Comments on exam problems 1 and 2, 2014 (Bo Holm Jacobsen, June 22, 2014)

In the following, I will comment on how the exam problems were supposed to be answered, and I will highlight some of the likely mistakes. Hopefully, this may be helpful for you as exam participants, and also for future students who use these exam problems for training.

In the following, the official text is in Times New Roman fontsize 10 and my comments are in Calibri fontsize 11.

General advice:

- **Possibly rip off figures and inspect carefully while reading the problem text.**
- **Remember that often you are supposed to draw results on figures and hand in these figures with your answers.**
- **Be very careful when reading data values from graphs. Use about 30 seconds per point you read, making sure that you get axis values and units right. You have plenty of time for that.**
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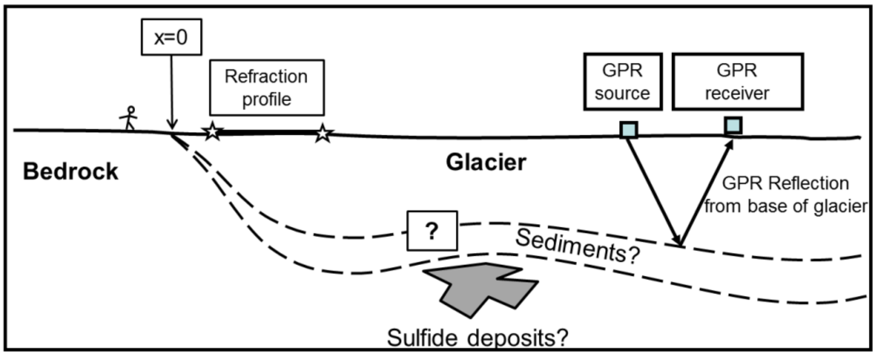
Introduction to problems 1 and 2



An economically challenged university in a cold and distant land hires this year's geophysical field course to the mining company CryoMines™. The company wants an exploration of a rather thin mountain glacier under which there may be sulphides in valuable quantities.

CryoMines asks the following questions:

a) Is the rocks below the glacier primarily crystalline rocks, or do we find thick sediments (more than 50 m)?
b) What is the thickness of the glacier?
c) Are there isolated occurrences of sulfides below the glacier?
This geological situation is outlined in the sketch above.

Field Course Team 1 examined the base of the glacier with the seismic refraction method. Problem number 1 below addresses this sub-study.
Field Course Team 2 examined the deeper parts of the glacier with GPR (Ground Penetrating Radar) and Team 3 examined the gravitational field. Problem number 2 below addresses these sub-studies.
The glacier has a horizontal surface. All data is measured along a profile perpendicular to the edge of the glacier. The profile reference point, x = 0, is located at the edge of the glacier.

The idea of such a lengthy introduction and the combination of several methods regarding the same target zone was to make the exercises more realistic and demanding, while still keeping the required computations at a very moderate level. Once you know what to do, you can do the calculations in less than 30 minutes. I am sure that after the field course you are actually much more prepared for such integrated problems.

Problem 1

Refraction data were measured with geophones along a 200 meter profile between x = 50 and x = 250 m. The source points (hammer points) were at x = 50 m and x = 250 m. Figur 1 and 2 show straight lines through first arrivals in the refraction seismic data for these two sections. The lines were extended as dashed lines across the whole section in order to make the reading of arrival times more accurate. Note that the time axis is pointing downwards. Note also that the values on the x-axis do not define distances from the source points but from the profile reference point.

Read carefully such an introduction while looking carefully at Figure 1 and 2. Note in particular that I point out that each straight line is full-drawn where it is the first arrival and dashed where it is second arrival. As you know from the field course (and TØ-exercises) we can generally only read the arrival times where the phase is the first arrival. Therefore, it was dashed where the wave is second arrival.

1. Figure 1 shows a straight line crossing through the points (50 m, 0 s) and (250 m, 0.067 s). Determine the velocity in the first layer.
   The fact that x is not the offset from the shot point should add some interesting complexity to this first question. This went well for almost all of you ☺

2. Determine the apparent velocity as well as the intercept times for the reflected waves seen in each of the two sections.
   Dashed line error: Several of you overlooked that the dashed lines did not define a single straight line. This lead to some wrong time readings.
   Intercept time confusion: Where the direct wave intersects the refracted wave we have the cross-over distance and the cross-over time. These data (xsk and tsk in Danish) may be used to find depths if the layer is parallel to the surface. The intercept time is the time where the line defined by the refracted wave intersects the time axis at shot point. Some of you got this mixed up. Check carefully "the red book" or the material for the SEIS at the field course, if in doubt.

3. Perform an interpretation using the two layer model with a dipping interface. Determine the dip of the interface as well as the velocity in the second layer and the distance to the dipping interface under each source point.
   Some of you got wrong up-dip/down-dip velocities. This lead to wrong dips and wrong V2. I was careful to only punish such errors once.
   ti-errors: When a wrong ti had been read in Q2 then it lead to a wrong depth. This made your discussion of combined models more difficult. Only when you computed positive dip, but got larger depth at 50 m than at 250 m did I deduct points for that.

4. What can this study say in relation to question a) from CryoMines? We may expect the velocity of glacier ice to be between 2000 m/s and 3500 m/s. Sketch carefully your interpretation of these data in Fig 7.
   This question was more ambiguous than planned. I assumed that you would associate "sediments" with the glacial sediments that you knew from the field course, i.e. velocity at or below 2000 m/s. Moreover, I had defined the velocity of the "bedrock" at 5000 m/s which is typical of the uppermost few tens of meters due to cracks and joints.
   However, your text-book table had crystalline rocks from 5500 m/s and up (which is typical in the upper and lower crust, and mantle), and a lot of different highly compacted and cemented sediments with velocities above 4000 m/s, like the Balka Quartizite and similar old stuff. This lead to the
   Sediment-crystalline rocks confusion: I have given full point value to all answers where your computed value (right or wrong), V2, is linked by correct arguments to your table 2.1 in the red book.

Problem 2

Questions 1 and 2 relate to the study of GPR (Ground Penetrating Radar) data. Questions 3 and 4 relate to the interpretation of the gravity field.

1. Figure 3 shows a CDP (Common Depth Point) section at x = 400 m. Between 600 and 800 nanoseconds we see a reflections hyperbola. Please determine the rms velocity between the surface and the reflector.
   Here it is important to grab the x^2-t^2 method. Note that the velocity which comes out is the rms velocity between the surface and the reflector.
   A few stayed with x/t computations which did not give good results.
   Some tried desperately to get several velocities and then compute RMS-velocities from that. Clever ideas, but unfortunately irrelevant in this case, so I cannot give points for that.

2. Figure 4 shows the GPR reflection section between x = 50 m and x = 1300 m. GPR traces are shown for every 25 meters. Read the two-way time for reflections at the points x = 50 m and x = 400 m. Calculate the thickness of the glacier at these two positions, and plot these depths in Figure 7.

The idea is simply to read the two-way times, divide by two, and multiply by the velocity from question 1. This gives the two depths at x=50 and x = 400.

Some regarded this GPR section as a CDP gather and tried to derive velocities once again. This was irrelevant.

A cute thing about the GPR-section is that it maps out the base of the glacier, so that from the two depth values it is possible to sketch rather accurately the base of the glacier in Figure 7.

3. Figure 5 shows the Bouguer anomaly. It is measured every 50 meters along the profile. Figure 6 focuses on the interval around the local maximum.
   Please interpret the local maximum in Fig. 6 using a homogeneous sphere as the model body. Determine the center coordinates (x_0, z_0) and anomalous mass ΔM.
   In your assessment of the residual anomaly you may assume that the regional field is constant. Draw the interpreted position in Figure 7

   The gravity anomaly in Figure 5 shows a strong ”swing” from above 14 mGal at x<0 down to the level ~10 mGal at x > 400 m. The zoom in Figure 6 is supposed to make you forget this complication.

   $x_{½}$ confusion: Some regarded $x_{½}$ as just some kind of “diameter” og the anomaly. I had to deduct when there was no clear indication of regional and residual anomaly from which to define the radius at half the residual maximum.

   mGal versus m/s^2 confusion: Some forgot the conversion 1mGal = 10^{-5} m/s^2. It lead to mass surplus values a hundred thousand times too large. It does matter in practice. I had to deduct for such errors ☹.

   g_{anom} confusion: The correct value is the difference between the maximum value and the regional value. In this case about 11.1mGal – 10mGal = 1.1 mGal. Some forgot to subtract the regional value.

4. Conduct a comprehensive assessment of the results of Tasks 1 and 2 focusing on the questions that the customer, Cryomines, asked:

   This last question is the most demanding question. Still, I believe that you can easily understand what I had in mind as answers.

   - What can we say about the presence of sediment under the glacier?

     This was already answered to some extent in the previous problem. But it is demanding to be able to drag out this information again, perhaps 1-3 hours later.

     What we can say it that if thick glacial sediments, i.e. V2 <2000 m/s was present under very thin ice then the thickness would be thinner than the ice we interpreted, i.e. thinner than 50 meters. But fast compact sediments like sandstone, limestone, dolomite, etc. may well be present.
   - What can we say about the shape of the base of the glacier?

     The GPR section is important. If you plot in the depth found at x = 400 m (about 60 m) you may draw the base of the glacier at this depth for x<250 m. And between x=0 and x=250 m we see that the base of the glacier drops steadily. Moreover, this shape plots right on top of the depths found by the refraction seismics. Cute!
   - Is there evidence of localized bodies of massive sulphides below the glacier?

     This may seem too easy to answer, as you have just analyzed a clear gravity maximum. But I need some argument from you like: “The gravity maximum detects an isolated mass surplus. The expected density of the sulfides is about 4300 kg/m3. The expected density for compact sediments or crystalline rocks as detected by the refraction seismics would be 2500-2800 kg/m3. Thus, the sulfide would have a positive density contrast of about 1500-1800 kg/m3. Therefore, a sulfide body would explain the observed anomaly. I have given full points also for much shorter arguments.

   - If so, what amounts of sulfide do the data suggest? It may be noted that the sulfides in outcrops in the area have densities around 4300 kg/m^3.

     The answer can be the total mass of the sulfide and/or the volume and/or the radius of the approximating sphere. In all these cases you will need the density contrast between the sulfide and the surrounding rock. As mentioned above, the correct arguments should arrive at +1500 to 1800 kg/m3. From this and the excess mass, ΔM, you may compute the sulfide mass.

Confusion about density surrounding the sulfides: Some have used the density of the glacier, i.e. 1000 kg/m3 to define the density contrast. I have only accepted this if your wrong calculations have led to a thickness of the glacier so large that the center of gravity lies within the glacier. However, it would be a very strange situation that the glacier had picked up such a large volume of material.

Advanced gravity argument: One og you noticed that the gravity decrease from above 14 mGal for x<0 m to about 10 mGal for x>400m may be explained by the low densities of the glacier body. You might even have tested the shape of the glacier by computing the “mild relief” gravity response of a layer with the negative density contrast 1000 - 2700 kg/m3 = -1700 kg/m3. None of you did, and I do not blame you. But I am sure that you understand that such a test of the simple model “Glacier and no unconsolidated sediment” could be tested in this way.

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%-----------------------------
%    s2014 PROBLEM 1 ANSWERS:
%-----------------------------
%Q1
x1 = 50; x2 = 250; x12 = x2-x1,
x12 =
        200.00
t1 = 0; t2 = 0.067; t12 = t2-t1,
t12 =
          0.07
v1 = x12/t12,
v1 =
       2985.07
%Q2
%refracted wave in Fig. 1:
ti_fig1 = 0.005; t2 = 0.055; t12 = t2-ti_fig1,
t12 =
          0.05
v2_fig1 = x12/t12,
v2_fig1 =
       4000.00
%Fig. 2: Direct wave is the same
%refracted wave in Fig. 2:
ti_fig2 = 0.026; t2 = 0.055; t12 = t2-ti_fig2,
t12 =
          0.03
v2_fig2 = x12/t12,
v2_fig2 =
       6896.55
%Q3
%Using eq. 2.36
vu = v2_fig2;
vd = v2_fig1;
invsinvd = asind(v1/vd), %degrees
invsinvd =
         48.27
invsinvu = asind(v1/vu),
invsinvu =
         25.65
ic = 0.5*(invsinvd+invsinvu),
ic =
         36.96
delta = 0.5*(invsinvd-invsinvu),
delta =
         11.31
v2 = v1/sind(ic),
v2 =
       4964.96
sqrt_expression = sqrt(1-v1^2/v2^2),
sqrt_expression =
          0.80
z_50m = ti_fig1/2*v1/sqrt_expression,
z_50m =
          9.34
z_250m = ti_fig2/2*v1/sqrt_expression,
z_250m =
         48.56

%-----------------------------
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%    s2014 PROBLEM 2 ANSWERS:
%-----------------------------
%Q1
twt5m = 590e-9; twt100m = 840e-9;
x1 = 5; x2 = 100;
vrms = sqrt((x2^2-x1^2)/(twt100m^2-twt5m^2)),
vrms =
  167039210.67

%Q2
twt50m = 120e-9; %ns
twt1000m = 708e-9; %ns
zGPR50m = twt50m/2*vrms,
zGPR50m =
         10.02
zGPR1000m = twt1000m/2*vrms,
zGPR1000m =
         59.13

%Q3
greg = 10;
dgmax = 1.15; %mGal
x0 = 750; %location of the maximum shows the location of the center of the
sphere
x_half = (850 - 640)/2;
z0 = x_half * 1.305, % equation 3.80
z0 =
        137.03

%Q4
DeltaM = dgmax*1e-5*z0^2/6.67e-11,
DeltaM =
 3237215625.00
drho = 4300-2800, %likely density contrast in normal crystalline bedrock
drho =
       1500.00
V = DeltaM/drho, %m^3
V =
    2158143.75
b = (3*DeltaM/(4*pi*drho))^(1/3), %radius of model sphere, meter
b =
         80.17
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Fig. 1: t(x)

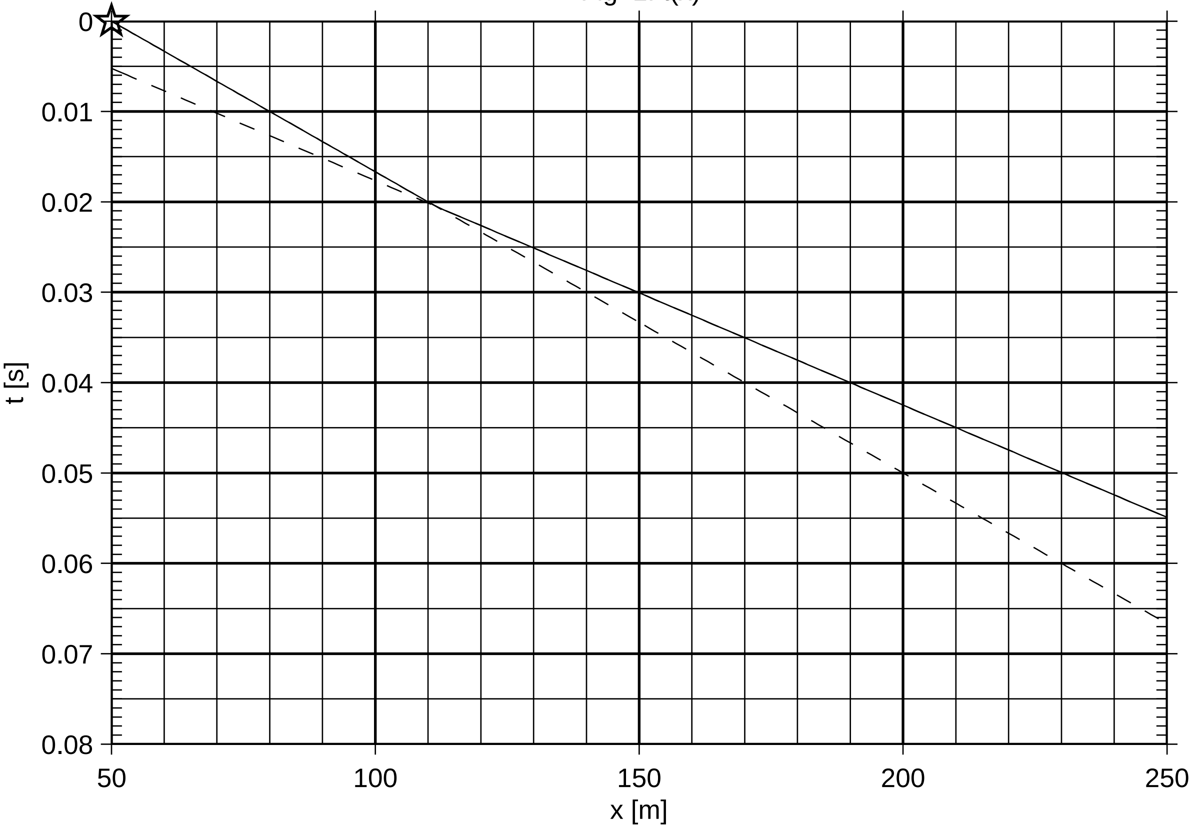

Fig. 2: t(x)

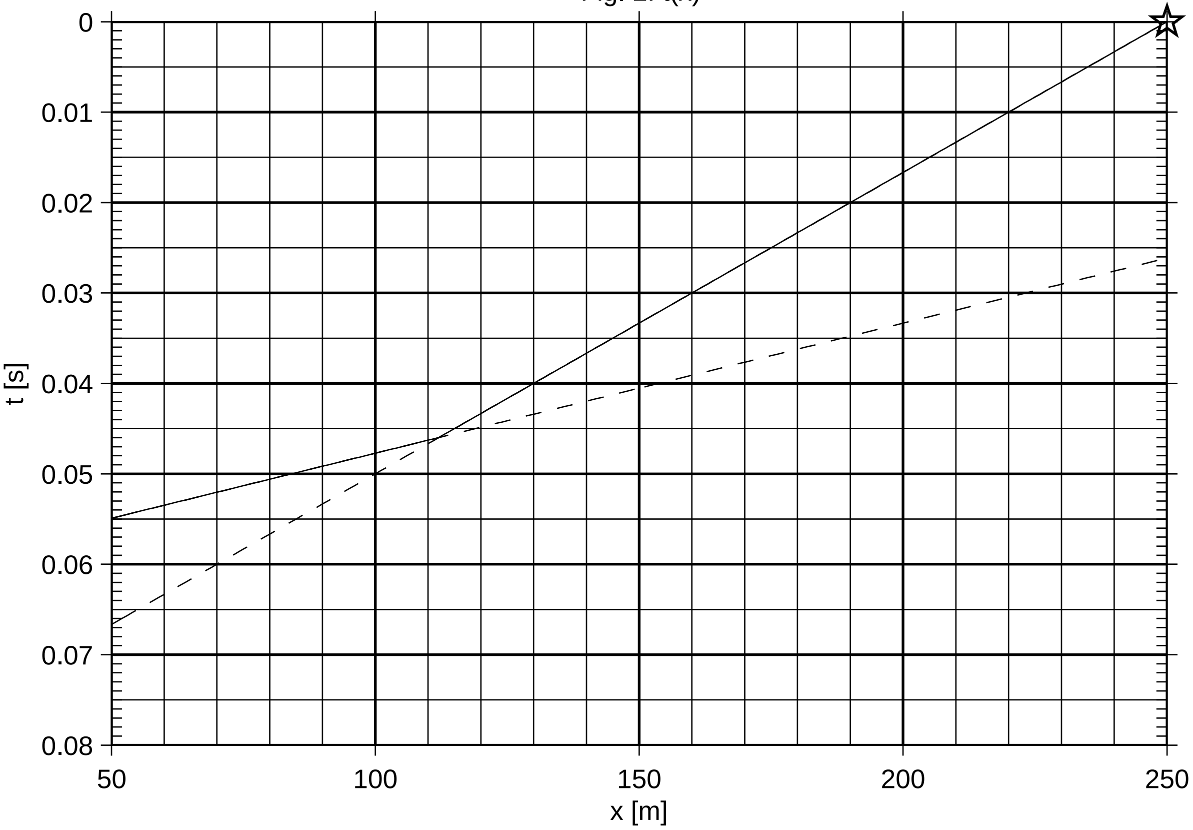

Fig. 3: CDP

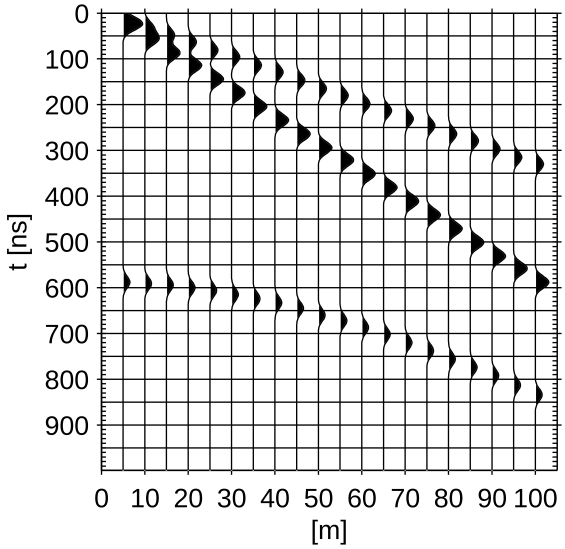

Fig. 4: t(x)

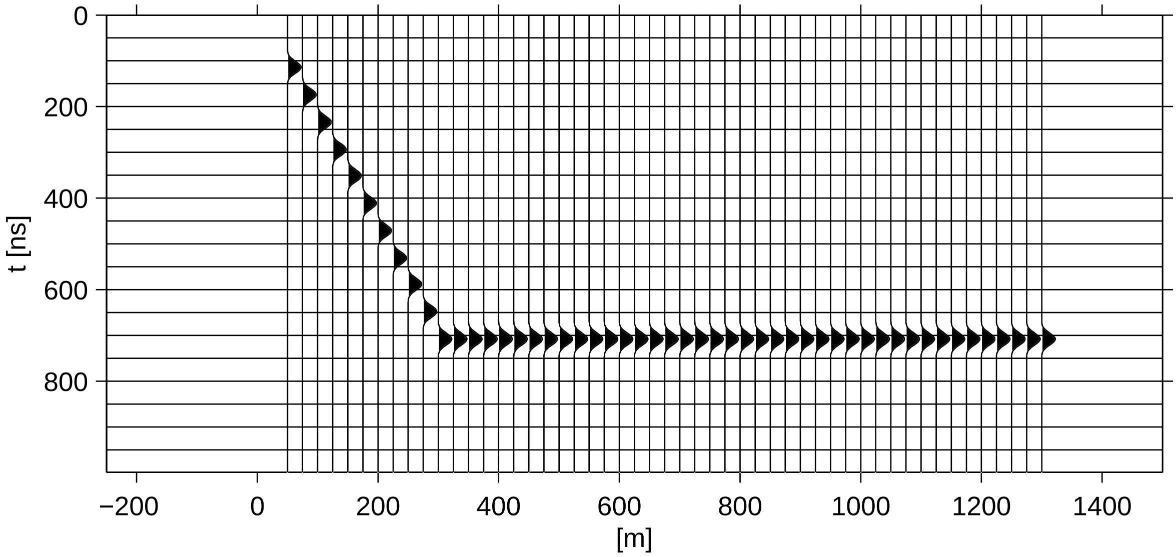

Fig. 5: $g_{BA}(x)$

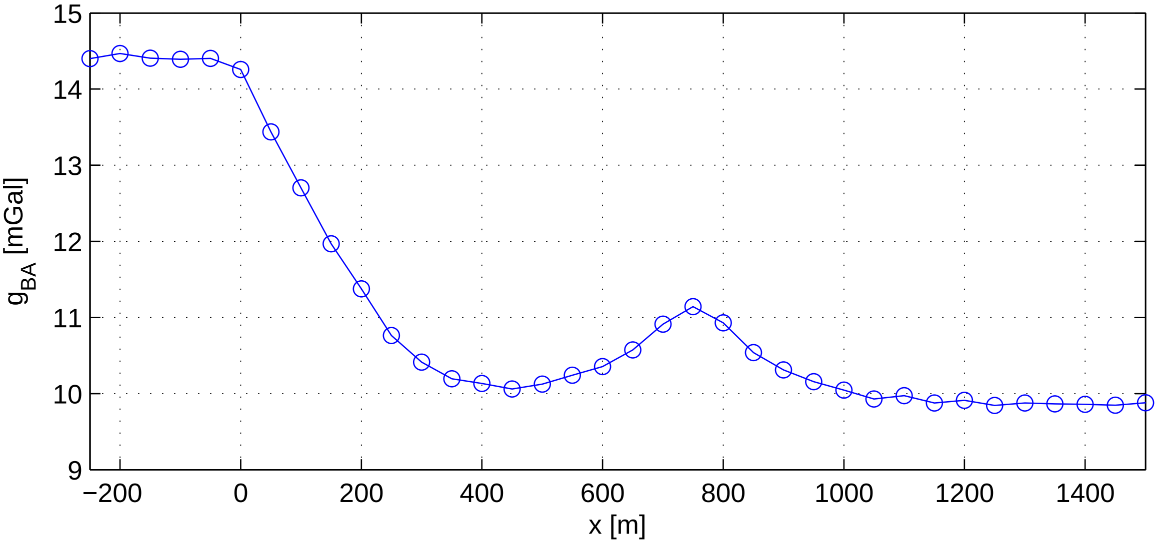

Fig. 6: $g_{BA}(x)$ zoom

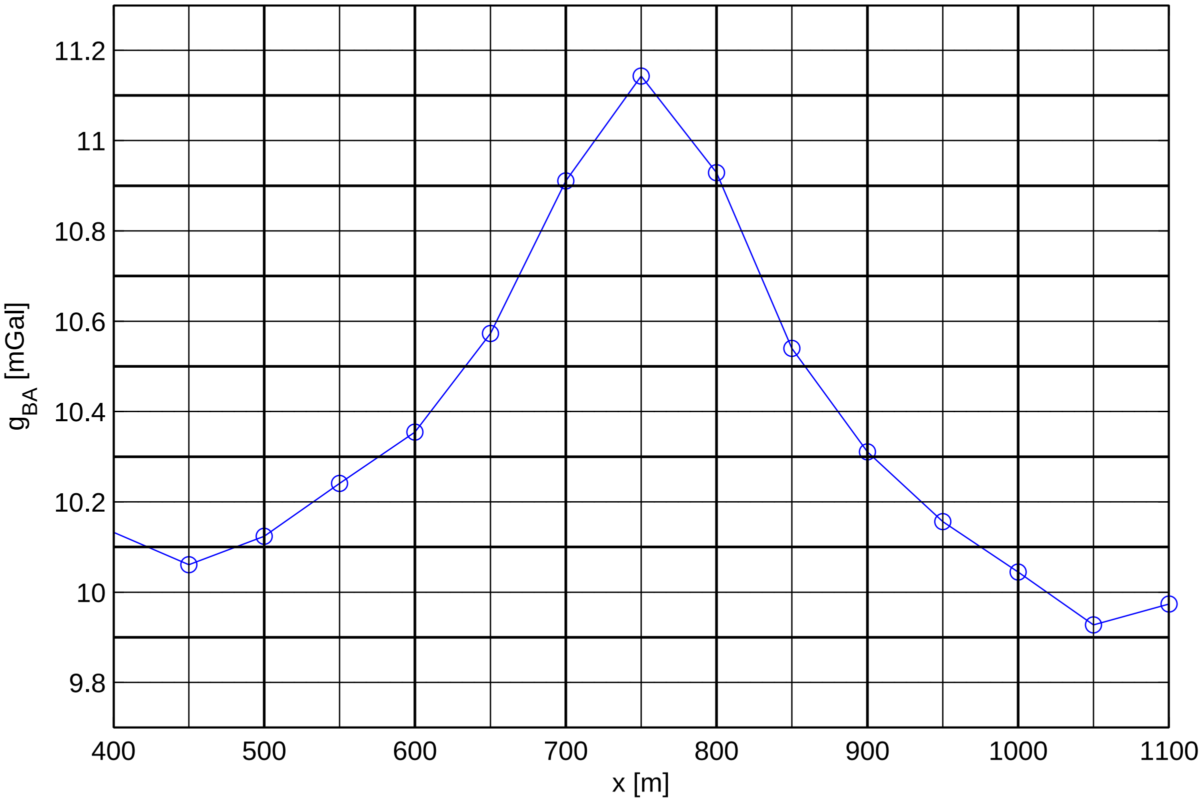

Fig. 7: z(x)