D system with the results obtained from the analysis of the GPR data in the 2D system will be performed.

8.0. PERSONNEL NECESSARY FOR THE PROJECT

a) Persons operating the GPR equipment:

Adam Szynkiewicz, PhD. - GPR operator;

b) Representative of the Ministry of Antiquity;

c) Person supporting field research:
Reda Abdelhaleem Mohamed Khalifa, PhD. . - supervision of research by the Ministry of Antiquities in Cairo;

d) Two or four technicians to assist in erecting the scaffolding needed to move the antennas

along the walls of the Chamber and over the floor of the Chamber;

e) Security guards (two or four).

f) Persons interpreting GPR data and preparing documentation:

Adam Szynkiewicz, PhD. - analysis of GPR data in the 2D system,

and preparing of documentation;

Magdalena Udyrysz-Kraweć, MA. - analysis of GPR data in the 3D system

9.0. TIME REQUIRED TO COMPLETE THE PROJECT

- 4-5 days of work are needed to perform the GPR field tests in the "Queen’s Chamber",
    - approximately 6-8 hours a day (depending on the battery discharge time).
    - Fieldwork can be carried out after the tourists leave the "Queen’s Chamber".

- It takes 30 days from the end of the field work to perform the analysis of the obtained GPR data and to prepare the documentation.

STAGE IV.

GPR RESEARCH PROJECT :
THE LIMESTONE IN THE CLOSE SURROUNDINGS OF THE GREAT PYRAMID ("CHEOPS' PYRAMID"), IN GIZA, EGYPT

Author:

Adam Szynkiewicz, PhD. (Poland)

Cooperation:

Reda Abdelhaleem Mohamed Khalifa, PhD. (Egypt)
Magdalena Udyrysz–Kraweć, MA. (England)

Poland, Wrocław, 2023

CONTENTS

1.0. THE GREAT PYRAMID ("CHEOPS PYRAMID") IN GIZA

In Northern Egypt, on the Giza plateau, in a complex of three pyramids (and a few small ones), there is the Great Pyramid, also called the "Cheops Pyramid". The Giza Plateau (50-115 m above sea level), is located on the western side of the Nile River Valley (18-20 m above sea level) and is located west of the center of Cairo. The plateau is built of limestone of the age of Eocene.

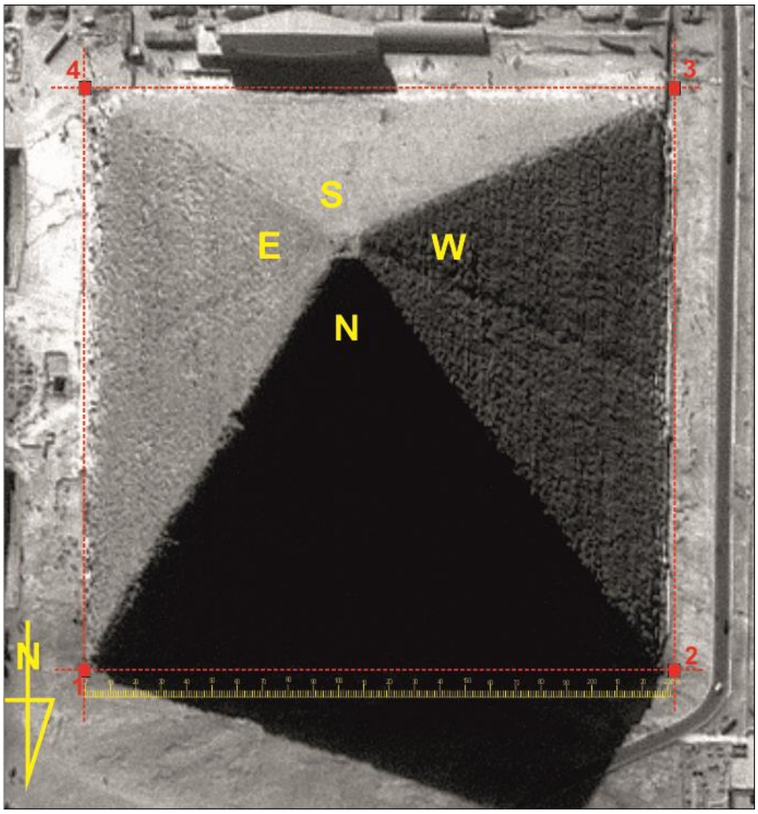


Fig. 1. Great Pyramid in Giza Plateau. View from the North
red square: 1, 2, 3, 4 - control point in the corner of the pyramid
dashed red line – baselines

The Great Pyramid ("The Pyramid of Cheops"), located at an altitude of 60 m above sea level. Currently, the pyramid has a height of about 146.59 m. The surface of the walls of the pyramid are blocks of Eocene limestone, arranged in steps (the limestone blocks are about 1m x 1m x 1m). Currently, the length of the northern, eastern, western and southern bases of the pyramid's walls is approximately 230.5 m (Fig. 1). The general inclination of the pyramid's walls is about 51˚52'.

In the closest vicinity of the pyramid (up to 20-30 m), the limestone surfaces are leveled. There are numerous fissures/cracks in the NW-SE direction in the limestone. Some wider fissures in the limestone are filled with sand and gravel with flint pebbles. The walls of the fissures show traces of karst corrosion and are covered with oxidized iron compounds. At the base of the pyramid's walls there are numerous, larger fragments of limestone (the former face of the pyramid's walls) and a fragment of granite rocks.

2.0. PURPOSE AND SCOPE OF THE RESEARCH

The aim of non-invasive GPR surveys of limestones in the close vicinity of the Great Pyramid ("Pyramid of Cheops") in Giza is to detect geophysical anomalies. GPR surveys should clarify: whether there are natural or artificial corridors, chambers, etc. Detailed GPR surveys will be conducted in 2D and 3D systems. It is assumed that GPR surveys will be conducted to a depth of about 10-20 m.

3.0. GPR EQUPMENT

3.1. Ground Penetrating Radar (GPR).

Ground Penetrating Radar (GPR) is an electronic apparatus for geophysical ground research. The GPR consists of: a transmitting antenna and a receiving antenna (in a shielded box), which are connected by optical fibers (or WiFi) to the central unit. The device works on the principle of counting the return delays of electromagnetic pulses of very high frequency (10 - 2000 MHz), sent by the transmitting antenna, which are reflected from various lithological boundaries of the ground, various types of rocks (dielectrics), are received by the receiving antenna and transmitted to the unit central to count the time of wave return delays. The boundaries reflecting the radar signal should be understood as the boundaries between the media differing in the value of the dielectric constant. Rocks have different dielectric constant values. The impulses sent by the transmitting antenna into the center, return with a delay to the receiving antenna and through optical fibers go to the central unit controlling the system, and then they are processed and sent to the recorder (e.g. a portable computer hard drive or XV monitor). In the field, these impulses are observed by the operator on the monitor in the form of an echogram/time waveform (i.e. linear, vertical, cross-section) of soil parameters variability. Such a chart can then be converted, for example, into metric units, it can be printed in colors (so-called filtration - a separate color for different wave speeds). The obtained image can be compared with model images of various objects hidden in the ground or with model images of geological structures or with cartographic documentation of uncovers, as well as with data obtained from geological drillings. Compared to other geophysical methods, the radar method (GPR) allows **non-invasive**, linear tracking of the geological structure in the field, i.e. tracking the variability of lithology and shallow geological structures. The use of interchangeable antennas (with different frequencies, e.g. from 10 MHz to 2 GHz) depends on the task and the assumed depth of ground monitoring. The lower the central frequency of the antennas, the greater the depth range of the profiling. For shallow archaeological and geotechnical research, antennas with a higher central frequency are used, enclosed in a specially shielded container (**shielded antennas**).

For non-invasive georadar surveys (GPR), it is proposed to use the RAMAC/GPR with 100 MHz shielded antennas (or the MALA Ground Explorer with GX80 or GX160 shielded antennas). The possibility of renting such apparatus on site in Egypt should be considered, or such apparatus may be rented and brought by the project contractor (perhaps loan from MALA in Sweden).

4.0 METHODOLOGY OF THE GPR RESEARCH FIELD WORKS

GPR field work in the close vicinity of the Great Pyramid ("Pyramid of Cheops") in Giza will be carried out with a portable RAMAC/GPR, powered by 12V batteries, with shielded antennas 100 MHz, or GPR System: MALA Ground Explorer, with shielded antennas GX80 (or GX160). The antennas will be moved along the ground surface. The tests will be performed using the linear profiling method (Fig. 2), to a depth of about 10-20 m. Trace interval: i = 0.05 m. Distances will be measured with a measuring wheel.

The GPR research project in the close vicinity of the Great Pyramid ("Pyramid of Cheops") in Giza was divided into the following tasks:

Task 1 – on the northern side of pyramid,

Task 2 – on the western side of pyramid,

Task 3 – on the southern side of pyramid,

Task 4 – on the eastern side of pyramid.

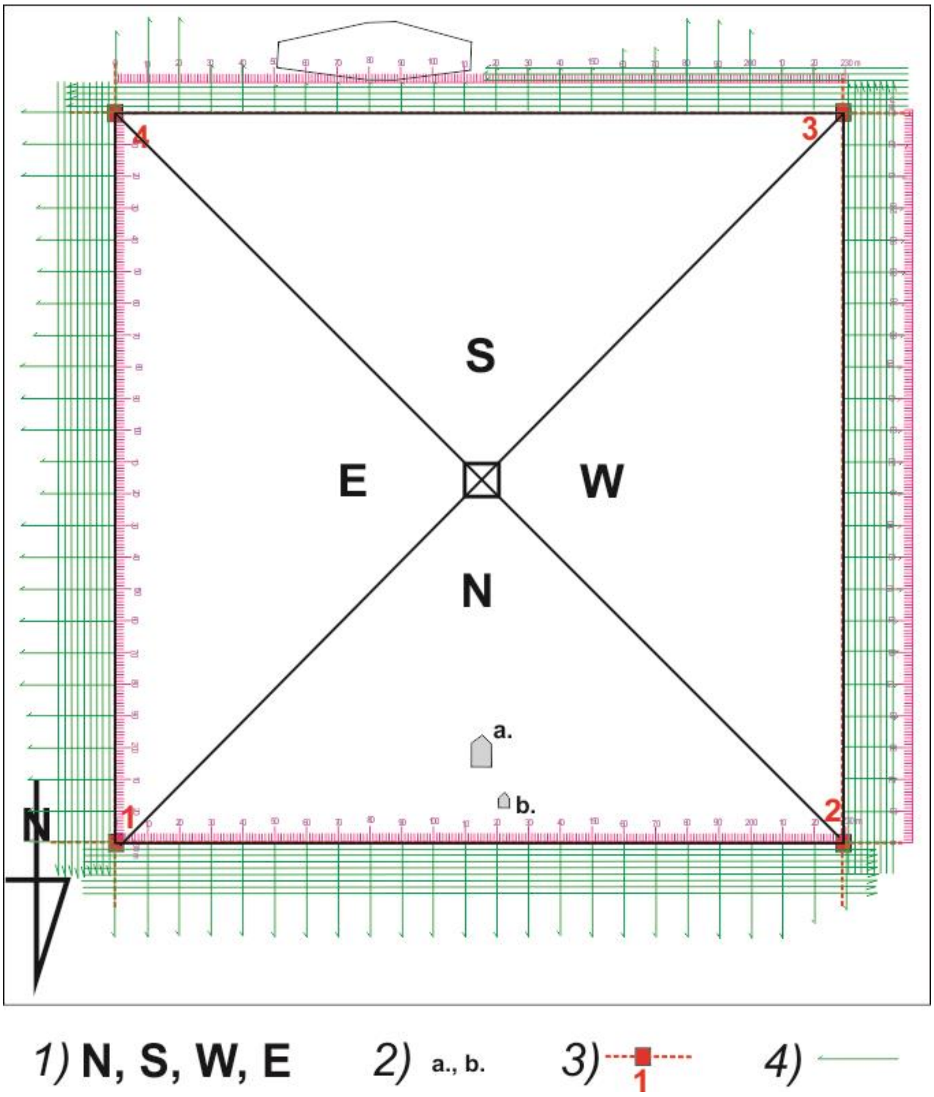


Fig. 2. Great Pyramid in Giza Plateau. View from the top

1) N, S, W, E – pyramid walls; 2) a., b. – entrance to the pyramid; 3) red square: 1, 2, 3, 4 - control point in the corner of the pyramid and dashed red line – baselines; 4) GPR cross-section

Task 1 – GPR research on the northern side of pyramid

Baseline X - measuring tape will be placed along the pyramid wall. The starting point of the measurements (X0, Y0) will be located in the north-eastern corner of the pyramid. Eight GPR cross-sectional lines will be run parallel, at 2.0 m intervals, from the East to the West. In addition, at 10 m intervals, it is proposed to make 24 cross-sectional lines from the pyramid wall in the north direction (about 20-30 m each line).

32 GPR cross-sectional lines will be made, with a total length of about 2 700 m

Task 2 – GPR research on the western side of pyramid

Baseline X - measuring tape will be placed along the pyramid wall. The starting point of the measurements (X0, Y0) will be located in the north-western corner of the pyramid. Eight GPR cross-sectional lines will be run parallel, at 2.0 m intervals, from the Nort to the South. In addition, at 10 m intervals, it is proposed to make 24 cross-sectional lines from the pyramid wall in the west direction (about 20-30 m each line).

32 GPR cross-sectional lines will be made, with a total length of about 2 700 m

Task 3 – GPR research on the southern side of pyramid

Baseline X - measuring tape will be placed along the pyramid wall. The starting point of the measurements (X0, Y0) will be located in the south-western corner of the pyramid. Eight GPR cross-sectional lines will be run parallel, at 2.0 m intervals, from the West to the East. In addition, at 10 m intervals, it is proposed to make 24 cross-sectional lines from the pyramid wall in the south direction (about 10-30 m). The building with the boat will limit the length of the section lines.

32 GPR cross-sectional lines will be made, with a total length of about 2 000 m

Task 4 – GPR research on the eastern side of pyramid

Baseline X - measuring tape will be placed along the pyramid wall. The starting point of the measurements (X0, Y0) will be located in the south-eastern corner of the pyramid. Eight GPR cross-sectional lines will be run parallel, at 2.0 m intervals, from the West to the East. In addition, at 10 m intervals, it is proposed to make 24 cross-sectional lines from the pyramid wall in the east direction (about 20-30 m).

32 GPR cross-sectional lines will be made, with a total length of about 2 700 m

To sum up.

The GPR research project in the "King's Chamber" provides for the construction of a total of 128 GPR cross-sectional lines, with a total length of about 10 000 m.

5.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 2D SYSTEM

The echograms (EM wave echoes) obtained from individual cross-sectional lines will be converted by the GPR central unit and saved on the hard disk of the computer or XV monitor (each profiling line is a separate result file .rd3). In the laboratory, the data files will be transferred to a stationary computing computer and filtered in the GroundVision and ReflexW programs. Different color palettes and different combinations of filters will be used when analyzing the data.

Calibration of the depth scale will be performed on the basis of the assumed average value of electromagnetic waves passing through the limestone. The error of the depth scale in 2D sections may be +0.2 m. This may be due to: A) - change in the color of the FM phase during filtration (the EM wave amplitude principle, positive phase and negative phase; B) - the assumed speed of propagation of EM waves in the studied rocks (limestone).

After selecting the color scale, filters, filtering and obtaining the optimal image for interpreting the GPR data and answering the questions, as well as after calibrating the depth scale, the echograms will be transferred to CorelDraw for interpretation and marking of anomalies.

Echograms, i.e. images of electromagnetic waves (EM), obtained as a result of filtration, will be compared with model images and with images obtained during experimental GPR surveys. Attention will be paid to: a) GPR anomalies in EM field images, and b) characteristic refractions of wave images in anomalous zones.

On echograms (drawings in 2D), in CorelDraw, detected anomalies will be marked. These anomalies will be transferred to the map (respectively, with an accuracy of ±1.0 m), and will be made it geological interpretation.

Comments:

1) *in the paper version of the documentation (WORD) the drawings will be difficult to read, therefore a CD has been attached to the documentation, where all the figures will be in JPG (or PDF) version, which can be enlarged.*
2) *the 2D sections will be surpassed (the distance scale will not equal the depth scale).*

6.0. METHODOLOGY OF INTERPRETATION OF GPR DATA IN 3D SYSTEM

GPR data obtained from cross-section lines will also be processed in the 3D Slices system. On the images of horizontal time slices (e.g. every 0.05 m), GPR anomalies will be analyzed. The analysis will be carried out from the surface to a depth of about 10 or 20 m (depending on the antennas used). Anomalies detected on individual horizontal time slices will also be shown on collective drawings (for selected depths, e.g. 0-1 m, 1-2 m, 2-3 m, etc.). In the horizontal time slices images, the "warm" colors - light blue, yellow to red - will indicate the places of GPR anomalies. Maps of GPR anomalies will be made for each task and it geological interpretation.

A comparison of the test results in the 3D system with the results obtained from the analysis of the GPR data in the 2D system will be performed.

7.0. PERSONNEL NECESSARY FOR THE PROJECT

a) Persons operating the GPR equipment:

- ➢ Adam Szynkiewicz, PhD. - GPR operator;

b) Representative of the Ministry of Antiquity;

c) Persons supporting field research:

- ➢ Reda Abdelhaleem, PhD. Reda Abdelhaleem Mohamed Khalifa, PhD. - supervision of research by the Ministry of Antiquities;
- ➢ two or four technicians;
- ➢ security guards (two or four).

d) Persons interpreting GPR data and preparing documentation:

- ➢ Adam Szynkiewicz, PhD. - analysis of GPR data in the 2D system; and preparing documentation;
- ➢ Magdalena Udyrysz-Kraweć, MA. – analysis of GPR data in the 3D system;

8. TIME REQUIRED TO COMPLETE THE PROJECT

To perform the GPR field tests in the close vicinity of the Great Pyramid ("Pyramid of Cheops") in Giza 5 days of work are needed in the approximately 6 hours a day (depending on the battery discharge time).

It takes 30 days from the end of the field work to perform the analysis of the obtained GPR data and to prepare the documentation.