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Depth to bedrock and bedrock morphology from gravity measurements at Stryn, Stryn Municipality, Sogn og Fjordane

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P.O.Box 6315 Sluppen
NO-7491 TRONDHEIM
Tel.: 47 73 90 40 00

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Depth to bedrock and bedrock morphology from gravity measurements at Stryn, Stryn Municipality, Sogn og Fjordane

Authors:	Client:
Georgios Tassis, Jomar Gellein, Jan Fredrik Tønnesen, Louise Hansen	NGU

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Summary:

This report presents geophysical interpretation of gravity data as part of a project whose main objective is to supplement the mapping of Quaternary geology at Stryn. This is achieved through the extraction of depth to bedrock information with the use of gravity data which in turn yields soil thickness and bedrock morphology maps. The gravity method is one of the best techniques when large sediment thickness estimation is required due to its low cost compared to other methods and it can be easily implemented in both rural and urban areas. Our study area is just east of the town of Stryn and farther up the Stryneelva valley.

The gravity survey contains 98 gravity stations in the valley area, 88 of which are positioned along 6 profiles with approximately 50 m spacing between each station. 8 of the remaining points are located on or close to bedrock exposures, six of them not far away from endpoints of some of the profiles. After the acquisition phase, the data has been transformed into Bouguer anomalies and the regional trend which is characterized by an increase in the field towards the north has been removed. The sediments in the valley are causing local anomaly lows along the measured profiles with a maximum of ~2 mGal.

Gravity modeling was performed with the use of GM-SYS module of the Geosoft Oasis Montaj software. Our models were constrained by geological data from NGU such as drillhole depths, density sampling, geological data and other geophysical interpretation results. During modeling, we have kept originally a constant sediment density of 1900 kg/m^3 (mainly Silt) while the bedrock was given a value of 2700 kg/m^3 (Granitic to Dioritic Gneiss). The sediment density was decided after comparing results with seismic data which coincided with part of one of our gravity profiles.

Gravimetric interpretation indicates that sediments in the region may locally acquire a maximum thickness of ~110 meters (~100 meters below sea level). These interpretations were then enriched with additional sediment thickness data originating from NGU. On this basis a total depth to bedrock map has been constructed. The final map presented in this report portrays a good approximation of the qualitative but also quantitative distribution of sediments in the study area. In brief, sediments appear to be deeper and more voluminous in the western part of the study area and closest to the Stryn town center. Uncertainty of depth to bedrock is estimated to 25% of calculated depth.

Keywords:	Geophysics (Geofysikk)	Gravimetry (Gravimetri)
Modeling (Modelering)	Bedrock (Berggrunn)	Soil Thickness (Løsmassemektighet)
		Scientific Report (Fagrapport)

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1. INTRODUCTION

Geophysical data provide important, supportive and supplementary information to Quaternary mapping, which generally focuses on the surficial geology. Therefore, during recent mapping of the Stryn area, many types of existing data sets are assessed including geophysics (e.g. Stokke 1980; Hilmo & Lauritsen 1998; Tønnesen & Hansen 2016). The gravimetric data presented in this report were acquired during a research project in 2005. The aim was to get information on bedrock depths to constrain the long-term geological history of the valley system. It is the purpose of the present report to document the full geophysical interpretation of the gravimetric data.

The survey area encloses a part of the Stryneelva valley just east of the Stryn town center in Sogn og Fjordane county and occupies a space of about 4 square kilometers in total. The valley is a typical fjord-type valley that was affected by glacier erosion and infill during deglaciation and glacioisostatic rebound. Deglaciation of the valley took place during the Preboreal (Fareth 1987). The survey area is rural and sparsely populated and the gravity method is easily applicable. The NGU has performed gravity measurements along 6 profiles in the area which have been processed and interpreted in this report with the use of suitable software. Through this process we have acquired reliable regional information on soil thickness and bedrock morphology, a task performed at lower costs and to greater depths than other available geophysical methods such as refraction seismic or electrical resistivity tomography. It should also be noted that similar gravity mapping of soil thickness and bedrock morphology has been conducted in several valleys in Trøndelag municipalities in the past (Tønnesen 1987; Tønnesen 1991a; Tønnesen 1991b; Tønnesen 1993; Tønnesen 1996; Tassis et al. 2014; Tassis et al. 2016) and in some other areas in Norway (Tønnesen 1978; Gellein et al. 2005).

2. DATA ACQUISITION AND PROCESSING

2.1 Data acquisition

Collection of almost all gravity data has been done with NGU's La Coste & Romberg gravimeter, model G nr. 569. The survey at Stryn consists of 98 gravity stations with 88 of them positioned along 6 profiles with normally 50 m spacing between the stations (**figure 1**). Beginning and end for each profile are positioned either on top or close to bedrock exposure. Six of the remaining 10 points, are also placed on top or close to bedrock near the end of some of the profiles but do not coincide with any profile line. The remaining four point positions were measured with another gravimeter (Scintrex CG-3) and are located on either bedrock outcrops or sediments of the river valley, three of them are located in the area between profiles P2 and P3. In order to control diurnal drift, designated measurements have been taken at a base station at Stryn town center. All of these data were tied to the Norwegian Mapping Authority's base gravity station in Stryn (Stryn P at the old Stryn town hall) for the correction to the absolute value of the gravity field.

Fieldwork for this particular project was carried out during four days in November 2005 (8th to 11th). The measurements were conducted by Jan Fredrik Tønnesen while at the same time Jomar Gellein did leveling measurements in order to determine the height above sea level and co-ordinate all the stations along the profiles. The leveling was performed using a Sokkia total station, giving both coordinates and leveling of the gravity stations. Additionally, Jomar has performed all pre-processing of the gravity data after the fieldwork period was finished.

As can be seen in **figure 1** all six gravity profiles are arranged in a sub-parallel manner at distances more or less in north – south direction varying from 600 to 1000 m from each other. The dimensions of the study region are roughly 800 m by 4.5 km resulting in a total area of about 4 km^2.

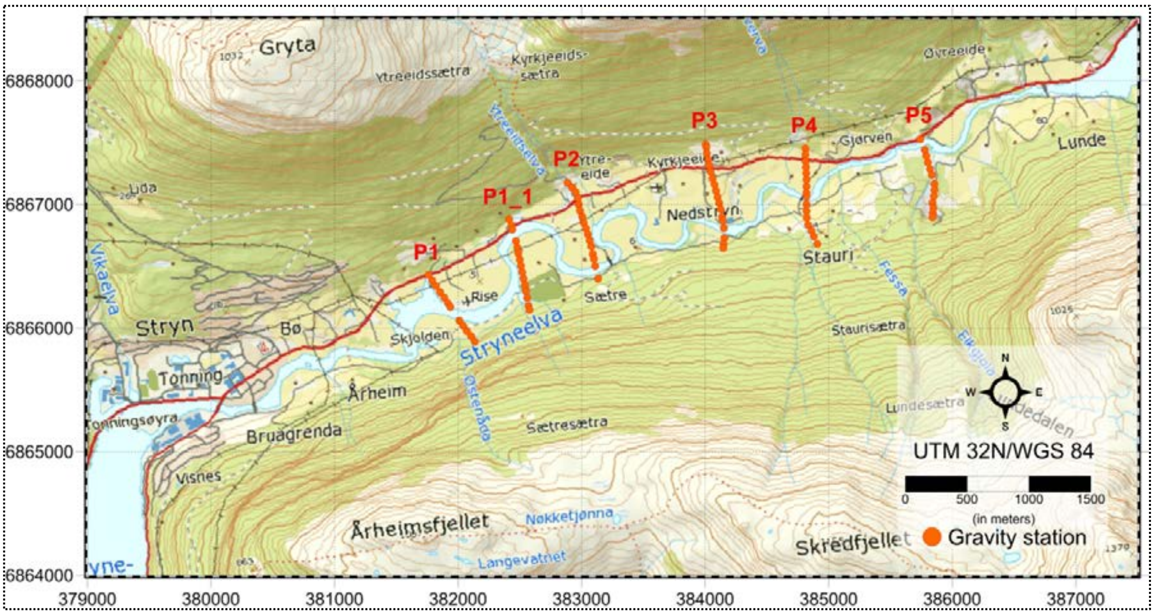

Figure 1: *Distribution of gravity measurements along profiles in the Stryn area.*

Profile no.	Beginning		Ending		Direction	Total length (in meters)
	Easting	Northing	Easting	Northing		
1	381759	6866432	382133	6865892	NNW-SSE	658
1_1	382411	6866882	382578	6866148	N-S	754
2	382884	6867176	383132	6866400	N-S	816
3	384006	6867488	384146	6866649	N-S	852
4	384811	6867454	384906	6866683	N-S	778
5	385741	6867530	385840	6866899	N-S	640

Table I: *Coordinates of beginning and ending of each gravity profile in UTM 32N/WGS84 as well as their general direction.*

2.2 Data pre-processing

The measured gravity data was first corrected for the diurnal drift and then for the free-air effect. Conversion to Bouguer anomalies was conducted by the standard NGU procedure (Mathisen, 1976). Both Bouguer and terrain corrections have utilized the standard density of 2670 kg/m^3. For the immediate neighboring area around the measuring points, the terrain correction was determined from point elevation data selected with the use of 5 circles with radii of 50, 100, 200, 400 and 800 m respectively and 8 points per circle.

3. BACKGROUND DATA

In order to be able to successfully process and interpret the gravitational anomalies present in our profiles, it is important to have sufficient knowledge of the geology of the region and realistic density values for both bedrock and the overlaying Quaternary sediments. Therefore, it is essential to establish which formations will be included in our models as dictated by the geology of the region and subsequently, what dimensions (depth and superficial spread) and density they should have. This kind of additional data may come from geological maps of the Stryn area (bedrock and Quaternary), as well as density of rock samples in the region and drillings that have reached as deep as bedrock. The NGU is in possession of such data which have been selected, evaluated and employed in our modeling procedure. Furthermore, the study area has also been subjected to other geophysical and modeling methods whose results aid us in further constraining the final product of this report.

3.1 Bedrock geology and petrophysical properties

The wider area is dominated by two rock types: mainly granitic to dioritic gneiss (banded in places) and secondly quartz monzonite (coarse-grained, in places deformed to augen gneiss). The study area is underlain by gneiss but the available petrophysical sampling does not coincide with it. Nonetheless, density information can be obtained from sampling done in nearby areas. **Figure 2** presents the bedrock map of the wider region which also includes four positions of petrophysical sampling, two on the gneiss and another two on the monzonite bedrock, and the measured density (from NGU petrophysical database). Although both formations appear to be quite similar in properties, we have decided that the most representative bedrock density value is the mean density for gneiss which in this particular area is equal to 2700 kg/m^3.

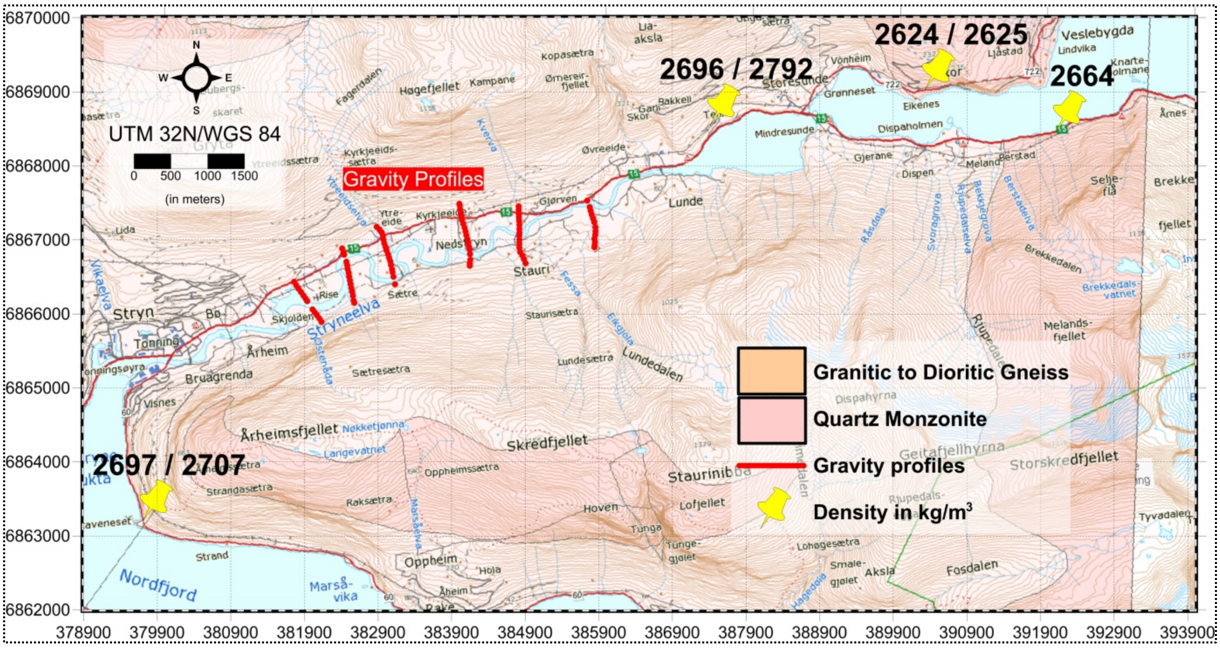

Figure 2: Positioning of gravity measurement profiles (red lines) and petrophysical sampling (yellow pins) in relation with major bedrock formations of the Stryn area (http://geo.ngu.no/kart/berggrunn/, Bedrock map 1:50000).

3.2 Drilling information and depth to bedrock

The Stryn area contains a number of boreholes drilled along the Stryneelva valley (from the GRANADA database at NGU, Fig. 3). Information from these boreholes can be used as a direct regulating factor in gravity modeling. A total record of 17 drillings are available from our study area (most of them for energy, household, water supply and other water related purposes and a few exploratory drillings), 7 managed to reach bedrock without providing much help since they are mainly positioned at the fringes of the basin. One deep drilling not yet in the database covers 77 meters of sediments without meeting any bedrock. It lies in the western part of the valley and coincides with gravity profile P1_1 (**figure 3**). This borehole indicates the minimum thickness that a sediment layer must obtain in this particular position. Drillings that have indeed reached bedrock will be used as point values to constrain the interpretation process. The other drillings without reaching bedrock are shallow in the west (7-9 m) and 15-25 m in the middle and eastern part of the area.

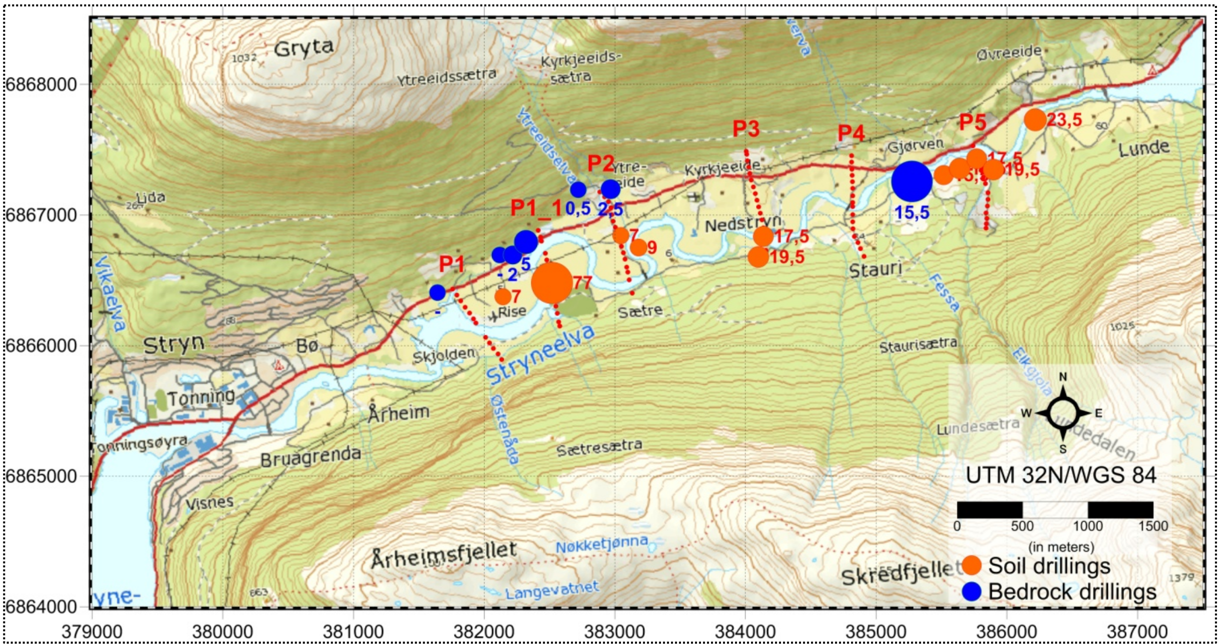

Figure 3: Positioning of NGU registrated boreholes in the Stryn area. Symbols sized in respect with the value they represent, both for depth to bedrock (blue) and minimum soil thickness (orange). Arrayed red dots depict gravity profiles. Data from NGU database GRANADA.

Table II shows the boreholes that give bedrock depth information. Unfortunately, not many drillings reach bedrock within the survey area and those that have are mainly positioned along the fringes of the basin offering no information about the soil thickness in the valley. **Table III** shows the boreholes that haven't reached bedrock. These drillings may be used in the sense that they indicate the minimum depth at which bedrock may be found. The uncoded borehole shown in **table III** is the most important of these soil drillings due to the fact that it coincides with gravity profile P1_1 and that it is rather deep (77 m). This gives us a first hint of the soil thickness in the western part of the study area.

Drill number	Easting UTM 32N	Northing UTM 32N	Depth to bedrock
24712	381641	6866405	-
14344	382118	6866692	-
14346	382218	6866692	2
14343	382317	6866793	5
14347	382718	6867193	0.5
64805	382966	6867198	2.5
47025	385272	6867257	15.5

Table II: Drilling down to bedrock (Data from NGU database GRANADA).

Drill number	Easting UTM 32N	Northing UTM 32N	Total borehole depth
9378	383045	6866840	7
9379	383181	6866750	9
9380	382145	6866374	7
8666	385515	6867305	15.5
8665	385639	6867356	19.5
8664	385767	6867430	17.5
8107	385897	6867349	19.5
8106	386216	6867728	23.5
9587	384098	6866679	19.5
9588	384135	6866835	17.5
Unpublished	382517	6866480	77

Table III: Soil drillings (haven't reached bedrock - Data from: NGU database GRANADA).

3.3 Valley-fill deposits and first-order density constraints

The nature of the valley-fill deposits of Stryneelva valley is known from Quaternary mapping (e.g. Stokke 1980; Sandøy et al. 2016), from the available drillholes listed above and from other geophysical surveys such as ground penetrating radar (Hilmo & Lauritsen 1998; Tønnesen & Hansen 2016). Most of the gravimetry data cross areas that are dominated by fluvial deposits of mainly sand and gravel. The deposits are, for the most part, relatively thin (<10 m) and cover fjord-marine deposits in silt and clay that are considered as representing the bulk of the valley fill with some coarser layers in the deepest part. Thick glaciofluvial sand and gravel are recorded locally at profile P3 (Sandøy et al., 2016). The easternmost gravity profile is also located in an area with relatively thick gravel and sand.

Unfortunately, no density information is available from the sediments in Stryn. In gravity, formations of slight density contrast (~200 kg/m^3) do not have a visible effect in the modeling procedure unless bearing a thickness which is at a scale of tens of meters. In this sense, our modeling has been focused on the dominating material which is considered as being silt without disregarding the presence of a clay content, the cover of sand/gravel and coarser layers in the deeper parts of the basin. Water saturated sediments dominated by sand, silt and clay will have densities of 1700-2200 kg/m^3 (Tønnesen, 1978). The density will mainly depend on the porosity which in turn is depended on the compaction of the sediments. In this research, we decided to assign an average density of 1900 kg/m^3 to the valley-fill deposits in our modeling as supported by density calibration explained below.

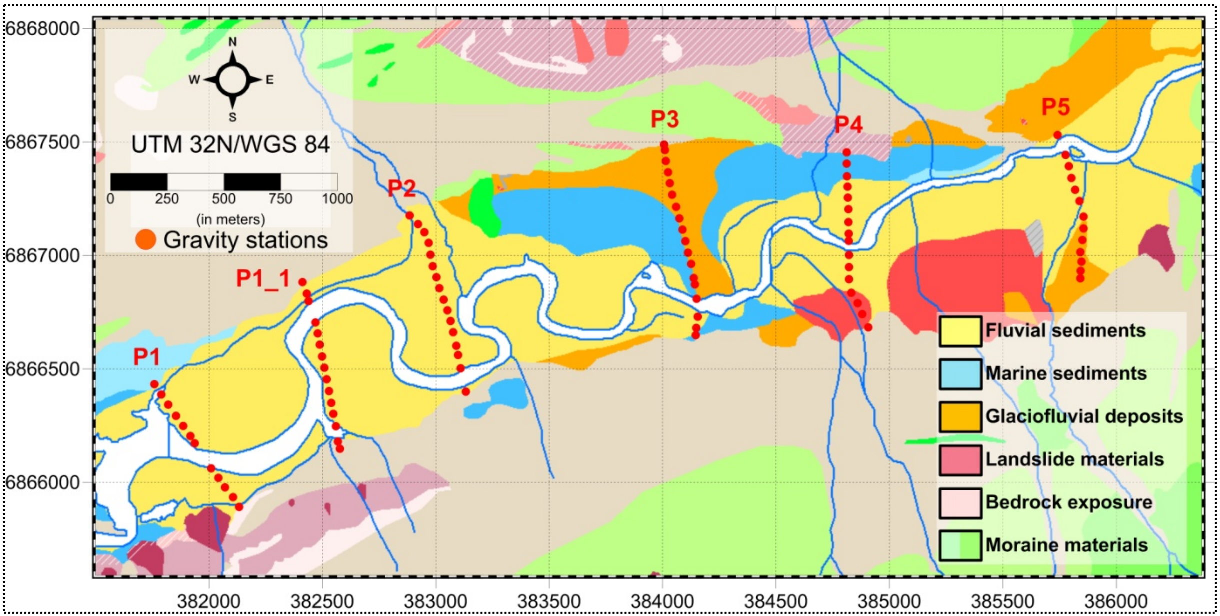

Figure 4: *Generalised Quaternary map from the Stryn area in relation with the gravity measurement profiles (Sandøy et al. 2016).*

3.4 Additional geophysical studies as a help to constrain densities

So far, we have assembled information about the density of bedrock (via prior petrophysical sampling) as well as some geometrical attributes of the sediments (minimum or absolute depth to bedrock from drillings) in an effort to successfully constrain the modeling procedure. No direct source for the determination of a realistic sediment density is available and an overall average value is applied as explained above. This is not ideal as sediment density is of critical importance to the gravity modeling. This value is unknown and cannot be retrieved from the neighboring areas either. However, other geophysical methods that have been applied in the study area can prove useful when trying to constrain modeling parameters such as soil density.

Primarily, seismic profiling has been recently done in the area (Tønnesen & Hansen, 2016). As can be seen in **figure 5**, refraction seismic profile S2 (numbering as in original report) coincides with the mid part of gravity profile 1_1. Thus, this seismic profile may be used as a constraining factor which can help us calibrate the densities used in gravity profile 1_1 in a more accurate manner. Additionally, seismic profile S2 is perpendicular to profile S1 while profile S3 lies to the east and is positioned between gravity profiles 4 and 5 (closer to 5). Although seismic profiles 2 and 3 cannot be used for constraining purposes directly, their interpreted bedrock morphology can be used for more consistent gridding at the end of the study.

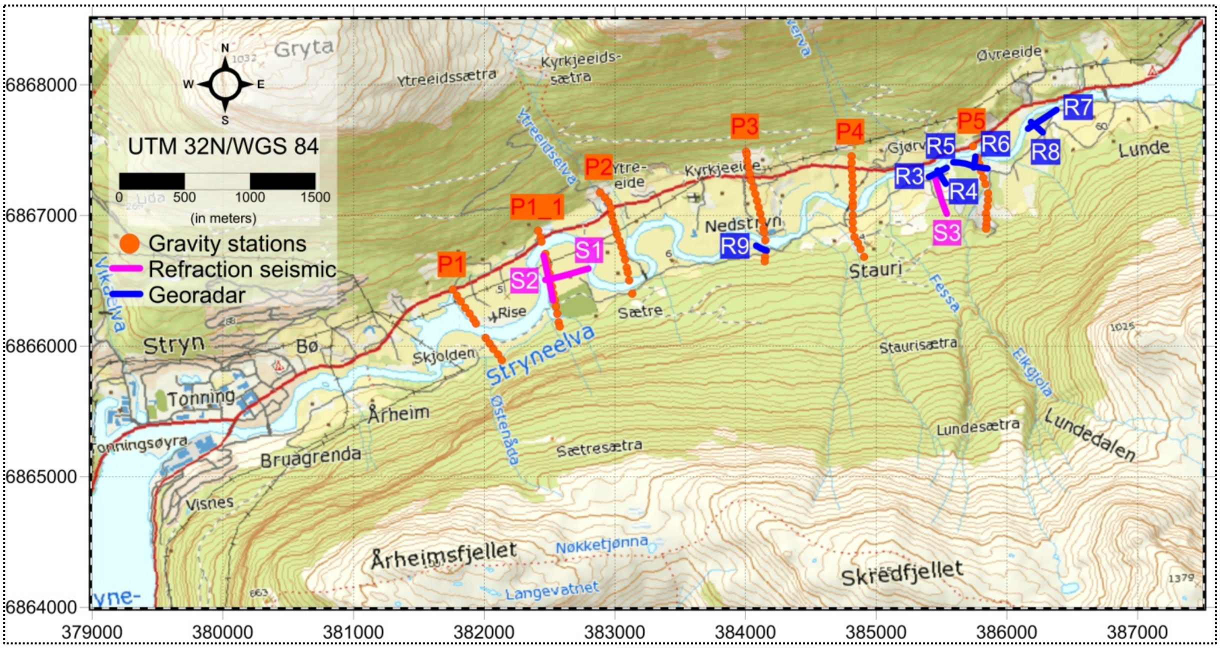

***Figure 5:** Older geophysical profiling in Stryn in relation to the gravity profiling (Blue lines: GPR; purple lines: refraction seismic).*

Hilmo and Lauritsen (1998) have also conducted a GPR survey in the area which is shown with blue colored lines in **figure 5**. No interpretation has been done regarding depth to bedrock by the authors of this report, therefore these profiles cannot be used for constraining gravity modeling. A more extensive GPR survey has been conducted in 2006 covering the whole sediment basin area, 31 profiles with total length of about 8 km (Tønnesen & Hansen, 2016).

4. DATA MODELING AND DENSITY CALIBRATION

Additionally to the conversion of raw gravity into Bouguer anomalies which has been performed by Jomar Gellein, the regional field must be removed from all profiles in order to isolate the anomaly caused by the valley fill in the survey area. Local and regional trends often mask the target gravity effects considerably. Sometimes regional gravity trend effects may exceed local desired anomalies by some tenfold although not in a study area of this size. Therefore, this field which is due to geological sources of a much larger scale than our study area must be removed before proceeding to the modeling procedure.

The Bouguer anomaly values in the area are assumed not to have as good accuracy as in other valley areas where the gravity method has been used (see references). This is because of the accuracy of the terrain corrections in the Bouguer reduction procedure. In the earlier studies the terrain corrections are in the order of 0,3 - 3,0 mGal, while in the Stryn area values varies between 15,5 and 22,0 mGal. A five percent uncertainty will cause an uncertainty of about 0,7-1,1 mGal in the Stryn area, but only up to 0,15 mGal in other areas. The high values of terrain corrections in the Stryn area are caused by the high altitude of the alpine mountains surrounding the valley basin. A qualitative check of the accuracy of the Bouguer anomalies along profiles can be done by checking the difference between neighbour points. If this difference is great and it correspond to about the same value as the difference between the terrain corrections, then it is assumed a greater uncertainty for one or both of these points. Research in the results of the data reduction process from the area (not shown in this report) indicates that some values are of special interest. These points will be mentioned in the interpretations of the profiles.

Furthermore, having decided that a representative density for gneisses is 2700 kg/m^3, an equally educated assessment must be made for the density of the valley fill thought as a whole. In order to calibrate the soil density, seismic profile S2 interpretation (Tønnesen & Hansen, 2016) will be utilized as a constraint. We will try to match the bedrock interpretation in that profile by maintaining a constant bedrock density and modifying the sediments in gravity profile 1_1 until the bedrock interpretation resulting from gravity modeling is as close as possible to the seismic profile.

4.1 Removal of regional trend

The regional gravity field in the wider Stryn area can be seen in **figure 6**. The contour grid has been compiled with minimum curvature method using the Bouguer gravity values produced for this present survey as well as measurements performed in previous years (red stars). Through this figure, a slight increase of the field towards the north can be identified.

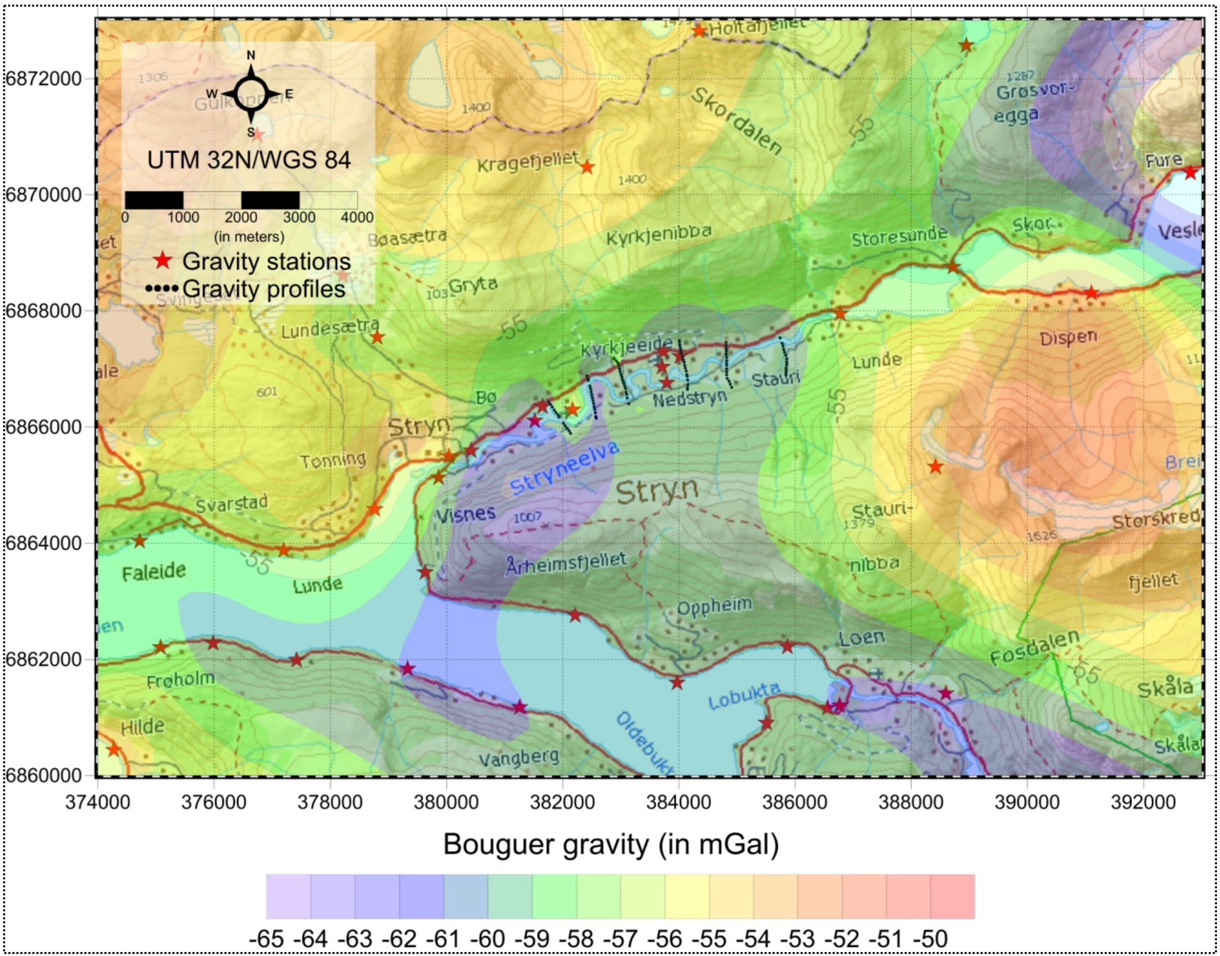

Figure 6: *Bouguer anomaly distribution in the wider Stryn area. Data from measurements performed in this project (black dots) and NGU database DRAGON (red stars).*

For the removal of the regional trend the following method was applied: all profile edge points have been fitted with a first order polynomial (linear). Each profile was then subtracted from its respective linear field and the resulting profile represents the residual field. The whole procedure is shown in **figure 7** where results are presented. Linear fitting was preferred due to the relatively small size of the survey area and the limited length of the gravity profiles. All mathematical operations performed during the regional field removal process have been compiled in a MATLAB code which yields the residual profiles automatically. **Figure 7** presents the regional removal results for gravity profile 1_1 only. Results for the rest of the profiles are in accordance to the scheme in **figure 7** and present a similar form in respect with the gravity increase trend towards the north.

The residual field for each profile is the isolated anomaly caused by low density formations in the Stryn area, stripped of the broader regional field. The resulting gravity varies between -2.25 to 0 mGal with the highest residual anomaly variation found in the third profile (~2 mGal - P2) and the lowest in the fourth (~1.1 mGal - P3). The relatively small measure of these anomalies shows us that we are not dealing with sediments of significant thicknesses. Experience dictates that 2 mGal anomalies portray deposits which are in the order of 100 meters thick.

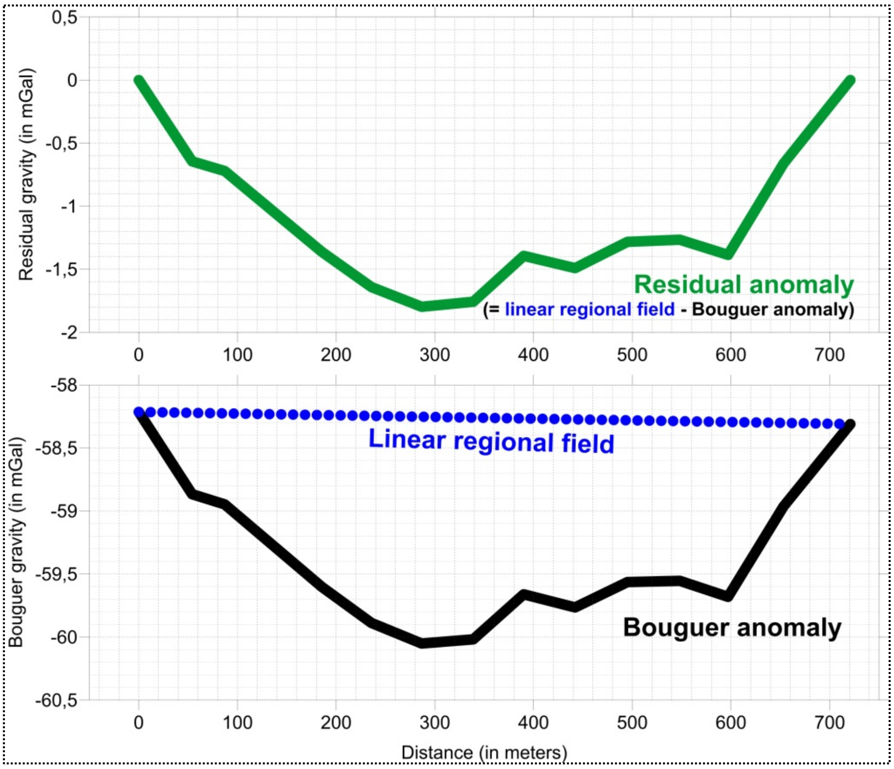

Figure 7: Fitting of a 1st order polynomial regional trend to the start and finish of profile P1_1 (bottom) Results of removing the regional trend from the original Bouguer anomaly (top).

4.2 Density calibration

After producing the residual gravity field, the next step is to proceed to the actual modeling. However, constraining the procedure beforehand is essential in order to diminish the non-uniqueness problem which plagues such modeling. In this sense, all additional information connected to the formations appearing in the models and their respective densities and dimensions (thicknesses) will be used to narrow down the possible outcomes and "force" our models to be precise.

Modeling has been performed with the use of GM-SYS GX menu of the Geosoft Oasis Montaj software Version 9. In all cases we have used a reduction density equal to 2670 kg/m^3 while each gravity station has been placed on the measured topographic height. Finally, the model was extended 30 km in both directions to achieve 2.5 D modeling conditions.

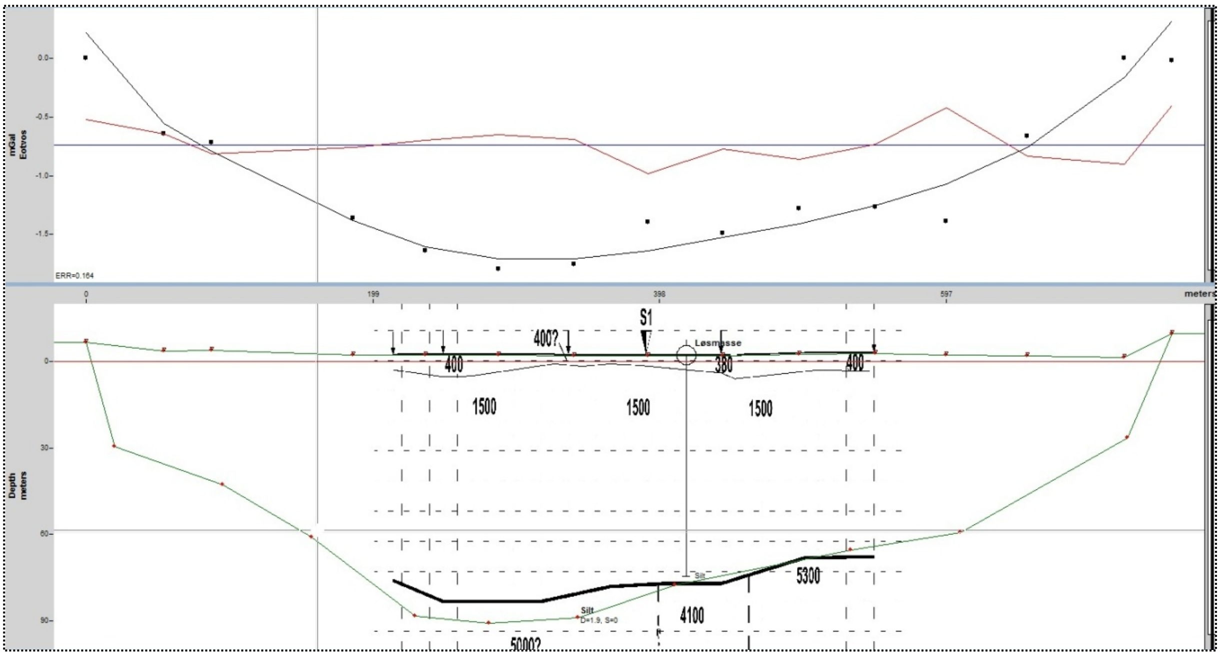

Figure 8: *Depth to bedrock interpretation using seismic profile S2 (Tønnesen & Hansen, 2016) to constrain gravity modeling along gravity line 1_1. Bottom: cross sections superimposed - gravity interpretation (green line with red dots) versus seismic depth to bedrock delineation (black line) Model soil density is 1900 kg/m^3. Top: Residual anomaly (black dots) versus calculated gravity based on the model below (continuous black line). Red line represents error (standard deviation - does not follow the axis units).*

The gravity modeling performed here contains at least two geological formations (soil and bedrock). Two formations in a model equals to four unknowns i.e. their geometrical shape (thickness vs. horizontal expansion) and densities. Three formations equal to six unknowns and so forth. Essentially this means that the more formations we add to our models, the more complex the problem becomes. Therefore, it is always advisable to begin with a simplified model containing two formations i.e. bedrock and soil. As already mentioned, the gneiss density in the area is 2700 kg/m^3 and its morphology has been locally outlined by seismic line S2 (Tønnesen & Hansen, 2016). In this way, using gravity modeling we are trying to extract the density of sediments by matching the morphology of bedrock and locking its density to 2700 kg/m^3. This procedure is shown in **figure 8** for profile 1_1 versus seismic line 2 by Tønnesen & Hansen (2016).

As can be seen in **figure 8**, we have shaped the model's bedrock formation in such a way that the modeled gravity (continuous black line - top graph) matches the observed gravity (dots - top graph) as best as possible. The 1900 kg/m^3 density represents a mean density for all the different sediment formations contained within the geometric shape we have given to soil. The match accomplished is not perfect but it is very good. The shape of the gravitational anomaly indicates that the first half of the profile contains thicker sediments than the second. This morphology is validated by the seismic profile regardless of the fact that the bedrock surface interpreted via seismic processing is relatively flatter. The use of a higher sediment density (2000 kg/m^3) makes the match worse producing even thicker modeled sediments so a more modest thickness compared to the seismic profile is preferable. A lower density on the other hand (1800 kg/m^3), pushes the bedrock surface above the borehole shown in the middle of the profile (**figure 8** - around 420 meters distance). This is not agreeable since this particular borehole indicates the minimum acceptable soil thickness at this point (77 m - **table II**) and the use of such a soil density does not satisfy this constraining factor. Therefore, a soil density of 1900 kg/m^3 was picked and all modeling was performed using this value.

5. MODELING RESULTS AND DESCRIPTION

Each interpreted profile is illustrated in two parts. The bottom part contains the resulting cross section which shows the formations included in the models, the densities attributed to them during processing and their eventual calculated dimensions. The valley fill (on average consisting of silt) is shown in yellow/blue while bedrock is shown in light brown. Doing so, we have tried to present results which are coherent with the already existing maps in terms of colors used. It should be noted though that the corresponding formations are not representative of the entire sediment body, especially in deeper parts. All models have been plotted down to 200 meters of depth. Both axes are in meters and the X and Y axis ratio is 1:1. In this way, the depth of sediments illustrated can be seen in its true extent compared to its lateral dimensions. A general direction of each cross section is given at the beginning and end of the X axis with geographical coordinates in the UTM zone 32N system. Beginning and ending of each profile as well as general direction have also been already given in **table I**.

Top part shows the values of the residual anomalies at the observed measuring points (black dots), the calculated values from the model (blue line) and a graph of the mathematical error of the model (red line). The calculated error given in each figure is equal to the standard deviation of the differences between observed and calculated residual values in each point in model. The error curve does not correspond to the Y axis scale but the red line represents the plot of these differences in each station. Areas where the red line is deflecting from its horizontal mean value are areas where the model is less reliable. A straighter line means better model fitting.

All resulting models have been exported from GM-SYS and illustrated in Golden Software's Surfer 12 program, version 12.8.1009. This was done in order to create a more presentable illustration of our results.

5.1 Profile 1

Profile number 1 is situated at the west end of the survey region with Stryn town center lying about 2.5 km to the west. It is 658 meters long and contains 12 gravity measuring points. Both starting and ending points are measured on exposed bedrock while the general direction of the line is NNW to SSE. The profile is crossing Stryneelva halfway with measurements performed on both river banks. The residual anomaly variation is equal to 2 mGal and the maximum anomaly effect of the sediments is about 1.5 to 2.0 mGal in the area between 450-625 meters.

As we can see in **figure 9**, sediments in the area reach a maximum depth of ~75 m below sea level near the southern end of the profile (~77.5 m total soil thickness) at about 550 meters of horizontal distance. However, the deepest sediment valley is confined to the southern part of the profile while in the northern one, the area presents much shallower sediments with smoother morphology (~34 m maximum thickness). No drilling information is available for this profile and the resulting sediment basin is based on the already set 800 kg/m^3 density contrast between soil (1900 kg/m^3) and bedrock (2700 kg/m^3). The calculated error for this modeling result has a moderate value 0.195 and the greatest discrepancies are in the southern part of the profile. Inspection of the anomaly data indicate that one of both of the points 8 and 9 and also one or both of 11 and 12 are less accurate than the other points because of greater uncertainty in the terrain corrections used for these points.

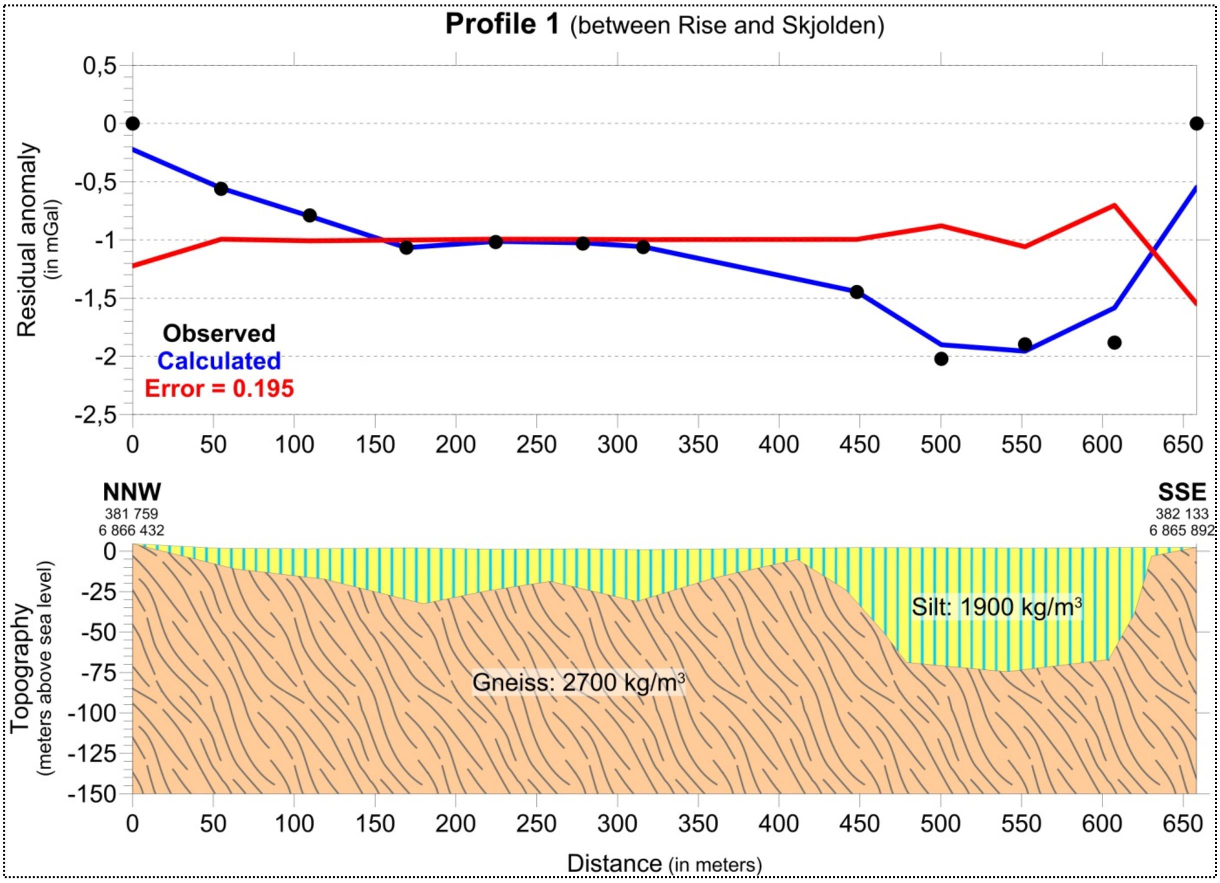

Figure 9: Modeled depth to bedrock - Profile 1. Bottom: cross section showing the sediment formation dimensions (in meters) and distribution as well as utilized densities for both sediments and bedrock (in kg/m^3). Top: Observed (points) and calculated gravity data graph with error estimation (red curve).

5.2 Profile 1_1

Profile number 1_1 is situated about 650 m east of profile 1 in a sub parallel position. The distance from profile 1 is about 800 m in the N and 500 in the S end. Profile 1_1 has a total length of just over 750 meters. It consists of 15 gravity measurements roughly taken every 50 (wherever possible). The general direction of the profile is almost N to S. Once again both end points have been measured on exposed bedrock in order to facilitate the modeling process. The residual variation along the profile is about 1.8 mGal, and the maximum anomaly effect of the sediments is found in the area between 200-400 meters. The modeling procedure has attributed this anomaly to a sediment layer which is ~100 m thick after 275 meters of horizontal distance as can be seen in **figure 10**.

As already described, the gravity dictates that the northern part of the profile presents larger bedrock depths than the southern. Therefore, the assessment derived from gravity is in good agreement with the seismic interpretation for the same profile (Tønnesen & Hansen, 2016). However, the sediment body thickness matches the constrain provided from the 77 m deep borehole which matches the gravity line at 415 meters. In that spot, soil has to be thicker than 77 m and the modeling procedure has found bedrock to be at about 80 m. The same soil thickness has been extracted from refraction seismic, indicating that bedrock did not lie much deeper than where the drilling stopped. The error estimate has a value of 0.170. Inspection of the anomaly data indicates that point 8 and 12 has greater anomaly uncertainties than the other points. Point 8 has too much terrain correction and point 12 one too low.

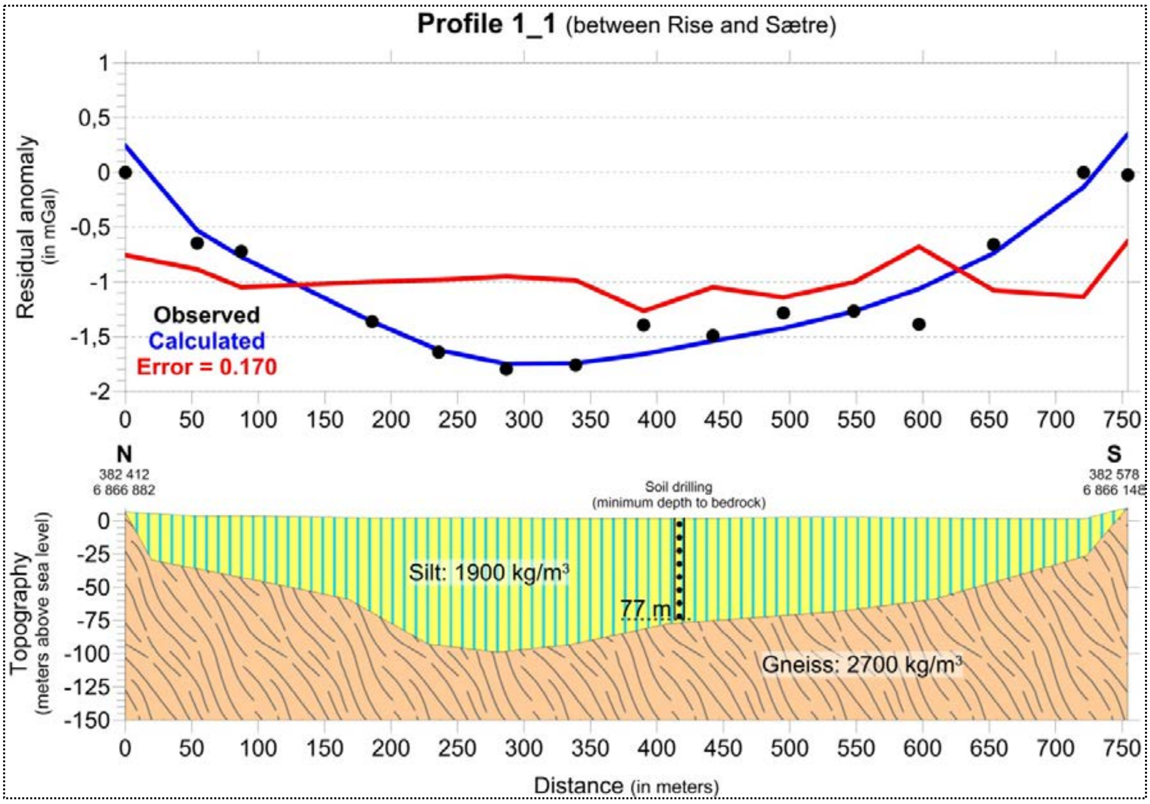

***Figure 10:** Modeled depth to bedrock - Profile 1_1. Bottom: cross section showing the sediment formation dimensions (in meters) and distribution as well as utilized densities for both sediments and bedrock (in kg/m^3). Top: Observed (black points) and calculated gravity data graph with error estimation (red curve).*

5.3 Profile 2

Profile number 2 can be found about 600 meters east of profile 1_1, stretching along an almost parallel N-S direction. Its total length is ~815 meters and measurements have been performed in 16 stations. The residual anomaly variation is about 2.2 mGal (the largest in the survey area) while the maximum effect of the sediments can be seen in the area between 400-650 meters.

Modeling results can be seen in **figure 11**.The setting utilized is the same as in profile 1_1, consisting of gneisses as bedrock and a valley fill which is dominated by silt. As in all other cases, beginning point near Ytreeide and ending point at Sætre were measured on bedrock exposure and the sediment valley is limited between these points. In this particular case, the calculated gravity matches the observed field quite successfully as can be deduced by the small error value of 0.092. The southern half of the profile demonstrates a deeper bedrock than the northern one which presents a rather smooth soil thickness of around 40 m.

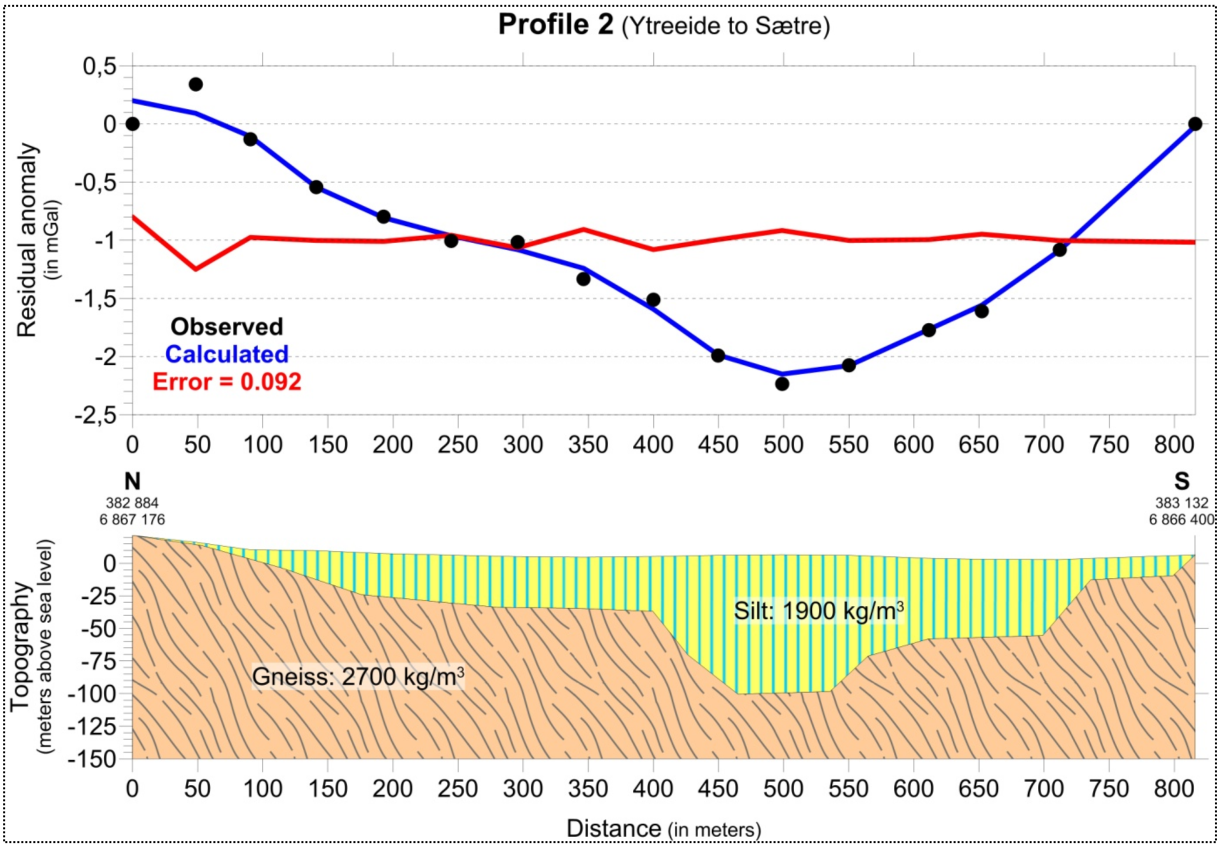

Figure 11: Modeled depth to bedrock - Profile 2. Bottom: cross section showing the sediment formation dimensions (in meters) and distribution as well as utilized densities for both sediments and bedrock (in kg/m^3). Top: Observed (black points) and calculated gravity data graph with error estimation (red curve).

5.4 Profile 3

Profile number 3 is once again following a N-S direction, positioned parallel and about 1100 meters east of profile 2. It is the longest profile measured for this project, (~850 meters long). It consists of 16 stations and displays a residual anomaly variation equal to 1.0 mGal with the maximum effect in the area between 350-500 meters distance (**figure 12**).

The resulting bedrock topography follows the gravity pattern and is rather smooth, revealing a relatively shallow soil bottom which can be found at around 30 m depth on average. The maximum soil thickness for profile 3 is found in a locally deep valley around the center of the profile between 400 and 500 meters distance and is equal to ~55 m. Two soil drillings match with this profile and their minimum depths are verified by the resulting model. The resulting error after fitting the calculated gravity with the observed one is 0.048, a value indicating a very good match.

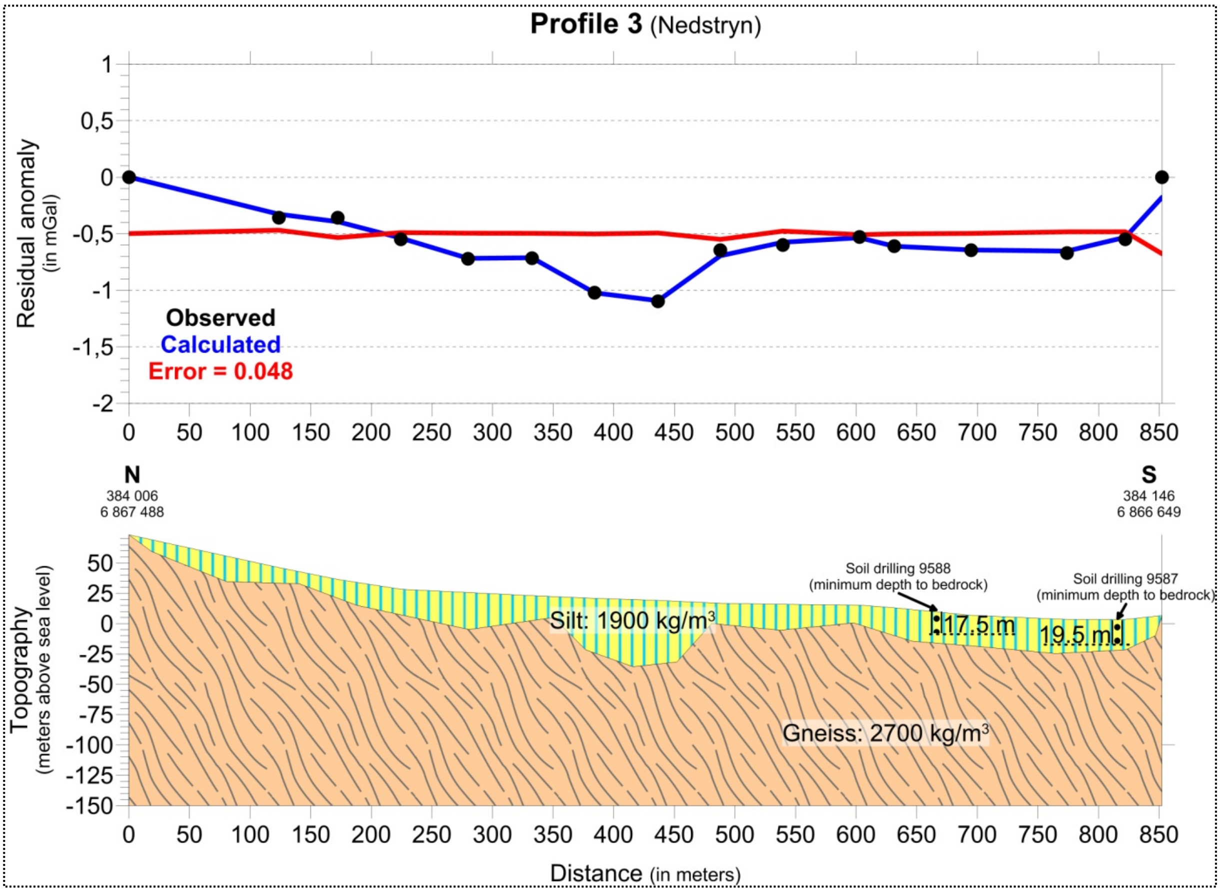

Figure 12: *Modeled depth to bedrock - Profile 3. Bottom: cross section showing the sediment formation dimensions (in meters) and distribution as well as utilized densities for both sediments and bedrock (in kg/m^3). Top: Observed (black points) and calculated gravity data graph with error estimation (red curve).*

5.5 Profile 4

Profile number 4 is located in Stauri and extends for about 780 meters from N to S. It is parallel to profile 3 and spaced 700 meters east of it. Gravity measurements done in 16 stations have delineated a 1.0 mGal anomaly with the maximum effect of the sediments spotted between 350 and 500 meters. **Figure 13** displays the result of the modeling procedure for profile 4.

The model assigned to the observed residual anomaly is not much different than profile 3 structurally. The northern part of the cross-section is smooth with a mean soil thickness of about 25 m, while the southern part presents a locally deepening sediment valley which encloses about 80 m thick soil at its lowest point. Farther to the south a second but shallower sediment valley appears as dictated by the local residual gravity low at 625 meters distance. The maximum thickness for these sediments is about 50 m. Once again, no matching drillings are available for further constraining our model. However, the calculated error for the model presented in **figure 13** is small (0.079). Inspection of the anomaly data indicates that points 10, 11, 15 and 16 have greater uncertainties. Point 10 is too low and point 11 possibly too high while point 15 is probably too low and point 16 possibly too high.

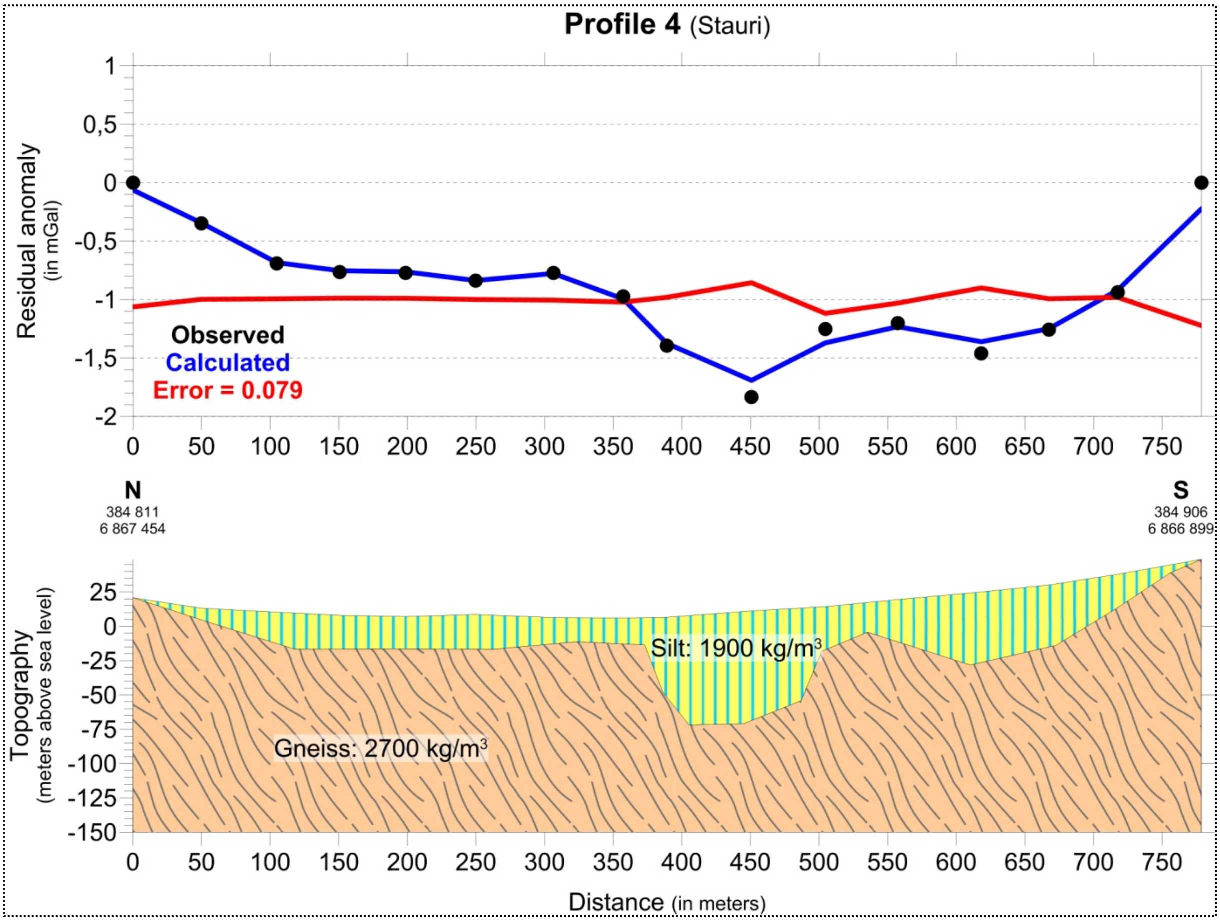

__Figure 13:__ Modeled depth to bedrock - Profile 4. Bottom: cross section showing the sediment formation dimensions (in meters) and distribution as well as utilized densities for both sediments and bedrock (in kg/m^3). Top: Observed (black points) and calculated gravity data graph with error estimation (red curve).

5.6 Profile 5

Profile number 5 (**figure 14**) is located another 1000 m east of profile 4 and about 6 km east of Stryn town center. It is stretching for 640 meters in an almost N to S direction and consists of 13 measurements. Profile 5 is the shortest profile in this survey and crosses Stryneelva at its northeasternmost point. The maximum effect of the sediments is found at 250-400 meters and is equal to about 1.0 mGal.

Only one drilling coincides with profile 5 and is a drilling that did not reach bedrock. This borehole provides us with the minimum depth that bedrock may be found at 17.5 m at position 100. The modeling procedure is fulfilling this constrain by placing bedrock at about 30 m depth at this particular point. Generally, sediments in the northern half of the profile are distributed in two depressions, with the sediments in first being slightly shallower than in the second. Both depressions demonstrate the limit between soil and bedrock at 20 m below sea level but the topography above the second depression is higher therefore the total thickness of sediments is higher. Namely, the maximum soil thickness for the northern depression is 30 m and for the southern valley 45 m. After about 400 meters distance, the bedrock morphology becomes smooth with a mean depth of around 20-25 m. The small error value (0.017) indicates a mathematically accurate model. Inspection of the anomaly data indicates the greatest uncertainties for the points 10 and 11.

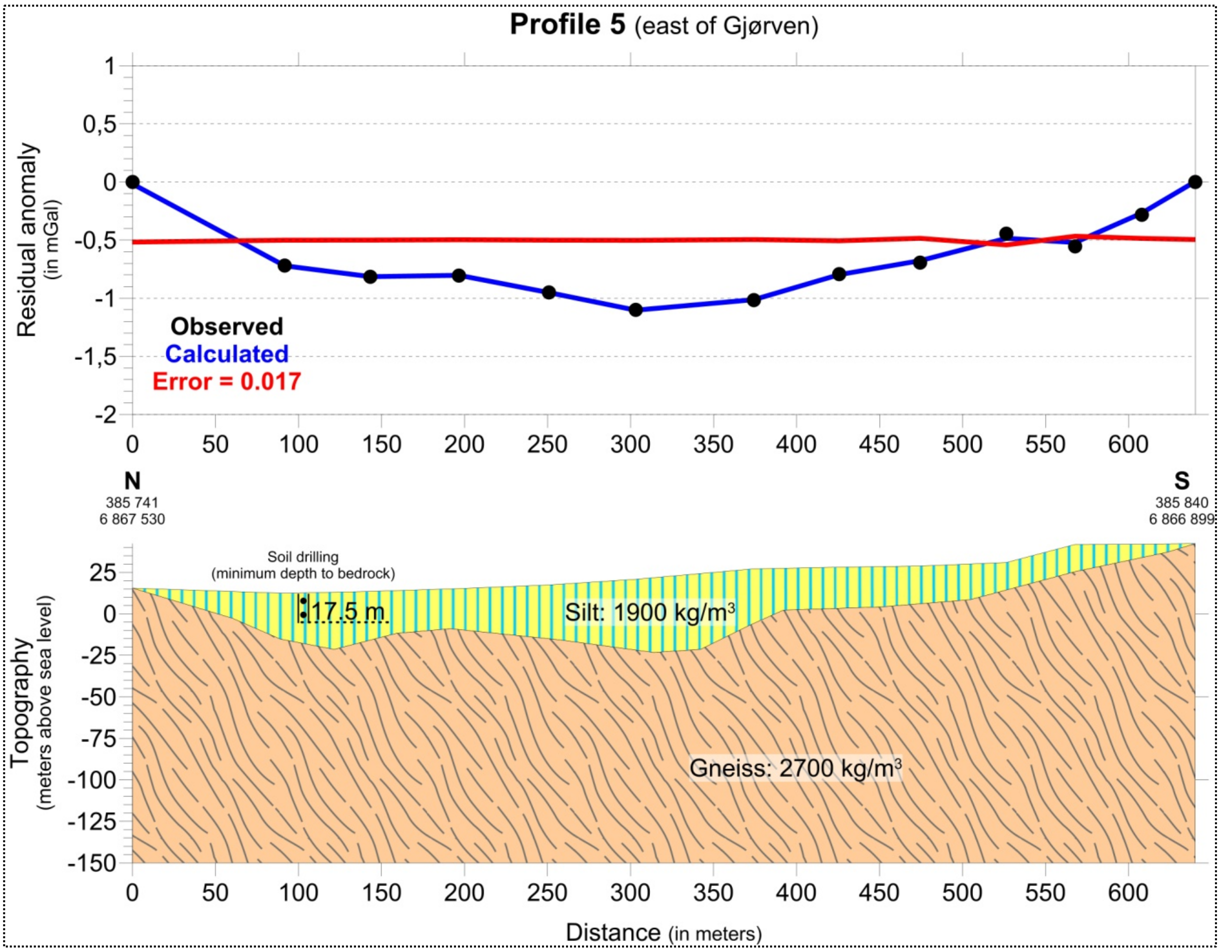

__Figure 14:__ Modeled depth to bedrock - Profile 5. Bottom: cross section showing the sediment formation dimensions (in meters) and distribution as well as utilized densities for both sediments and bedrock (in kg/m^3). Top: Observed (black points) and calculated gravity data graph with error estimation (red curve).

6. DEPTH TO BEDROCK

As seen in **figure 1** the profiles measured in Stryn may be parallel to each other but they are not evenly spaced and their point measurements are not placed on the nodes of a normal grid. Instead they are distanced hundreds of meters apart. It is easily understood that trying to create a depth to bedrock grid will result in large areas of interpolated values i.e. areas where depth to bedrock is an educated guess at best. To overcome this problem we had to enrich our depth to bedrock point file with several additional data. The final depth to bedrock data compilation from the Stryneelva valley consists of:

a) gravity modeling interpreted depths
b) drillings that reached bedrock (**table II**),
c) bedrock exposure positions throughout the area
d) seismic interpretations by Tønnesen & Hansen (2016).

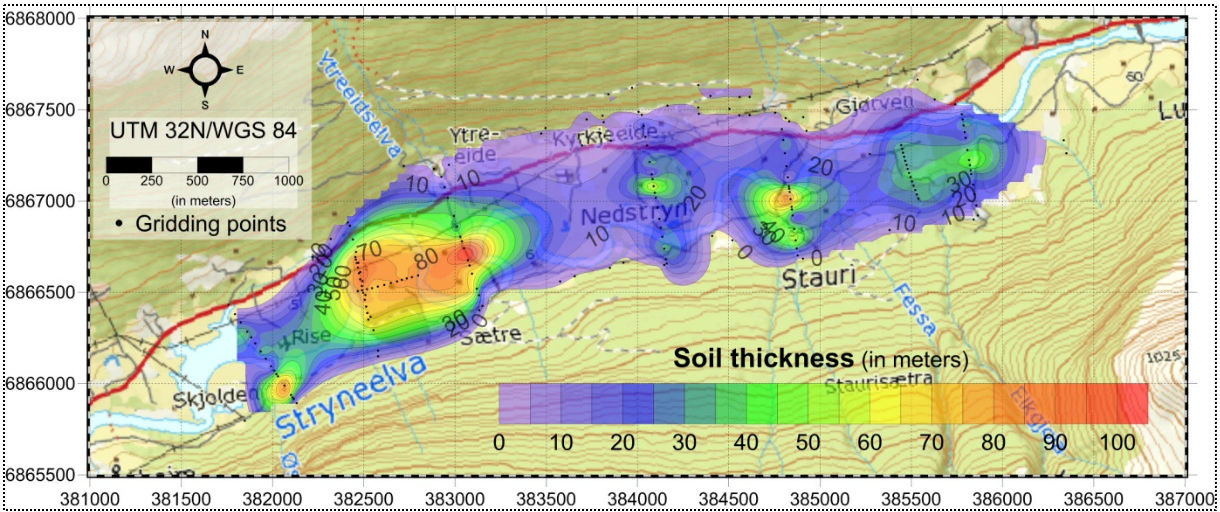

Figure 15: Depth to bedrock distribution in meters as measured from topography (soil thickness). Black dots represent all depth to bedrock points used in the calculation of the grid.

Although the effect of uneven spacing throughout the gridded area is not possible to overcome 100%, the available data included in the depth to bedrock data compilation give us an acceptable coverage of the study area. The resulting grid has been compiled using minimum curvature. The grid spacing designated was 50 m per axis and the areas not containing data were blanked. **Figure 15** shows the final depth to bedrock contour map and displays soil thickness i.e. how deep a drilling on the surface would have to go in order to meet bedrock. **Figure 16** shows the same grid plotted in Google Earth giving a pseudo-3D impression of the Stryn area sediment distribution.

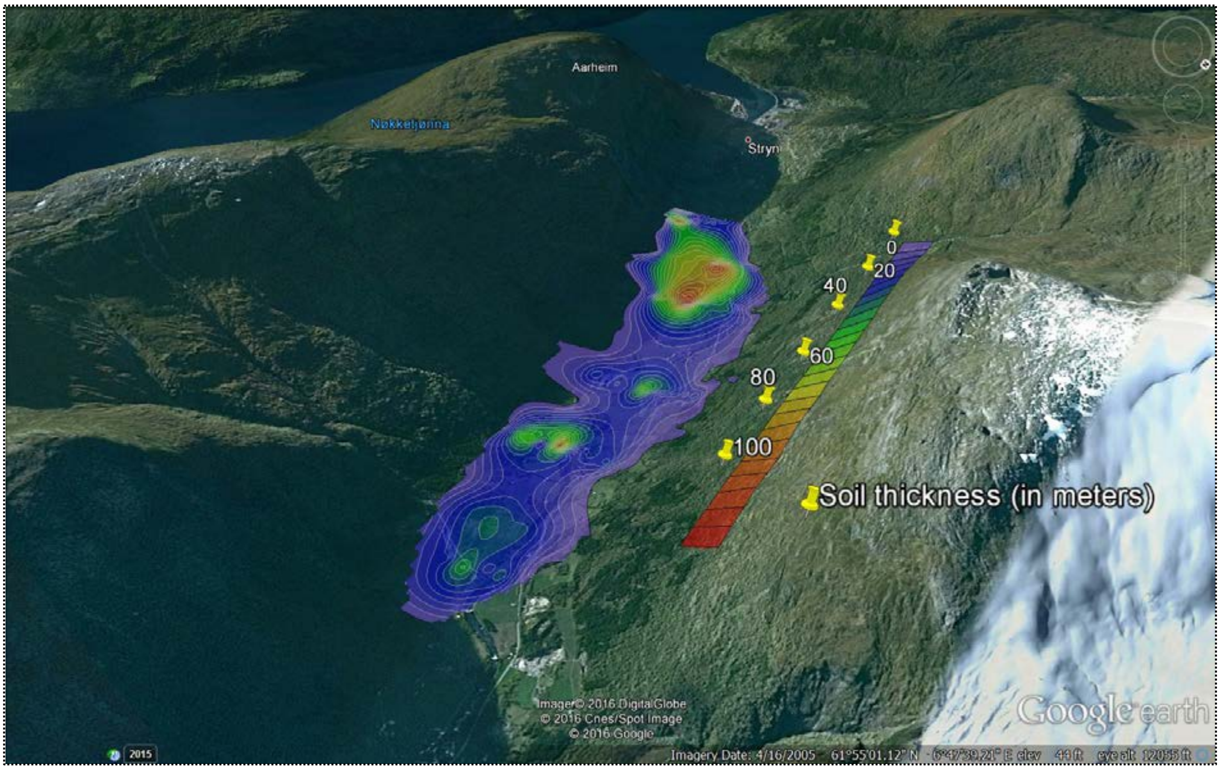

Figure 16: Google Earth image of the Stryn area with gridded depth to bedrock plotted.

Figure 17 exhibits a 3D representation of the sediment body enclosed in the sediment hosting valley. The 3D body was constructed in Geosoft Oasis Montaj by initially forming a geostring containing 2D slices of all the valley fill modeled and then wireframing them together by connecting their edges. In all sub-figures we have used a vertical exaggeration of 4 in order to highlight the thickness of sediments. This was done due to the fact that the 3D body is 40 times longer than it is deep (~4 km vs. 100 meters respectively). The depiction in **figure 17a** (view from above and west by northwest) illustrates the positioning of each individual sediment valley floating in 3D space before any wireframing took place. **Figure 17b** (view from southeast) shows how the profiles are positioned in 3D and the empty space between them.

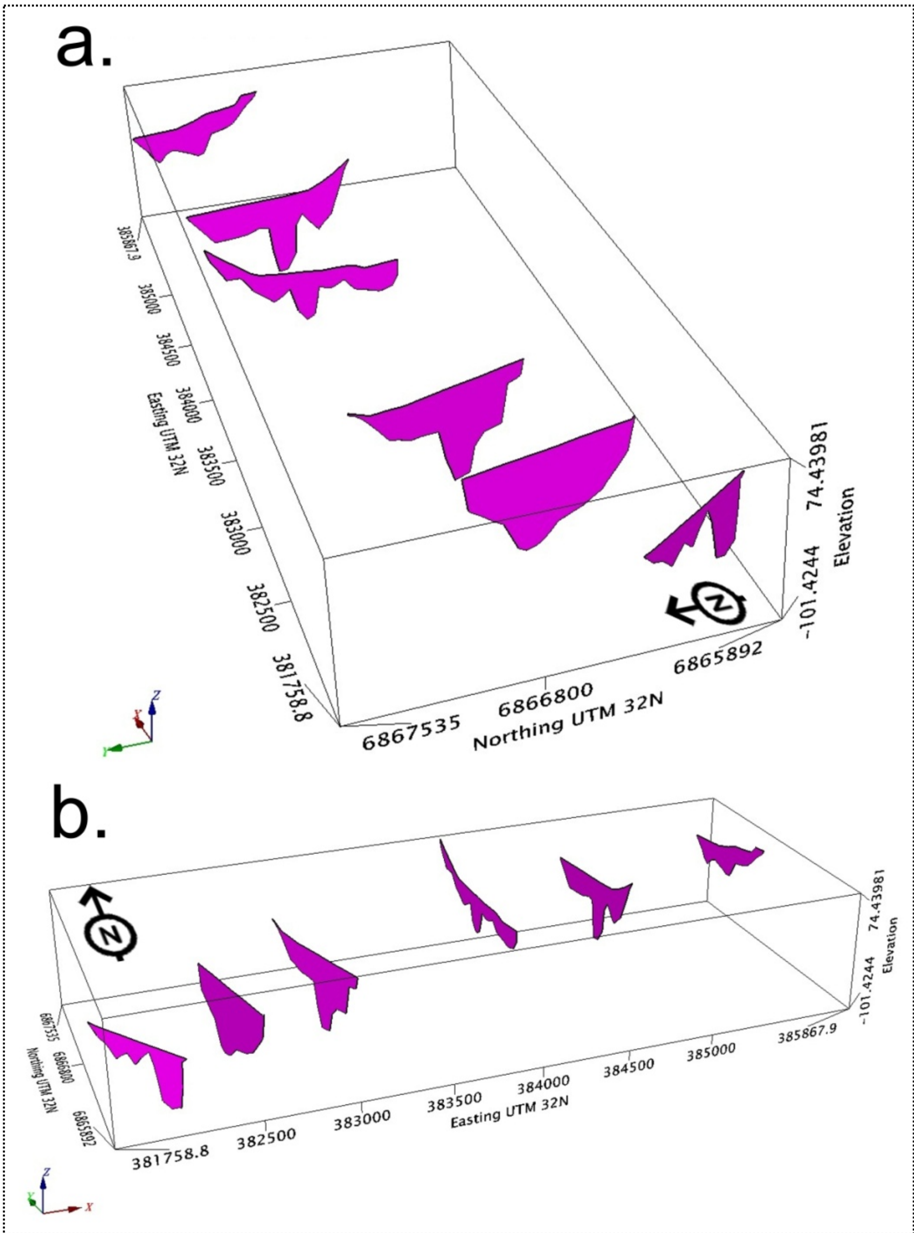

Figure 17: *3D representation of the calculated sediment body at Stryn: a. 3D plotting of the interpreted profiles (view from WNW). b. Profiles floating in 3D space (view from SE). All distances and depths in meters, all coordinates in WGS84/UTM 32N and all profiles are vertically exaggerated by 4.*

Figure 18 shows the morphology of the bedrock surface in 3D space compiled in Surfer 12. This is done by using height from sea level as shown in all the 2D profiles. Positive sign means meters above and negative meters below sea level. In this figure it can be noticed that areas where no depth to bedrock data are available (like the areas between the gravity profiles) present lower resolution and are generally shallower than expected. This is due to the fact that the easting resolution is not as high as the one along the northing axis.

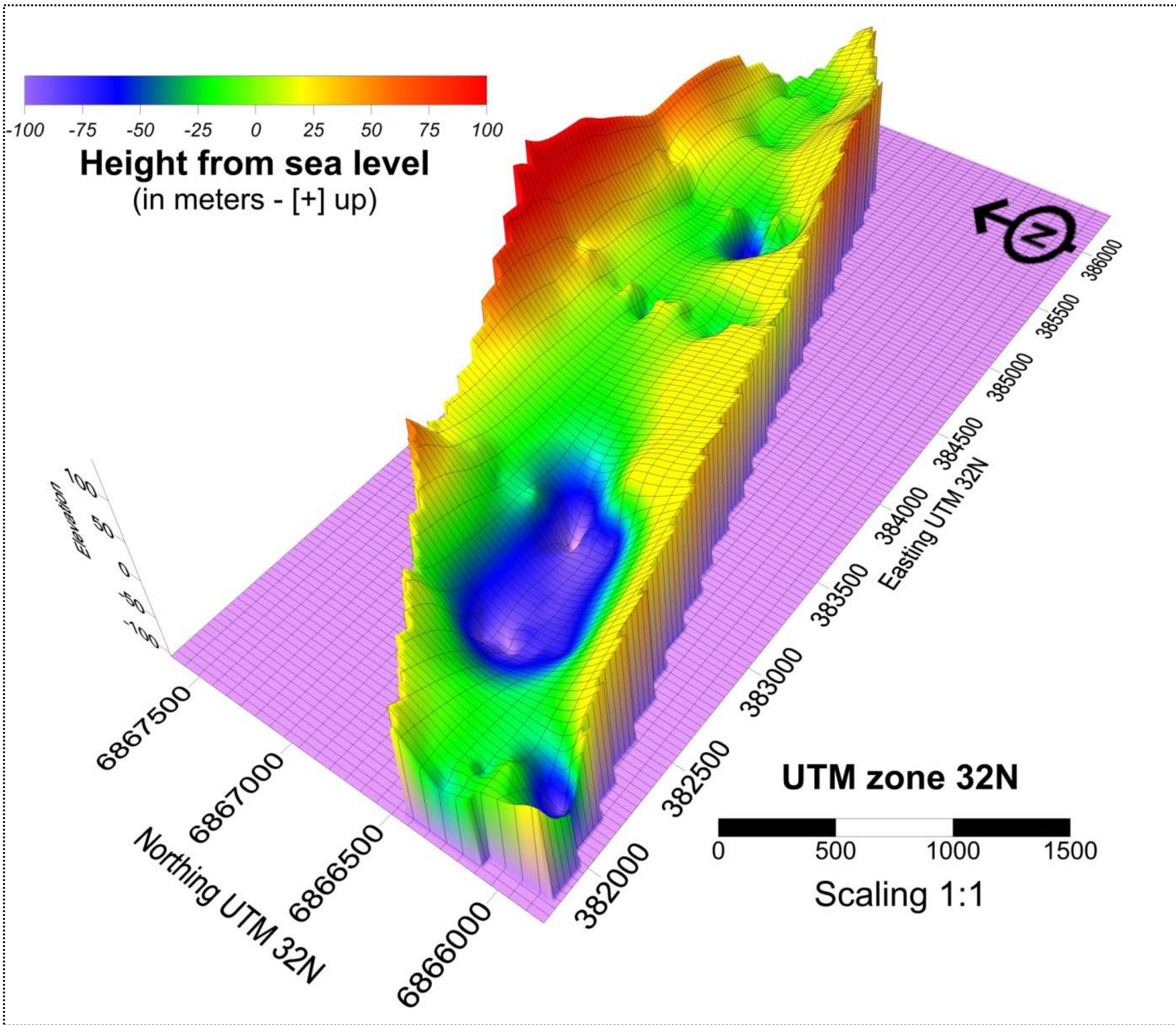

Figure 18: Bedrock morphology as calculated from gravity modeling using height from topography.

7. DENSITY VARIATION EFFECT

It has already been stated that the depth to bedrock estimations presented in this report are as accurate as the assumptions made about the densities of the participating formations. Exactly how accurate, is a reasonable question to ask. In order to answer this question we had tested the effect of an extra sediment density in gravity modeling, on the grounds that bedrock's density is more trustworthy than that of the valley fill's.

We have tested the effect of one extra sediment density in connection to the utilized average value of 1900 kg/m^3. Modeling was then repeated with the use of densities equal to 2000 kg/m^3 and the resulting soil thicknesses (depth to bedrock) where again gridded and mapped. These results are shown in **figure 19**. The top side of this figure displays the depth to bedrock grids obtained with the new density value together with the selected final result. The bottom part shows the resulting 2D bedrock delineation for profile 1_1 after using both sediment densities described above. It should be noted that a lower soil density like 1800 kg/m^3 was not applicable because the resulting bedrock surface did not match the drilling depths.

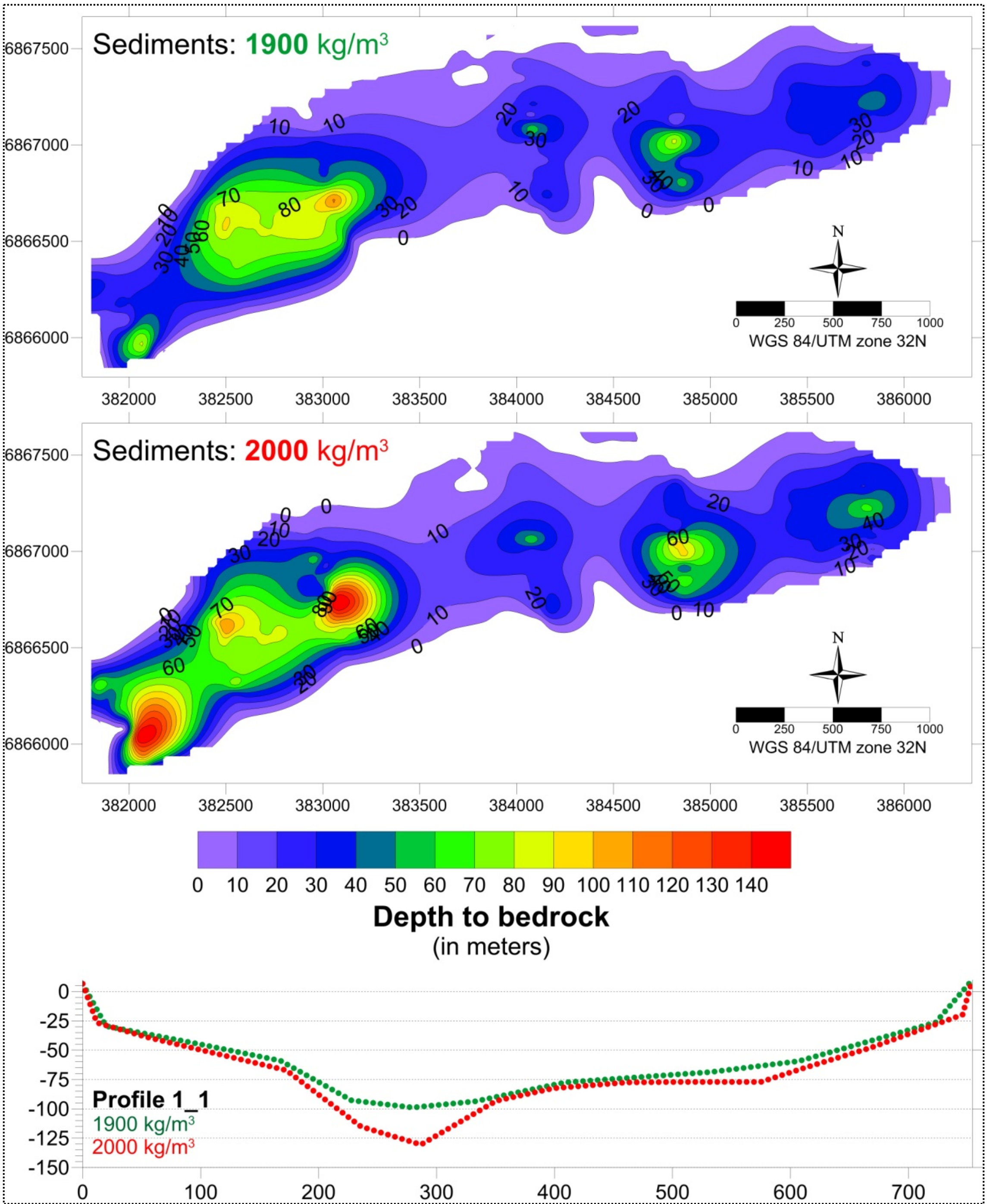

Figure 19: Top: effect of two variations of sediment density on the resulting depth to bedrock grid (1900 and 2000 kg/m^3). Bottom: same effect on the 2D interpretation of profile 1_1.

Primarily, we may deduce that a change in sediment density does not affect the shape of the resulting valley much and the depth contours retain the same pattern for the most part. Secondly, increase in sediment density (less density contrast) means increase in calculated depth to bedrock. If we narrow it down to profile 1_1 shown at the bottom of **figure 19**, we can see that a 100 kg/m^3 increase in sediment density equals to a ~25 meter increase in depth at the deepest part of the resulting basin. This difference in soil thickness becomes smaller and smaller along the slopes of the bedrock valley until the interpretations almost match each other at shallower depths. Once again we can observe that besides the quantitative difference between interpretations, the shape of the valley follows a similar pattern regardless of sediment density.

Considering the geological composition of the sediment formation we may assume that the densities chosen for the above described test also represent the minimum and maximum values that they can obtain i.e. the margin of error. Essentially, this means that a projected error for the map presented in **figure 16** would be maximum 25 m for the deepest parts of the sediment valley and reducing towards the fringes. In short, variation in sediment density may give an uncertainty of 25% of calculated depth.

8. DISCUSSION AND CONCLUSIONS

In this study, we have attempted to map the thickness of sediments east of Stryn town center in Stryn municipality by using gravity in combination with other data available at NGU. More specifically and in addition to gravity data, we have also incorporated borehole depth and density measurements, bedrock delineations originating from other geophysical studies in the region (seismic) as well as bedrock and Quaternary geological data. By doing so, we have ensured that our models share properties (at least to the knowledge database extent) with the actual formations in the area. **Figures 15**, **16**, **17** and **18** present the valley profile assuming a homogenous silty valley fill overlaying a gneiss basement. Their densities have been set equal to 1900 and 2700 kg/m^3 respectively and kept constant throughout the whole process.

Gravity measurements along profiles near Stryn reveal that sediments cause negative anomalies with amplitudes up to 2 mGal. Thereby, density models have been compiled and after fitting the observed gravity with the theoretical response of these models, sediment thicknesses have been calculated over an area of about 4 km^2. Gravimetric interpretation indicates that sediments in the region may acquire a maximum thickness of ~110 meters (~100 meters below sea level). These interpretations were then enriched with additional sediment thickness data originating from various NGU related sources and a total depth to bedrock map has been constructed. The additional information has helped the gridding process by constraining it in areas where no gravity interpretation was available. The final map portrays a good approximation of the qualitative but also quantitative distribution of sediments in the study area. In brief, sediments appear to be deeper and more voluminous at the western end of the study area.

Our gridded results verify that the sediment thickness is greater at the western part of the study area (around 100 meters) than at its eastern counterpart (~80 meters or less). Most of the thickest sediments have been deposited in overly deep basins of limited extent mainly positioned at the southern half of the profiles. The shape of the basin presents a rather uniform width throughout the valley's extent. However, the gridding process cannot overcome the lack of data in the areas between profiles. This is especially the case around profile 3 located at some distance from its neighboring profiles compared to the rest of the survey. Theoretically, the bedrock topography should be more continuous than presented in this report and such areas as the aforementioned ones should be thought of as less reliable. Uncertainty in the soil density estimation on the other hand may give a variation of 25 m in depth to bedrock in the deepest parts of the valley or in average of 25 % of estimated depth.

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APPENDIX I

Bedrock topography and soil thickness point values used as input for gridding.
**Bedrock topography in meters above sea level (positive upwards), all other values in meters*

Easting UTM 32N	Northing UTM 32N	Elevation	Bedrock Topography	Soil Thickness	Database
381758.9	6866432.6	4.6	4.6	0	Gravity
381794.5	6866380.1	1.1	-11	12.07	Gravity
381825.6	6866335.1	2	-17.26	19.22	Gravity
381860.6	6866284.6	1.8	-32.5	34.34	Gravity
381882.8	6866252.6	1.4	-24.58	26	Gravity
381905.2	6866220.2	1.4	-18.66	20.01	Gravity
381935.6	6866176.3	1.3	-31.1	32.37	Gravity
381963.4	6866136.2	1.1	-16.22	17.3	Gravity
381992	6866094.8	1.5	-5.12	6.58	Gravity
382009	6866070.2	1.9	-23.92	25.85	Gravity
382021.9	6866051.7	2.4	-49.3	51.75	Gravity
382030.4	6866039.5	2.4	-68.81	71.19	Gravity
382065.5	6865988.6	2	-74.56	76.55	Gravity
382101.4	6865936.8	2.1	-67.06	69.12	Gravity
382110.5	6865923.8	2.5	-38.86	41.31	Gravity
382116.5	6865915.1	2.5	-3.14	5.64	Gravity
382132.9	6865892.6	2.4	2.4	0	Gravity
382411.9	6866882.6	6.6	6.6	0	Gravity
382423.8	6866865	3.9	-29.49	33.35	Gravity
382441	6866788.7	3.6	-44.7	48.29	Gravity
382456.3	6866721	2.8	-59.02	61.84	Gravity
382469.6	6866662.5	2.1	-92.81	94.93	Gravity
382481	6866612	2.4	-98.89	101.26	Gravity
382492.7	6866560.4	2.2	-93.64	95.81	Gravity
382509.4	6866486.3	2	-77.5	79.48	Gravity
382536.6	6866366	3	-68.66	71.64	Gravity
382553	6866293.5	2.3	-59.35	61.63	Gravity
382578.6	6866180.6	2.5	-26.45	28.98	Gravity
382577.9	6866148.6	9.9	9.9	0	Gravity
382884.9	6867176.6	21.4	21.4	0	Gravity
382924.4	6867133.3	12.5	13.64	1.16	Gravity
382942.6	6867076.3	9.9	-3.19	13.05	Gravity
382961.4	6867017	8.8	-24.06	32.88	Gravity
382993.1	6866917.6	5.6	-33.8	39.36	Gravity
383011.2	6866860.5	4.7	-34.48	39.21	Gravity
383029.2	6866804	5.7	-36.85	42.51	Gravity
383037.3	6866778.6	6	-70.18	76.15	Gravity
383049	6866741.9	6.4	-100.48	106.86	Gravity
383070.4	6866674.7	6.5	-98.36	104.85	Gravity
383079.2	6866647	5.6	-71.23	76.79	Gravity
383093.2	6866603	4.7	-58.06	62.75	Gravity
383119.8	6866519.4	2.8	-55.43	58.24	Gravity

383130.9	6866484.4	3.3	-12.61	15.93	Gravity
383150.1	6866424.3	4	-9.54	13.59	Gravity
383131.9	6866400.6	6.5	6.5	0	Gravity
384005.9	6867488.6	73.3	73.3	0	Gravity
384023.7	6867472.6	58.5	59.48	0.95	Gravity
384033.9	6867411.7	52.1	34.64	17.44	Gravity
384043.8	6867352.7	41.2	32.9	8.28	Gravity
384051.6	6867305.7	32.1	15.03	17.1	Gravity
384066.8	6867214.8	24.1	-4.81	28.88	Gravity
384078.2	6867146.2	22.3	5.13	17.21	Gravity
384082.6	6867120.1	21.6	-21.57	43.2	Gravity
384089	6867081.5	20.1	-35.51	55.59	Gravity
384094.9	6867046	18.3	-31.59	49.92	Gravity
384099.7	6867017.7	17.5	0.22	17.3	Gravity
384108.9	6866962.2	16.2	-5.45	21.7	Gravity
384118.9	6866902.6	16	0.65	15.34	Gravity
384126.8	6866854.9	9.9	-14.45	24.38	Gravity
384135.3	6866804.4	4.9	-18.52	23.46	Gravity
384146.2	6866738.7	3.9	-24.62	28.56	Gravity
384155.8	6866681.5	3.3	-21.57	24.9	Gravity
384159.8	6866657.3	4.1	-9.8	13.92	Gravity
384145.9	6866649.6	6.7	6.7	0	Gravity
384810.9	6867454.6	20.8	20.8	0	Gravity
384790.5	6867394.4	10.6	2.32	8.25	Gravity
384798	6867334.5	9.4	-16.66	26.09	Gravity
384807	6867261.8	6.9	-16.38	23.25	Gravity
384815.8	6867191.4	8	-16.75	24.72	Gravity
384823.3	6867130.8	5.9	-11.25	17.13	Gravity
384829.4	6867081.8	6	-13.57	19.55	Gravity
384831.1	6867068.6	6	-48.21	54.24	Gravity
384833.4	6867049.9	8	-71.79	79.75	Gravity
384838.2	6867010.9	9.7	-71.07	80.77	Gravity
384843.5	6866969	12.1	-54.29	66.37	Gravity
384845.3	6866954.2	12.9	-18.21	31.08	Gravity
384849.4	6866921.2	16.8	-4.29	21.08	Gravity
384858.7	6866846.9	21.8	-28.21	49.97	Gravity
384866.3	6866785.2	34.4	-13.93	48.37	Gravity
384871.9	6866740.1	41.1	13.93	27.14	Gravity
384876.6	6866702.7	44	38.93	5.08	Gravity
384906.9	6866683.6	48.8	48.8	0	Gravity
385740.9	6867530.6	15.5	15.5	0	Gravity
385776.8	6867475.4	13	-2.7	15.67	Gravity
385781.3	6867447.1	12.4	-15.18	27.57	Gravity
385786.3	6867415.1	12.9	-21.41	34.35	Gravity
385792.2	6867378	13.7	-11.75	25.45	Gravity
385797.3	6867346	14	-8.94	22.97	Gravity
385807.7	6867280.1	19.2	-15.8	35.04	Gravity
385816.4	6867225.4	22.5	-23.28	45.82	Gravity

385820.8	6867197.5	24.3	-21.41	45.74	Gravity
385825.4	6867168.8	25.9	-7.07	33	Gravity
385828.6	6867148.4	27.7	2.2	25.5	Gravity
385837.8	6867090.4	28.6	4.16	24.44	Gravity
385846.2	6867037.5	28.7	8.52	20.22	Gravity
385856	6866975.4	36.8	25.36	11.46	Gravity
385864.7	6866920.6	41.8	37.07	4.71	Gravity
385840.9	6866899.6	42.3	42.3	-0	Gravity
382467.6	6866507	2.07	-73.66	75.74	Refraction seismic
382491.6	6866511.3	2.05	-74.94	76.99	Refraction seismic
382517.4	6866516.6	2.02	-74.13	76.16	Refraction seismic
382545.8	6866523.1	1.95	-74.62	76.57	Refraction seismic
382577.6	6866531	3.18	-74.65	77.83	Refraction seismic
382612.8	6866540.4	2.74	-75.09	77.83	Refraction seismic
382648.7	6866550.5	3.47	-75.61	79.08	Refraction seismic
382681.6	6866560	3.9	-76.33	80.23	Refraction seismic
382709.3	6866568.3	3.87	-76.47	80.34	Refraction seismic
382735.1	6866576	3.84	-76.08	79.92	Refraction seismic
382763.6	6866584	3.77	-77.82	81.59	Refraction seismic
382797.6	6866593	4.16	-78.69	82.85	Refraction seismic
382524.6	6866351	2.79	-73,86	74.91	Refraction seismic
382519	6866386.4	2.74	-74.68	76.16	Refraction seismic
382512.7	6866422.3	2.69	-78.81	79.93	Refraction seismic
382505.6	6866459	1.64	-81.16	82.86	Refraction seismic
382497.4	6866496.8	1.59	-80.69	82.44	Refraction seismic
382488.8	6866534.5	1.38	-80.95	82.41	Refraction seismic
382480.6	6866571	1.46	-78.96	80.35	Refraction seismic
382473.3	6866604.9	1.74	-74.15	75.74	Refraction seismic
382466.9	6866634.9	1.69	-74.10	75.74	Refraction seismic
382461.6	6866660	1.12	-65.94	68.63	Refraction seismic
382457.1	6866679.2	1.48	-65.47	68.21	Refraction seismic
382453.6	6866693	1.05	-65.42	68.21	Refraction seismic
385539.6	6867013	47.81	16.54	31.27	Refraction seismic
385530	6867037.1	44.58	15.62	28.96	Refraction seismic
385520.8	6867061	37.72	5.67	32.05	Refraction seismic
385512	6867084.6	34.87	0.51	34.36	Refraction seismic
385503.6	6867108	32.32	-3.12	35.45	Refraction seismic
385495.5	6867131.1	29.95	-5.96	35.91	Refraction seismic
385487.9	6867154	27.88	-7.64	35.52	Refraction seismic
385480.5	6867176.6	22.95	-10.25	33.2	Refraction seismic
385473.6	6867199	20.88	-10.78	31.66	Refraction seismic
385467.1	6867221.1	18.41	-11.7	30.12	Refraction seismic
385460.9	6867242.9	15.57	-14.16	29.73	Refraction seismic
385455.1	6867264.5	14.65	-17.01	31.66	Refraction seismic
385449.7	6867285.9	13.35	-18.31	31.66	Refraction seismic
385444.6	6867307	10.8	-20.08	30.89	Refraction seismic
382218.6	6866693	4	2	2	Drillhole
382318.6	6866793	13.6	8.6	5	Drillhole

382718.6	6867193	68.2	67.7	0.5	Drillhole
382966.6	6867198	16.3	13.8	2.5	Drillhole
385272.6	6867257	12.8	-2.7	15.5	Drillhole
381847.4	6865796.3	4.7	4.7	0	Bedrock outcrop
383575.3	6866559.4	9.6	9.6	0	Bedrock outcrop
383655.8	6866587.6	9.7	9.7	0	Bedrock outcrop
383848.3	6866633.2	7.7	7.7	0	Bedrock outcrop
383922	6866661.6	4.3	4.3	0	Bedrock outcrop
385380	6866841.6	61.8	61.8	0	Bedrock outcrop
384519.4	6866784.2	9.5	9.5	0	Bedrock outcrop
384409	6866808.4	5.4	5.4	0	Bedrock outcrop
386349.4	6867262.1	32.9	32.9	0	Bedrock outcrop
386335.3	6867333.1	18.2	18.2	0	Bedrock outcrop
384925.2	6867384.5	16.8	16.8	0	Bedrock outcrop
383696.4	6867304.8	19.9	19.9	0	Bedrock outcrop
383854	6867330.2	27.8	27.8	0	Bedrock outcrop
384830.9	6867437	22.4	22.4	0	Bedrock outcrop
384907.8	6867458.6	33.5	33.5	0	Bedrock outcrop
385191.7	6867499.8	37.7	37.7	0	Bedrock outcrop
383798.5	6867372.4	40.5	40.5	0	Bedrock outcrop
385627.7	6867556.6	33.6	33.6	0	Bedrock outcrop
384614.5	6867471.1	30	30	0	Bedrock outcrop
384754.2	6867485	34.6	34.6	0	Bedrock outcrop
384558.8	6867470.5	37.4	37.4	0	Bedrock outcrop
383471.3	6867370.2	43.8	43.8	0	Bedrock outcrop
383495.8	6867399.6	56.5	56.5	0	Bedrock outcrop
384336.4	6867478.2	52	52	0	Bedrock outcrop
383814.1	6867432.1	61.5	61.5	0	Bedrock outcrop
384503.4	6867505.6	54.6	54.6	0	Bedrock outcrop
383720.6	6867447	70.1	70.1	0	Bedrock outcrop
384333.3	6867512.6	63.3	63.3	0	Bedrock outcrop
383808.9	6867468.5	78.2	78.2	0	Bedrock outcrop
384163.6	6867523	78.3	78.3	0	Bedrock outcrop
384614.2	6867569.8	70.9	70.9	0	Bedrock outcrop
384559.6	6867570.4	77.8	77.8	0	Bedrock outcrop
385534.5	6867664.7	60	60	0	Bedrock outcrop
384400.2	6867575.6	91	91	0	Bedrock outcrop
383841.2	6867584.4	143.1	143.1	0	Bedrock outcrop
384332.4	6867635.3	125.4	125.4	0	Bedrock outcrop
383970.5	6867621.1	148.8	148.8	0	Bedrock outcrop

GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

Geological Survey of Norway
PO Box 6315, Sluppen
N-7491 Trondheim, Norway

Visitor address
Leiv Eirikssons vei 39
7040 Trondheim

Tel (+ 47) 73 90 40 00
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/