Processing of gravity data (1/7)

1. dumping of data (transfer CG5→computer)
2. residual drift correction and recalculation to absolute values (removed diurnal variations, relative $\delta g \rightarrow g_{obs}$)
3. evaluation of simple Bouguer anomalies (SBA):

   $SBA = g_{obs} - g_{theor} + FAC + BC$

   FAC = free air correction ($+0.3086 \cdot h$)

   BC = Bouguer correction ($-0.0419 \cdot \rho \cdot h$)

   (ρ = correction density, default 2.67 $g \cdot cm^{-3}$, here 2.1 $g \cdot cm^{-3}$)
4. terrain corrections (TC) evaluation
5. finally complete Bouguer anomalies evaluation:

   $BA = g_{obs} - g_{theor} + FAC + BC - B + TC$

Processing of gravity data (2/7)

g_{theor} (theoretical grav. field or so called normal grav. field)

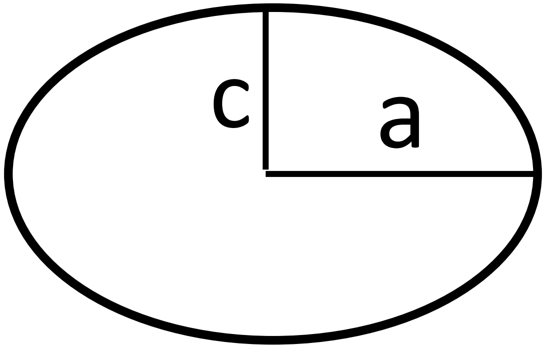
so called Somigliana-Pizetti formula:

$$g_{theor} = \frac{a g_e \cos^2\varphi + c g_p \sin^2\varphi}{\sqrt{a^2\cos^2\varphi + c^2\sin^2\varphi}}$$

a, c – major and minor semi-axis of the reference ellipsoid
(WGS84: a=6378137 m, c=6356752.3 m)

g_e – gravity acceleration on the equator
(WGS84: g_e= 978032.68 mGal)

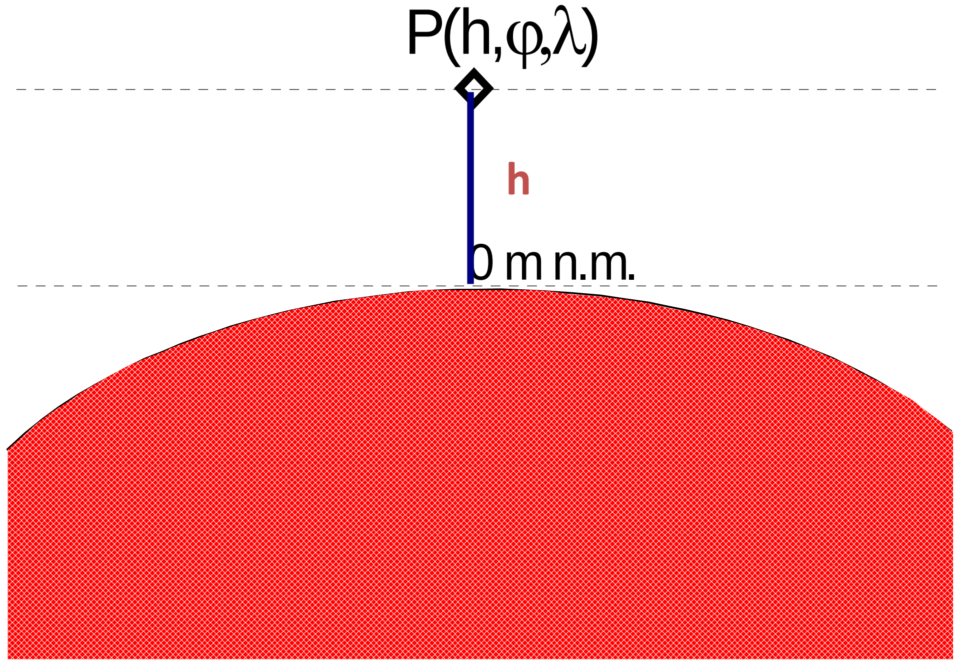
g_p – gravity acceleration on the pole
(WGS84: g_p= 983218.64 mGal)



Processing of gravity data (3/7)

free air correction (so called Faye's correction)

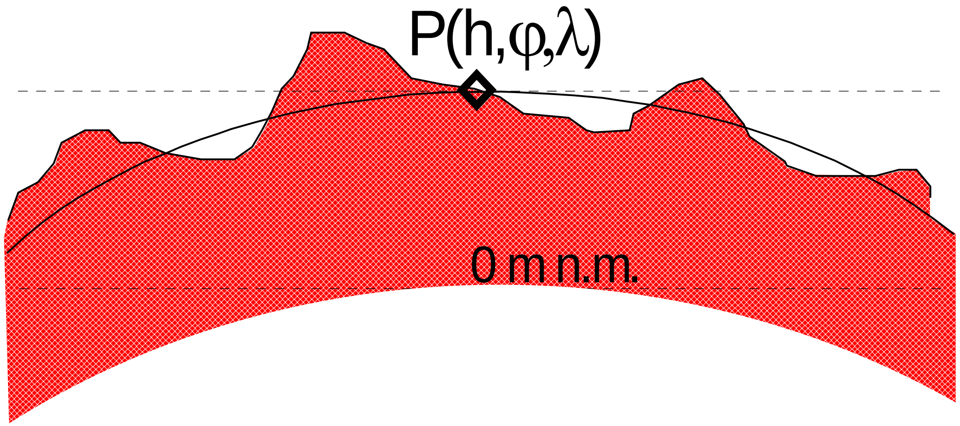
$$SBA = g - g_{theor} + 0.3086h - 0.0419h\rho$$

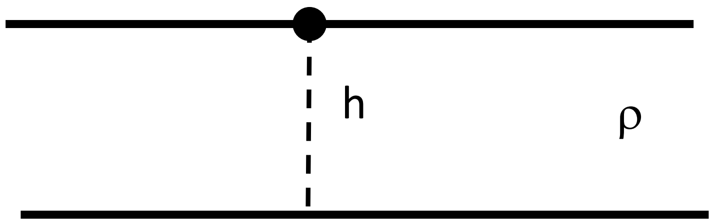


Processing of gravity data (4/7)

Bouguer (planar) correction

$$SBA = g - g_{theor} + 0.3086h - 0.0419h\rho$$





effect of planar (Bouguer) slab:

$$2\pi\kappa\rho h \cong 0.0419\rho h$$

(in [mGal] for [$g\cdot cm^{-3}$])

Processing of gravity data (5/7)

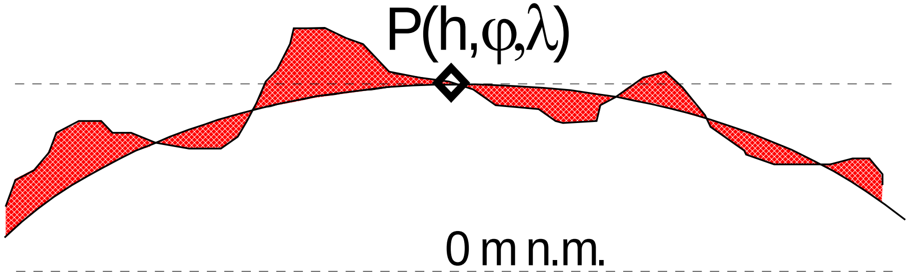
Task to be done:

- evaluate the SBA values for different correction densities (e.g. , 2.0, 2.2, 2.4, 2.6, 2.8 $g \cdot cm^{-3}$) and try to display them as graphs in one plot window (Matlab)

Processing of gravity data (6/7)

comment: terrain corrections (TC) are small in such flat regions

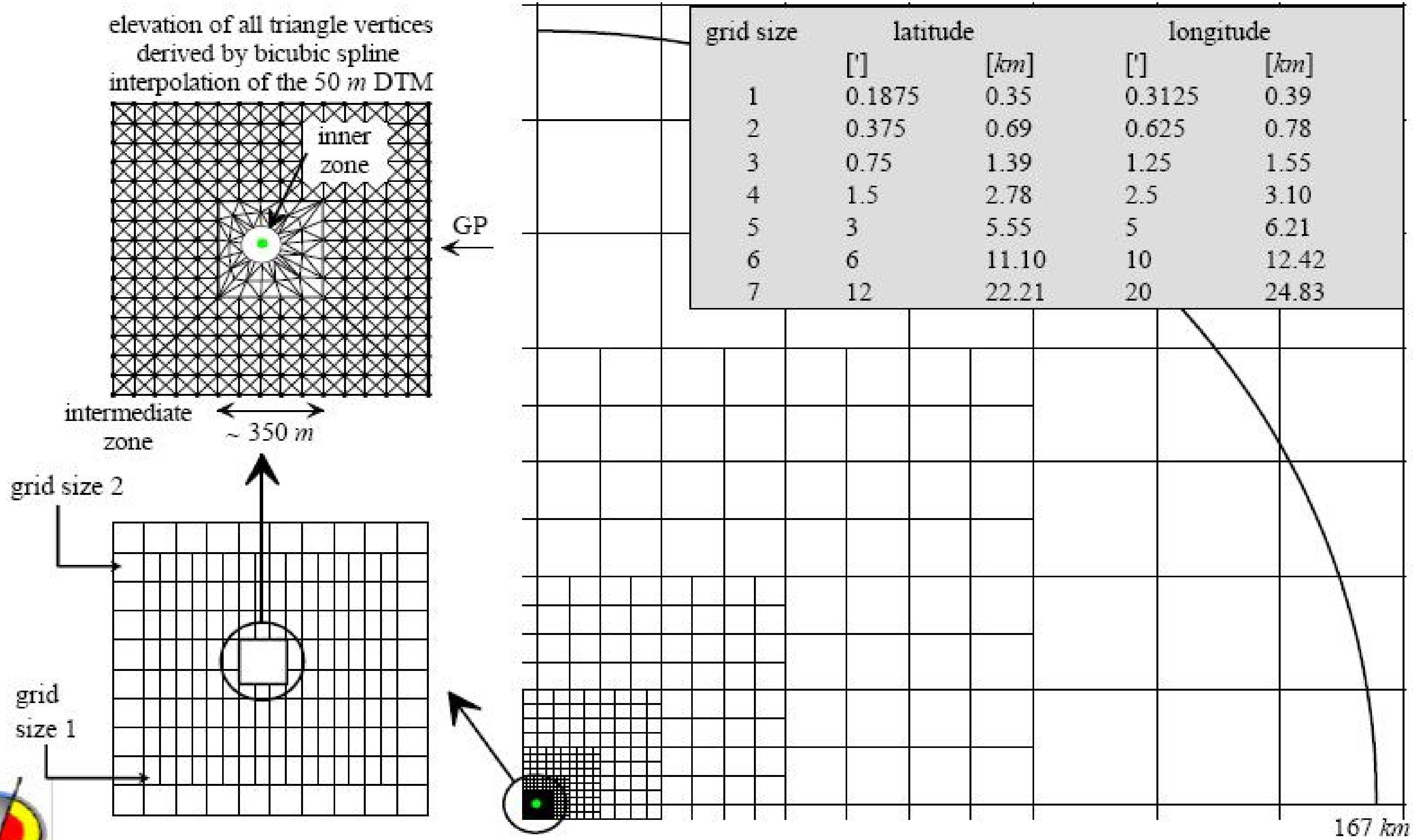
$$SBA = g - g_{theor} + 0.3086h - 0.0419h\rho - B + TC$$



- -TC evaluates the correction for the gravitational effect of positive (hills) and negative terrain shapes (valleys)
- usually the surroundings of the measurement point is divided into several zones up to the max. distance of 167 km
- during this meeting we will make a trial with the software Toposk for an intermediate zone

Processing of gravity data (7/7)

Combination of rectangular prism and polyhedron approximation



grid size	latitude [′]	latitude [km]	longitude [′]	longitude [km]
1	0.1875	0.35	0.3125	0.39
2	0.375	0.69	0.625	0.78
3	0.75	1.39	1.25	1.55
4	1.5	2.78	2.5	3.10
5	3	5.55	5	6.21
6	6	11.10	10	12.42
7	12	22.21	20	24.83

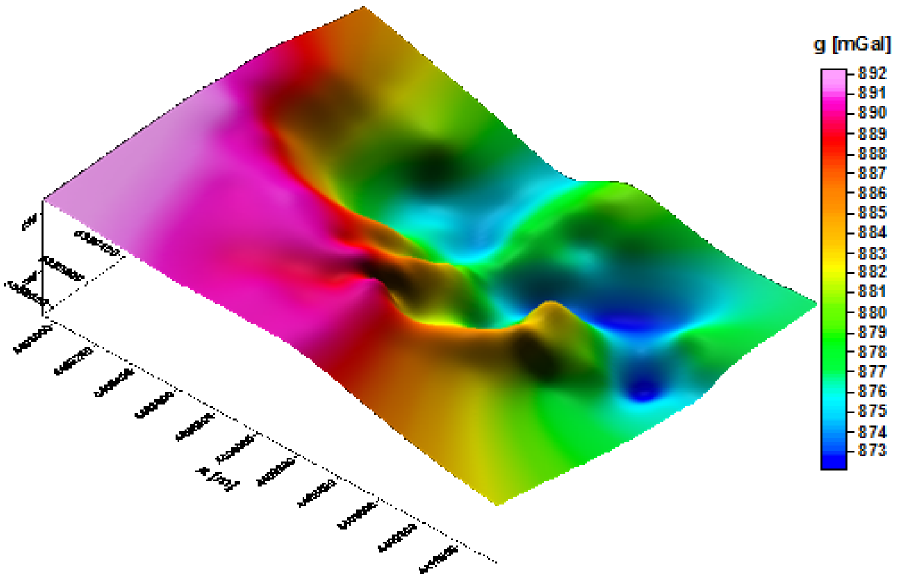
B. Meurers, Institute of Meteorology and Geophysics - University of Vienna

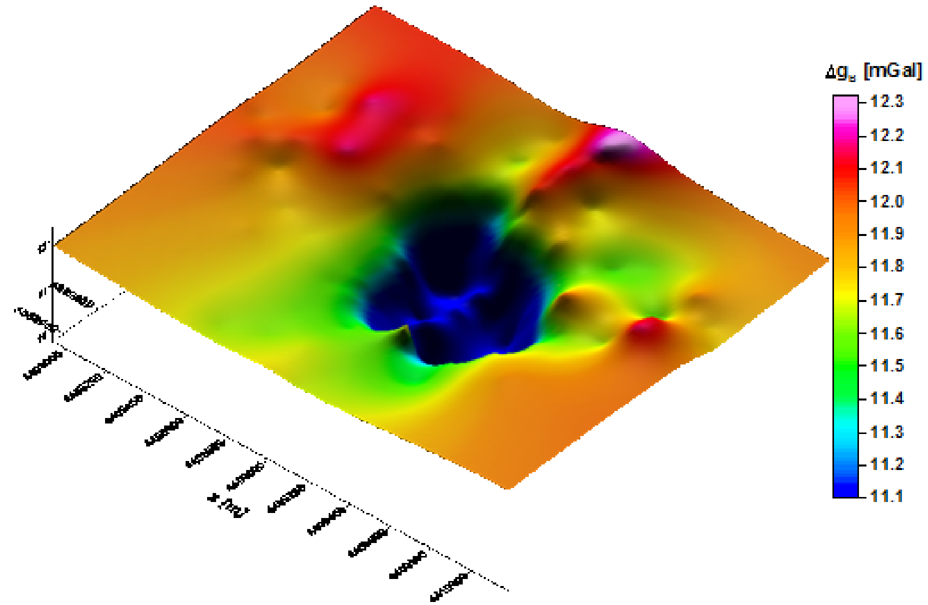
Few examples from gravimetrical applications

Importance of Bouguer anomalies evaluation

Extracting effects of interesting objects – an example

Micogravity survey over an old filled volcano (SE Slovakia)



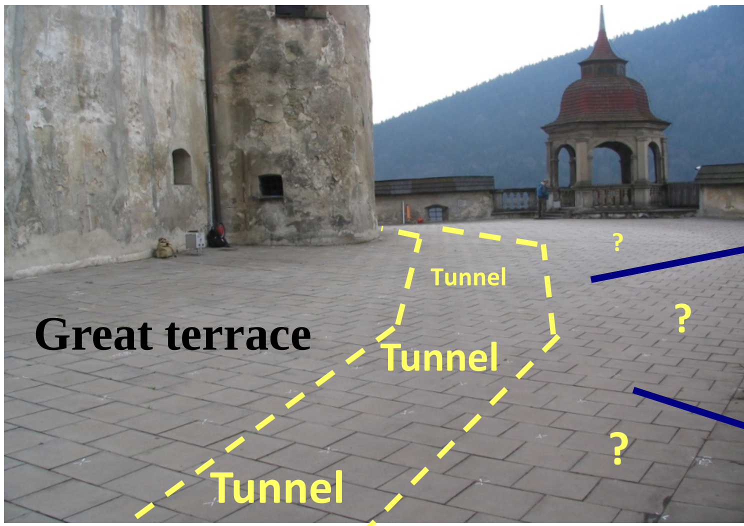


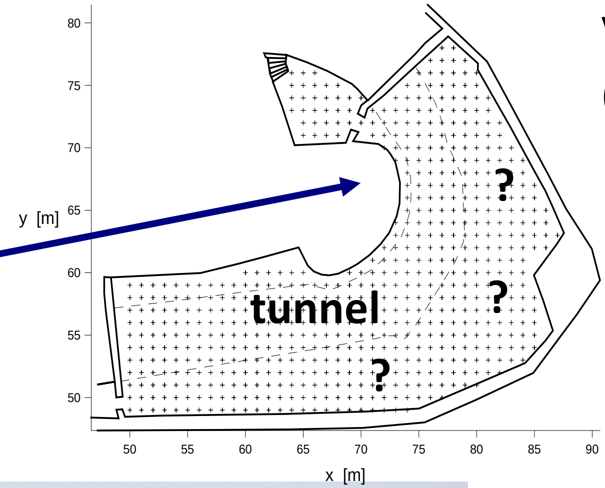
Measured gravity (g) reflects mainly the elevations of the gravity sites …

… Bouguer anomaly values (Δg_B) display the structure of the volcano – the light filling (old Maar-lake sediments)

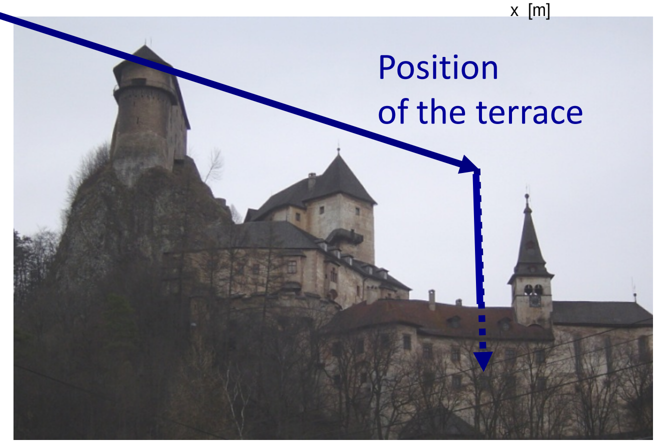
Importance of Bouguer anomalies evaluation

Castle Orava, Slovakia – microgravity survey (M. Vrzba et al., 2005)





View from top (grid of 1x1 m observational points).

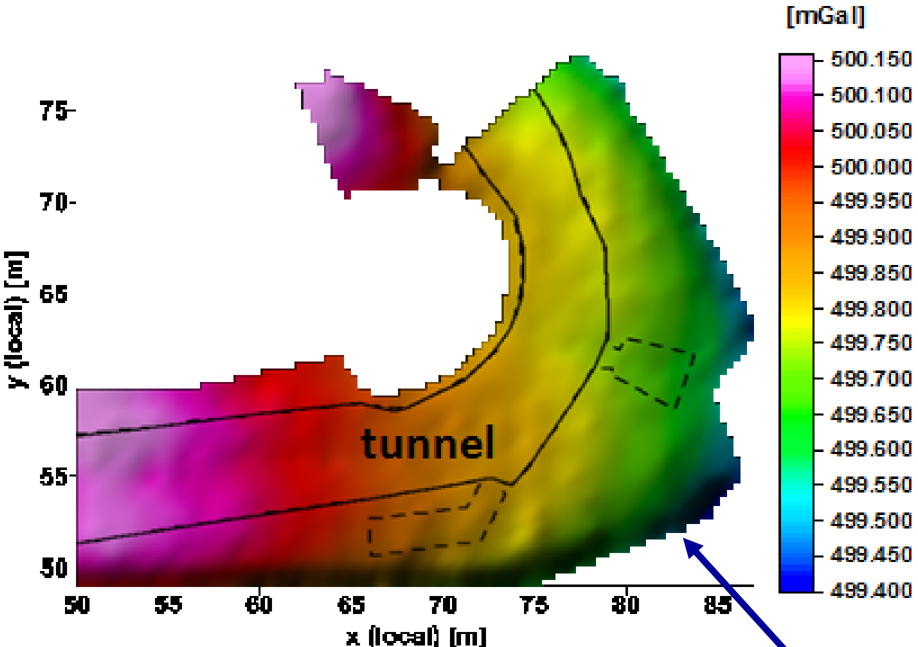


Search for possible positions of defense channels below the terrace - - so called „casemats“ (running from the tunnel to the protection wall)

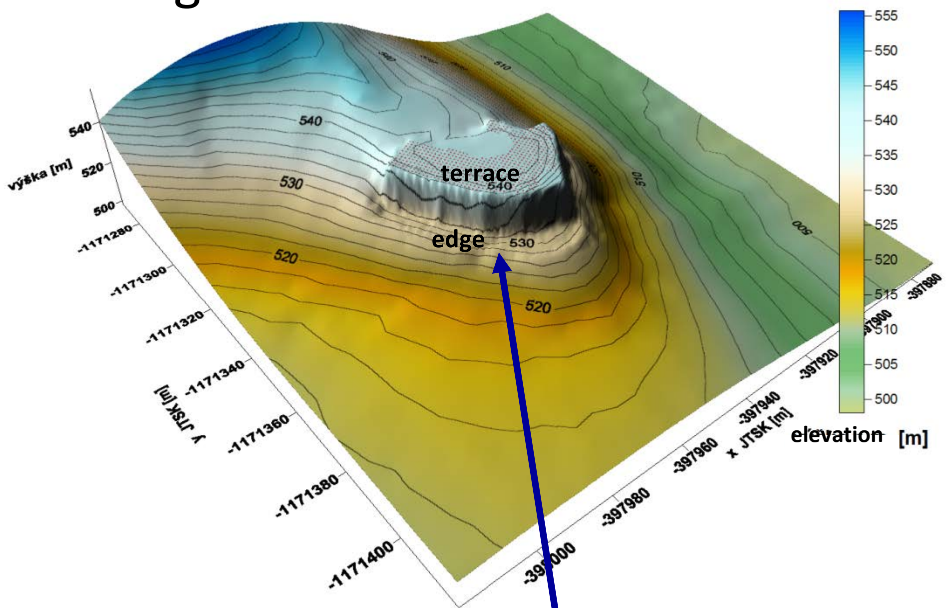
Importance of Bouguer anomalies evaluation

Castle Orava, Slovakia – microgravity survey (M. Vrzba et al., 2005)

Measured gravity (g)



Digital Elevation Model

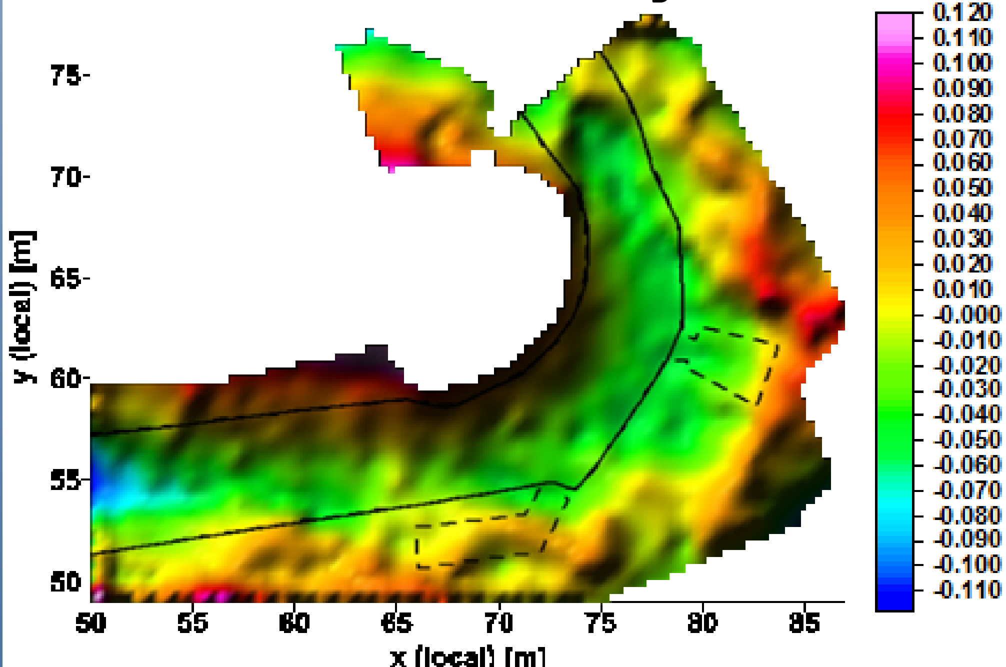


Terrace edge is strongly causing observed gravity (g) weile the existence of the tunnel is not visible.

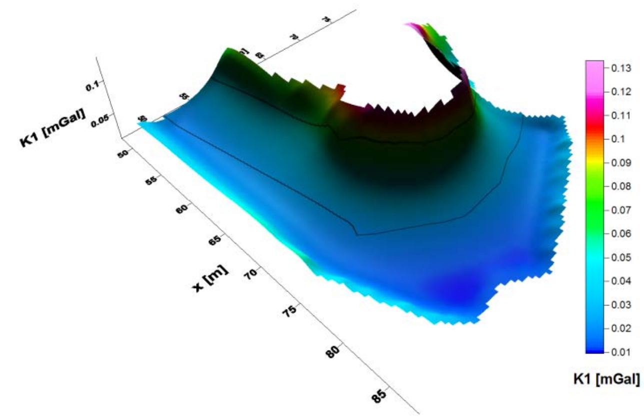
Importance of Bouguer anomalies evaluation

Castle Orava, Slovakia – microgravity survey (M. Vrzba et al., 2005)

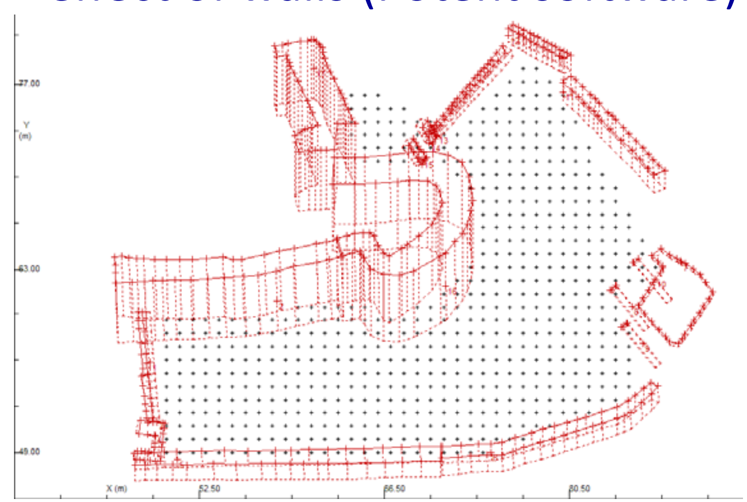
Boguer anomaly (Δg_B)



after applying all needed corrections (mainly terrain corrections and attraction of walls) Bouguer anomaly displays the effect of the tunnel.



effect of walls (Potent software)

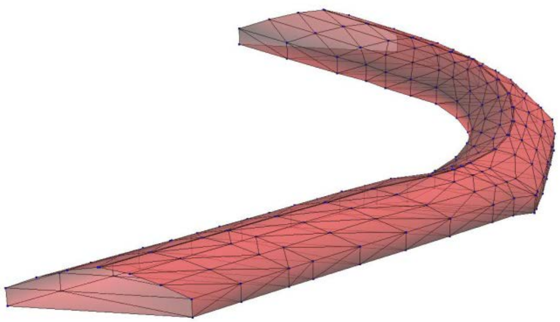


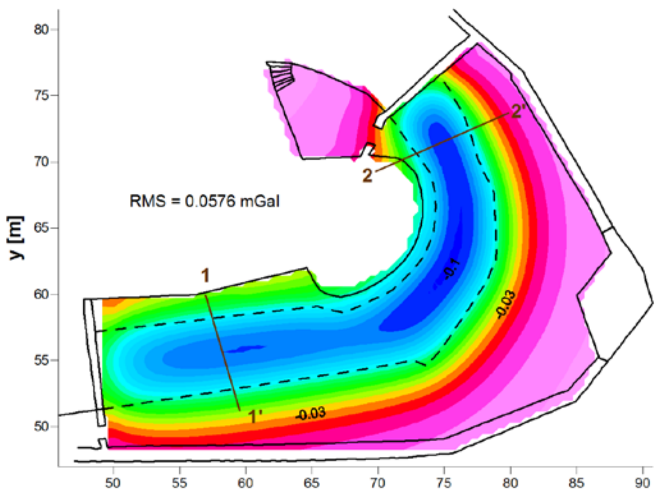
wall model

Importance of Bouguer anomalies evaluation

Castle Orava, Slovakia – microgravity survey (M. Vrzba et al., 2005)

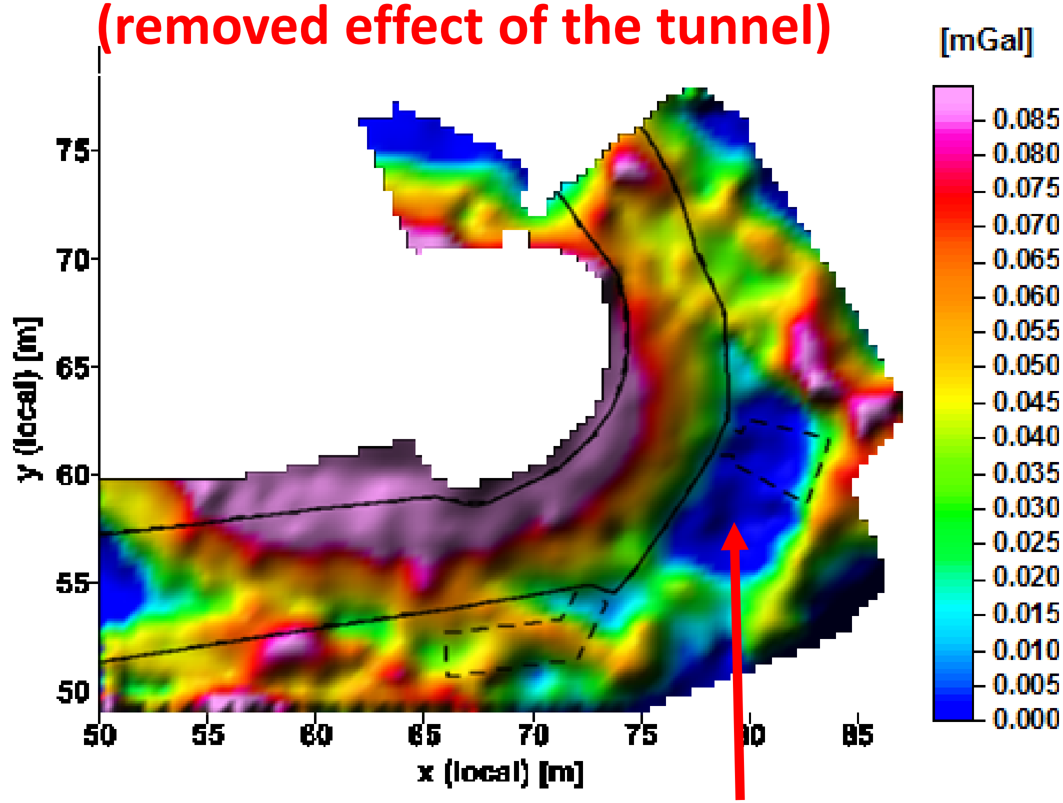
Model of the tunnel
(GOCAD software)





Effect of the tunnel (IGMAS software)

Final result:
"stripped" Boguer anomaly (Δg_B)
(removed effect of the tunnel)



Important anomalous area -
unknown cavity?

Micro-gravity: case-studies

Case-studies: an application of the micro-gravity method in archaeology - 2 examples

- Great pyramid, Egypt – French project, 1986-88

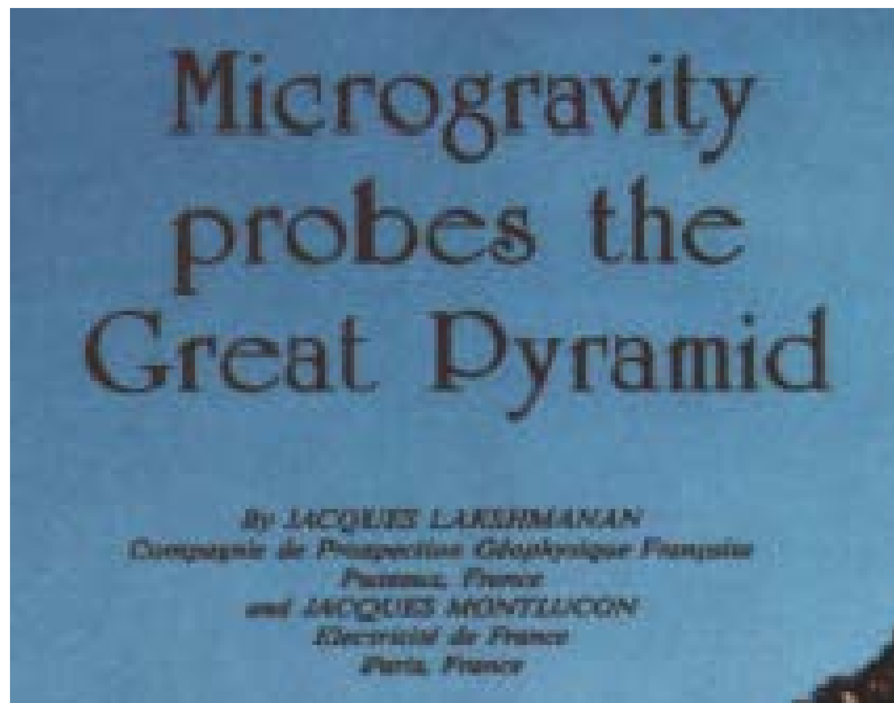
- St. Nicholas church, Trnava, Slovakia - 2006

Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

For further reading refer to:

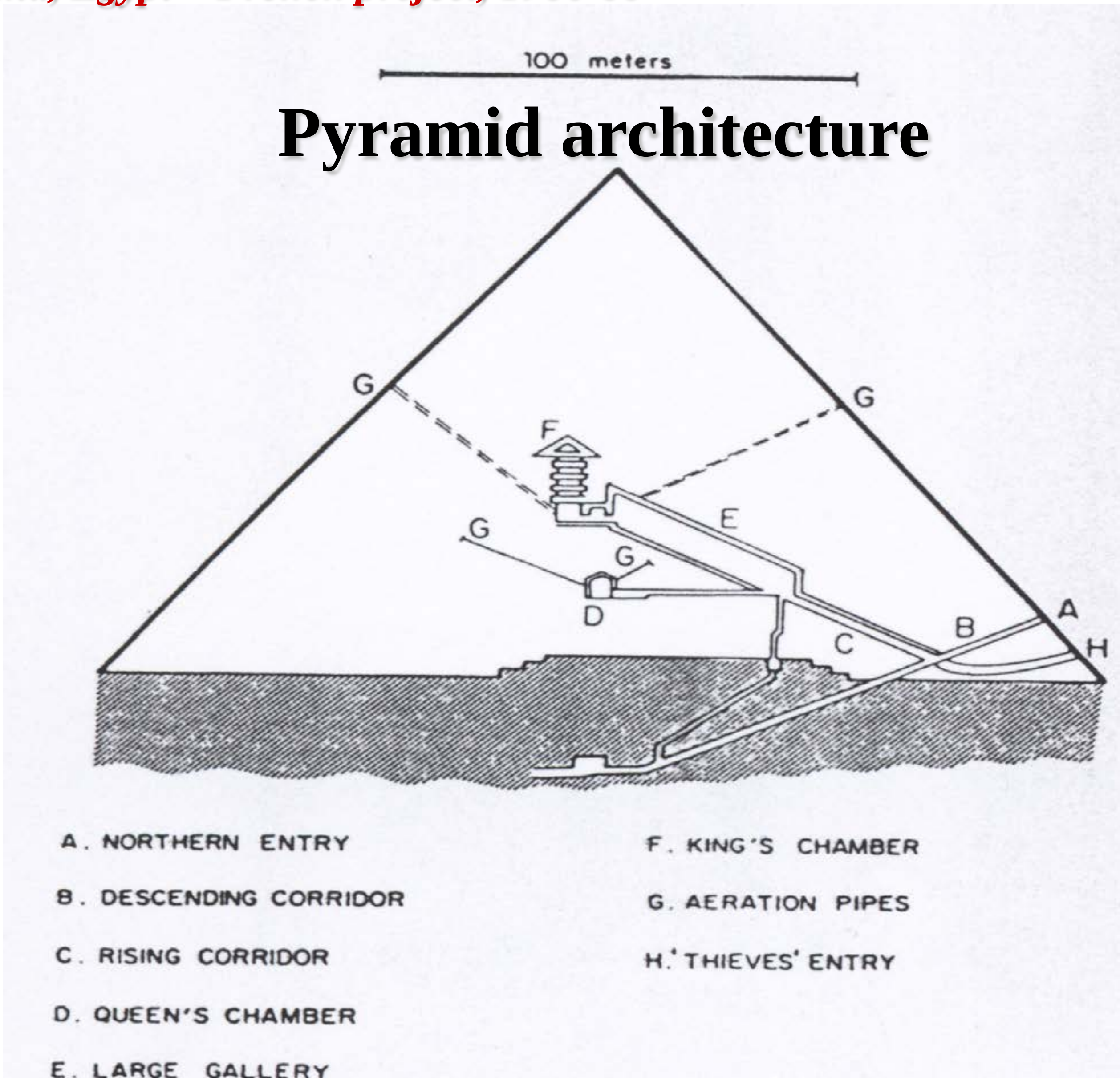
Lakshmanan J., Montlucon J., 1987: Microgravity probes the Great Pyramid, The Leading Edge 6, 10 - 17



Micro-gravity: case-studies

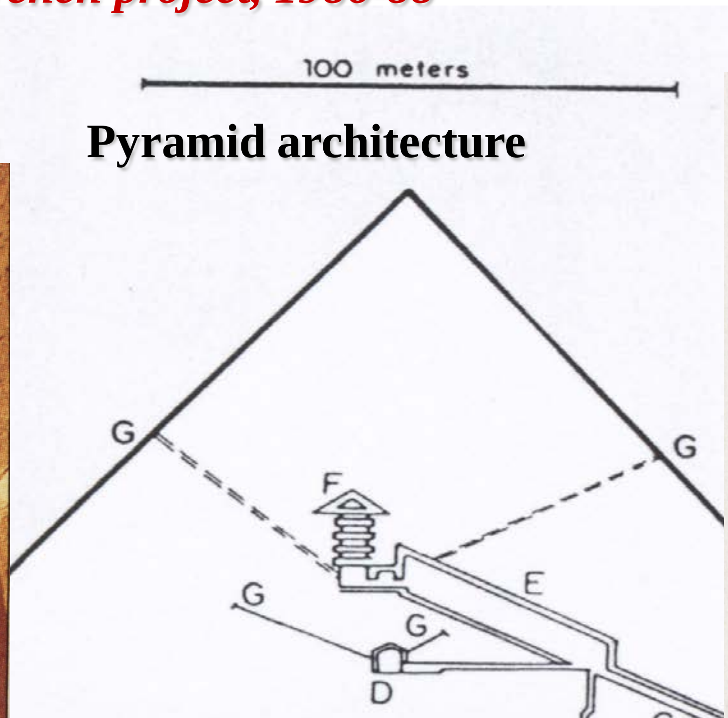
Great pyramid, Egypt – French project, 1986-88

Pyramid architecture

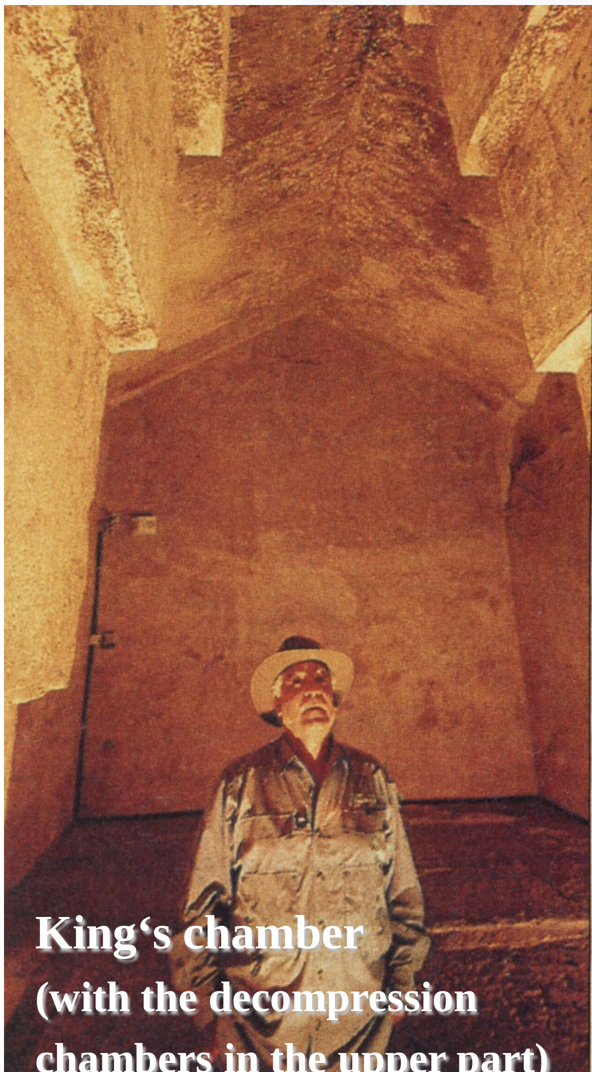


Micro-gravity: case-studies

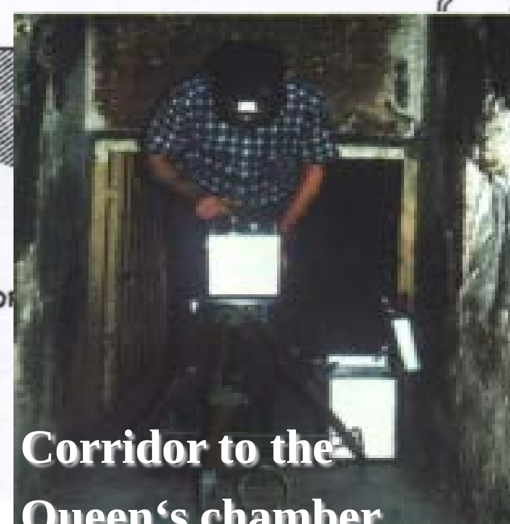
Great pyramid, Egypt – French project, 1986-88



Pyramid architecture



King‘s chamber
(with the decompression chambers in the upper part)



Corridor to the Queen‘s chamber

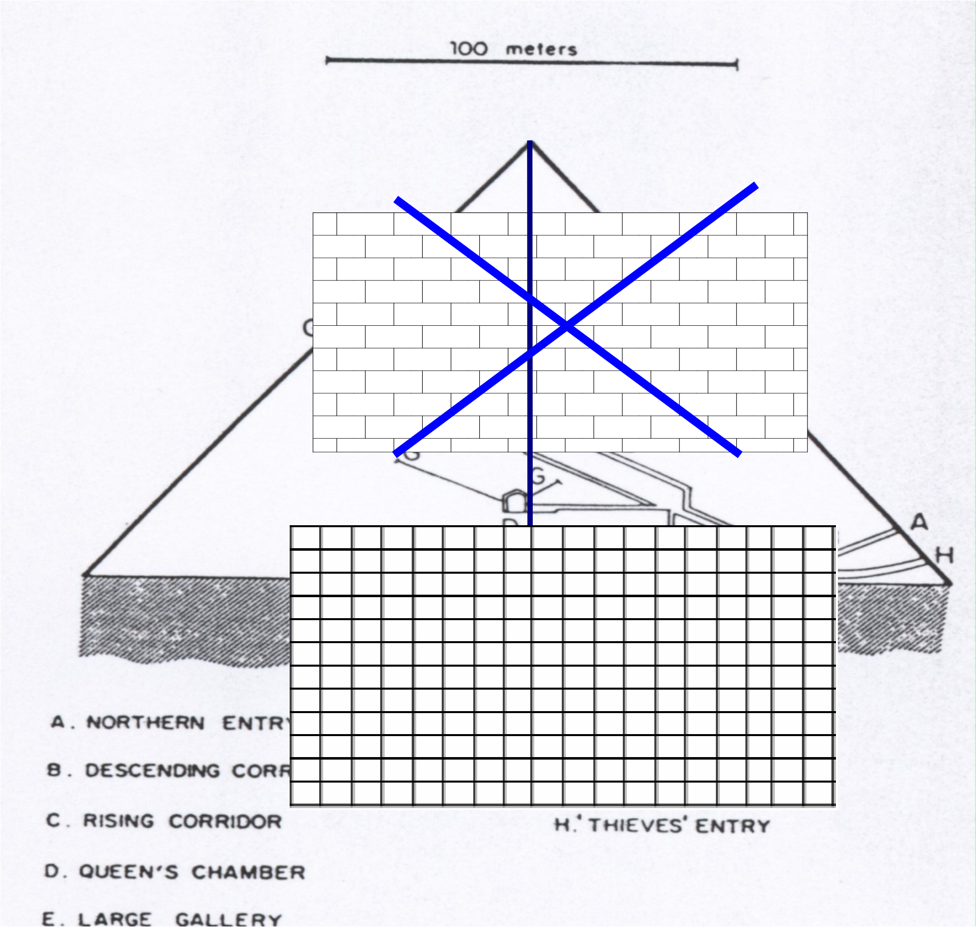
Large gallery

Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

„Arguments“ for starting the exploration –
architectonic „anomalies“ of a pyramid structure:

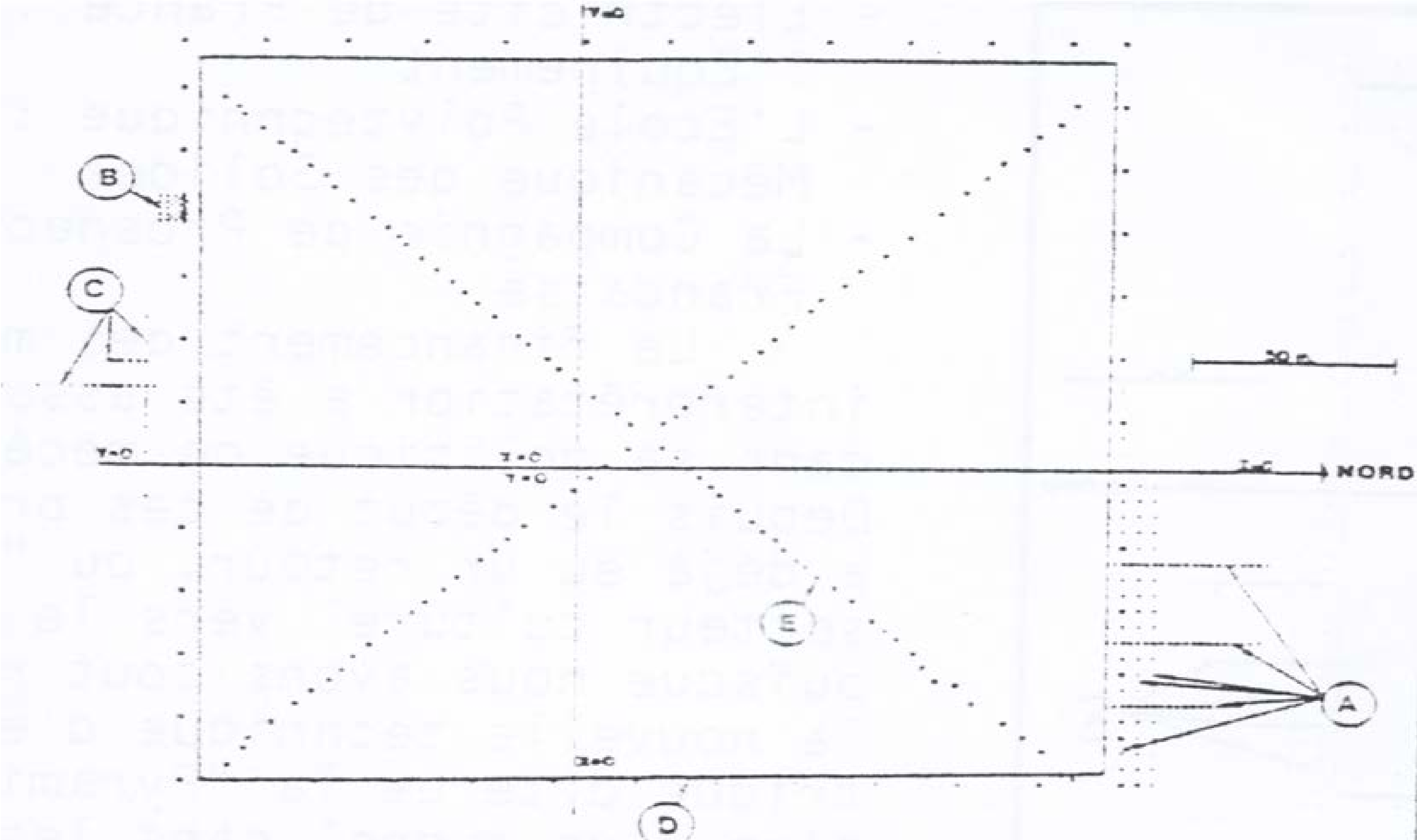
- Position of the „King's“ chamber is not exactly on the vertical axis of the pyramid,
- position of the blocks in the corridor to the „Queen's“ chamber doesn't have the typical „brick“ pattern, and
- the abnormal large super-structure (decompr. chambers) above the „King's“ chamber.



Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

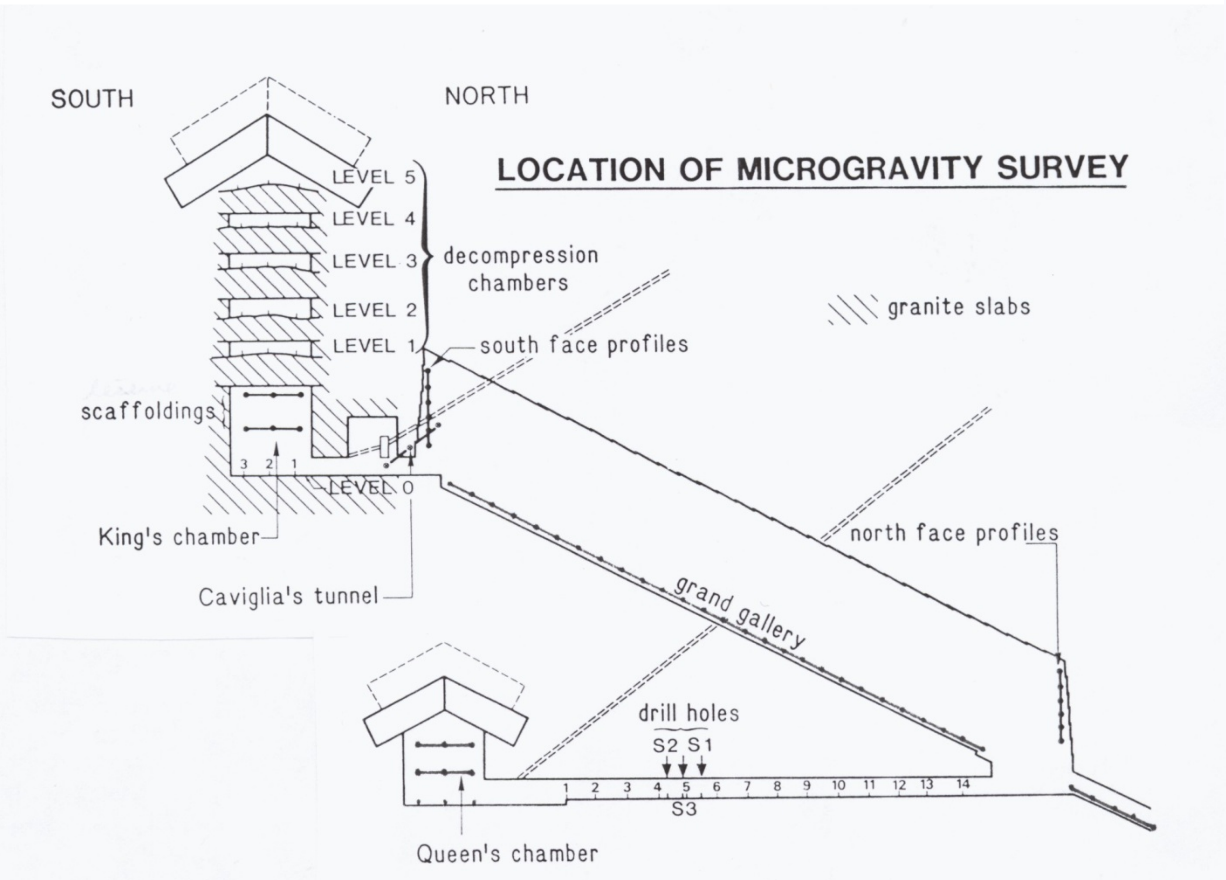
Positions of microgravity observations – outside the pyramid.

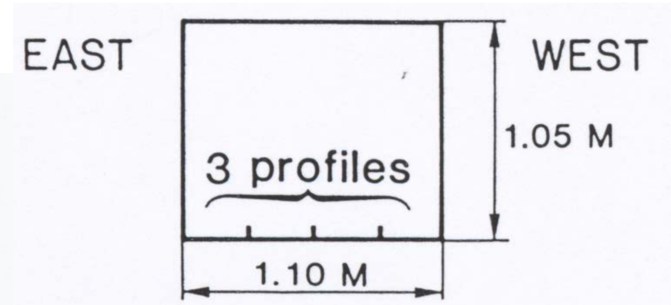


Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

Positions of microgravity observations – inside the pyramide.



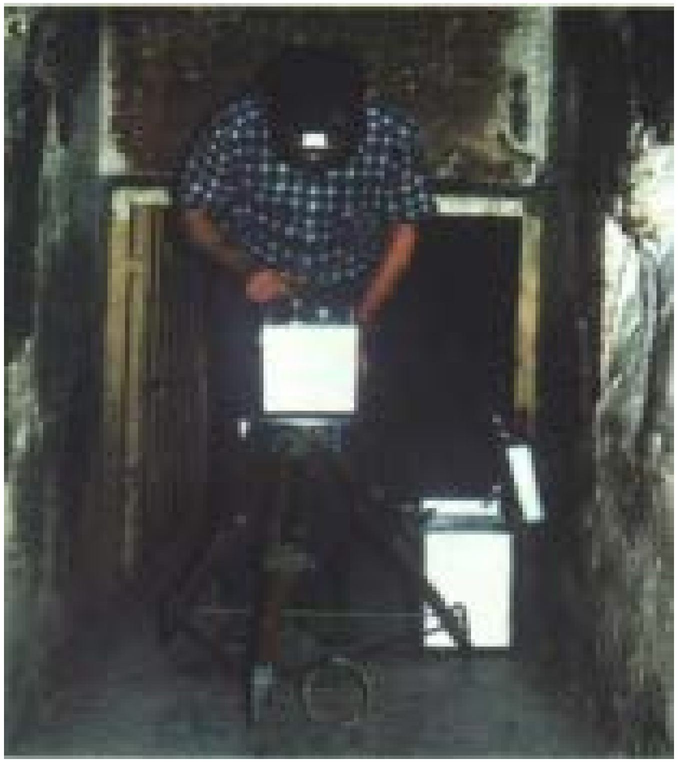


Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

Data acquisition:

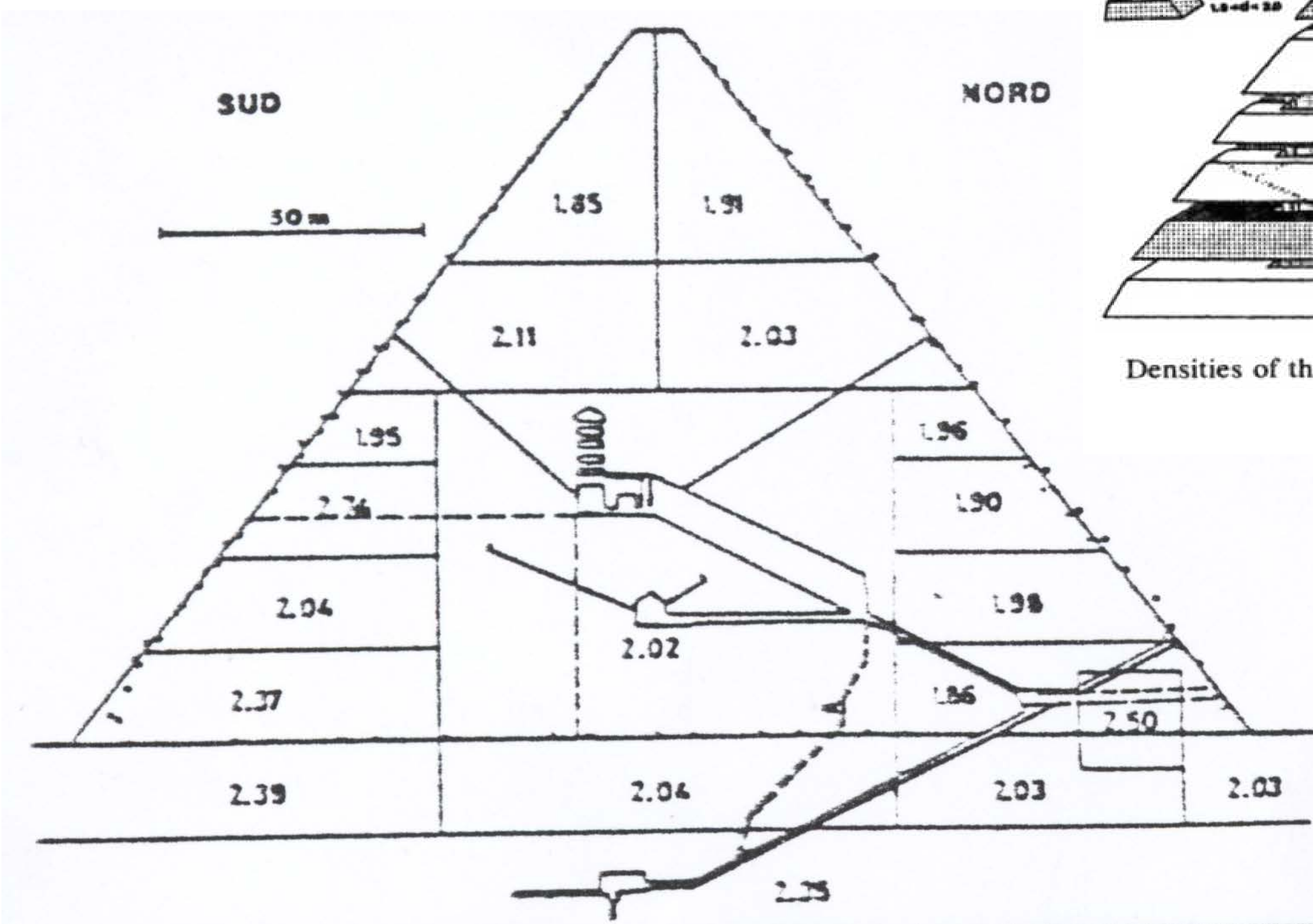
- LaCoste&Romberg gravity meters
- Observational time: over the night

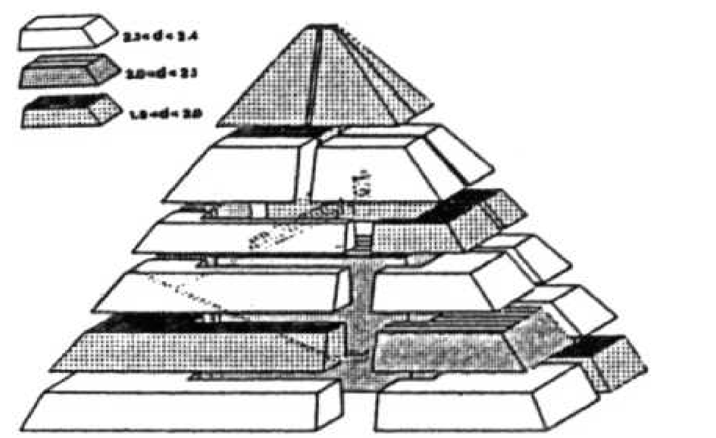


Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

Data processing:





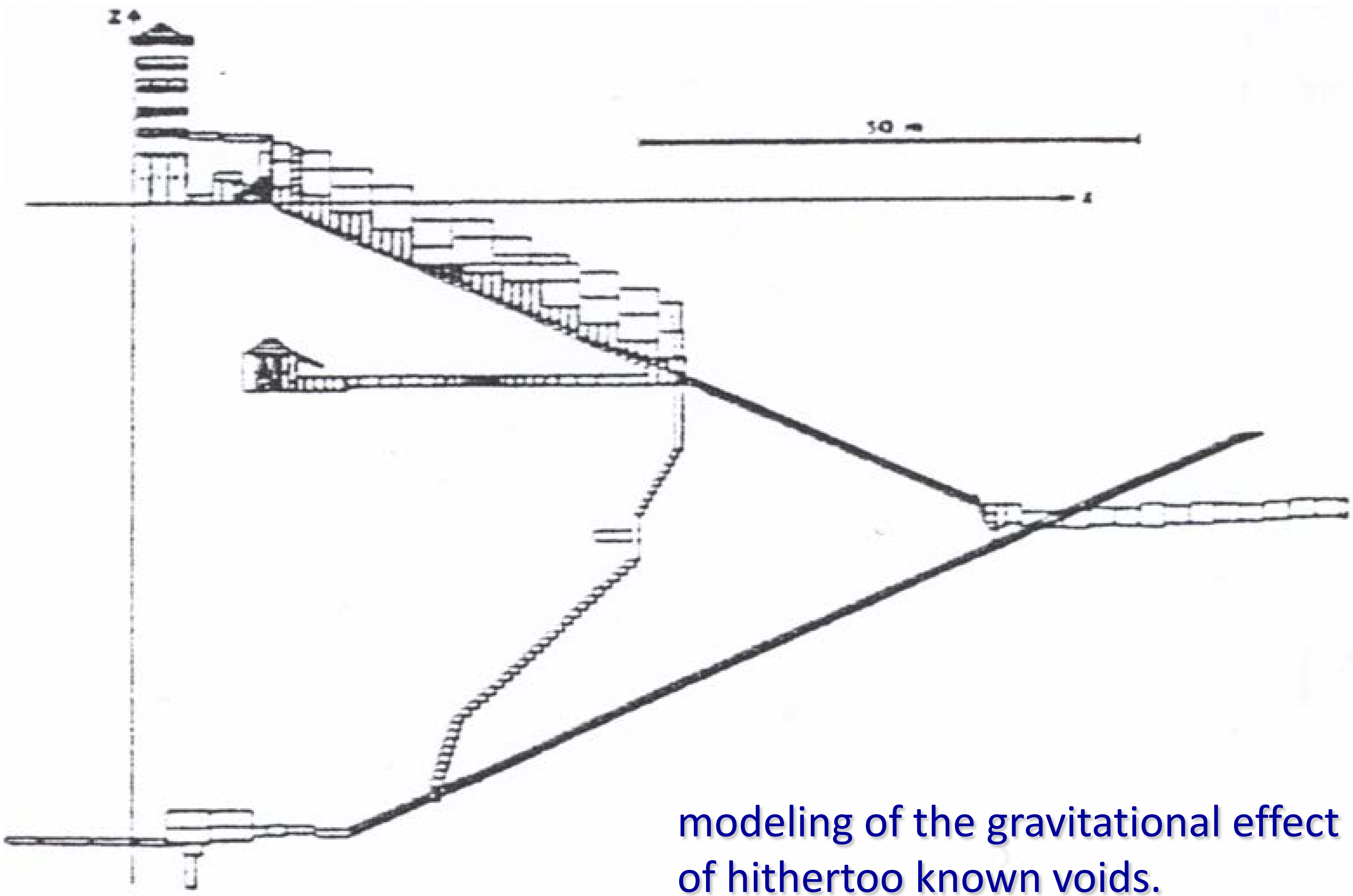
Densities of the large block structure of the Cheops Pyramid.

Density determination for the evaluation of the gravitational effect of the whole pyramid.

Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

Data processing:

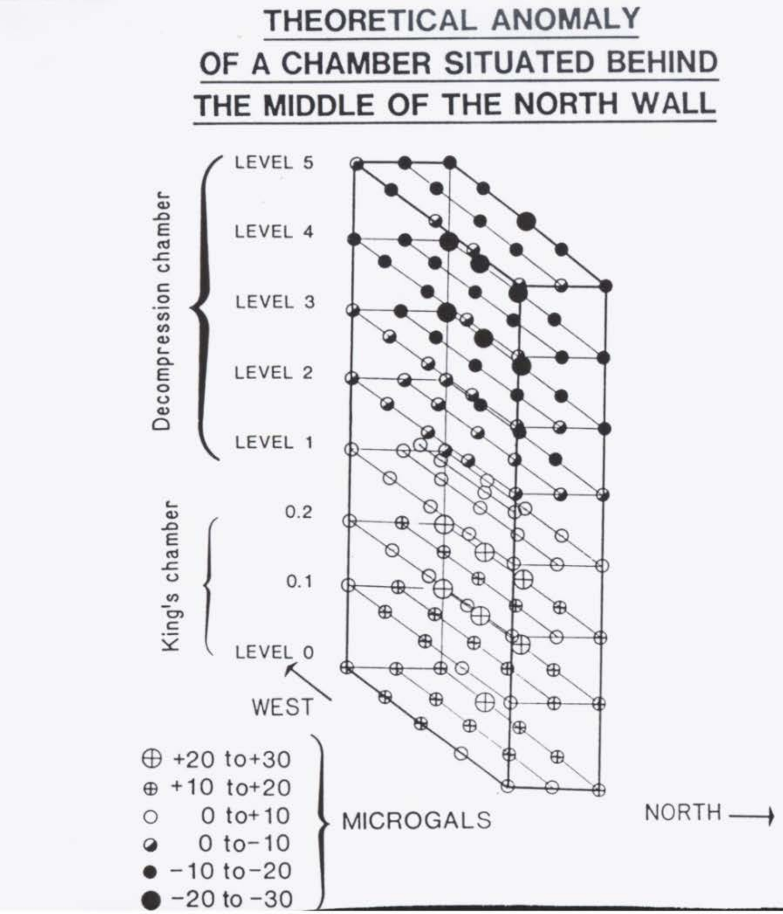


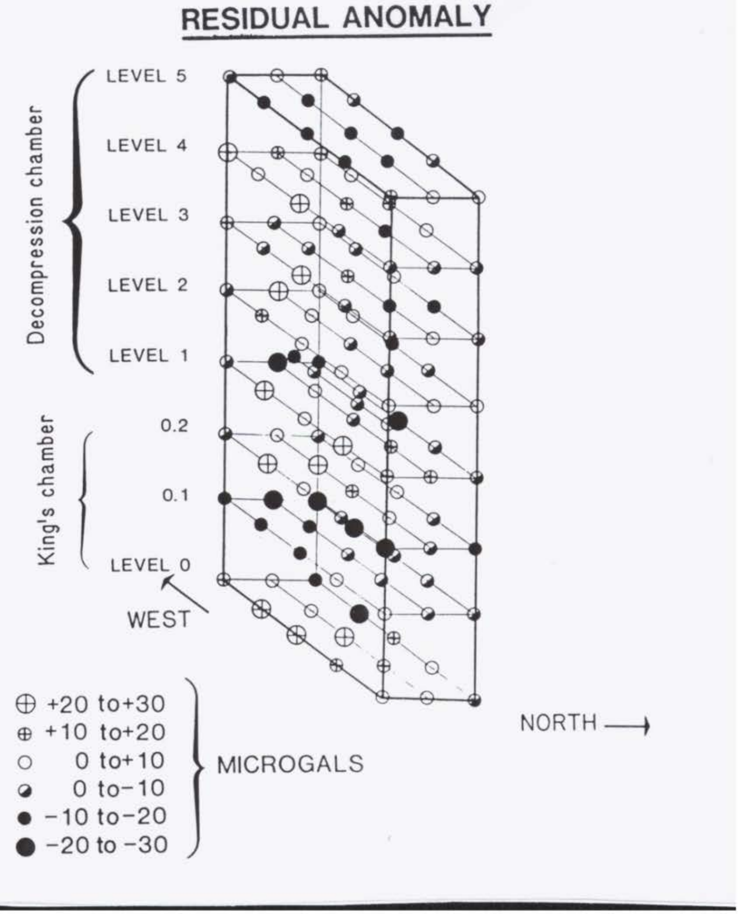
modeling of the gravitational effect of hithertoo known voids.

Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

Results: King's chamber



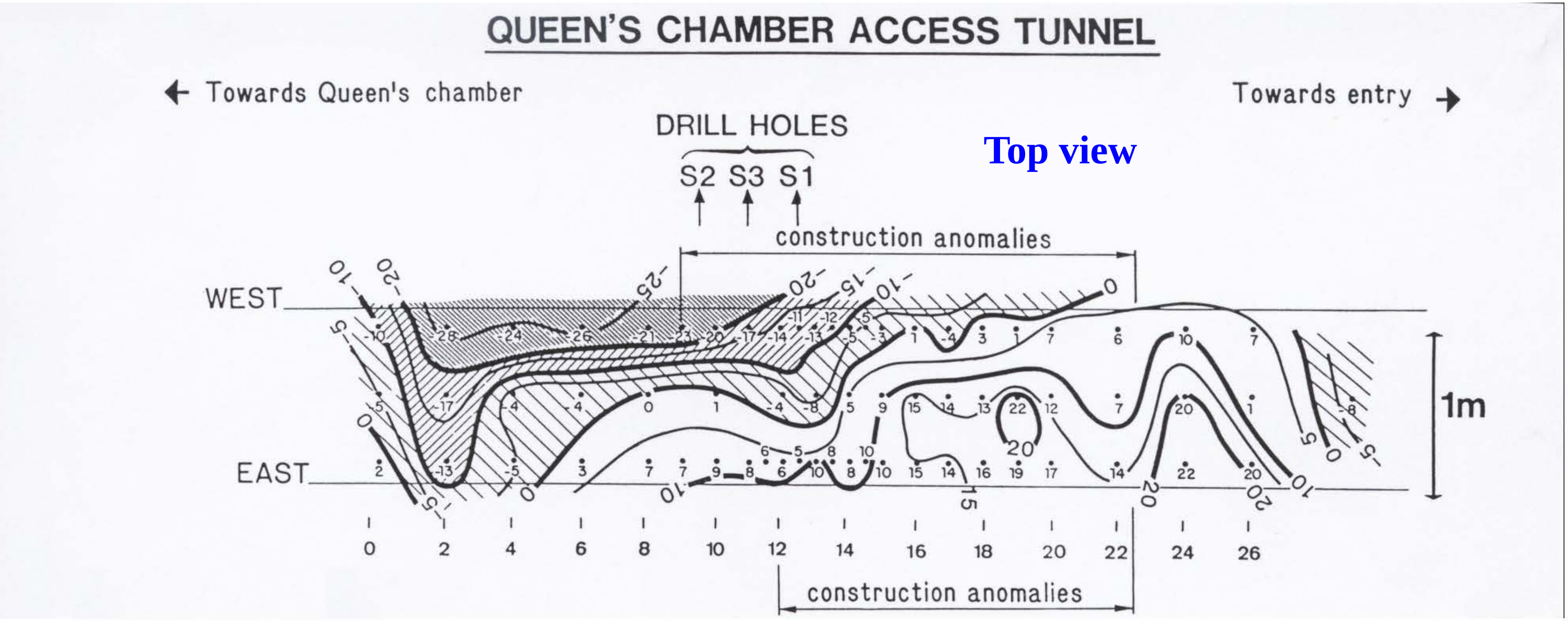


Ideal situation

Real situation

Micro-gravity: case-studies

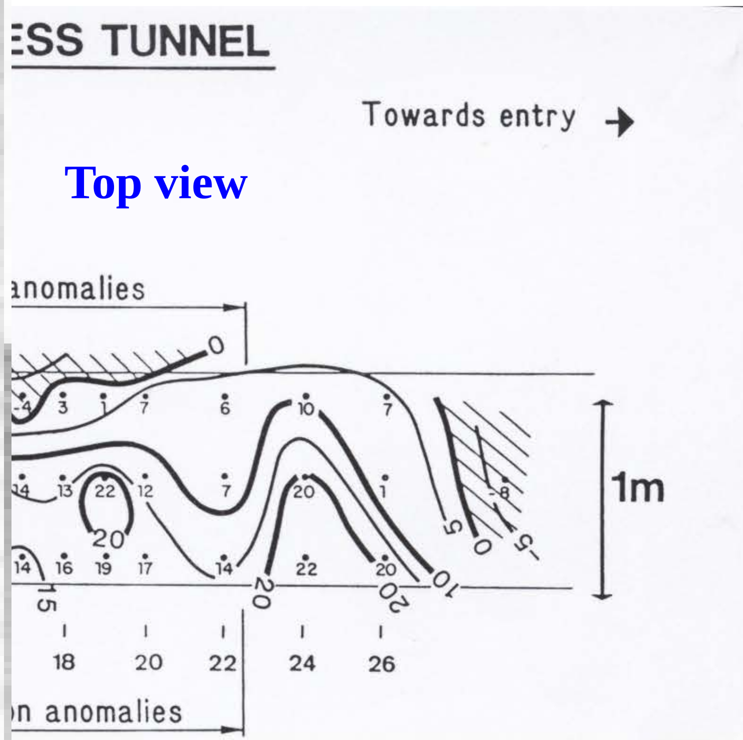
Great pyramid, Egypt – French project, 1986-88



Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

Results: corridor to the Queen's chamber.



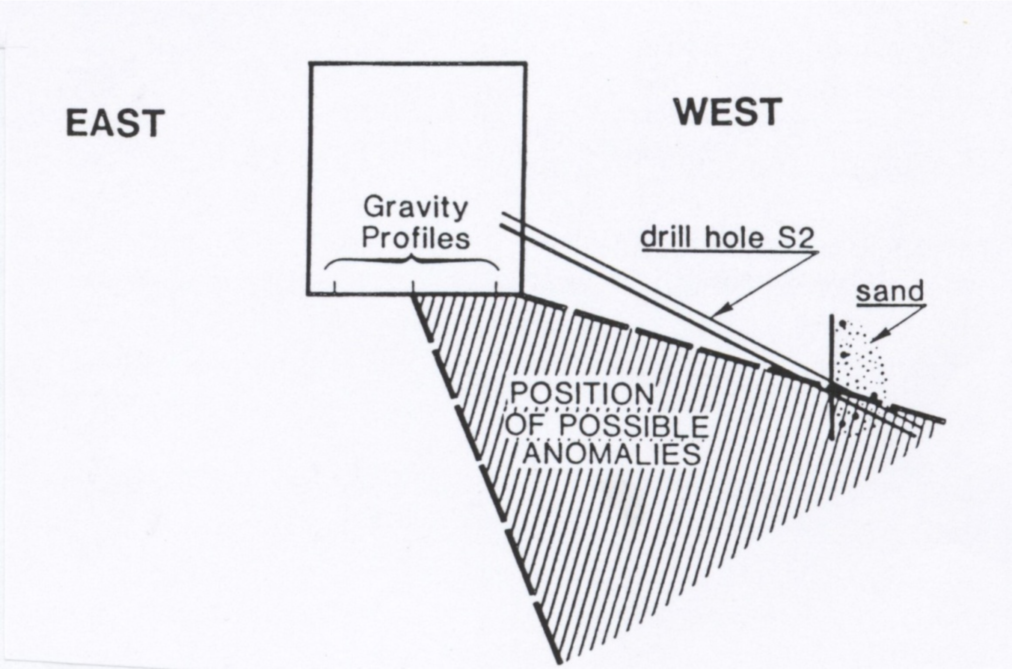
Top view

Drilling: three drillings, each 2.6 m long.

Micro-gravity: case-studies

Great pyramid, Egypt – French project, 1986-88

Results: corridor to the Queen‘s chamber

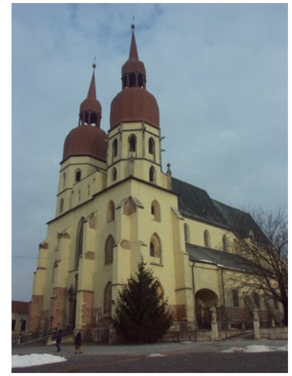


After a drill distance of 2.1 m an unknown chamber, full of sand was recovered -

what is/was the purpose of this chamber?

Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006



Data acquisition:

Microgravimetry: 1 x 1 m grid

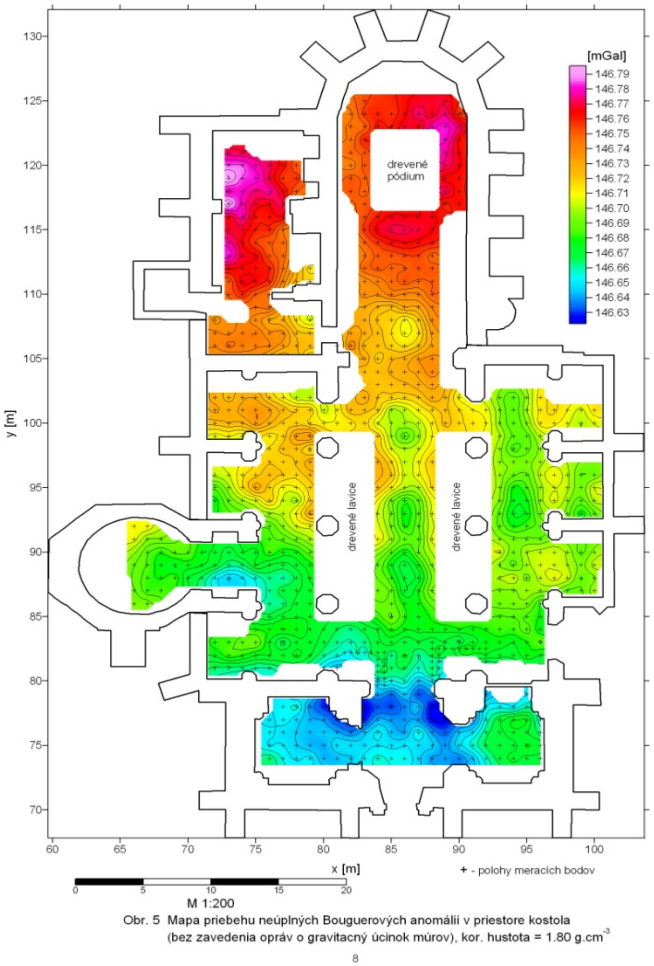
- in total 854 points, 7% (59) - control points
- used instruments: Scintrex CG-3M, CG-5
- (estim. average error: 0.007 mGal = 7μGal)

GPR

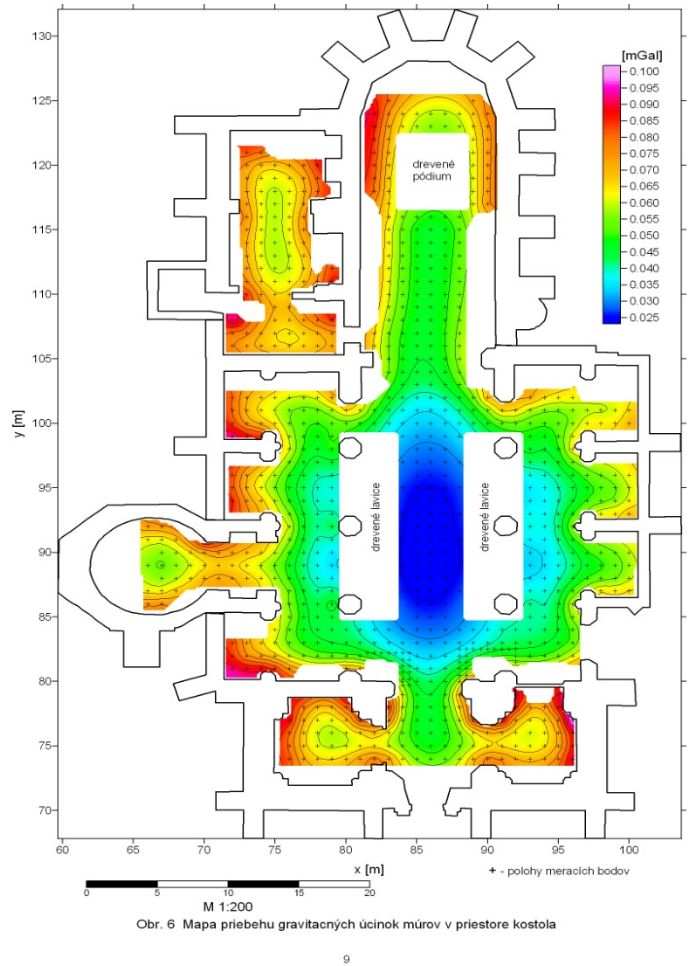
- along selected lines,
- used instrument: Mala Easy Locator EXM+ with 500 MHz and 350 MHz antenna
- (good underground conditions - loess)

Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006



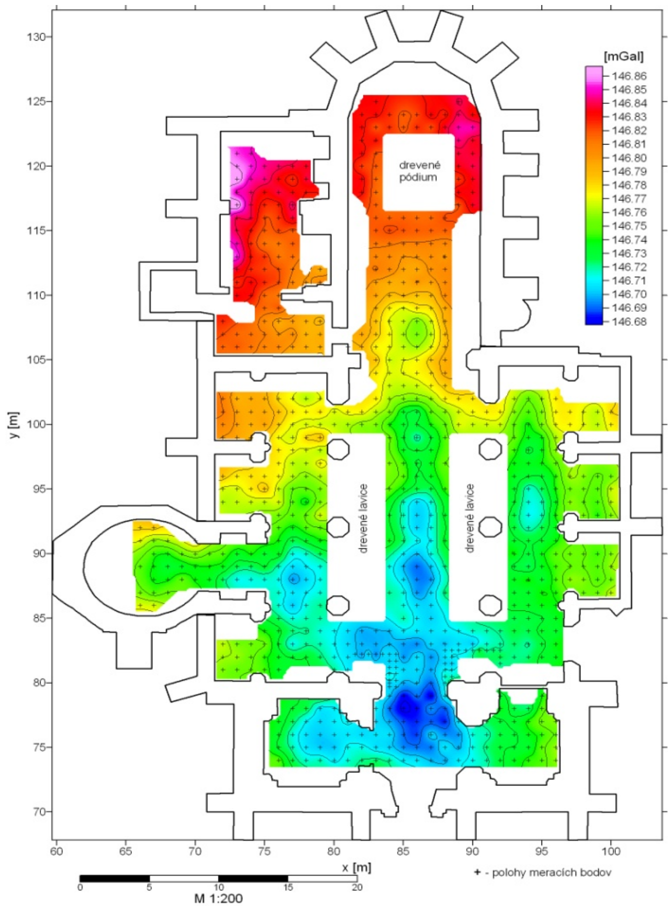
Incomplete Bouguer anomalies
<u>without</u> any “wall correction”
(for $\boldsymbol{\sigma}$ = 1.80 t m^{-3})



Gravitational effect of walls
(1.70 g.cm^{-3}, brick, “wall correction”)

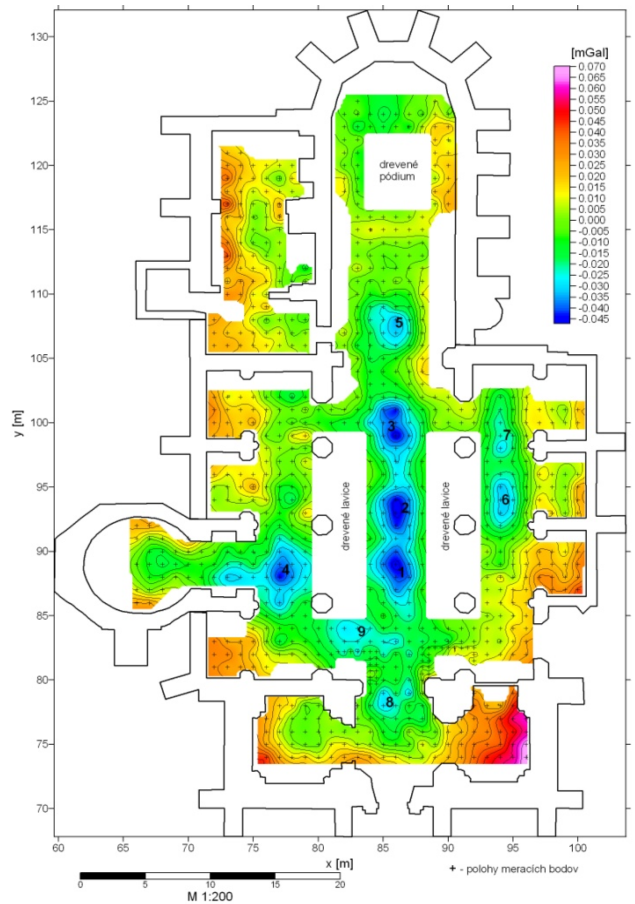
Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006



Obr. 7 Mapa priebehu neúplných Bouguerových anomálií v priestore kostola (so zavedením opráv o gravitacný úcinok múrov), kor. hustota = 1.80 g.cm^{-3}

10



Obr. 8 Mapa priebehu lokálnych neúplných Bouguerových anomálií v priestore kostola (so zavedením opráv o gravitacný úcinok múrov a odstráneným trendom), kor. hustota = 1.80 g.cm^{-3}

11

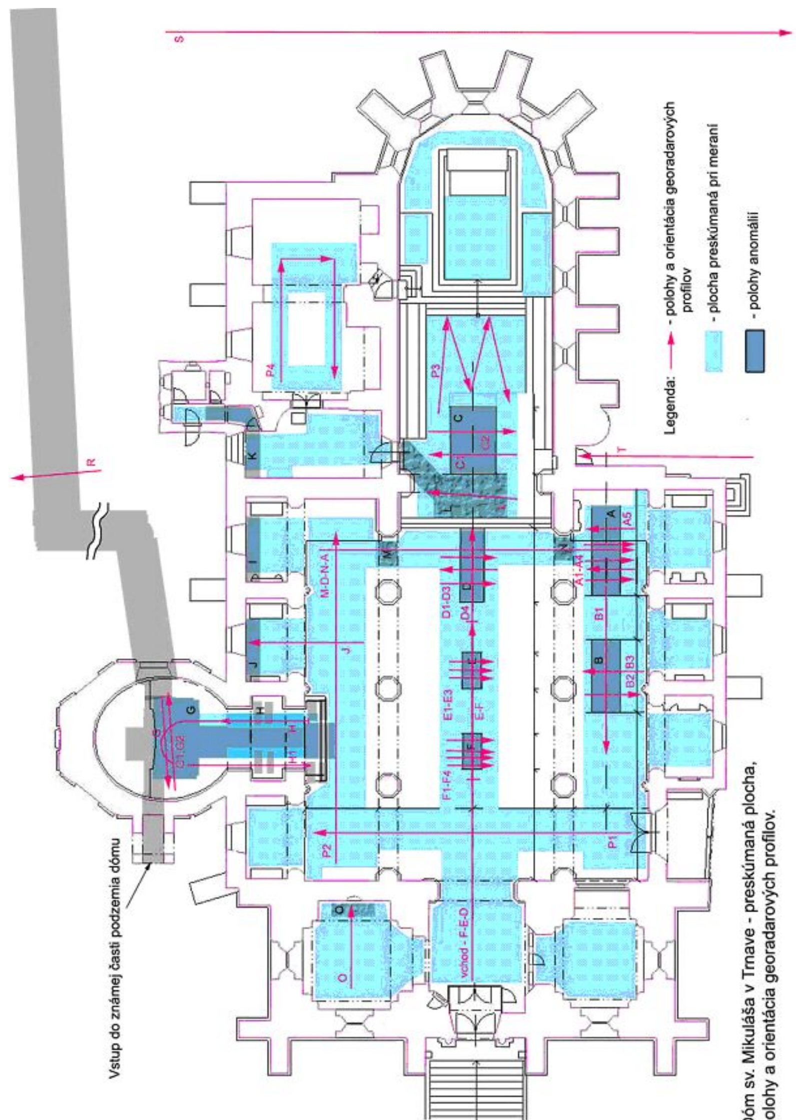
Incomplete Bouguer anomalies <u>with</u> “wall correction” (pre **σ** = 1.80 t m^{-3})

Incomplete Bouguer anomalies with “wall correction” and removed linear trend.

Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006

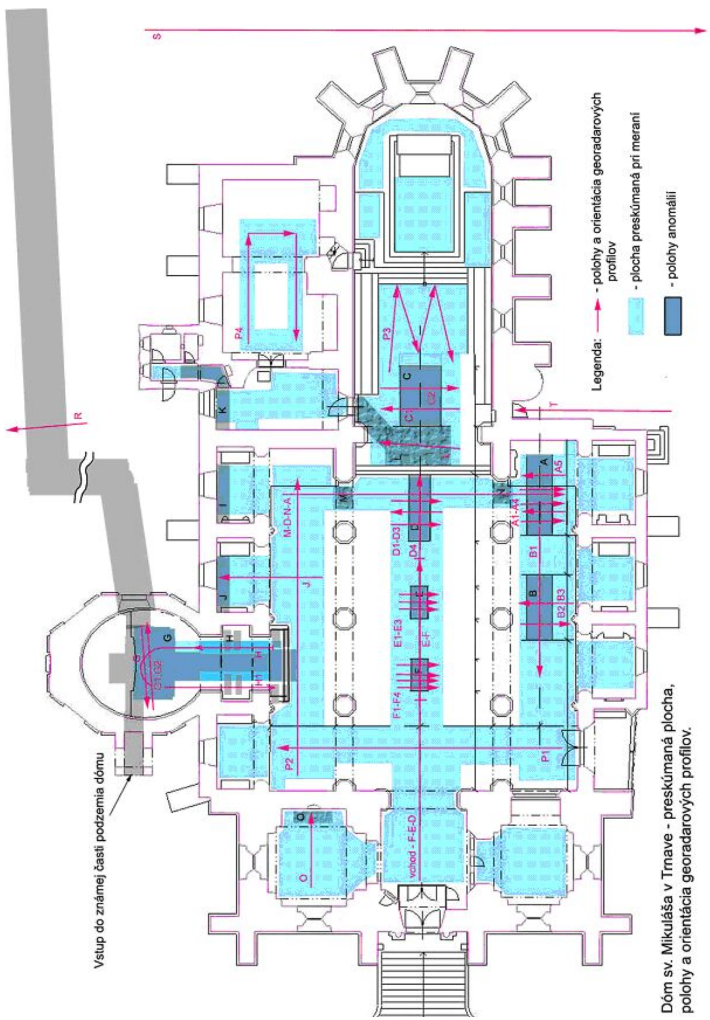
Mala Easy Locator EXM+
with 500 MHz and
350 MHz antenna

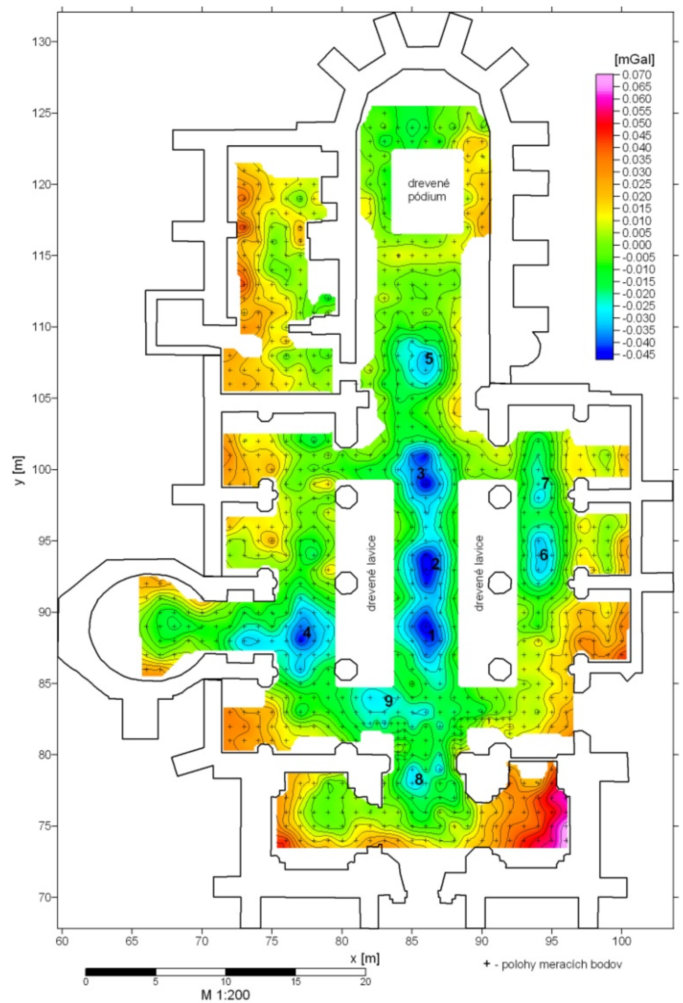


GPR lines scheme with detected cavities

Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006





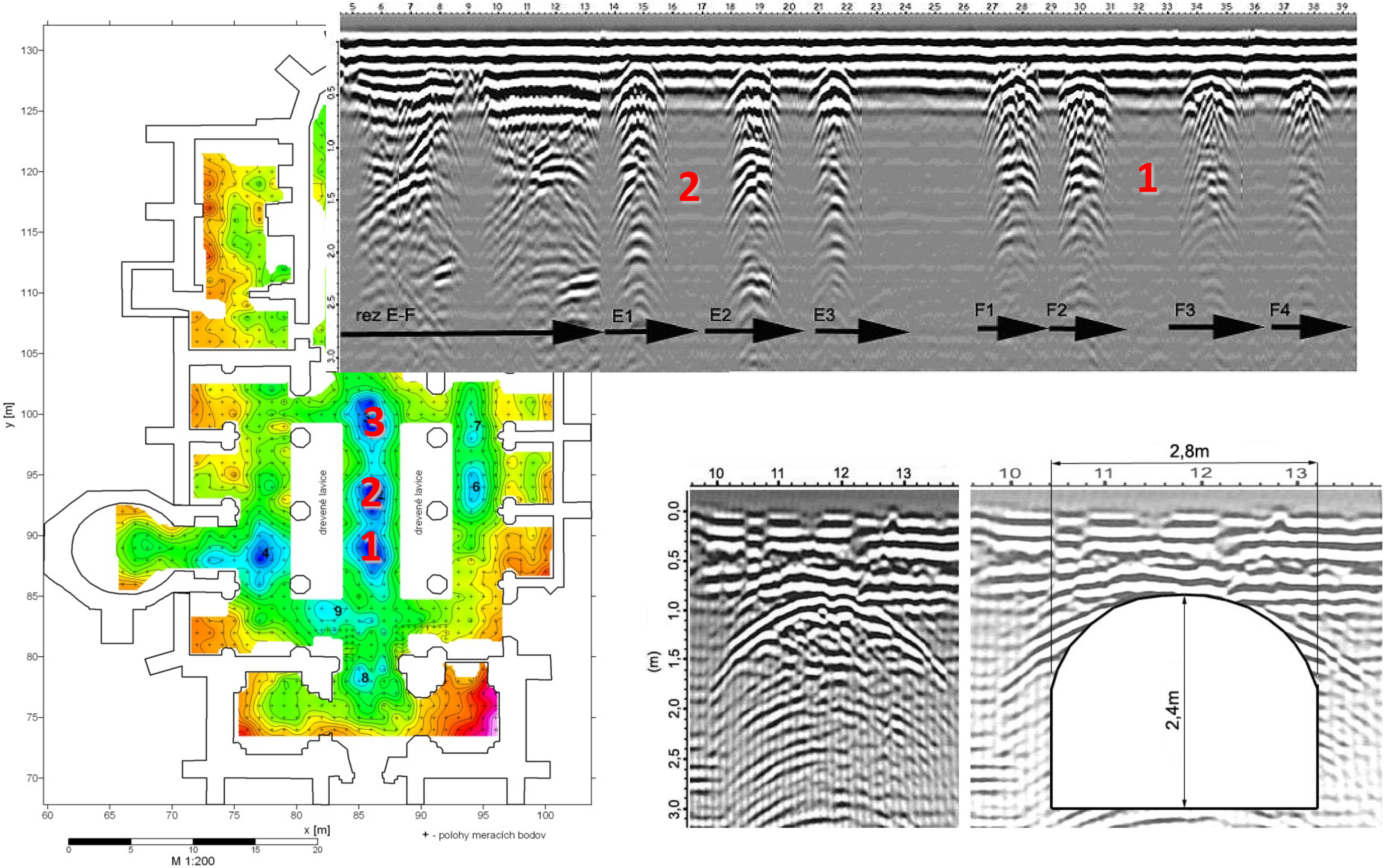
Obr. 8 Mapa priebehu lokálnych neúplných Bouguerových anomálií v priestore kostola (so zavedením opráv o gravitacný úcinok múrov a odstráneným trendom), kor. hustota = 1.80 g.cm^{-3}

11

GPR and microgravimetry results

Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006



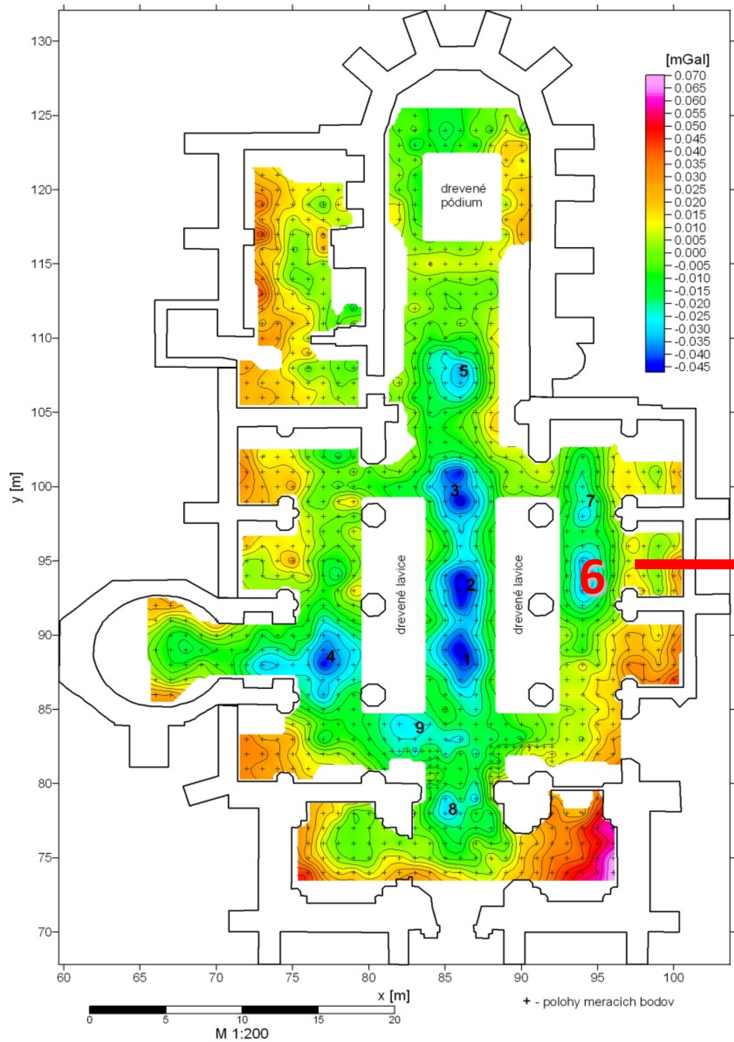
Obr. 8 Mapa priebehu lokálnych neúplných Bouguerových anomálií v priestore kostola (so zavedením opráv o gravitačný účinok múrov a odstráneným trendom), kor. hustota = 1.80 g.cm^{-3}

11

GPR and microgravimetry results

Micro-gravity: case-studies

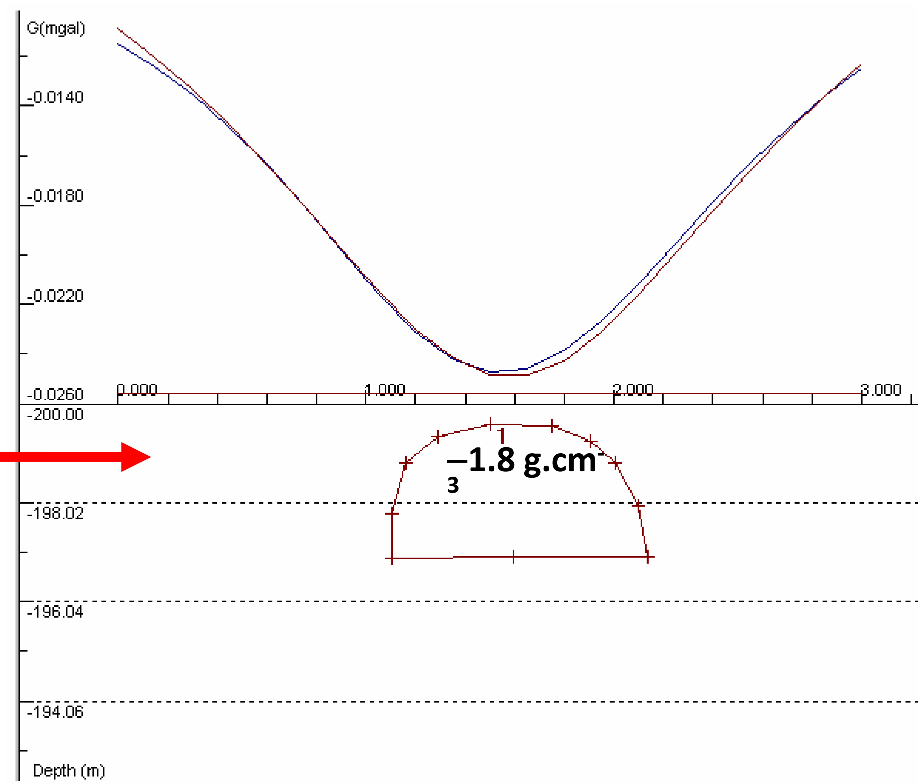
St. Nicholas church, Trnava, Slovakia, 2006



Obr. 8 Mapa priebehu lokálnych neúplných Bouguerových anomálií v priestore kostola (so zavedením opráv o gravitacný úcinok múrov a odstráneným trendom), kor. hustota = 1.80 g.cm-3

11

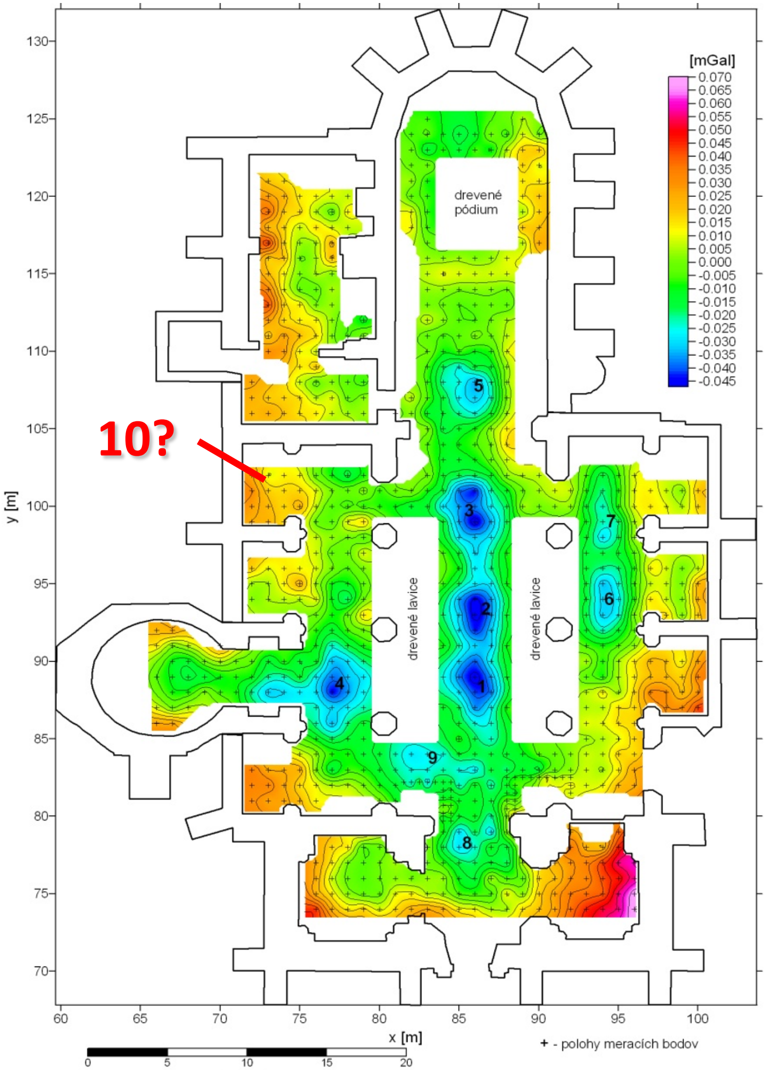
quantitative interpretation – 3D density modeling



(accounting the differential density equal to -1 $g.cm^{-3}$, the lower depth boundary of the body would exceed to 18-19 m)

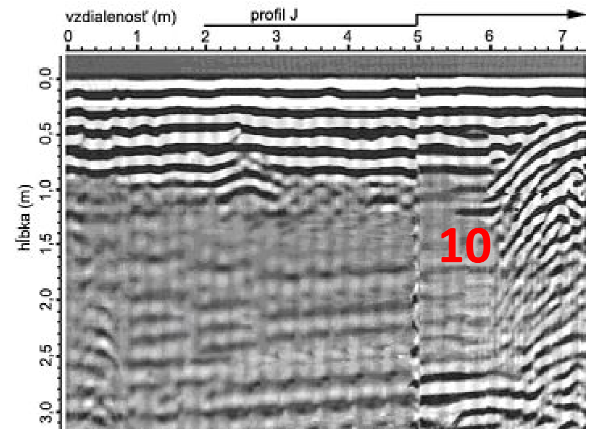
Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006



Obr. 8 Mapa priebehu lokálnych neúplných Bouguerových anomálií v priestore kostola (so zavedením opráv o gravitačný účinok múrov a odstráneným trendom), kor. hustota = 1.80 g.cm-3

11



GPR gives a clear indication in a close vicinity of the wall, but microgravimetry without any significant anomaly

explanation - the crypt was filled by building waste

GPR and microgravimetry results

Micro-gravity: case-studies

all detected anomalies have been verified by means of a technical mini-camera system

video-inspection

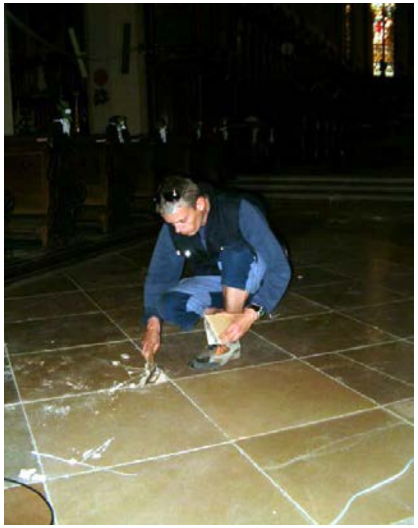
1. drilling

2. stabilsing

3. entering of camera

4. first shots

5. saving of a video-sequence

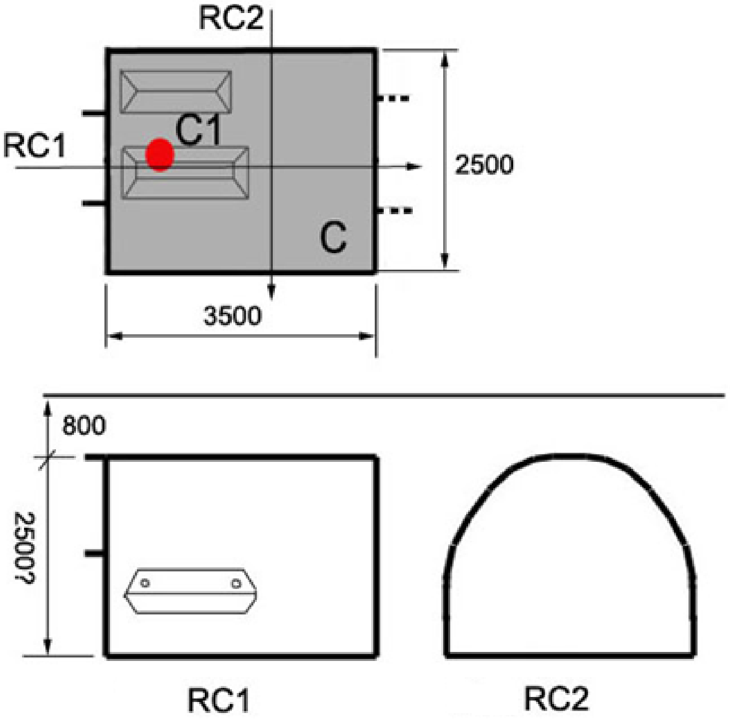


6. fixing of the floor

Micro-gravity: case-studies

St. Nicholas church, Trnava, Slovakia, 2006

Results of video-inspection:



Charted architectural features are of great interest for historians and conservators of monuments.

Summary

- To perform traditional fieldwork we use **relative gravity meters (gravimeters).**
- Units of gravitational attraction g: **mGal**, **μGal.** However, detectable microgravity anomalies >≈20 μGal).
- Interpreted physical parameters in gravity are **densities.**
- In applied gravimetry the **Bouguer anomaly Δg_B** is always interpreted instead of observed gravity attraction **g.**
- Voids (cavities, crypts, cellars, tombs,...) always cause **local minima** in the Δg_B field.
- Interpretation is made possible through **qualitative and quantitative procedures** and results in position-, depth-, dimension- and density determinations ...