Hands on LithoFlex

The West Siberian Basin as exemplary case

LithoFlex course

Work book

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LithoFLEX

Overview

1° Day

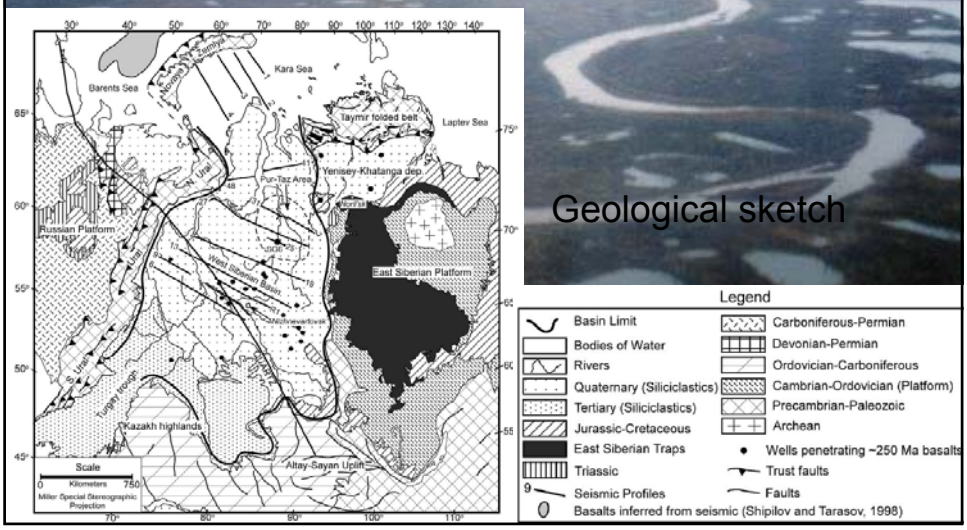
- Introduction to grids
- Gravity inversion
- Gravity forward calculation
- Gravity sediment modelling

2°Day

- Equivalent load calculation
- Make synthetic topography
- Flexure forward modelling
- Flexure inverse modelling

LithoFLEX

Working Area: West Siberian Basin (WSB)



Geological sketch

Before using LithoFlex pay attention that:

1) Use the international option:
   - in the Control Panel click on ***hours or language and international options***;
     then click on ***change the format of numbers, date and time / customize / numbers.***
   - *the decimal separator must be **the point** (“.”), and*
   - *the symbol of digit grouping **the comma** (“,”)*
2) The format grid file must be ASCII, not binary

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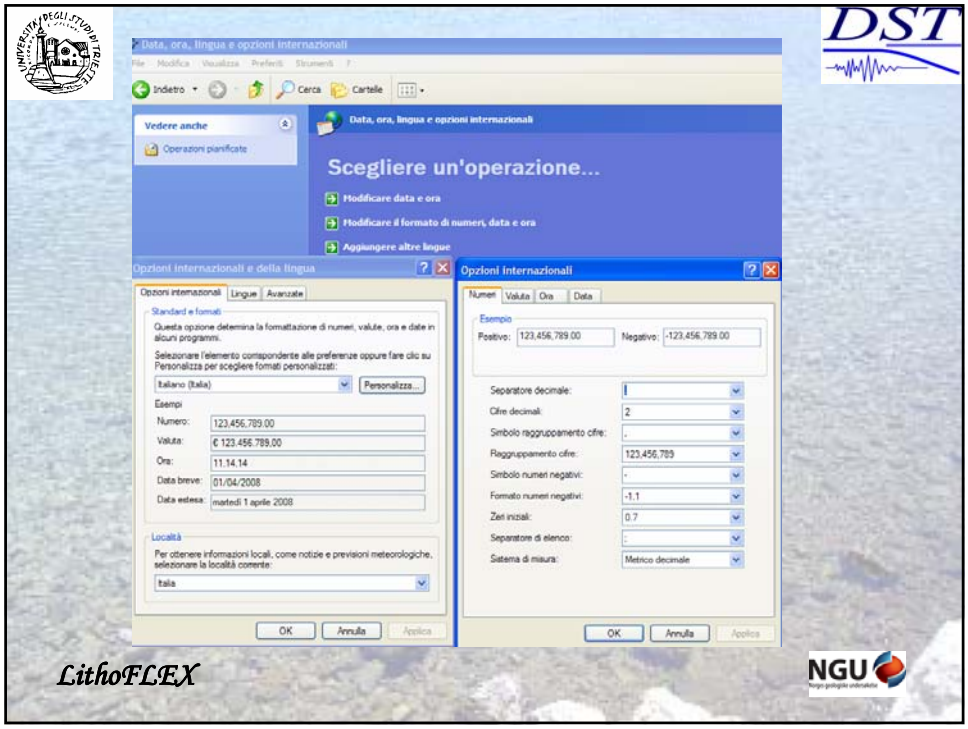

FORMAT OF FILES

- *LithoFlex* uses:

1) Cartesian coordinates in meters (x,y,x)
2) The Z axis is positive upward (m)

   Therefore the Moho depth is negative downwards (m)
3) The thickness is positive (m)

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Grid preparation

- *LithoFlex* requires *Surfer ASCII Grids*
- Geosoft format *GXF* grids (uncompressed) can also be used, but must be converted using the gridMan option in *LithoFlex*.

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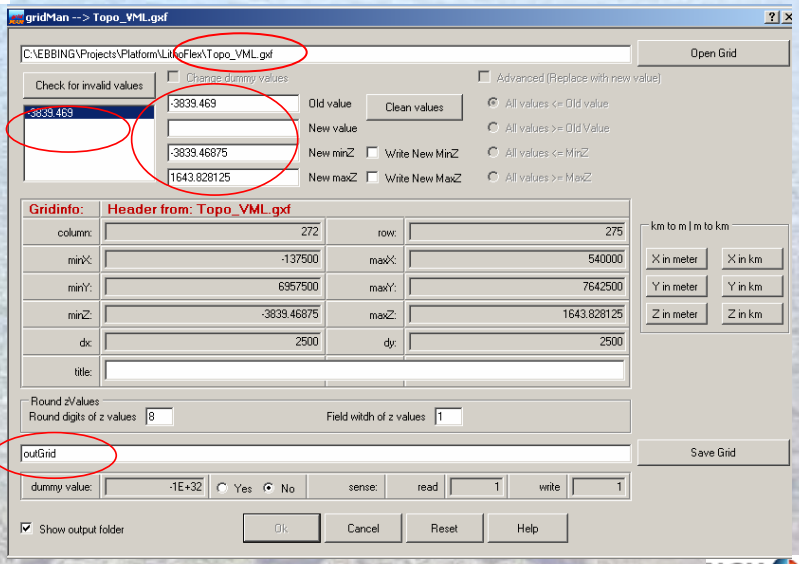
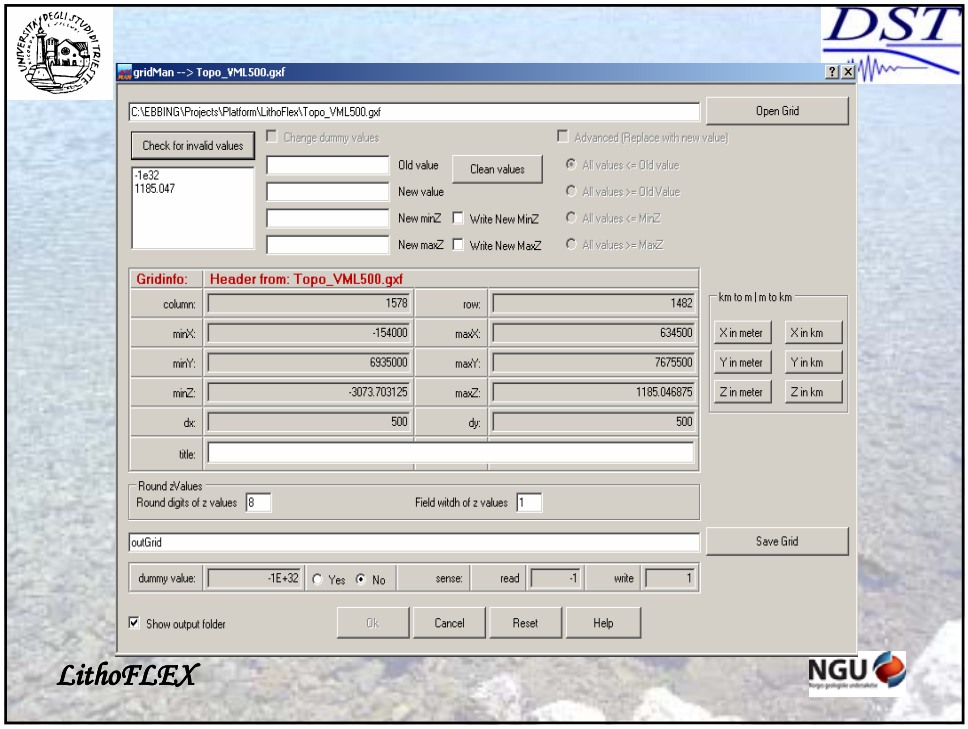
Tool: GRIDS/GridMan



LithoFLEX

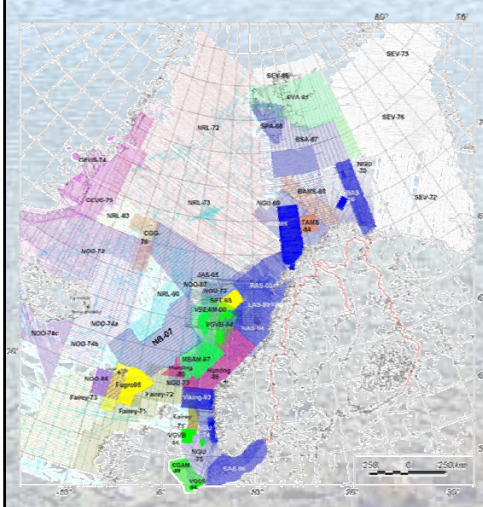


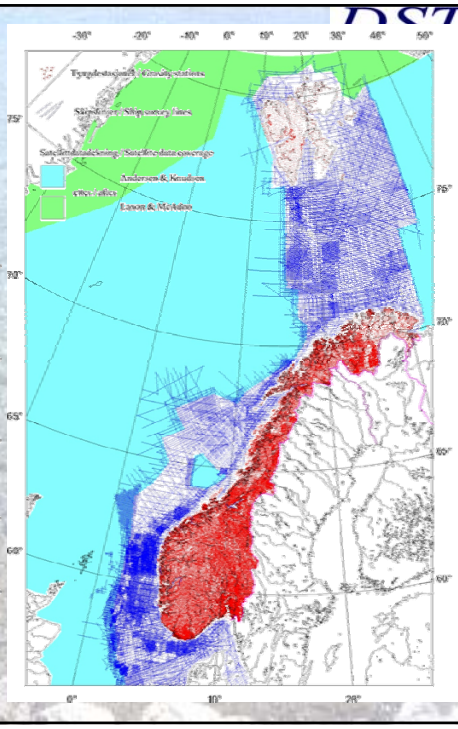
Grid Preparation step by step

- Define study area
  - Boundary effects: grids should be larger than study area
  - If not possible: Use techniques like mirroring
- Define grid spacing
  - Do not use numbers of grid cells (e.g. 100 x 100), which could result in 7.498 km and 1.2887 km grid spacing
  - Use a constant grid spacing in X and Y-direction: e.g. 5000 m
  - use a grid size appropriate for your study area; e.g. Barents Sea, North Atlantic: 10000 m, Froan basin: 2000 m; and your input data!
  - smaller grid-sampling barely lead to more realistic results, but increase computing time exponentially and pretend detailed results which may not be justified by the input data

LithoFLEX NGU

NGUs gravity and magnetic database





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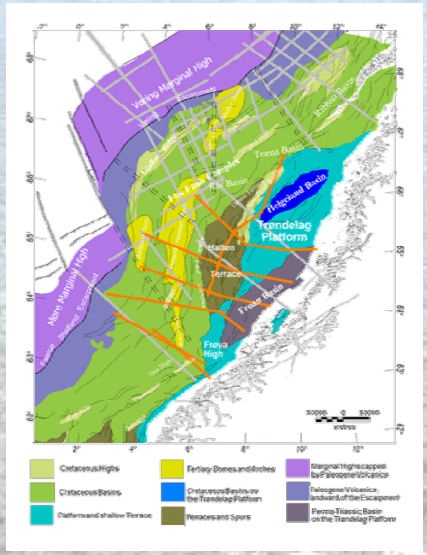
Seismic information of Mid-Norwegian margin



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Grid Preparation step by step

- Carefully check definition of thickness, heights etc. in terms of **+/-** signs
- Save grid as *Surfer ASCII* or *GXF-grid*
- Load grid in *gridMan* and check for dummies/errors and correct them (!)
- Save grids in Surfer *ASCII* format and use *LithoFlex*

Before start:
Customize programs (Grapher etc.)

LithoFlex/Surfer/Grapher :
C:/*LithoFlex*/Exercises/Example/WSB;

- Surfer/File/Prefereces/Default path:
  C:/*LithoFlex*/Exercises/Example/WSB;
- Grapher/File/Preferences/General/Browse/
  C:/*LithoFlex*/Exercises/Example/WSB;
- Lithoflex: Extras/Options/Use Project Path/
  C:/*LithoFlex*/Exercises/Example/WSB.

1st step: Describe given fields and maps

- Use Surfer or Geosoft
- Create maps and simple profiles
- give short description of properties of fields

- Topography
- Sediment thickness
- Bouguer anomaly
- Free airy anomaly
- Moho undulation

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Working files for WSB

Bouguer field	→	**boug.grd**
Topography	→	**topo.grd**
Sediment thickness	→	**sedithick.grd**
Moho discontinuity	→	**Moho.grd**
Free air anomaly	→	**FA.grd**
Variable Te grid	→	**Var_te.grd**
Layer synthetic density	→	**density.grd**
geografical coordinate	→	**wsb_topo.grd**

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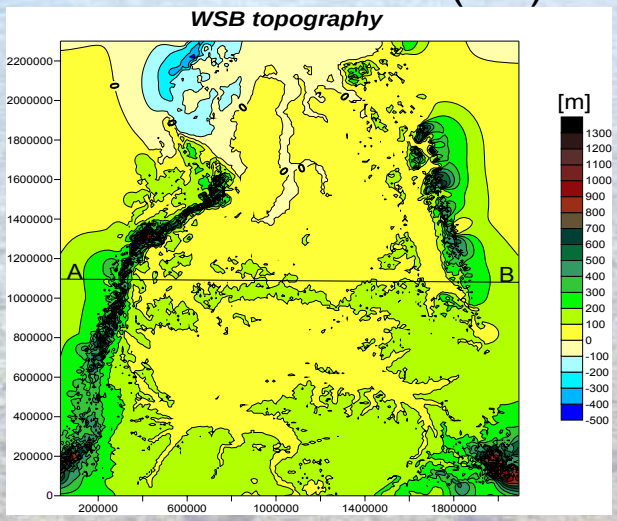
Grids in folder ..\Wb_grids

Example profile along a west-east section (AB)



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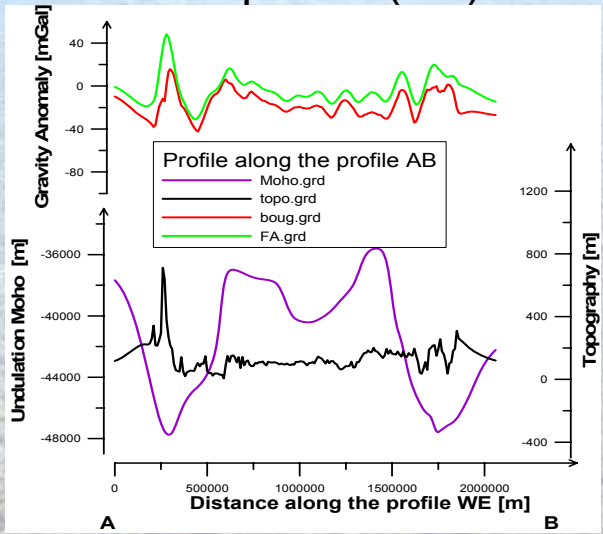
Different quantities along the WE profile (AB)



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In the following the maps of the grids are shown:

- Topography
- Sediment thickness
- Free air anomaly
- Bouguer anomaly
- Moho undulation

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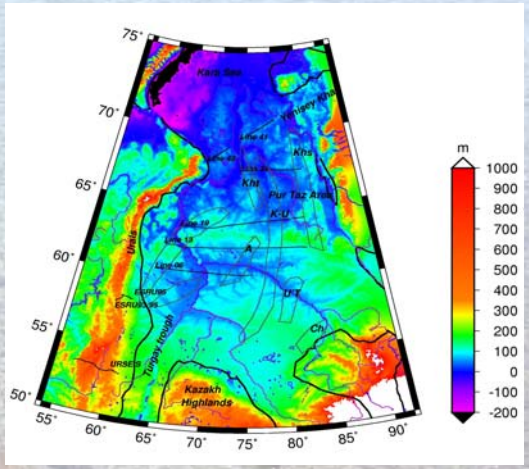
Topo

Extended grid

2 070 000 m sidelength (X)
2 300 000 m widelength (Y)

Xmin=30 000 m
Xmax=2 090 000 m
Ymin=0 m
Ymax=2 300 000 m



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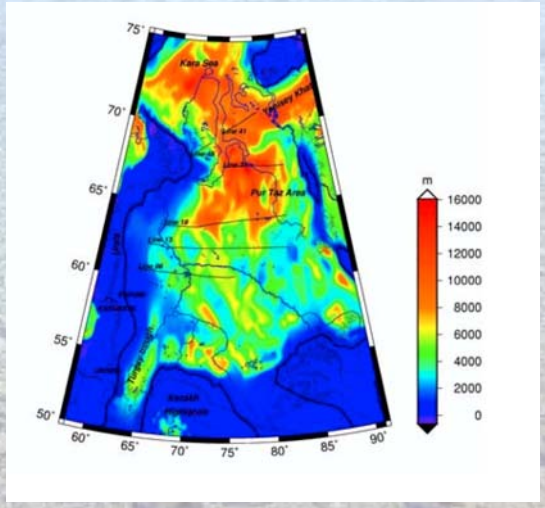
Sediment thickness



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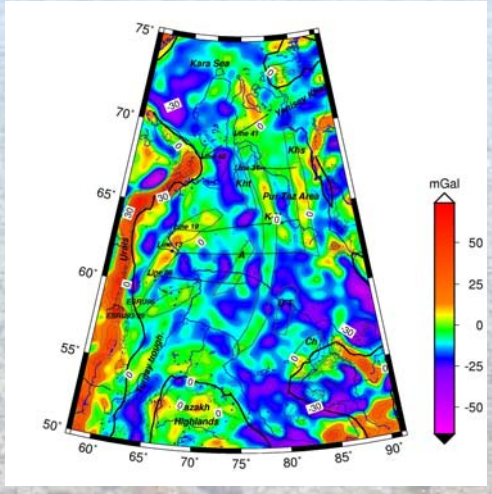
Gravity anomaly



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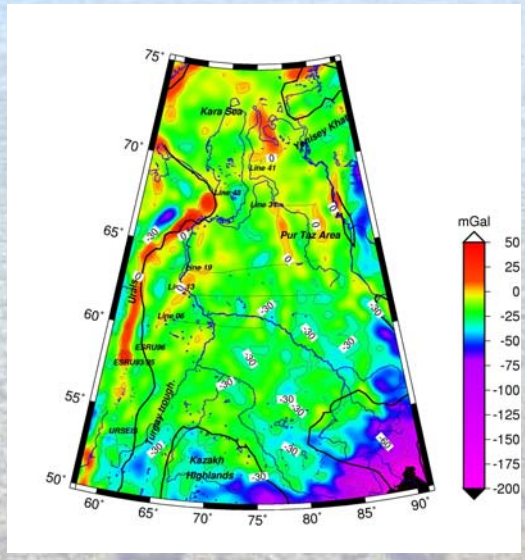
Bouguer field



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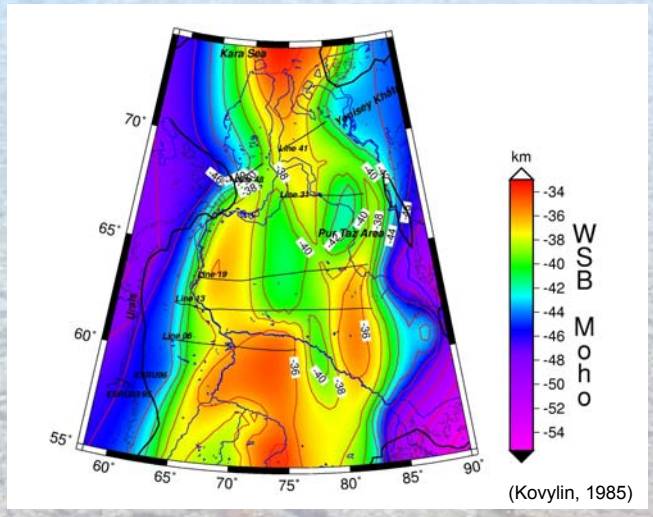
Moho



(Kovylin, 1985)

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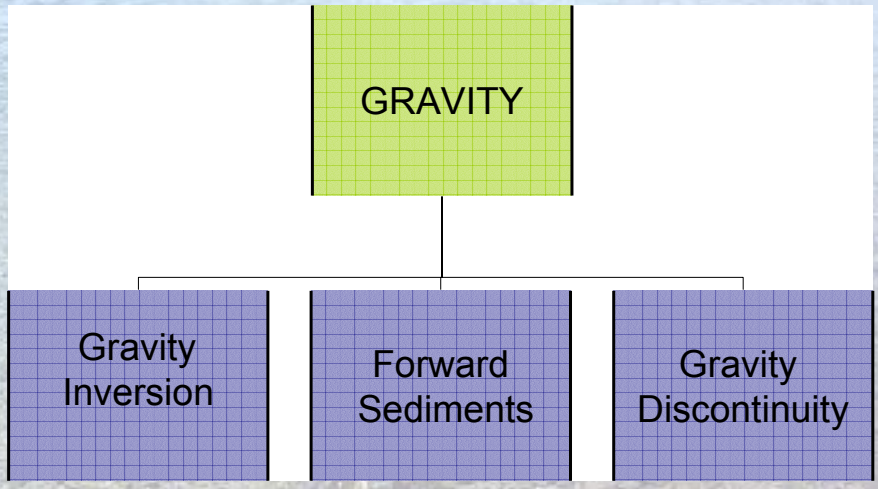
The *LithoFlex* GRAVITY tool



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2nd step

- Goal: Estimation of the Crust-Mantle Interface→ Moho undulation of WSB
- Method: *Gravity Inversion*

  Inversion of Bouguer gravity field
- *LithoFlex* Tool→GRAVITY/Gravity Inversion

LithoFLEX

Gravity Inversion

- Input files:

1) gravity grid: **boug.grd**
2) density grid → if '99' is the dummy value
- Reference depth
- Minimum period (Pmin)
- Number of iteration

- Output files:

1) Output surface: **root_final.grd**
2) boundary gravity: **gravroot.grd**
3) residual gravity: **gresid.grd**

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Complete Table of Input and Output files

GRAVITY/GRAVITY INVERSION		*Description*
INPUT FILE	bouguer.grd	Input gravity field
	density.grd	Input density grid, if for the contrast density is "99"
OUTPUT FILE	root_final.grd	Output undulation
	gravroot.grd	Gravity of undulation
	gresid.grd	Gravity residual (observed gravity minus undulation gravity)
	outg0.grd	Copy of input gravity field
	Gravity Inversion_log.txt	Log file
	g_parkerinv_SI.inp	Parameter input file
	invert2d_SI.inp	Parameter input file
	prism.dat	Approximation of inverted layer by rectangular prisms
	resuld2d.dat	Summary of iteration step

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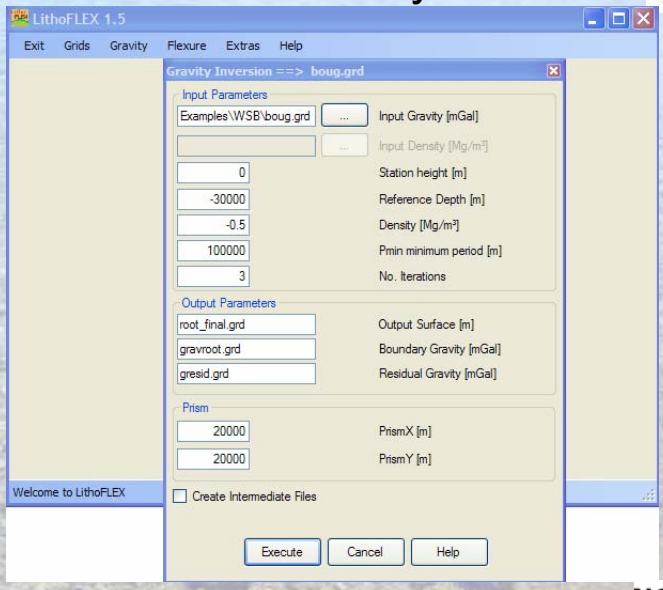
Tool: GRAVITY/ Gravity Inversion



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Test 2nd step:

LithoFlex Tool→Gravity/Gravity Inversion:

- Input file: boug.grd [mGal]
- Station height: **3175** [m]
- Test different cut-off wavelengths [Pmin]:
- **100 000**, **200 000**, **300 000** [m];
- Station height: **3175** [m];
- Test different reference depth:
- **-10 000**, **-30 000**, **-50 000** [m];
- Contrast density: **-0.35** [Mg/m^3];
- Give the names and save the files;
- Give a synthetic description of resulting boundary.

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Comparison: Gravity-Moho (Root_final_re.grd) and Seismologic Moho (Moho.grd)

- Run again Inversion Gravity with these values:
- Input file: **boug.grd** [mGal]
- Station height: **3175** [m]
- Reference depth: **-35 000** [m]
- Contrast density: **-0.35** [Mg/m^3]
- Pmin: **270 000** [m]
- Save the output files: Root_final_re.grd
- Compare two files: How can you explain the differences?

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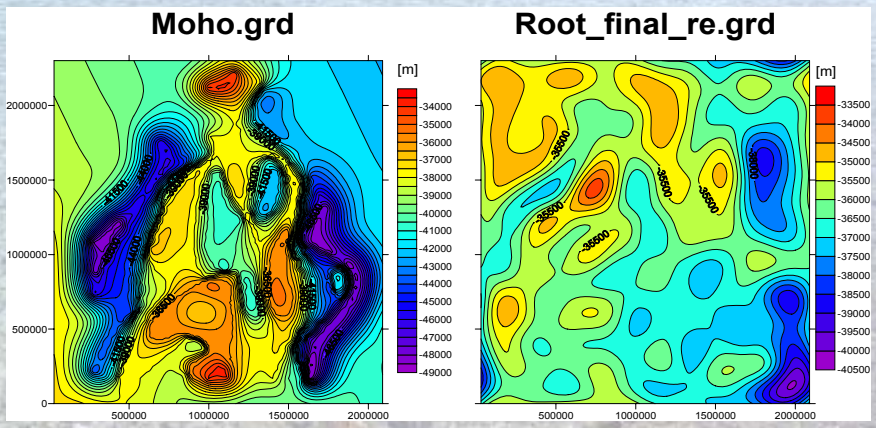
Comparison



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3rd step

- Goal: Estimate the gravity field corresponding to the Moho
- Method: forward calculation of gravity field
- *LithoFlex* Tool→GRAVITY/Gravity Discontinuity

Gravity Discontinuity

- Input file:

1) Undulation CMI
   use the seismic moho: "Moho.grd"
1) density grid → if '99' is the dummy value

- Reference depth
- Density contrast

- Output file

1) gravity field of undulation: **grav.grd**

Complete Table of Input and Output files

GRAVITY/ GRAVITY DISCONTINUITY		*Description*
INPUT FILE	**root_final.grd**	**Undulation of input discontinuity**
	density.grd	**Input density grid, if for the contrast density is "99"**
OUTPUT FILE	**grav.grd**	**Gravity of discontinuity**
	parker_rho_SI.inp	**Parameter input file**
	Gravity discontinuity_log.txt	**Log file**

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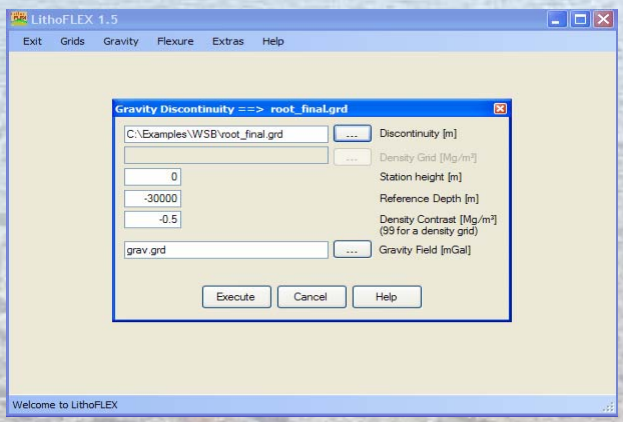
Tool: GRAVITY/Gravity Discontinuity



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Test 3rd step (a)

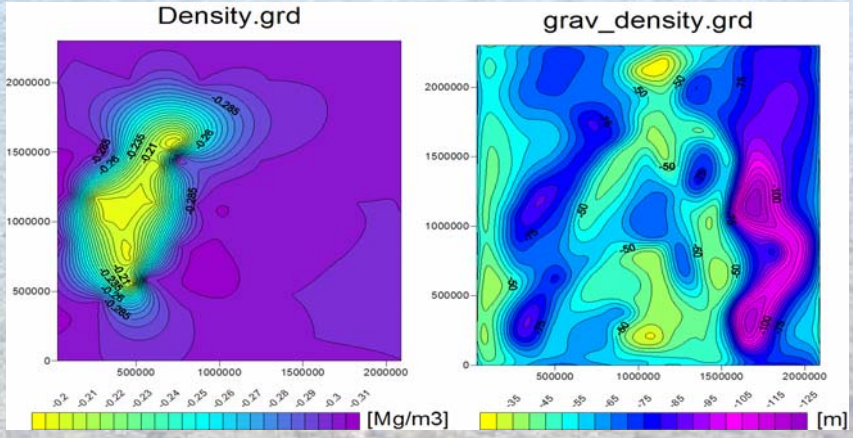
LithoFlex Tool→Gravity/Gravity Discontinuity:

- Type an input file for the discontinuity: **Moho.grd** [m]
- Change the density contrast: **-0.35, -0.5** [Mg/m^3];
- Use a constant reference depth: **-35 000** [m]
- Save the files with a suffix of the applied values;
- Give a description of the results

Test 3rd step (b)
Use a synthetic density grid

- Insert a grid file for discontinuity: **Moho.grd**
- Type "**99**" in the box for the density contrast;
- Insert grid file for the density field: **density.grd**;
- Station height: **3175** [m],
- Reference depth: **-35 000** [m];
- Give the output name: **grav_density.grd**

Synthetic density field



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4th step:

- Goal: Calculate bottom of sediments
- Method: *LithoFlex* tool→ GRIDS/Combine Grids
- Open 1st input file: topo.grd
- Open 2ndinput file: sedithick.grd
- Save the output: basement.grd
- Click: subtraction

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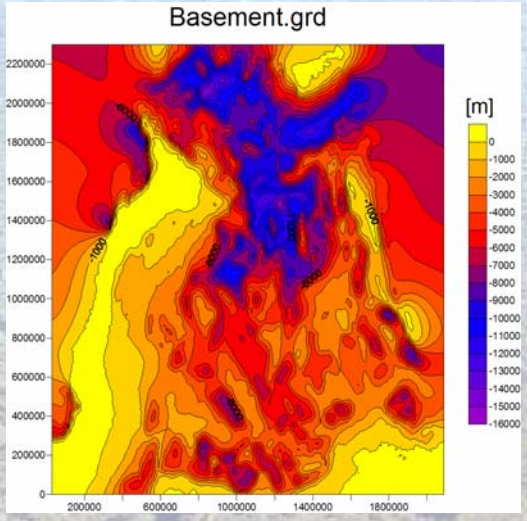
Basement



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5thstep

- Goal: Calculate the gravity corresponding to the sedimentary succession
- Method: Forward modelling
- *LithoFlex* Tool → GRAVITY/Gravity Forward Sediments
- *LithoFlex* offers two methods

GRAVITY EFFECT of sedimentary cover

LINEAR DENSITY

EXPONENTIAL COMPACTION

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LINEAR-EXPONENTIAL SEDIMENT

GRAVITY FORWARD SEDIMENT			
INPUT FILE	sedithick.grd topo.grd	FILTER*	batfilt.grd filterh.grd
OUTPUT	gsed → loadsed.grd →	Gravity of sediment Load of sediments	

NB: To distinguish between the linear and exponential test, the user should add a suffix for description: example: gsed_lin.grd and gsed_exp.grd

*** Filter is applied to reduce high-frequency components in topography**

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Complete Table of Input and Output files

GRAVITY/GRAVITY FORWARD SEDIMENTS			
INPUT FILE	**sed.grd**	**FILTER**	**batfilt.grd**
	Bathy.grd (topo)		**filterh.grd**
OUTPUT FILE for Linear density	***Description***	**OUTPUT FILE for Exponential compaction**	
gsed.grd	**Gravity of sediments [mGal]**	**gsed.grd**	
loadsed.grd e.g. *loadsed_linear.grd*	**Load of sediments [kg/m^2]**	**loadsed.grd e.g.*loadsed_expo.grd***	
Gravity Forward Gravity_Sediment_Linear_Density.log.txt	**Log file**	**Gravity Forward Gravity_Sediment_Linear_Density_Exponential_Compation.log.txt**	
filterf90_SI.inp	**Parameter input file**	**filterf90_SI.inp**	
g_fette2d_sedlin.inp	**Parameter input file**	**g_fette2d_sed.inp**	
testsed_SI.dat	**Density depth profile at given location**	**testsed_SI.dat**	

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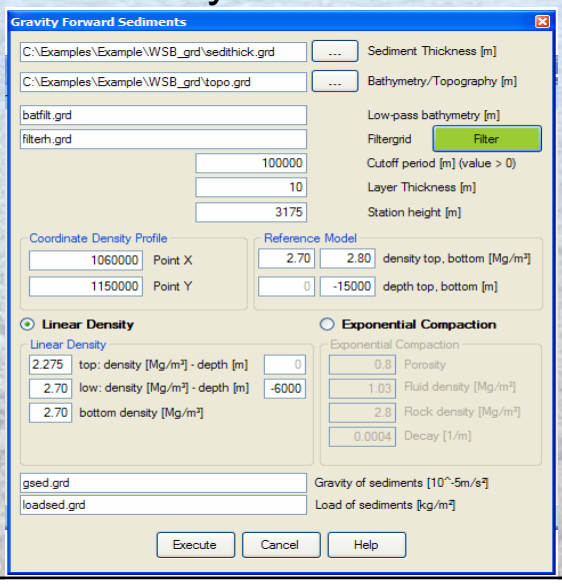
Tool:
GRAVITY/Gravity Forward Sediments



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Testing several parameters

Input files: sedithick.grd
topo.grd

Cutoff period: 100000 [m]
Layer thickness: 10 [m]
Station height: 3175 [m]

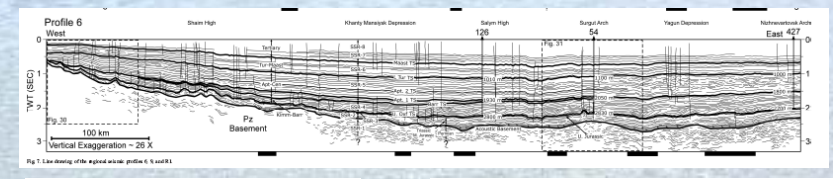
Reference model

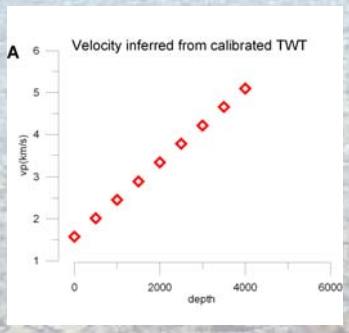
Reference density:	Reference depth:
-top layer= **2.7** [Mg/m^3]	-top: **0** m
-bottom layer= **2.8** [Mg/m^3]	-bottom= **-15000** m

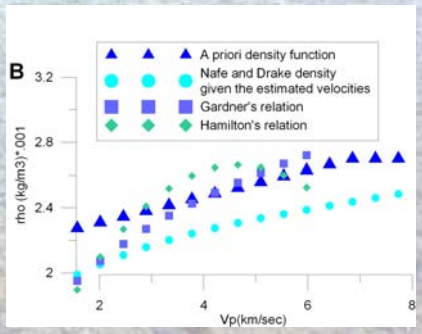
Parameters for linear density:
- Top density: **2.275** [Mg/m3]
- Depth of top density: **0** m
- Lower density: **2.7** [Mg/m3]
- Depth of lower density: **-6000** m
- Bottom density: **2.7** [Mg/m3]
- Save: **gsed_lin.grd**
- Save:**loadsed_lin.grd**
- Click **execute** bottom

Parameters for exponential compaction:
- Porosity: **0.8, 0.70**
- Fluid density: **1.03** [Mg/m3]
- Rock density:**2.7** [Mg/m3]
- Decay [1/m]: **0.0009**
- Save: **gsed_exp.grd**
- Save: **loadsed_exp.grd**
- Click **execute** bottom

Converting TWT to velocity-depth







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A) Equation for "Linear density"

- The linear variation is calculated as follows:

The density rho(z) at depth z is (z inside sediments):

$$\rho(z) = \rho_{top} + (\rho_{low} - \rho_{top})\, h_{sed} / (h_{low} - h_{top})$$

otherwise:

- rho(z)=[BottomDensity].

- The parameters for linear density defined by users:

- Top and low density
- Reference depth of top and low density
- Bottom density

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B) Exponential compaction

$$\rho(z) = \Phi_0 \cdot e^{-b \cdot z} \cdot \rho_f + (1 - \Phi_0 \cdot e^{-b \cdot z}) \cdot \rho_S$$

The parameter must to be defined by the user:

$\Phi 0$ = initial [Porosity] of the sediments
ρf = [Fluid density]
ρs =[Grain/Rock density]
b =[Decay] (1/m)
z = [depth] (m)

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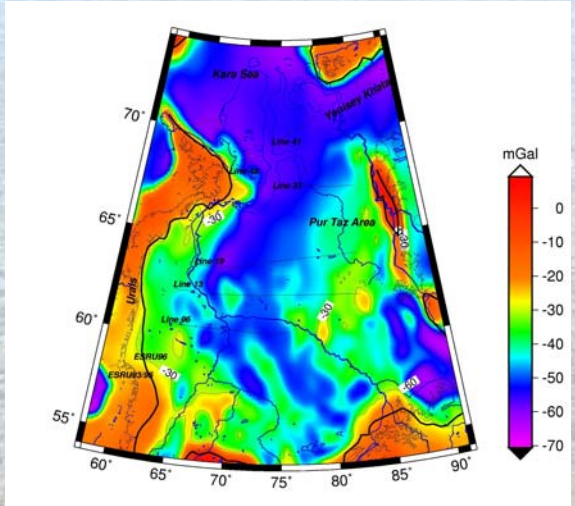
Gravity of sediments for linear density



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6th Step

Goal: Correction of known masses:

- Gravity effect of underlying structures
  - Gravity effect of sedimentary rocks
  - Gravity effect of crustal thickness

Method: *LithoFlex* tool→ GRIDS/Combine Grids

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Correct for gravity effect of sedimentary rocks

- Goal: Calculate the residual between the Bouguer anomaly and the field of Gravity Sediment
- Use the function: *LithoFlex*/GRIDS/Combine Grids:

-Open grid1→open the file: **boug.grd**

-Open grid2→open the file: **gsed_lin.grd**

(linear tests)

-Give a name for the output grid: **residual1_grav.grd**

-Check **subtraction**

-Click **Execute**

LithoFLEX

Gravity effect of crustal thickness

- Goal: Calculate the residual by subtracting from **residual1_grav.grd** the field of the Moho
- Use the function: *LithoFlex*/GRIDS/Combine Grids:

-Open grid1→open the file: **residual1_grav.grd**;

-Open grid2→open the file: **grav_density.grd**;

-Give a name for the output grid: **residual2_grav.grd**

-Check **subtraction**

-Click **Execute**

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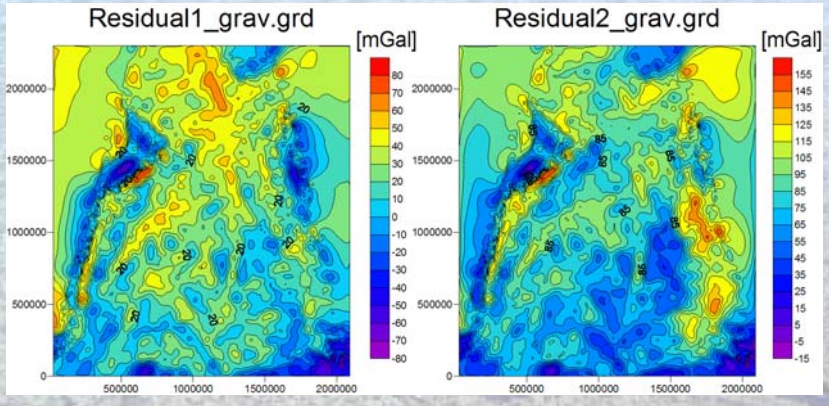
Residual field



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Filtered residual

One can use the filter available in *Gravity Forward Sediment*

- Gravity/Gravity Forward Sediment:
- Sediment thickness: **residual2_grav.grd**;
- Bathymetry: **residual2_grav.grd**;
- Give a name for: Low pass bathymetry: **residual2_filt100.grd** or **residual2_filt270.grd**
- Filter grid: **filterh.grd**
- Cut-off period: **100 000** and **270 000** [m];
- Layer thickness: not important, click a number;
- Station height: 3175 [m];
- Click "**Filter button**"
- Give a description of the result: **residual2_filt100.grd** or **residual2_filt270.grd**

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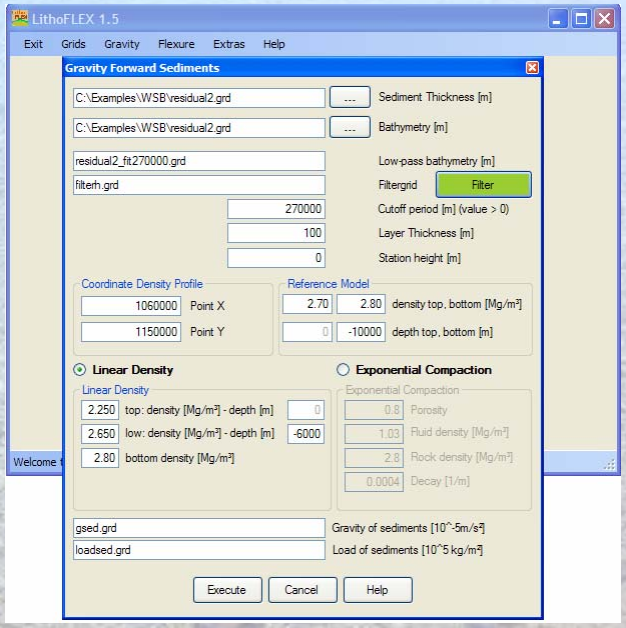
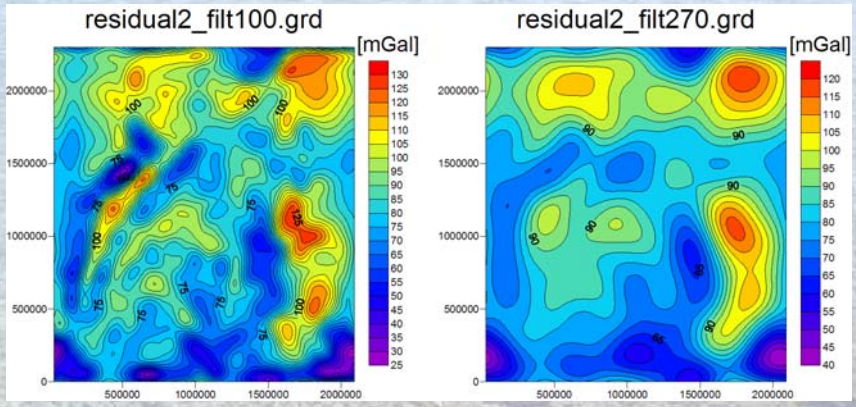


LithoFLEX

Residual field filtered



LithoFLEX

7th step

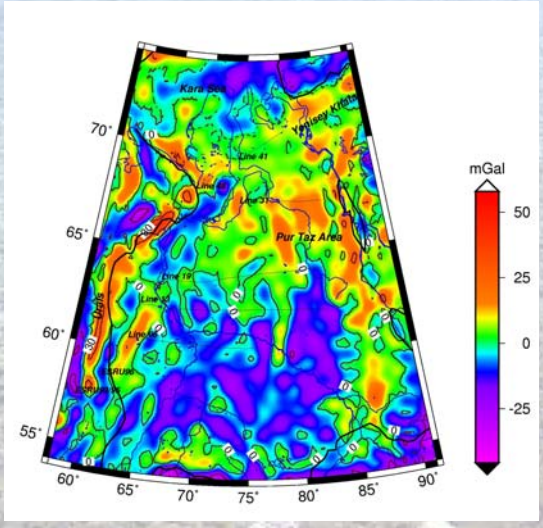
- Goal: Gravity Inversion of residual field
- Make a gravity inversion of the high-pass residual field to obtain:
  - Superficial masses

- LithoFlex/GRIDS/Combine Grids:

- Open grid1→open the file: **residual2_grav.grd**;
- Open grid2→open the file: **residual2_filt270.grd**;
- Give a name for the output grid: **residual2_highpass.grd**
- Check **subtraction**
- Click **Execute**

LithoFLEX

Residual gravity high-pass filtered



LithoFLEX

…continues: Gravity Inversion of residual field

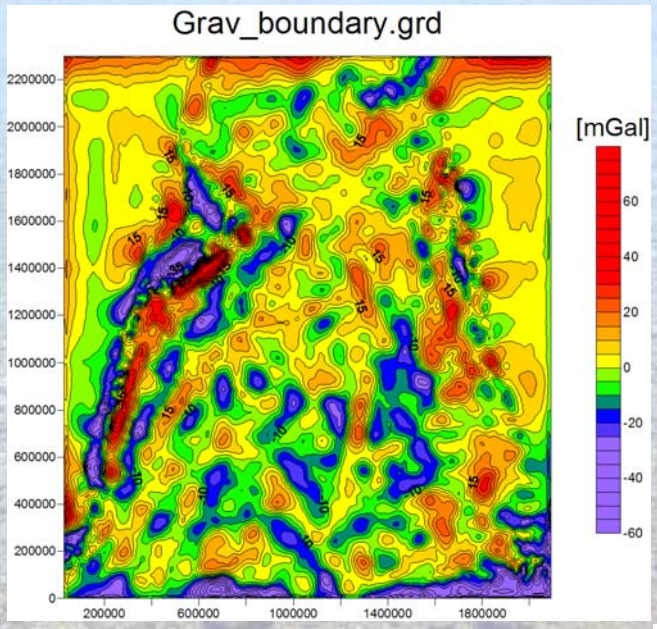
Model: positive anomalies due to basalt filling rifts

Example parameters for: *LithoFlex*/GRAVITY/Gravity Inversion:

- Input file: **residual2_highpass.grd**
  - Station height: **3175** m
  - Reference depth=**-5000** m
  - Density contrast= **+0.3** Mg/m^3
  - Pmin= **20 000** m
  - Test different cut-off wavelengths

- Save the Output file:
1) Boundary_high.grd [m];
2) Grav_boundary.grd [mGal];
3) Gresid_boundary.grd [mGal]

LithoFLEX



LithoFLEX

NGU

Interpretation of the high-pass filtered residual field

- Interpretation: boundary below reference depth: increased basalt thickness
- Negative anomalies would correspond to density variations, and result here as boundary above reference depth.
- This inversion allows a first estimate of what the basalt filling amounts to be in order to explain the anomalies.

LithoFLEX

NGU

Second day

Testing the tools:

- GRIDS/Make Equivalent Topo
- GRIDS/Make Synthetic Topo
- FLEXURE/Forward Te
- FLEXURE/Inverse Te

LithoFLEX

Work files for the 2nd day

Topography	→	**topo.grd**
Variable Te grid	→	**Var_te.grd**
Moho discontinuity	→	**Moho.grd**

LithoFLEX

1st Step
EQUIVALENT TOPOGRAPHY

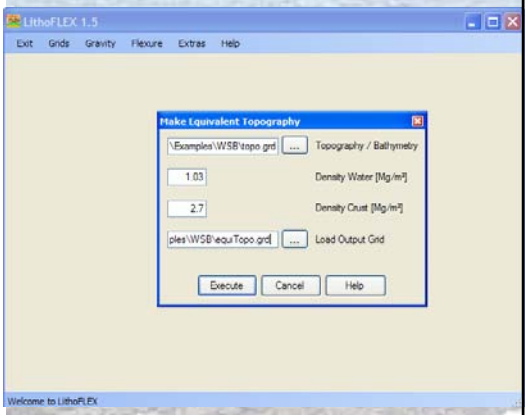
- Goal: Consider the gravity and the load of water in the sea or ocean
- Method: replace water with crustal mass
- *LithoFlex* tool: *LithoFlex/*GRIDS/ Make Equivalent Topography
- To be created, if the topography grid includes bathymetry
- It is the input file for the FLEXURAL test

Complete Table of Input and Output files

GRID/MAKE EQUIVALENT TOPO		***Description***
INPUT FILE	topography.grd or bathymetry.grd	Topography or bathymetry
OUTPUT FILE	equiTopo.grd	Equivalent topography
	pseudo_topo.inp	Parameter Input file
	Make Equivalent Topography_log.txt	Log file

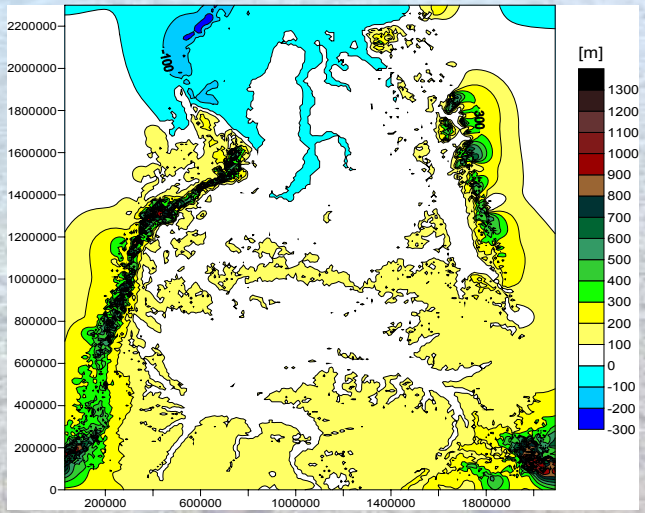
CREATION OF EQUI TOPOGRAPHY

- In GRIDS tool choose "Make equivalent topography"
- Choose **topo.grd**
- Put the value for the density water (**1.03**) and crustal density (**2.7**)
- Give a name for the output grid: **equiTopo.grd**
- Click the button **Execute**
- Plot a output file



LithoFLEX

equiTopo.grd



LithoFLEX

2nd step
MAKE A SYNTHETIC TOPOGRAPHY

Goal: Creation of a Synthetic Topography

Method: a bell shape topography is synthetically created

Application: study the flexure response to different types of bodies.

LithoFlex tool: Grids/ Make Synthetic Topography

There are two methods for topography creation:

1) Choose each parameter
2) Random parameters: in this case the program decides automatically the values for the synthetic topography

LithoFLEX

THEORETICAL BACKGROUND
How to make synthetic topography

The solid surface is described by:

$$z(x, y) = h \cdot amp \cdot e^{-\frac{y_r^2}{sig}}$$

-"*sig*" is the square of halfwidth of topo bell,
-"*len*" is the length along the topo bell,
-"*amp*" is the amplitude of topo bell
-"alfa" is the azimuth

$$x_r = ac\ x - as\ y$$
$$y_r = as\ x + ac\ y$$
$$ac = \cos(alfa); as = \sin(alfa)$$

$$h(x,y) = \left[\cos\left(\frac{x_r}{len}\pi\right) + 1\right] * 0.5$$

(for argument of cosine < π)

h(x)=0 (otherwise)

LithoFLEX

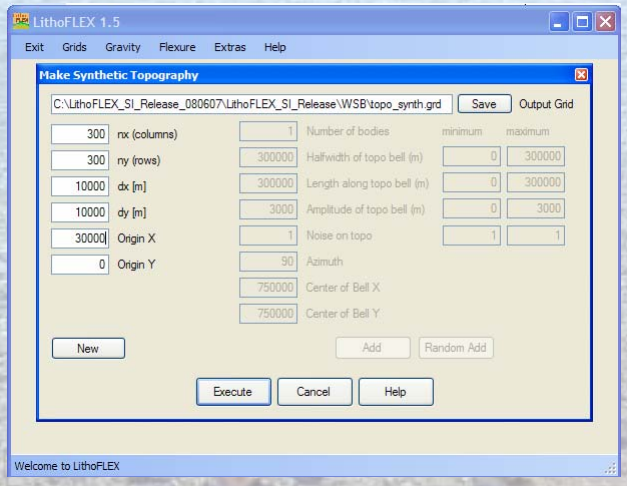
Complete Table of Output files

GRID/ MAKE SYNTHETIC TOPO		Description
OUTPUT FILE	**topo.grd**	Synthetic topography
	Make_Synthetic Topography_log.txt	Log file
	make_topo.inp	Parameter input file

LithoFLEX

NGU

Tool: GRIDS/ Make Synthetic Topo



LithoFLEX

NGU

Application of Make topo (1 case)

- On the tool *Grids/Make synthetic topography*
- Give a name for the output file: topo_synth.grd,
- Save into the folder Example/Load
- Choose the value for the grid dimension:
  - **[nx columns] [ny row]**: dimension of the grid, type (300, 300);
  - **[dx]** (m), **[dy]** (m): sampling of grid, type (10000,10000);
  - **[Origin (X)],[Origin (Y)]**: centre of grid, type (30000, 0).
  - Press the button **New**
  - Type 1 for number of bodies.

- Type 400000 for the value of the **[halfwidth of topo bell]**;
- Type 1200000 for the value of the **[length of topo bell]** it is the x direction of topography;
- Type 300 for the value of the **[amplitude of topo bell]**;
- Type 0 for the value of the **[noise of topo];**
- Type 90° for the value of the **[azimuth]**;
- Type (1500000, 1500000) for the value of the **[Center of bell X, Center of bell Y];**
- Finally, click **Execute**

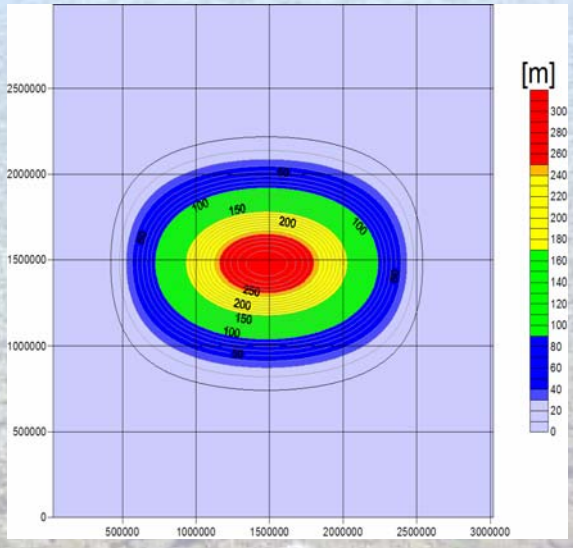
Parameters to apply

nx	*ny*	*dx*	*dy*	*Origin x*	*Origin y*
300	*300*	*10000*	*10000*	*30000*	*0*

Model	Halfwidth	Length	Amplitude	Noise	Azimuth	Center x	Center y
A	400000	1200000	300	0	90°	1500000	1500000

LithoFLEX

Topo_synth.grd



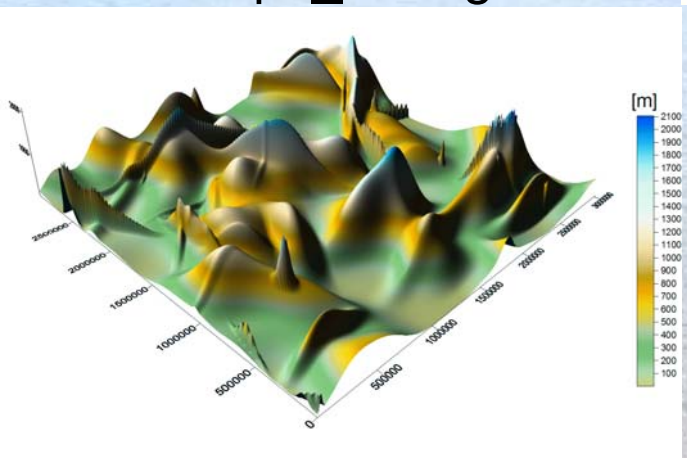
LithoFLEX

Application of Make topo (2nd case): Random function

- On the tool *LithoFlex/GRIDS/Make synthetic topography*
- Give a name for the output file:
- Save the output file *Example/load/**topo_rand.grd***
- Use the same values as previously for n, m, dx, dy, origin x, origin y
- Press **[new]** button and choose *the number of bodies:* "**100"**
- Choose the range for **minimum and maximum** values of:
  halfwidth of topo bell (m), length along of topo bell (m), amplitude of topo bell (m), and noise of topo:
- Type "**0 and 300000**" for the **[minimum and the maximum]** value of the ***halfwidth of topo bell***. The values limit those used by the random function
- Type "***0, 1000000"*** for the **[minimum and maximum]** ***length of topo bell***
- Type "***0, 1000"*** for the **[minimum and maximum]** value for the ***amplitude of topo bell***
- Type "0,0"for **[the minimum and maximum]** value for the ***noise on topo***
- Click the **[Random Add]** button: the program decides automatically the values of halfwidth of topo bell (m), length of topo bell (m), amplitude of topo bell (m), of that are limited into a range decide by user.
- Click the [**Execute**] button and the output will be created.

LithoFLEX

Topo_rand.grd

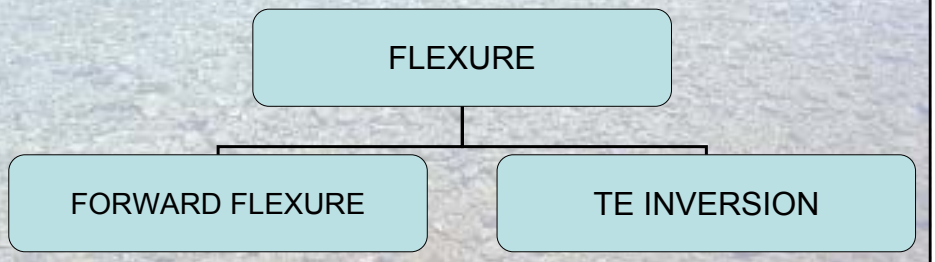


nx	*ny*	*dx*	*dy*	*Origin x*	*Origin y*
300	*300*	*10000*	*10000*	*30000*	*0*

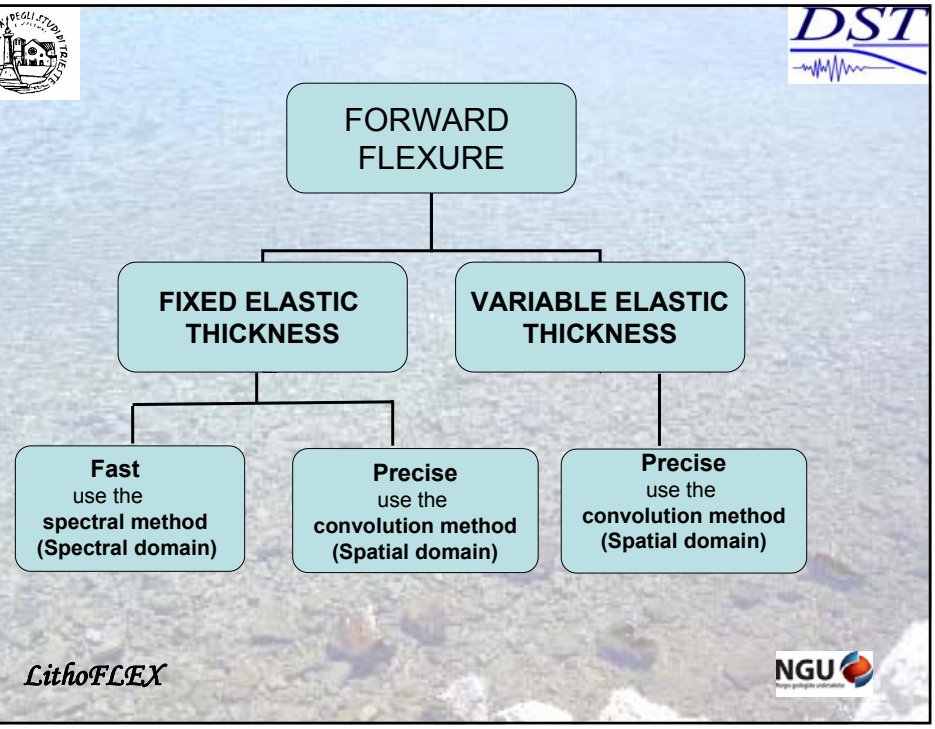
LithoFLEX

3rd step: FLEXURE TOOL

- Goal: Use Regional Isostasy
- Methods: Forward modelling using two methods (see next slide: convolution and spectral method)
- *LithoFlex* Tool→/FLEXURE, one can choose between two tools:

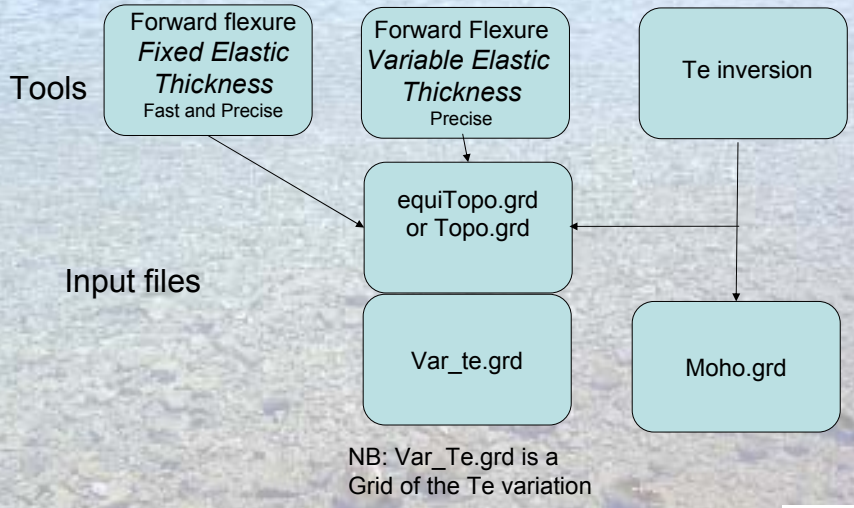


LithoFLEX



LithoFLEX

Input file for the Flexure tool



NB: Var_Te.grd is a Grid of the Te variation

LithoFLEX

FORWARD FLEXURE INPUT AND OUTPUT

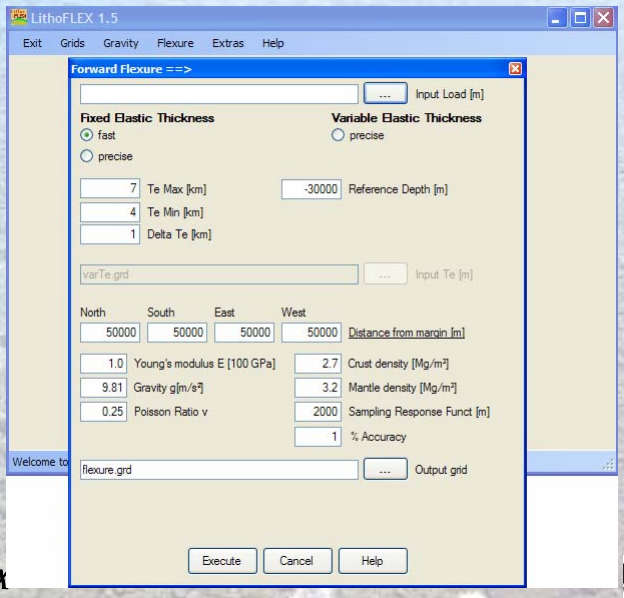
FLEXURE/FORWARD FLEXURE		*Description*
INPUT FILE *for Fixed Elastic Thickness/ Fast and Precise*	**load.grd** (topo.grd for only topography); or **equiTopo.grd** (for land and sea area)	Topography or equivalent topography grid
OUTPUTFILE *for Fixed Elastic Thickness/ fast*	**flexure.grd** (flexure10.grd for Te=10 km)	Flexure grid
OUTPUTFILE *for Fixed Elastic Thickness/precise*	**flexure.grd** (flexure_precise10 for Te= 10 km)	Flexure grid

LithoFLEX

Complete Table of Input and Output files

FLEXURE/FORWARD FLEXURE		*Description*
INPUT FILE ***for Fixed Elastic Thickness/ Fast and Precise***	**load.grd** (topo.grd for only topography); or **equiTopo.grd** (for land and sea area)	Topography or equivalent topography grid
OUTPUTFILE ***for Fixed Elastic Thickness/ fast***	**flexure.grd** (flexure10.grd for Te=10 km)	Flexure grid
	Forward Flexure_log.txt	Log file
	sptopo.grd	Fourier spectrum of topography
	modflex_spect_SI.inp	Parameter Input file
OUTPUTFILE ***for Fixed Elastic Thickness/precise***	**flexure.grd** (flexure_precise10 for Te= 10 km)	Flexure grid
	flexpar.txt	Log file
	Forward Flexure_log.txt	Log file
	modflex_conv_sub_SI.inp	Parameter input file
	flex_sub.dat (e.g. for te=10 km: flex10_sub.dat)	Flexure response function

Tool: FLEXURE/Forward Flexure



LithoFLEX

Testing 3rd Step
Creation of FORWARD FLEXURE

Common parameters for the Flexure tool:

- Young's modulus: E= 1.0 [100 GPa]
- Gravity: g= 9.81 [m/s^2]
- Poisson ratio: v= 0.25
- Crust density: 2.7 [Mg/m^3]
- Mantle density: 3.2 [Mg/m^3]
- Sampling response function: 2000 m
- Accuracy: 1%

LithoFLEX

Testing 3rd Step
Forward Flexure/ Fast (a)

The program uses the **spectral method**
Test with different Te:

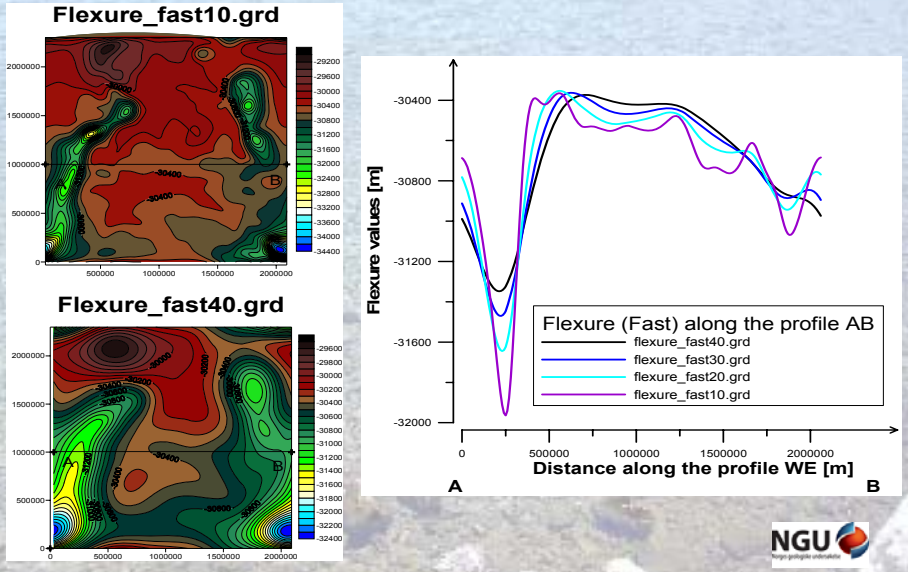
- Te max: **40**, Te min **10**, ΔTe=**10** km,
- refererence depth= **-30000** m (or **-30000** m)
- Input file: **equiTopo.grd**

- Notice: the [distance to margin] not used here.
- Eventually the border effect at grid margins can be eliminated by the user.

- Choose and create the sections along the grid
- Describe the flexure for several Te's with Grapher

LithoFLEX

Flexure (fast)



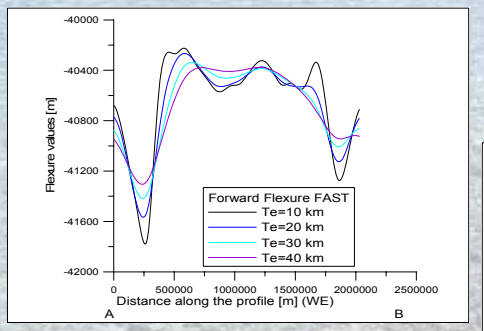
Testing 3rd Step
Forward Flexure/Precise (b)

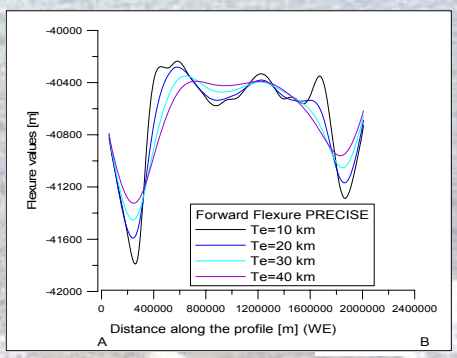
- Test the same values of Te with the **Precise method (ASEP)**
- Type different values for [distance to margin]: test: **50 000** m, **250 000** m
- Save the file and create the plots of flexure for all Te and method
- Compare the results

- The flexure for the different methods is the same, it is seen that the grid size varies.
- Overlay the grid in Surfer to test different grid-sizes.

LithoFLEX

Comparison between the different metods





LithoFLEX

4thstep FLEXURE / Te INVERSION a Synthetic Test

- Goal: test the FLEXURE/ Te Inversion tool
- Method: Convolution method

LithoFLEX

Create necessary grids for the Synthetic Test

Necessary grids: input load and synthetic Moho

1) Synthetic Moho: Compute flexure response of a variable elastic thickness plate to a given load.

- NB: Variable elastic thickness: Var_Te.grd

2) Load: use equivalent topography of previous example.

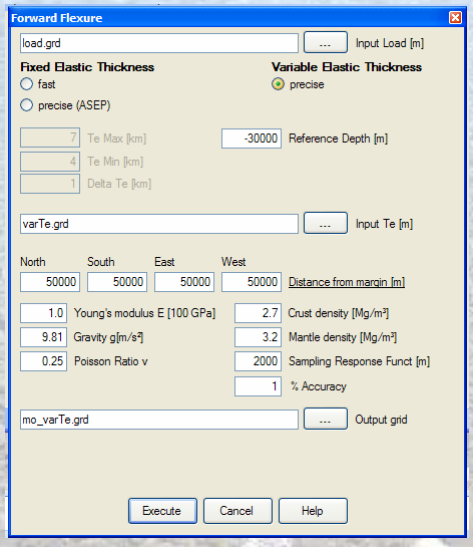
LithoFLEX

Variable Elastic Thickness

FLEXURE/FORWARD FLEXURE/ variable elastic thickness		*Description*
INPUT FILE	**equiTopo.grd** (topo.grd for only topography); or (for land and sea area)	Topography or equivalent topography grid
	var_Te.grd	Grid of Te variation
OUTPUTFILE	**mo_var_Te.grd**	Flexure Moho grid

LithoFLEX

Tool: FLEXURE/Forward Flexure/ Variable Elastic Thickness



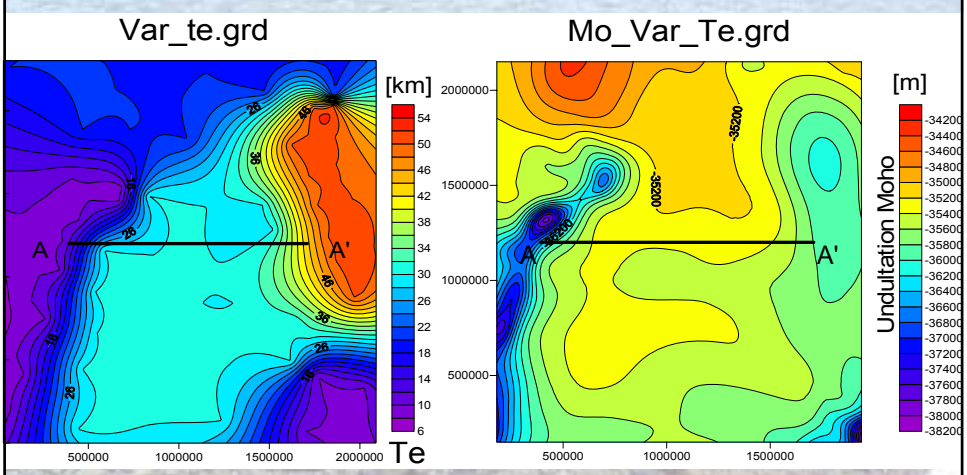
LithoFLEX

Testing 4thstep
(a) *Create synthetic flexure Moho*

- *LithoFlex*/Forward Flexure/Variable elastic thickness (precise)
- Input load: equiTopo.grd
- The reference depth is: -35000 m.
- Input Te grid: Var_Te.grd
- Distance from margins: 150000 m
- Ouput grid: Mo_VarTe.grd

LithoFLEX

Te grid and Moho for a Te grid



LithoFLEX

NGU

Testing 4thstep
(b) Now proceed with Te inversion

- *Lithoflex*/FLEXURE/TeInversion
- Goal: test if we are able to reproduce the Te-variation we used to construct the synthetic Moho.
- As input files we now use the equiTopo.grd (as load) and the Mo_var_Te.grd (as known Moho).

LithoFLEX

NGU

Input and Output files for Te Inversion:

FLEXURE/Te INVERSION		*Description*
INPUT FILE	**equiTopo.grd**	Load grid use the equitopography because there are land and sea
	mo_var_te.grd	Te variation root grid
OUTPUT FILE	te.grd	Te grid
	mo.grd	Moho grid for the "Te grid"
	mor.grd	Residual Moho with the best Te
	admicur.out	Statistic file

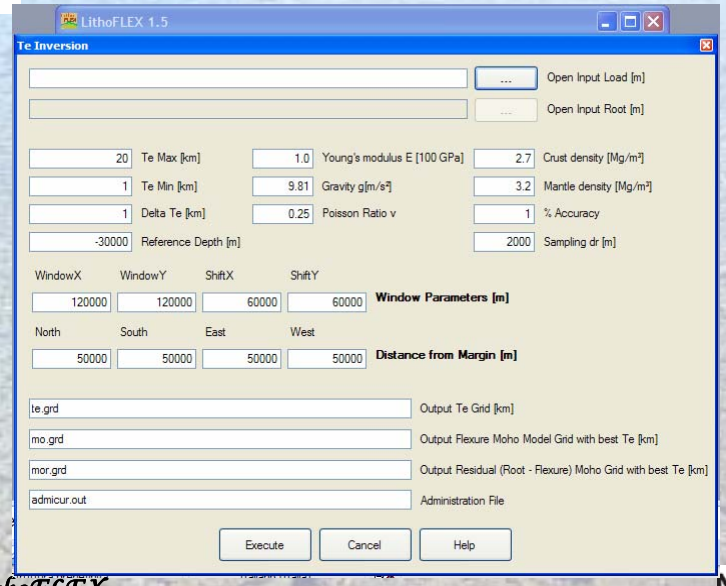
LithoFLEX

NGU

Complete Table of Input and Output files

FLEXURE/Te INVERSION		*Description*
INPUT FILE	**load.grd**	Topography or equivalent topography grid
	root.grd	Undulation to be modelled by flexure (e.g. use undulation from gravity inversion)
OUTPUT FILE	**te.grd**	Te grid
	mo.grd	Flexure Moho model grid with the best Te
	mor.grd	Residual (Root–Flexure) moho grid with best Te
	Te_inversion_log.txt	Log file
	admicur.out	Statistics file
	admicur7_SI.inp	Parameter input file
	admicur7b_SI.inp	Parameter input file
	19.00000	Flexure response function, (e.g. Te=19 km)
	telast.dat	Best Te for each window

Tool: FLEXURE/Te Inversion



LithoFLEX

For the test:

The parameters of Te inversion are:

1) Te max, Te min, Delta Te [km] the values employed for the output grid;
2) Reference depth [m] Reference model crustal thickness
3) Windows parameters [m] the grid is divided into rectangular areas and for each of these the program calculates the best Te value, with these boxes the user can choose the favorite values;
4) Distance from margin [m] the dimension of the output grid is smaller than the input grid.

In the next table the values to use are shown.

Parameters applied

	Te min, max [km]	ΔTe [km]	Reference Depth [m]	Window x,y [m]	Shift x,y [m]	Distance from margin [m]
Test	5, 60	5	-35000	120000, 120000	60000, 60000	150000,150000 150000,150000

LithoFLEX

So what do we expect?

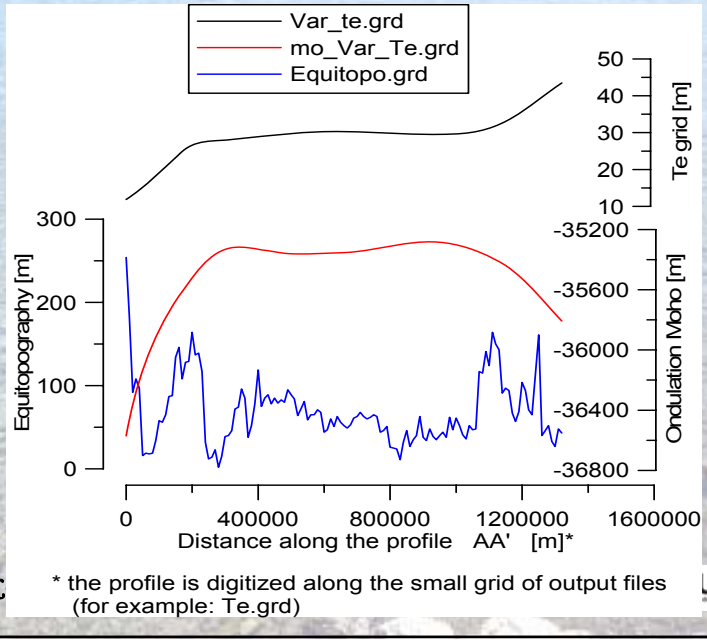
We want that **mo.grd** is similar to **mo_var_Te.grd**, and that **te.grd** is similar to **var_Te.grd**.

Now proceed with **Execute** button. Be patient, it takes some time.

Then compare the above grids.

LithoFLEX

Plots of input files



* the profile is digitized along the small grid of output files (for example: Te.grd)

LithoFL

Comparison of results along profiles

- Create the profiles for “te.grd”, “mo.grd” and “mor.grd” for the “test”.
- What is the “mor.grd”?
  - It’s the residual Moho between the input flexure Moho and the flexure with the best Te.
  - The smaller the residual, the better the Te

LithoFLEX

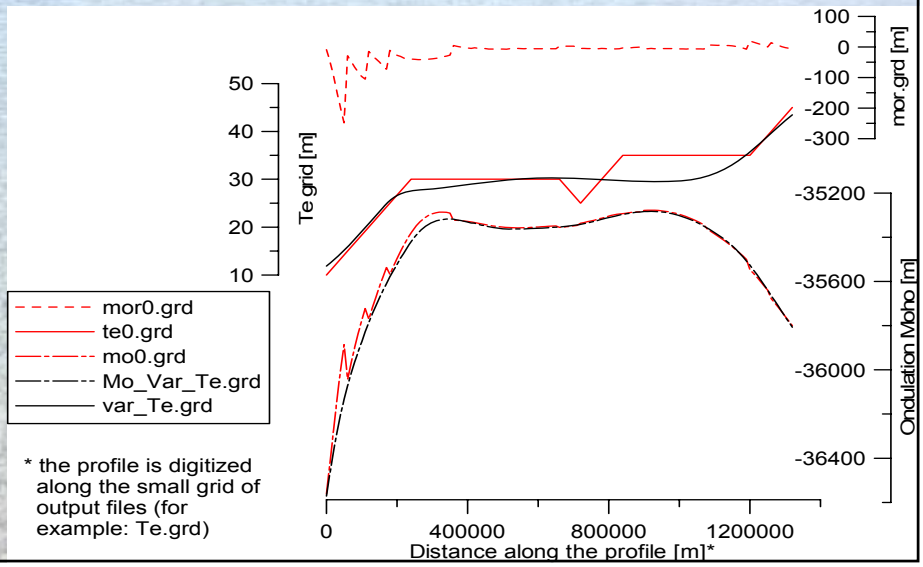
Create profiles

- You can create profiles in Surfer by:
- MAP/Contour map (select grid)- MAP/digitize (save profile as AB.bln)
- GRID/Slice-select grid (mo.grd) and profile (AB.bln); save output dat-file (e.g. mo_AB.dat).
- In Grapher display the profile (mo_AB.dat), selecting columns D (as *x*) and C (as *y*). Add the profiles of the other grids for comparison.

- Otherwise use Geosoft for profiling

LithoFLEX

Comparison with input and output files



Conclusion of Te Inversion test

1. The decrease of the Delta Te, increases the precision of calculation
2. The decrease of the x,y window and the shifting parameter, increases the precision in the calculation of Te grid (from model 0 to model 2) but the Program runs a long time.
3. The values of distance to margin limit the extension of output file.

NB: The better output files are shown with a small Delta Te values and small windows used for the calculation; but the program runs a long time: in this case the Te-input file and Te-output file (and moho-input and output files) are very similar.