TARAS SHEVCHENKO NATIONAL UNIVERSITY OF KYIV

INSTITUTE OF GEOLOGY

DEPARTMENT OF GENERAL AND HISTORICAL GEOLOGY

MODELLING OF GEOLOGICAL PROCESSES AND STRUCTURES
GUIDELINES FOR PRACTICAL CLASSES

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Рецензент: **Шабатура Олександр Вікторович**, канд. геол. наук, доцент кафедри геофізики ННІ «Інститут геології» Київського національного університету імені Тараса Шевченка

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Abstract

The discipline "Modelling of Geological processes and Structures" discusses the concepts of Models and Modelling, types of Models. The main types of modelling, including physical and symbolic modelling are analysed. The special attention is given to physical and mathematical modelling in geology. This discipline teaches the main principles of algorithms for mathematical modeling of geological processes and structures, analyses and determines the stress-strain state of the natural and man-made systems. This discipline uses real geological objects and situations as examples for modelling based on special software. The main objective isintroduction of students with: 1) main types of physical and symbolic models; 2) main methods of physical and mathematical modelling; 3) functional ability of special software for modelling; 4) modelling of exogenic geological processes; 5) modelling of tectonic structures; 6) interpretation of modelling results; 7) calculation of stress-strain state of geological systems; 8) using the results of modelling in different areas of geology. *Practical classes description*: spatial modelling in GIS, stochastic and deterministic modelling in geology, modelling of impact of geological processes on the man-made systems, modelling of stress-strain state of the nature-technical systems.

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Class #1. "Data Conversion, georeference and geodatabase development by tools of ArcGIS"

Students should have knowledge of basics of GIS and be able to apply the GIS methods in geomodelling

Concepts, goals for this activity: Become more familiar with general tools of GIS modelling

Task: Input and Data Conversion, changing of the projection and coordinate system by tools of ArcGIS, create a database of geological objects

Procedure:

1. **Assign the information on projections and coordinate system to shp-files**.

Assign the projection information and coordinate system to shape files located in the GIS_Practic folder. (Recall that the maps of the CIS countries typically use geographic coordinates Pulkovo 1942, while the U.S. data (e.g. GPS data), tend to use a coordinate system WGS 1984).

To do this:

a) Open in ArcGIS (ArcGIS 10.4 version is used) - ***ArcToolbox***.

b) In the ***Data Management Tools*** open ***Projections and Transformations*** and then ***Define Projection*** tool.

c) add to the list (using ***Shift***) the following layers:

- ***flood_areas.shp***
- ***nas_punkty.shp***
- ***reki.shp***
- ***vodoemy.shp***

and highlight them in the menu ***Define Projection***.

d) select a coordinate system - ***Coordinate System*** field - ***Geographic Coordinate Systems - Europe - Pulkovo 1942***

2. Create data in ArcGIS.

a) In ArcGIS block open - ***ArcCatalog***.

b) Go to the folder ***edit1***, which you would create the data.

c) Create new data sources of three types: (***poly***) - polygon, (***lines***) - linear and (***point***) – point objects. To do this, using the menu section ***File - New***, select the file format that will be created (in this case – ***shape file***), its name, type and coordinate system (***Projected Coordinate Systems - Gauss Kruger - Pulkovo 1942 - Pulkovo 1942 GK Zone 4N)***.

For all three types of objects add a field ***NAME*** of text type.

d) Open ***ArcMAP***, add the created layers, rivers and locality layers (for further raster georeferencing) and a raster map for digitizing ***M_34_143.JPG***.

e) Georeference the raster map, using the ***Georeferencing*** menu.

- Set map projection the same as that of previously created layers - ***Pulkovo 1942 GK Zone 4N.***
- Open the menu ***Georeferencing*** from ***Customize - Toolbars***.

- Set the extent of the map on the layer of rivers.
- Align at the screen the vector and raster layers.
- Analyze the relative position of the layers, set the control points (using the "***Add Control Points"*** tool of the ***Georeferencing*** toolbar).
- Clarify georeferencing by the grid coordinates on the raster.
- Save raster using «***Update Georeferencing***» from the toolbar menu ***Georeferencing***.
- Create a new raster by selecting «***Rectify ..***» from the toolbar menu ***Georeferencing.***

f) Using the functionality of the editing block of ArcMAP - ***Editor*** start editing the new layers and vectorize 5-6 items for each element of a raster map so that the point objects were evenly distributed throughout the project, and polygon objects would create a continuous layer meeting the requirements of topology.

- Open the ***Editor*** menu and select «***Start Editing***».
- In the **Create Features** menu click on the layer you want to work with and then in the **Construction Tools** menu choose the shape you want to create. (For linear and polygonal objects you can use for example the tool **Straight Segment** in the **Editor** menu to create new objects and the **Trace** tool in order to trace the borders of already existing objects.)

3. Change the projection in ArcGIS.

a) Create your own working directory ***proj***, where you would place the newly created and projected files.

b) Similarly to the process of assigning the projection (point 1), but using a tool ***ArcToolbox - Project***, create a copy of the existing map layers with the projection of the Gauss-Kruger 1942 Zone IV in the new folder: ***Output Coordinate System - Projected Coordinate Systems - Gauss Kruger - Pulkovo 1942 - Pulkovo 1942 GK Zone 4N.***

4. Converting data in ArcGIS.

a) Open ArcGIS – ***ArcCatalog***.

b) Set the folder where you would place the data.

c) Using the menu section ***File - New***, create a new spatial database (Personal Geodatabase).

d) Open the box ArcGIS – ***ArcToolbox***.

e) In the ***Conversion Tools*** section open subsection **To Geodatabase** and perform the conversion of all shape files from a folder ***GIS_Practic*** in a Geodatabase format using the tool **Feature Class To Geodatabase.**

Self-Test Questions:

1. What ArcGIS tools would you use to set or change the coordinate system of your data? What is the difference between projected and geographic coordinate system?
2. What are the ways to add/change attributes of the newly created features (objects)?

Reference:

1. https://desktop.arcgis.com/ru/arcmap/10.3/tools/spatial-analyst-toolbox/an-overview-of-the-spatial-analyst-toolbox.htm
2. https://www.coursera.org/specializations/gis-mapping-spatial-analysis
3. Mallet J.-L. Numerical Earth Model / J.-L. Mallet. – EAGE, 2008. – 147 p

Pelletier J. Quantitative modelling of Earth processes / J. Pelletier. – Cambridge, 2008. – 295 p.

Class #2. "Analysis of location, determination of the area of flooding by tools of spatial modeling"

Students should have knowledge of the basics of GIS and be able to apply the GIS methods in GIS-analysis.

Concepts goals for this activity: Become more familiar with general tools of GIS analysis, develop practical skills in searching for objects according to the specified criteria**,** quarries to database.

Task*:* searching for objects according to the specified criteria, displaying categories and quantitative indicators of objects, building spatial queries, determining the area of flood propagation using spatial modeling

Procedure:

1. **Start ArcMap (**ArcGIS 10.4 version is used)**.**

2. **Add the following layers to the map,** which are located in the folder ***GIS_Practic****:*

File name	**Layer content**
Nas_punkty	Settlements
Reki	Rivers
Vodoemy	Water bodies
Relief_isol	Relief contours
Flood_areas	Flood inundation area of Borzhava

3. **Set the required order of layers and assign them the usual names and symbols** (Double click on the name of each layer and in the ***General*** menu change the name to an alias, and in the ***Symbology*** menu select the desired color and symbol for displaying objects)

4. **Display the layer of settlements according to the class of each point** (***Symbology*** - ***Categories*** function – ***Unique values***), which is indicated in the "P_127" field of the attribute table:

Field code P_127	**Type of settlement**
41100000	Cities
41200000	Townships
42100000	Villages

5. **Divide settlements into 4 categories** according to the total area of their territory ***("Area"*** field).

To do this: Select the function ***Quantities - Graduated Color*** in the legend editor (displaying the number of colors by range) and divide into ranges using four standard classification methods:

Classification method name	**Class range technology**
Equal intervals	division into intervals equal to the difference between the minimum and maximum values
Quantile	breakdown into intervals equal to the number of objects that fall into them

Natural breaks	breakdown by natural differences in values
Standard deviation	disaggregation by size deviation from sample mean

Pay attention to the change in the nature of the distribution of objects that are classified depending on the choice of the classification method.

6. **Assign different colors to different classes of relief contours**.

This requires:

- Open the attribute table of the Relief contours layer and make a statistical analysis of the "**P4**" field, which contains the data on the absolute elevation values of the contours.
- To do this, right-click on the layer name and select **OPEN ATRIBUTE TABLE**, right-click on the "**P4**" field header and select the **Statistics** function**.**
- According to the resulting table, determine the maximum, minimum and average values of relief in Transcarpathia.
- Assign the colors of contour display, conventionally dividing them into 2 categories (classes):
- From min to medium - lowland, 2) from medium to max - mountainous area. Indicate these names of ranges in the right column of the legend generation window. Please note that the division into classes in this case was carried out exclusively using the legend editor without creating a new field in the attribute table

7. **Assign the "flood" category to settlements that can be flooded when there is 1% of the flood along the Borzhava River**.

This requires:

- Open the attribute table of the "Settlements" layer and add to it a new field with the name "Flood" and type "Character".
- Using the spatial query tools, select the settlements that fall into the flood zone: Menu **SELECTION – Select by location**, set the layer which objects are selected - **nas_punkty**, the coincidence condition - Intersect, the layer that is selected - **Flood_areas**.
- After completing the selection, fill in the new field "**flood**" with the value "**flooding**" (GIS automatically fills in only those fields of the table that are highlighted).

To do this: Make the layer editable (Menu ***Editor – Start Editing***); go to the table of the ***nas_punkty*** layer, right-click on the title and select the "**Field calculator**" function. The system will offer to enter or calculate a value for each of the highlighted fields. In this case, let us enter "flooding". Now you can assign different colors to the "flood" and "" categories by specifying this field in the legend editor to build a new layer legend by category.

Self-Test Questions:

1. What tool would you use to select several features (objects) based on their location and spatial relations with other features (objects)?
2. What classification methods do you know? What are their differences?

References:

1. https://desktop.arcgis.com/ru/arcmap/10.3/tools/spatial-analyst-toolbox/an-overview-of-the-spatial-analyst-toolbox.htm
2. https://www.coursera.org/specializations/gis-mapping-spatial-analysis
3. Mallet J.-L. Numerical Earth Model / J.-L. Mallet. – EAGE, 2008. – 147 p
4. Pelletier J. Quantitative modelling of Earth processes / J. Pelletier. – Cambridge, 2008. – 295 p.

Class #3. Implementation of overlay analysis capabilities using GIS

Students should have knowledge of basics of GIS and be able to apply the GIS methods in GIS-analysis

Concepts goals for this activity: Develop practical skills in analytical operations using cartographic overlay using ArcGIS tools.

Tasks: perform an overlay analysis operations using spatial modeling tools.

Procedure:

1. **Start ArcMap.**

2. **Add vector layers of the following data sources of the GIS_practic directory to the map:**

- *flood_areas.shp*
- *nas_punkty.shp*
- *reki.shp*
- *vodoemy.shp*
- *rayony.shp*
- *points.shp*

3. **Dissolve boundaries between flood-prone areas**
(*Dissolve features based on attribute*):

- Enter the rayony.shp theme table and add the "Flood Type" field of type string
- Select areas, territories of which intersect objects of the flood_areas layer (Selection-Select by Location)
- Enter edit mode and enter (Field - Calculate) into the created field Flood Type for selected objects type "1" (flooded), give all others the code "0" (not flooded)
- Dissolve the boundaries between areas based on the unity of the Flood Type field values.

4. Merge features from flood_areas.shp and vodoemy.shp layers into one map layer using the Merge Layers together function.

5 Find the difference between Clip one layer based on another and Intersect two layers functions when nas_punkty.shp layers are superimposed on flood_areas.shp

6. Find the difference in the action of Union of two Layers and Intersect of two Layers when overlaying nas_punkty.shp layers on flood_areas.shp

7. Assign the polygon attributes of the area layer to the points point objects using the Join data from another layer based on spatial location function, which can be accessed by right-clicking on the layer name from the Join and Relate - Join menu.

Self-Test Questions:

1. What Overlay tools are available in ArcGIS? What are their functionalities?
2. What tool would you use if you need to get the common parts of the two polygon layers?

References:

1. https://desktop.arcgis.com/ru/arcmap/10.3/tools/spatial-analyst-toolbox/an-overview-of-the-spatial-analyst-toolbox.htm
2. https://www.coursera.org/specializations/gis-mapping-spatial-analysis
3. Mallet J.-L. Numerical Earth Model / J.-L. Mallet. – EAGE, 2008. – 147 p
4. Pelletier J. Quantitative modelling of Earth processes / J. Pelletier. – Cambridge, 2008. – 295 p.

Class #4. Statistical models. Multiple correlation analysis. Multiple regression. Determining the correlation between the main and one of the related components

Students should have knowledge of basics of geochemistry and petrography and be able to apply the stochastic methods in geomodelling.

Concepts goals for this activity: Become more familiar with methods of multiple correlations and their application for geomodelling.

Task:

1. It is necessary to test the hypothesis of the presence of a correlation between the main and one of the associated components;
2. Determine which of the main components is most closely related to the associated component;
3. Get a correlation matrix, select significant correlation coefficients.

The ores of the polymetallic deposit, in addition to the main useful components – zinc, lead and copper, contain related useful components – gold, silver, cadmium, antimony, barium, extracted from the ores during processing. In the presence of a correlation between the concentrations of the main and one of the associated components of the content of the latter in individual areas of the field, can be estimated by the presence of the main components, which significantly reduces the cost of analysis. To address the question of the possibility of applying the correlation method of calculating the stocks of the associated component and the calculation of the regression equation, the results of analyzes of samples of major and related components are used (Table 1–5).

Table 1. The content of the main and related components in the ores of the polymetallic deposit

№	Cu,%	Pb,%	Zn,%	Au,г/т	№	Cu,%	Pb,%	Zn,%	Au, g/t
1	0,28	1,73	8,68	0,2	**26**	0,02	0,39	1,19	0,1
2	0,20	1,66	4,47	0,1	**27**	0,15	0,08	2,90	0,1
3	1,26	3,29	2,02	0,6	**28**	0,25	0,06	2,92	0,1
4	0,34	3,08	8,46	0,4	**29**	1,17	0,12	9,25	0,1
5	0,06	0,21	0,42	0,2	**30**	0,06	0,06	1,00	0,1
6	0,11	1,50	3,20	0,4	**31**	0,05	0,02	1,58	0,1
7	0,14	1,60	3,49	0,1	**32**	0,23	0,09	3,12	0,1
8	0,09	0,65	1,70	0,2	**33**	0,09	0,05	0,63	0,1
9	0,26	2,05	3,82	0,2	**34**	0,15	0,12	0,90	0,1
10	0,29	2,05	4,66	0,1	**35**	0,06	0,75	1,71	0,1
11	0,12	1,43	3,30	0,1	**36**	0,10	0,10	3,20	0,1
12	0,02	0,55	1,85	0,1	**37**	0,44	2,32	8,20	0,1
13	0,12	0,25	2,60	0,1	**38**	0,08	0,49	1,05	0,1
14	0,38	0,08	5,53	0,4	**39**	0,02	0,22	0,65	0,4
15	0,30	0,14	8,41	0,4	**40**	0,02	0,46	1,30	0,1
16	0,02	0,46	1,76	0,2	**41**	0,02	0,47	0,94	0,1
17	0,34	3,08	8,46	0,4	**42**	1,06	5,61	29,30	0,8
18	1,26	3,29	22,82	0,6	**43**	0,58	4,51	18,28	2,2
19	2,22	0,66	15,88	0,1	**44**	0,54	3,41	6,15	0,4
20	0,75	0,78	4,20	0,1	**45**	0,11	0,83	1,92	0,1
21	4,64	0,37	13,48	0,4	**46**	0,08	3,21	7,44	0,4
22	3,64	0,85	35,97	0,8	**47**	0,52	1,69	3,30	0,2
23	0,95	0,56	8,02	0,2	**48**	0,30	7,02	24,37	0,2

24	0,09	0,66	1,47	0,1	**49**	0,26	1,69	2,60	0,4
25	0,02	0,46	0,85	0,1	**50**	0,37	5,61	11,34	0,4

Table 2. The content of the main and related components in the ores of the polymetallic deposit

№	Cu,%	Pb,%	Zn,%	Ag,г/т	№	Cu,%	Pb,%	Zn,%	Ag, g/t
1	0,26	1,73	8,67	32,8	**26**	0,02	0,39	1,18	5,0
2	0,20	1,66	4,47	28,8	**27**	0,15	0,08	2,90	10,0
3	1,26	3,29	2,02	126,8	**28**	0,25	0,06	2,90	12,4
4	0,34	3,08	8,46	28,8	**29**	1,17	0,12	9,25	112,8
5	0,06	0,21	0,42	16,8	**30**	0,06	0,06	1,00	7,0
6	0,11	1,50	3,20	39,6	**31**	0,05	0,02	1,58	8,4
7	0,14	1,60	3,49	19,6	**32**	0,23	0,09	3,12	26,0
8	0,09	0,65	1,70	35,2	**33**	0,09	0,05	0,63	11,0
9	0,26	2,05	3,82	35,7	**34**	0,15	0,12	0,90	12,8
10	0,29	2,05	4,66	12,4	**35**	0,06	0,75	1,71	16,8
11	0,12	1,43	3,30	24,8	**36**	0,10	0,10	3,20	4,2
12	0,02	0,55	1,85	11,6	**37**	0,44	2,32	8,20	68,8
13	0,12	0,25	2,60	11,6	**38**	0,08	0,49	1,05	27,0
14	0,38	0,08	5,53	52,8	**39**	0,02	0,22	0,65	10,2
15	0,30	0,14	8,41	18,4	**40**	0,02	0,46	1,30	7,2
16	0,02	0,46	1,76	19,6	**41**	0,02	0,47	0,94	21,0
17	0,34	3,08	8,46	20,8	**42**	1,06	5,61	29,30	97,6
18	1,26	3,29	22,82	131,4	**43**	0,58	4,51	18,28	119,2
19	2,22	0,66	15,88	106,6	**44**	0,54	3,41	6,15	141,2
20	0,75	0,78	4,20	91,2	**45**	0,11	0,83	1,92	23,6
21	4,64	0,37	13,48	63,2	**46**	0,08	3,21	7,44	38,0
22	3,64	0,85	35,97	94,4	**47**	0,52	1,69	3,30	64,2
23	0,95	0,56	8,02	122,0	**48**	0,30	7,02	24,37	160,0
24	0,09	0,66	1,47	10,0	**49**	0,26	1,69	2,60	33,0
25	0,02	0,46	0,85	3,8	**50**	0,37	5,61	11,34	90,4

Table 3. The content of the main and related components in the ores of the polymetallic deposit

№	Cu,%	Pb,%	Zn,%	Cd,10^{-4}%	№	Cu,%	Pb,%	Zn,%	Cd,10^{-4}%
1	0,26	1,73	8,67	32	**26**	0,02	0,39	1,18	4
2	0,20	1,66	4,47	19	**27**	0,15	0,08	2,90	40
3	1,26	3,29	2,02	4	**28**	0,25	0,06	2,90	10
4	0,34	3,08	8,46	33	**29**	1,17	0,12	9,25	37
5	0,06	0,21	0,42	2	**30**	0,06	0,06	1,00	3
6	0,11	1,50	3,20	7	**31**	0,05	0,02	1,58	6
7	0,14	1,60	3,49	9	**32**	0,23	0,09	3,12	14
8	0,09	0,65	1,70	4	**33**	0,09	0,05	0,63	3
9	0,26	2,05	3,82	15	**34**	0,15	0,12	0,90	3
10	0,29	2,05	4,66	13	**35**	0,06	0,75	1,71	6
11	0,12	1,43	3,30	10	**36**	0,10	0,10	3,20	12

12	0,02	0,55	1,85	7	**37**	0,44	2,32	8,20	31
13	0,12	0,25	2,60	9	**38**	0,08	0,49	1,05	3
14	0,38	0,08	5,53	22	**39**	0,02	0,22	0,65	2
15	0,30	0,14	8,41	34	**40**	0,02	0,46	1,30	4
16	0,02	0,46	1,76	7	**41**	0,02	0,47	0,94	2
17	0,34	3,08	8,46	32	**42**	1,06	5,61	29,30	101
18	1,26	3,29	22,82	84	**43**	0,58	4,51	18,28	62
19	2,22	0,66	15,88	62	**44**	0,54	3,41	6,15	26
20	0,75	0,78	4,20	16	**45**	0,11	0,83	1,92	6
21	4,64	0,37	13,48	51	**46**	0,08	3,21	7,44	28
22	3,64	0,85	35,97	160	**47**	0,52	1,69	3,30	13
23	0,95	0,56	8,02	35	**48**	0,30	7,02	24,37	96
24	0,09	0,66	1,47	5	**49**	0,26	1,69	2,60	10
25	0,02	0,46	0,85	3	**50**	0,37	5,61	11,34	38

Table 4. The content of the main and related components in the ores of the polymetallic deposit

№	Cu,%	Pb,%	Zn,%	Sb,10^{-4}%	№	Cu,%	Pb,%	Zn,%	Sb,10^{-4}%
1	0,27	1,73	8,68	560	**26**	0,02	0,39	1,18	16
2	0,20	1,66	4,47	108	**27**	0,15	0,08	2,90	31
3	1,26	3,29	2,02	40	**28**	0,25	0,06	2,90	50
4	0,34	3,08	8,46	660	**29**	1,17	0,12	9,25	408
5	0,06	0,21	0,42	73	**30**	0,06	0,06	1,00	26
6	0,11	1,50	3,20	223	**31**	0,05	0,02	1,58	71
7	0,14	1,60	3,49	118	**32**	0,23	0,09	3,12	71
8	0,09	0,65	1,70	60	**33**	0,09	0,05	0,63	35
9	0,26	2,05	3,82	103	**34**	0,15	0,12	0,90	105
10	0,29	2,05	4,66	229	**35**	0,06	0,75	1,71	93
11	0,12	1,43	3,30	96	**36**	0,10	0,10	3,20	133
12	0,02	0,55	1,85	49	**37**	0,44	2,32	8,20	317
13	0,12	0,25	2,60	31	**38**	0,08	0,49	1,05	100
14	0,38	0,08	5,53	220	**39**	0,02	0,22	0,65	33
15	0,30	0,14	8,41	434	**40**	0,02	0,46	1,30	55
16	0,02	0,46	1,76	15	**41**	0,02	0,47	0,94	144
17	0,34	3,08	8,46	410	**42**	1,06	5,61	29,30	3100
18	1,26	3,29	22,82	2200	**43**	0,58	4,51	18,28	2310
19	2,22	0,66	15,88	464	**44**	0,54	3,41	6,15	920
20	0,75	0,78	4,20	55	**45**	0,11	0,83	1,92	220
21	4,64	0,37	13,48	684	**46**	0,08	3,21	7,44	164
22	3,64	0,85	35,97	3160	**47**	0,52	1,69	3,30	56
23	0,95	0,56	8,02	272	**48**	0,30	7,02	24,37	1980
24	0,09	0,66	1,47	57	**49**	0,26	1,69	2,60	164
25	0,02	0,46	0,85	9	**50**	0,37	5,61	11,34	638

Table 5. The content of the main and related components in the ores of the polymetallic deposit

№	Cu,%	Pb,%	Zn,%	Ba,%	№	Cu,%	Pb,%	Zn,%	Ba,%
1	0,26	1,78	8,67	9,97	**26**	0,02	0,39	1,19	2,22
2	0,20	1,66	4,47	5,07	**27**	0,15	0,08	2,90	4,19
3	1,26	3,29	2,02	19,95	**28**	0,25	0,06	2,90	3,12
4	0,34	3,08	8,46	9,41	**29**	1,17	0,12	9,25	2,52
5	0,06	0,21	0,42	2,54	**30**	0,06	0,06	1,00	1,94
6	0,11	1,50	3,20	7,63	**31**	0,05	0,02	1,58	2,45
7	0,14	1,60	3,49	6,87	**32**	0,23	0,09	3,12	4,84
8	0,09	0,65	1,70	2,18	**33**	0,09	0,05	0,63	4,10
9	0,26	2,05	3,82	7,34	**34**	0,15	0,12	0,90	4,81
10	0,29	2,05	4,66	8,01	**35**	0,06	0,75	1,71	4,21
11	0,12	1,43	3,30	10,15	**36**	0,10	0,10	3,20	3,41
12	0,02	0,55	1,85	2,19	**37**	0,44	2,32	8,20	27,78
13	0,12	0,25	2,60	3,06	**38**	0,08	0,49	1,05	1,73
14	0,38	0,08	5,53	4,00	**39**	0,02	0,22	0,65	1,73
15	0,30	0,14	8,41	3,36	**40**	0,02	0,46	1,30	1,89
16	0,02	0,46	1,76	2,24	**41**	0,02	0,47	0,94	1,88
17	0,34	3,08	8,46	9,41	**42**	1,06	5,61	29,30	23,82
18	1,26	3,29	22,82	10,95	**43**	0,58	4,51	18,28	18,53
19	2,22	0,66	15,88	0,92	**44**	0,54	3,41	6,15	35,0
20	0,75	0,78	4,20	2,56	**45**	0,11	0,83	1,92	2,0
21	4,64	0,37	13,48	6,29	**46**	0,08	3,21	7,44	9,98
22	3,64	0,85	35,97	5,58	**47**	0,52	1,69	3,30	6,65
23	0,95	0,56	8,02	3,25	**48**	0,30	7,02	24,37	19,92
24	0,09	0,66	1,47	3,01	**49**	0,26	1,69	2,60	7,76
25	0,02	0,46	0,85	1,66	**50**	0,37	5,61	11,34	9,00

Self-Test Questions:

1. What is the correlation analysis?
2. Why do we use it?

References:

1. *Dekking, F.M. (Frederik Michel) (2005). A modern introduction to probability and statistics : understanding why and how. Springer. ISBN 1-85233-896-2. OCLC 783259968.*
2. Pav Kalinowski, "Understanding Confidence Intervals (CIs) and Effect Size Estimation", *Observer* Vol.23, No.4 April 2010.
3. Sandercock, Peter A.G. (2015). "Short History of Confidence Intervals". *Stroke*. Ovid Technologies (Wolters Kluwer Health). 46 (8). doi:10.1161/strokeaha.115.007750. ISSN 0039-2499.
4. https://onlinestatbook.com/Online_Statistics_Education.pdf

Class #5. Determination of statistical characteristics of the Neogene lava horizon based on a sample of values

Students should have knowledge of basics of geochemistry and petrography and be able to apply the statistic methods in geomodelling

Concepts goals for this activity: Become more familiar with methods of basic statistics and their application for geomodelling

Task:

1. Determine the average composition of the rows by constructing diagrams "stem-and-leaf plot" and "box-and-whisker plot".
2. Determine the preferred composition for most samples.
3. Determine the diversity of values.

Table 1. The content of SiO_2 (%) in Neogene lavas

№	SiO_2	№	SiO_2	№	SiO_2	№	SiO_2
1	59,5	9	73,2	17	69,3	24	61,1
2	66,8	10	64,6	18	64,6	25	63,8
3	60,5	11	62,9	19	67,8	26	67,5
4	63,7	12	62,4	20	56,6	27	65,3
5	72,5	13	71,6	21	71,4	28	69,9
6	69,2	14	65,8	22	67,7	29	73,2
7	61,2	15	63,1	23	63,6	30	60,7
8	66,3	16	61,2				

Self-Test Questions:

1. Why and when do we use the diagrams "stem-and-leaf plot" and "box-and-whisker plot"?
2. What does each element of the "whisker plot" diagram show?

References:

1. Dekking, F.M. (Frederik Michel) (2005). A modern introduction to probability and statistics : understanding why and how. Springer. ISBN 1-85233-896-2. OCLC 783259968.

2. Pav Kalinowski, "Understanding Confidence Intervals (CIs) and Effect Size Estimation", *Observer* Vol.23, No.4 April 2010.

3. Sandercock, Peter A.G. (2015). "Short History of Confidence Intervals". *Stroke*. Ovid Technologies (Wolters Kluwer Health). 46 (8). doi:10.1161/strokeaha.115.007750. ISSN 0039-2499.

4. https://onlinestatbook.com/Online_Statistics_Education.pdf

Class #6. Determination of statistical dependences in associations and behavior of chemical elements within the silicate nickel deposit

Students should have knowledge of basics of geochemistry and petrography and be able to apply the basics statistic in geomodelling

Concepts goals for this activity: Become more familiar with methods of basic statistics and their application for geomodelling

Task:

In the lateritic weathering crust can be identified areas:
1 - glandular penalties
2 - ocher unstructured
3 - structural ocher (final)
4 - structural hemispheres
5 - parent breeds that have undergone leaching
6 - disintegrated parent rocks

Required:
1 - identify differences in the chemical composition of different zones
2 - to establish the nature of the behavior of chemical elements in the process of corrosion
3 - to identify associations of chemical elements that are similar in nature to the behavior in the process of corrosion

To identify differences in the chemical composition of the weathering crust of different zones, it is necessary to present the results of analyzes for each chemical element in a form convenient for comparison. The original data can be converted into graphic diagrams "box sounds". The problem is solved using the procedures of the STATISTICA program, and then by analyzing the obtained graphic information.

1. Create a data file using one of the numerical tables1-7.

2. In the STATISTICA program menu, select Basic Statistics / Tables and the sub-item "Descriptive statistics". In the Descriptive Statistics-Box & whisker plot dialog box for all variables. The new window contains the names of the variables for the study. You must select Select All. Thus, on one graph will be placed diagrams characterizing different areas.

3. Diagrams can be used to analyze the behavior of chemical elements in the process of rock formation. Decreasing the value of the median in the transition from the lower zone to the upper indicates the removal of this element, and increase - to its slight mobility and accumulation in the weathering crust. The increase in the variation of variation (mustache length) without a noticeable shift in the median indicates a local redistribution of this element within the zone.

Table I. The content of Fe_2O_3 in different areas of the weathering crust

№	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1	56,26	68,78	65,90	52,08	13,11	5,95
2	57,20	71,21	69,70	54,31	14,05	5,79
3	61,06	63,49	61,01	48,85	20,28	6,24
4	58,63	65,49	67,72	33,07	21,37	5,09
5		70,04	59,60	32,08		
6		70,13	61,32	33,41		
7		70,38	61,92	28,18		
8				28,58		
9				32,17		
10				40,19		
11				27,51		
12				29,83		

Table 2. The content of NiO in different areas of the weathering crust

№	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1	0,35	1,65	1,36	1,23	0,42	0,27
2	0,38	1,36	0,90	2,59	1,33	0,41
3	0,50	1,06	1,35	3,63	1,22	0,44
4	0,29	1,44	1,30	2,32	1,12	0,32
5		1,35	0,66	1,17		
6		1,12	1,65	1,41		
7		1,10	2,69	1,16		
8				2,58		
9				2,09		
10				3,28		
11				1,50		
12				2,55		

Table 3. The content of CoO in different areas of the weathering crust

№	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1	0,089	0,200	0,197	0,206	0,019	0,090
2	0,073	0,046	0,056	0,213	0,027	0,013
3	0,013	0,143	0,320	0,078	0,037	0,015
4	0,027	0,255	0,085	0,108	0,039	0,013
5		0,028	0,039	0,091		
6		0,016	0,076	0,104		
7		0,095		0,067		
8				0,069		
9				0,059		
10				0,080		
11				0,045		
12				0,070		

Table 4. The content of SiO_2 in different areas of the weathering crust

№	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1	6,73	2,30	3,98	12,48	36,00	37,52
2	7,91	3,27	2,32	13,26	38,77	38,96
3	4,40	7,92	6,32	18,99	33,44	41,30
4	5,28	4,21	2,02	26,19	34,15	38,21
5		1,97	6,37	24,20		
6		3,09	10,89	26,51		
7		2,00	11,26	27,04		
8				28,36		
9				26,10		
10				21,94		
11				37,86		
12				31,12		

Table 5. The content of MgO in different areas of the weathering crust

№	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1	2,85	0,75	1,00	8,78	32,66	38,96
2	0,95	1,05	0,50	8,26	28,54	38,22
3	0,80	1,25	2,60	7,72	27,69	37,28

4	1,10	1,00	0,85	17,64	26,74	39,18
5		0,75	2,85	18,25		
6		1,75	3,15	18,35		
7		1,05	2,70	19,68		
8				20,58		
9				19,54		
10				15,20		
11				12,92		
12				18,25		

Table 6. The content of Al_2O_3 in different areas of the weathering crust

№	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1	14,45	10,62	9,95	7,91	1,88	0,92
2	15,99	6,26	6,53	5,52	2,16	0,66
3	14,14	10,05	6,94	4,32	2,51	0,66
4	14,17	10,35	6,55	4,08	1,77	0,39
5		7,63	10,88	8,08		
6		6,81	6,43	4,18		
7		7,55	4,54	7,13		
8				3,42		
9				3,98		
10				3,14		
11				5,10		
12				2,63		

Table 7. The content of Cr_2O_3 in different areas of the weathering crust

№	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1	2,70	2,36	2,32	2,49	1,22	0,40
2	2,24	2,97	2,76	2,42	0,49	0,36
3	2,80	2,34	2,03	0,24	0,94	0,28
4	3,28	2,19	2,62	1,79	1,12	0,28
5		3,53	3,11	1,58		
6		2,81	2,31	1,81		
7		2,69	2,06	1,72		
8				1,28		
9				1,68		
10				1,88		
11				1,23		
12				1,50		

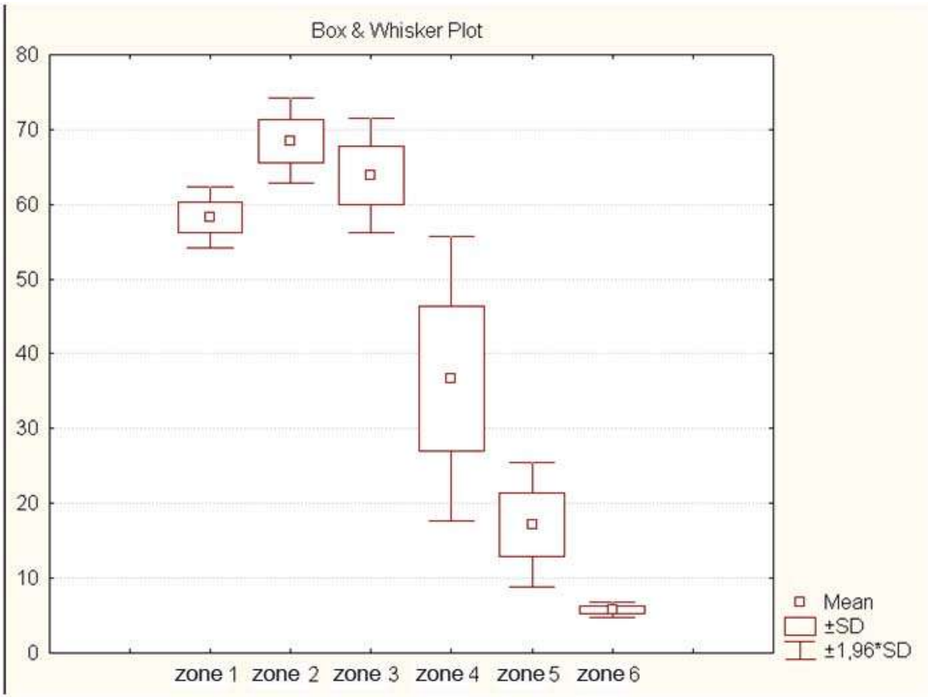


Fig. I. Construction of the diagrams in STATISTICA

Self-Test Questions:

1. How can we use the Box & Whisker plot diagrams to analyze the behavior of chemical elements in the process of rock formation?
2. What can the change of the median values show when we analyze the Box & Whisker plot diagram?

References:

1. *Dekking, F.M. (Frederik Michel) (2005). A modern introduction to probability and statistics : understanding why and how. Springer. ISBN 1-85233-896-2. OCLC 783259968.*
2. PavKalinowski, "Understanding Confidence Intervals (CIs) and Effect Size Estimation", *Observer* Vol.23, No.4 April 2010.
3. Sandercock, Peter A.G. (2015). "Short History of Confidence Intervals". *Stroke*. Ovid Technologies (Wolters Kluwer Health). 46 (8). doi:10.1161/strokeaha.115.007750. ISSN 0039-2499.
4. https://onlinestatbook.com/Online_Statistics_Education.pdf

Class #7. Using confidence intervals of planar or volumetric ore-bearing coefficients when planning exploration works

Students should have knowledge of basics of and be able to apply the basics statistics in geomodelling

Concepts goals for this activity: Become more familiar with methods of basic statistics and their application for geomodelling

Task:

Within the bauxite-bearing area, 26 promising areas were identified by search and assessment works. Preliminary reconnaissance was conducted on 6 of them. 2 deposits and 6 ore occurrences were discovered. It is established that the bauxite-bearing layer lies on the karstic surface of reef limestones and is covered with bituminous limestones and marls with a thickness of 25-30 m. In the contours of the deposits there are protrusions and xenolithic-containing limestones, as well as areas of substandard quality of bauxite-like rocks. Along with industrial deposits within the bauxite-bearing formation, there are numerous small accumulations of bauxite, confined to karst cavities, funnels and cracks.

Bauxite mining in this area is expected to be conducted in an open way. Therefore, the main indicator that determines the efficiency of mining is the planar ore-bearing coefficient, i.e. the ratio of the area of bauxite deposits to the total area of the bauxite-bearing formation in the contour of the project quarry. In different areas of explored deposits, the planar ore-bearing coefficient ranges from 0.5 to 0.9. In ore manifestations that received a negative economic assessment, it is 0.1 - 0.4.

Necessary:

1) In areas of unexplored prospective areas to perform interval estimates of planar ore-bearing coefficients, using the results of exploration and evaluation work (Table 1);

2) Divide the plots into promising and unpromising. Allocate areas for priority preliminary intelligence.

Table 1. The results of prospecting and evaluation work

№ perspective area	**№**	**Number of wells**	
		general, *n*	**found bauxite, n_p**
1	1	15	4
	2	22	10
	3	13	8
	4	15	4
2	1	12	3
	2	28	8
	3	19	16
	4	22	5
	5	31	6
3	1	19	4
	2	25	12
	3	21	5
	4	20	3
4	1	34	11
	2	22	4
	3	15	6
5	1	27	3
	2	31	9
	3	19	8

	4	15	14
6	1	18	4
	2	24	7
7	1	19	4
	2	33	7
	3	30	22
	4	17	4
	5	11	5
8	1	23	6
	2	21	8
	3	17	4
9	1	20	7
	2	25	3
	3	30	8
	4	15	3
	5	16	2
10	1	29	4
	2	22	6
	3	18	4
	4	20	12
11	1	31	7
	2	12	10
	3	16	2
12	1	21	3
	2	22	7
	3	17	9
	4	28	4
13	1	15	13
	2	21	6
	3	20	5
	4	31	7
14	1	32	5
	2	19	2
	3	21	3
	4	24	3
	5	31	8
15	1	29	3
	2	28	4
	3	15	2
	4	16	4
16	1	15	11
	2	19	4
	3	26	7
	4	27	5
17	1	19	7
	2	17	2
	3	19	4
18	1	23	2
	2	30	4
	3	31	8
	4	15	3
19	1	18	14
	2	31	6
	3	15	7
	4	16	2
20	1	18	3
	2	14	4
	3	31	3
	4	35	20

Progress:

1.1 When conducting exploration and evaluation works on promising areas, wells were drilled on a sparse but uniform grid. Therefore, planar ore-bearing coefficients (K_p) in individual areas can be estimated in relation to the number of wells detected bauxite (n_p) to their total number (n): $K_p = n_p/n$.

1.2 The number of wells in each section differs, but they are still few. Therefore, the obtained point estimates of ore-bearing coefficients may differ significantly from the true values, and they cannot be used as a reliable criterion for determining the prospects of each site. To do this, it is necessary to calculate interval estimates that take into account the magnitude of possible errors. The distribution of sample estimates of ore-bearing coefficients corresponds to the binomial law, so to calculate the boundaries of confidence intervals, you can use the formula

$$K_p \pm \lambda = \frac{n}{Z^2_{1-\alpha/2} + n}\left[K_p + \frac{Z^2_{1-\alpha/2}}{2n} \pm Z_{1-\alpha/2}\sqrt{\frac{K_p(1-K_p)}{n} + \left(\frac{Z_{1-\alpha/2}}{2n}\right)^2}\right]$$

$Z_{1-\alpha/2}$ – the value of the normal distribution function (see Appendix 3) for a given confidence probability $P = 1 - \alpha/2$.

1.3 Errors of the I and II kind are undesirable at definition of prospects of sites therefore at calculation of interval estimations it is not necessary to set high enough trust probability.

2. Promising areas include areas for which the upper limit of the interval estimation of the ore-bearing coefficient is less than 0.5.

It is necessary to recommend the site for priority preliminary exploration only if the lower limit of the interval assessment exceeds 0.5.

If the upper limit of the confidence interval is more than 0.5, and the lower - less than 0.5, the site can be considered promising, but not a priority for preliminary exploration. With a small total number of wells, further exploration and evaluation work can be recommended at the sites.

Self-Test Questions:

1. What is the planar ore-bearing coefficients (K_p) and how to calculate it?
2. What is considered a promising area?

References:

1. *Dekking, F.M. (Frederik Michel) (2005). A modern introduction to probability and statistics : understanding why and how. Springer. ISBN 1-85233-896-2. OCLC 783259968.*
2. Pav Kalinowski, "Understanding Confidence Intervals (CIs) and Effect Size Estimation", *Observer* Vol.23, No.4 April 2010.
3. Sandercock, Peter A.G. (2015). "Short History of Confidence Intervals". *Stroke*. Ovid Technologies (Wolters Kluwer Health). 46 (8). doi:10.1161/strokeaha.115.007750. ISSN 0039-2499.
4. https://onlinestatbook.com/Online_Statistics_Education.pdf

Class #8. Modeling of the stress-strain state of the system "geological environment-pipeline" and assessment the impact of the cryogenic, gravitational and water flows processes on the pipelines.

Students should have knowledge of basics of general geology, rheological models and be able to apply the main methods of the assessment of the stress-strain state of the rocks in geomodelling

Concepts goals for this activity: main methods of the assessment of the stress-strain state of the rocks in geomodelling

Task: Determine the stress intensity dependence on the parameters of the distance to the warping source for these characteristics. Create graphs for all possible combinations, using Excel and screenshots of the obtained diagrams. To analyze dependencies use literature sources and own knowledge.

Rock modulus of elasticity, MP (modulus of general deformation)	Poisson ratio of the rock	Rock density kg/m3	Force parameters of warping, sm	Frost injury, %	Pipe thickness, m	Depth of deposition, m	Pipe radius, m	distance from source of warping, m	iground, MP	intens_tube_int, MP	intens_tube_ext, MP
22500	0,41	1750	0	0	0,0186	1	1,4	**0,1**			
22500	0,41	1750	0	0	0,016	1	1,4	**0,4**			
22500	0,41	1750	0	0	0,016	1	1,4	**0,6**			
22500	0,41	1750	0	0	0,016	1	1,4	**0,8**			
22500	0,41	1750	0	0	0,016	1	1,4	**1**			
22500	0,41	1750	0	0	0,016	1	1,4	**1,2**			
22500	0,41	1750	0	0	0,016	1	1,4	**1,4**			
22500	0,41	1750	0	0	0,016	1	1,4	**1,6**			
22500	0,41	1750	0	0	0,016	1	1,4	**1,8**			
22500	0,41	1750	0	0	0,016	1	1,4	**2**			
22500	0,41	1750	0	1	0,0186	1	1,4	**0,1**			
22500	0,41	1750	0	1	0,016	1	1,4	**0,4**			
22500	0,41	1750	0	1	0,016	1	1,4	**0,6**			
22500	0,41	1750	0	1	0,016	1	1,4	**0,8**			
22500	0,41	1750	0	1	0,016	1	1,4	**1**			
22500	0,41	1750	0	1	0,016	1	1,4	**1,2**			
22500	0,41	1750	0	1	0,016	1	1,4	**1,4**			
22500	0,41	1750	0	1	0,016	1	1,4	**1,6**			
22500	0,41	1750	0	1	0,016	1	1,4	**1,8**			
22500	0,41	1750	0	1	0,016	1	1,4	**2**			
22500	0,41	1750	0	2	0,0186	1	1,4	**0,1**			
22500	0,41	1750	0	2	0,016	1	1,4	**0,4**			
22500	0,41	1750	0	2	0,016	1	1,4	**0,6**			
22500	0,41	1750	0	2	0,016	1	1,4	**0,8**			
22500	0,41	1750	0	2	0,016	1	1,4	**1**			
22500	0,41	1750	0	2	0,016	1	1,4	**1,2**			
22500	0,41	1750	0	2	0,016	1	1,4	**1,4**			
22500	0,41	1750	0	2	0,016	1	1,4	**1,6**			
22500	0,41	1750	0	2	0,016	1	1,4	**1,8**			
22500	0,41	1750	0	2	0,016	1	1,4	**2**			

Progress:

Mathematical model and algorithm

The forecast of the qualitative and quantitative characteristics of the geological environment and assessment of their impact on the pipeline are underpinned by using mathematical models of the stress-strain state (Pelletier, 2008)

Pipeline-environment stress-strain state problem. Mathematical modeling and stress-strain state evaluation were carried out using authors approach for solving this kind of problems. We studied the problem of the stress-strain state of the pipeline located in the heavy medium (Figure 1).

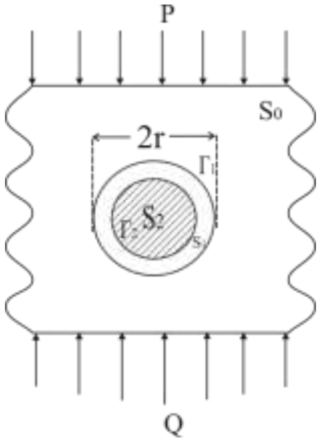


Figure 1: Given fragment of a pipeline (section al view)

Estimation has been undertaken of the mechanical forces affecting the pipeline due to the freeze-thaw effects of the ground regime, especially the volumetric effects caused by these processes.

The main factors that result in the pressure on the pipeline areas follows: (i) the impact of gravitation on the pipeline (the weight of the medium); (ii) the impact of the forces arising due to the volumetric expansion of the water-saturated environment during freezing; (iii) the impact of loads from the pipeline warping; (iv) the differences in the temperature of the heated pipeline and of the surrounding area; (v) the internal pressure of the gas in a pipeline (Ivanik et al., 2009). Stresses and strains obey the Duhamel-Neumann law:

$$\sigma_{ij} = s_{ij} - 3K\alpha T\delta_{ij},\ i, j = 1,2 \quad (1)$$

where $K = \frac{E}{3(1-2\nu)}$, $s_{ij} = \lambda\theta\delta_{ij} + 2\mu\varepsilon_{ij}$, $\psi_i = \frac{\partial p}{\partial x_i}$, (2)

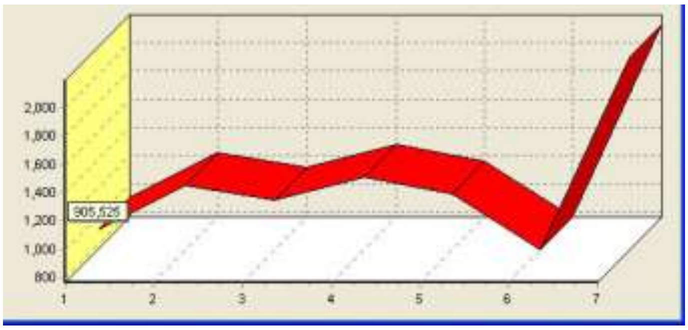
The assessment of the stress-strain state of pipeline fragment subjected to bending due to the influence of water flows, debris flows, etc. is adjacent to the above considered problem and can be solved separately using stress analysis of the pipeline bending when treating pipeline as a beam.

Example of cryogenic effect assessment. Developed modules based on the above described algorithm assumes an assessment of the impact of cryogenic processes on the pipeline complex.

Examples of the cryogenic processes inpact on the pipeline.

Estimation has been considered of the mechanical forces acting on the pipeline due to the freeze-thaw effects of the regime of grounds, especially the volumetric effects caused by these processes. From the research and the development of the program algorithm the main factors that result in loading on the pipeline are follows: a) the influence of gravitation forces on the pipeline (the weight of environment); b) the influence of the forces arising owing to volumetric expansion of the water-saturated environment during freezing; c) the influence of loads from pipeline warping; d) the influence of temperatures differences of the heated pipe and its environment; e) the influence of internal pressure of gas in a pipe.

To demonstrate this impact we propose here, as an example, the computation of the stress intensity of the ground stress on the pipe edge. We study the system "pipe – geological environment" with the following parameters. The type of the rock is frozen sand (modulus of general deformation 22500 MP, Poisson ratio 0.41, density 1750 kg/m^3). The force parameters of warping are changing from 20 to 90 sm, frost injury 3 %, depth of pipe deposition 2 m, distance from source of warping 2 m, pipe thickness 0, 0186 m, pipe radius 0,71 m. The stress intensity on the external pipe edge ranging from 514,03 MP to 970, 48 MP. The intensity of the ground stress on the pipe edge ranging from 492,8 MP to 995 MP.



The changes of the ground stress intensity on the pipe edge

Self-Test Questions:

1. What are the main factors that result in the pressure on the pipeline areas?
2. What parameters are used in order to determine the stress intensity?

References:

1. Ivanik O., Shevchuk V., Kravchenko D. and Lavrenyuk M. Modeling of Natural Hazards Impact on the Safety of Gas Pipelines // Extended abstract: 81st EAGE Conference and Exhibition 2019 , 2019, DOI: 10.3997/2214-4609.201901501

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3. Pelletier J., 2008. Quantitative modelling of Earth processes.

4. Revie, R Winston, 2015. Oil and Gas Pipelines: Integrity and Safety Handbook.

Class #9. Modeling the influence of geological-geomorphological and paleogeographic conditions on the patterns of formation of amber-bearing strata. Creating maps of paleo-relief and determining the amber prospects

Students should have knowledge of basics of general geology, geomorphology and be able to apply the main methods of the assessment of the stress-strain state of the rocks in geomodelling

Concepts goals for this activity: main methods of the assessment of the stress-strain state of the rocks in geomodelling

The amber deposit is located within the Pripiat amber-bearing basin in the Klesiv-Rokytne amber-bearing zone. Amber strata is represented by weakly clayey, multi-grained sands of the mezhygirska suite of the Oligocene. They contain fragments of carbonized and lignified wood.

The area within which the deposit is located in the Oligocene was a shallow lagoon (sea bay), as evidenced by the presence of lagoon-delta sediments with glauconite and a specific particle size distribution. This lagoon was separated from the sea by a sandy-clay spit. The resin of trees, which was buried in lagoon-delta sediments, was carried to the lagoon from the east by a water stream from the coastal forests, together with silt and plant remains.

The lagoon was connected to the open sea through straits in the northwestern and northern parts, where new placers could be found.

The data used in the analysis of factors of formation of amber-bearing strata are the result of exploration and evaluation works at the amber deposit.

These are wells and pits (247 in total), which have the following positional and non-positional attributes: geographical location; depth; thickness of productive layers; geological description of the layers; amber content within the intervals; groundwater level, etc.

Tasks:

1. Create a map of isoconcentrates of amber content in the sediments of the mezhygirska suite of the Oligocene, choosing the optimal method of interpolation.
2. Create a thickness map of the productive stratum, choosing the optimal interpolation method.
3. Build a map of the paleo-relief of the Early Oligocene.
4. Determine the paleogeomorphological conditions of formation of amber-bearing strata and to outline the prospects of amber-bearing area of the studied area.

***Procedure**:*

One of the methods of modeling geological systems is paleoreconstruction. The structure of the top and bottom of the geological body plays an important role in modeling some mineral deposits, primarily of sedimentary origin - phosphorites, amber, placer deposits, etc.

Successful solution of the problem of modeling geological conditions allows, based on the features of paleorelief and paleogeography, to predict the possibility of formation in certain places, mineral accumulations, or vice versa - to trace and outline areas that are not promising for search.

The use of standard interpolation methods is impractical because they work purely on a mathematical or statistical algorithm, without taking into account the real picture of the terrain. For such reconstructions, it is necessary to use the tool "***Topo to raster***".

The ***Topo to Raster*** tool is an interpolation method specifically designed to create hydrologically correct digital terrain models (DEMs). It is based on the ANUDEM program developed by Michael Hutchinson.

Hydrology tools are used to model the flow of water on the surface. In our case, we are dealing with a digital terrain model that extends both on the surface and underwater, however, in this case, we can predict the hydrodynamic conditions and migration paths of precipitation.

1. Download the previously created Topo to Raster DEM into the ArcGis software environment.

2. **Fill** tool. Serves to fill in local depressions in the surface raster to remove minor errors and inaccuracies possessed by interpolated surfaces.

3. **Flow Direction** tool. Creates a raster of the direction of a drain from each cell to the nearest next cell on a slope of the greatest steepness.

4. **Flow Accumulation** tool (internal option "**Integer**"). Creates an accumulation flow raster in each cell.

5. **Stream Order** tool (Strachler method). Assigns an order number to raster segments representing segments of a linear grid.

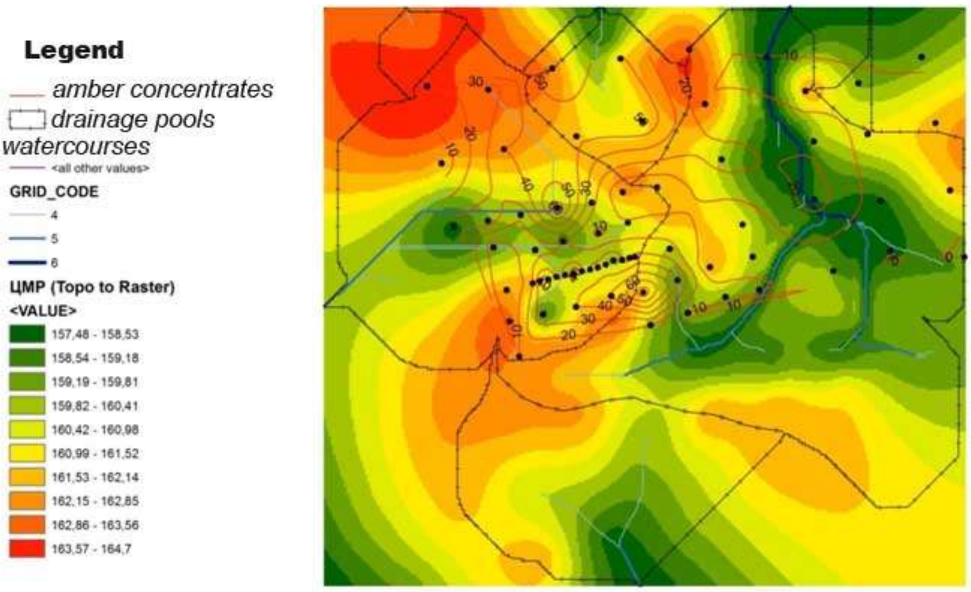
6. **Stream to Feature** tool. Converts a raster, which is a linear grid, to vector objects.

7. Function **Definition quary** (Grid code <> 1 and grid code <> and grid code <> 3). Used to display only certain layer objects using an expression. In our case we select the main streams.

8. **Symbology** function. Serves for visual representation of attributive data. In **Categories,** in the **Unique values** subcategory, we need to select GRID_CODE in the Value Field field and assign each GRID_CODE value its own visual representation, and the larger it is, the more intense the color and the thicker the line.

9. **Basin** tool. Creates a raster that contains the contours of all drainage basins. They are especially important for our study because they allow us to determine the contours of areas where hydrodynamic conditions have changed in one way or another.

10. **Conversion from raster to polygon** tool. Used to convert a raster to a vector object. The result of such a model is a digital terrain model, which shows the main ways of migration of sediments and the movement of water and underwater currents and the boundaries between different hydrodynamic zones (basins). The next step in modeling will be the imposition of is concentrates on the finished graphic model and the search for the patterns in its accumulation.



Self-Test Questions:

1. What methods of interpolation do you know? Which method did you use in this class and why?
2. Why it can be useful to build the paleo-relief reconstructions for the sedimentary deposits (phosphorites, amber, placer deposits, etc.)?

References:

1. Ivanik O., Shevchuk V., Tustanovska L., Yanchenko V. &Kravchenko D. Paleogeography and neotectonics of Kaniv dislocations (Ukrainian Shield, Ukraine) in the Neogene-Quaternary period, Historical Biology, 2019; DOI: 10.1080/08912963.2019.1665039

2. Ivanik O.M., Koval D.M. *Analysis of the factors of amberbearing strata based on geoinformatical approach (on "Oleksiivka" amber deposit),* 16th International Conference Geoinformatics - Theoretical and Applied Aspects, Conf. Paper,15 – 17 May 2017. – Kyiv.: AUG, 2017.

3. Seyfullah, Leyla &Beimforde, Christina &Perrichot, Vincent & Rikkinen, Jouko& Schmidt, Alexander. (2012). Understanding amber deposits through modern resin studies.

4. NEL, A., DE PLOËG, G., MILLET, J., MENIER, J.-J. & WALLER, A. 2004a. The French ambers: a general conspectus and the Lowermost Eocene amber deposit of Le Quesnoy in the Paris Basin. GeologicaActa 2 (1): 3–8.

Class #10. Geomechanical modelling. Importing and creating well data and case setup

Students should have knowledge of basics of general geology, geophysics and be able to use the special software for geomechanical modelling

Concepts goals for this activity: main approaches and tools for the geomechanical modelling

This exercise is devoted to the general arrangement of a project and connection to the so called WITSML server, from where normally data for logs and wells are to be imported. This requires a special setup, involving an access to a Baker Hughes proper server with the corresponding stuff.

Exercise is meant for offline use and Learning Session 2.jewel should be loaded from the dataset location listed above. Navigate to the dataset location listed above and open Learning Session2.jewel.

Progress:

1. Creating a well schematic and markers.

The data imported from the WITSML server did not include well schematic or marker information. For that reason, you will create this data in this exercise of the tutorial.

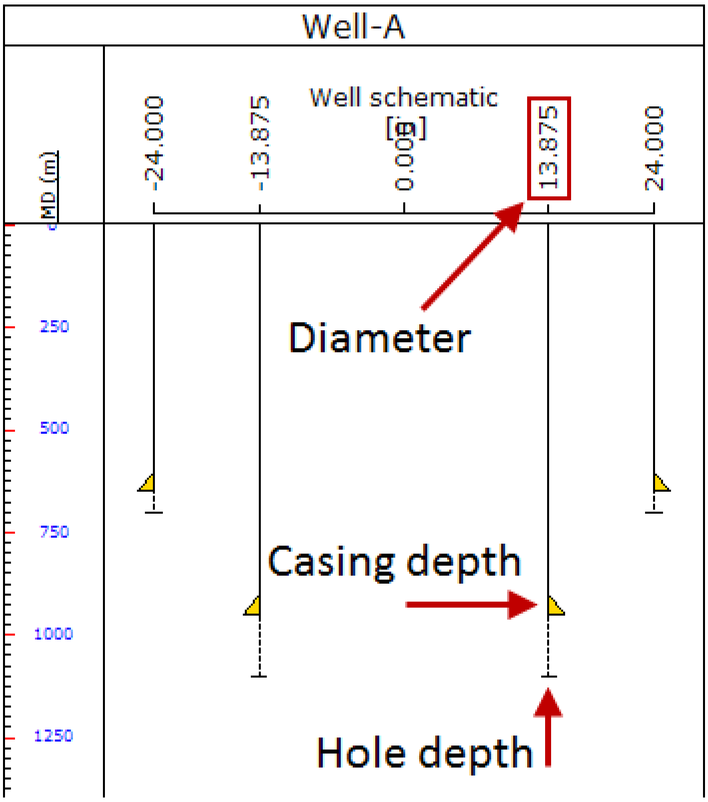
1. Click the Well Schematic icon in the DATA > Static Data strip. Ensure that the Well-A wellbore is selected and click Create to open the Well Schematic view of the Well Table.

2. The Well Schematic tab in the Wellbore View contains a table in which you can define the details of the well schematic. Enter the parameters from the table below (leaving the two Liner Top columns blank) and ensure that the units are specified correctly for each column:

Hole Depth MD [m]	Hole Depth TVDSS [m]	Hole Size [in]	Casing MD [m]	Casing TVDSS [m]	OD[in]
700	670	30	650	620	24
1100	1069.59	17.5	950	919.99	13.875

Note: You can change unit for a column by right-clicking the column header and selecting the unit from the Units menu.

3. On the Wellbore Schematic form, click the Show button to open the Wellbore Schematic Track.



The well schematic shows the hole depth, casing depth and diameter. You can move the casing graphically up and down by clicking a casing shoe and dragging it. This action automatically updates the table view.

If the casing diameter value is rounded, right-click the value and then change the format to a three decimal digits.

4. Click OK on the Well Schematic form to proceed to the Well Markers form.

5. The Well Markers form is used to create or import markers. In this tutorial you will create the markers in a table view, similar to how you created the well schematic data. Click Create to open the Markers form.

6. On the Markers form, ensure that Well-A is selected as the active wellbore and switch the Depth input mode to TVDRT.

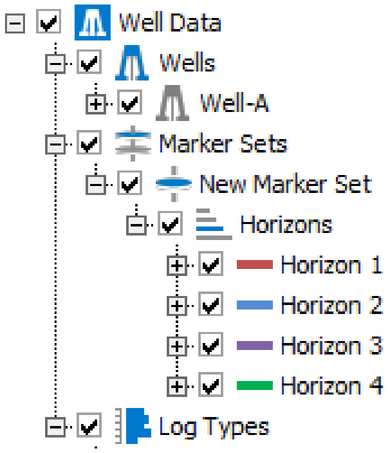
7. Enter the following markers:

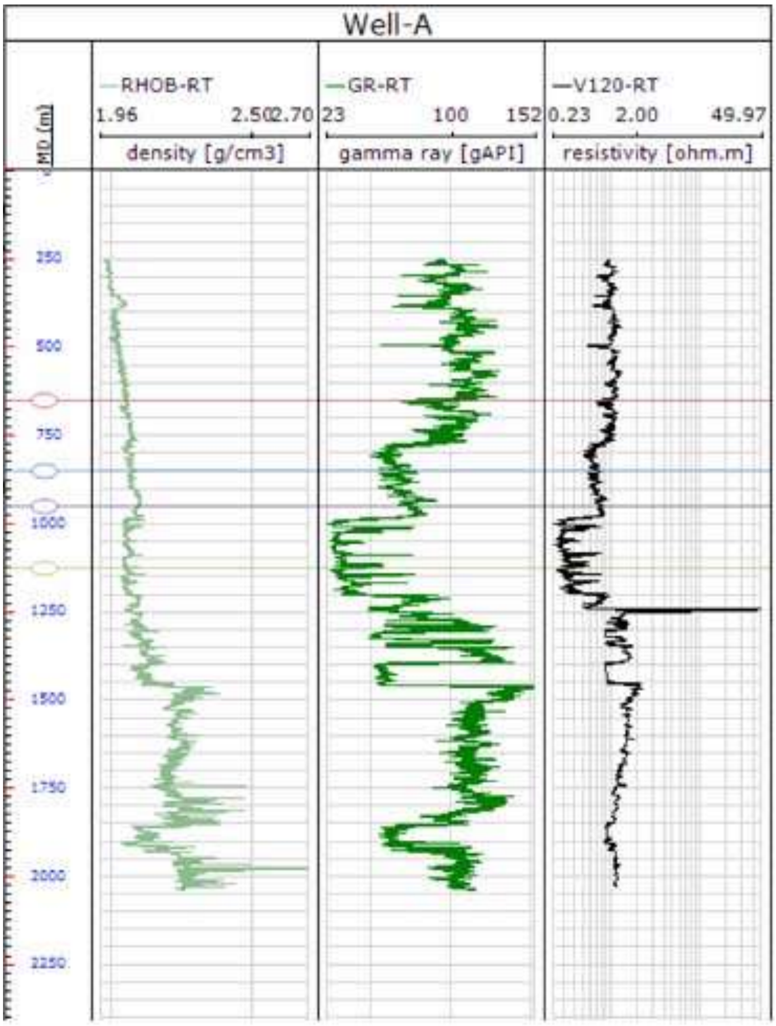
Name	TVDRT[m]	MD[m]	Type	Color
Horizon 1	650	650.00	Horizon	Red (192, 80, 77)
Horizon 2	850	850.00	Horizon	Blue (84, 141, 212)
Horizon 3	950	950.01	Horizon	Purple (128, 100, 162)
Horizon 4	1125	1125.73	Horizon	Green (0, 176, 80)

You can change the color of the markers by clicking in the drop-down menu in the Color column.

8. Click Apply to create the markers based on your input, then close the form. This action creates a marker set that can be accessed in the Jewel Explorer under the Well Data > Marker Sets folder. Close the Markers and Well Markers forms.

9. Activate the Well Correlation view you previously opened. This view already displays the three logs. In the Jewel Explorer, check the boxes for each of the markers to add them to the view.





2.Importing additional logs and creating calibration data

In this section an Overburden Density log is imported in order to demonstrate the log import process when dealing with data stored in plain text files. As a final step in the data import and creation phase of this tutorial, you will create calibration data using the Calibration Data form.

1. In the DATA > Static Data sub-strip open the Logs form.

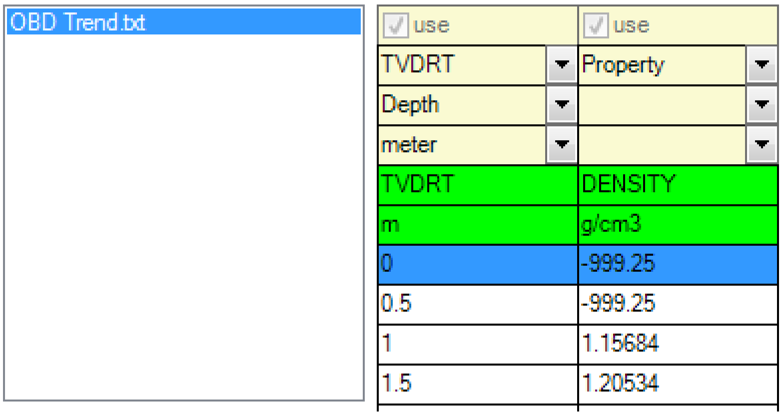
2. On the Logs form, click Import to open the import dialog.

3. Select as Import type Custom format (*.*). This is a generic file reader type that you can use to import all data like wells, logs and markers when the data is formatted in multiple columns (such as Excel).

4. Browse to the tutorial data location (C:\Users\Public\Public Documents\Baker Hughes\JewelSuite 6.2 GeoMechanics Tutorials\Tutorial 1 - Full Pore Pressure Prediction Workflow), select OBD Trend.txt, and click Open.

5. In the Well table settings section on the left side of the form, set Start import at line to 3.

Specify TVDRT as the data type for the first box of the first column, and select Depth and meter in the two boxes immediately beneath. Specify Property in the first text box of the second column. Properties are specified in the next step of the process.



Import settings are at the left side of the form. These settings are similar to Excel settings for importing text-based data into a sheet (Text to Columns option).

6. Click Next to display the property validation screen.

On this form, you connect the imported density data to a well (in this case Well-A, which is the only well in the project).

7. Ensure that Data type is Density, and that the import units are gram per cubic centimeters. Click Finish to import the log.

	Import	Name	Wellbore	Data type	Unit	Local measurement	Depth unit	Dim1	Dim2
▶	☑	DENSITY	Well-A	Density	gram per cubic centimeter	☐	meter	0	0

8. Click OK on the Logs form to proceed to the Calibration Data form.

9. The Calibration Data form is used to create or import calibration point data. In this tutorial you will create additional LOT data to demonstrate how to input and use additional well data points.

10. In the Calibration Data drop-down box, select Shmin calibration – EMW (LOT, FIT, Ballooning..). Click Create to open the Logs form.

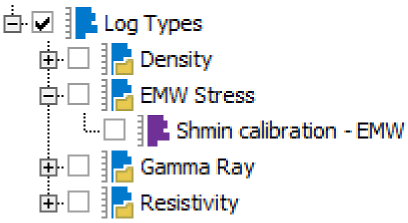
11. In the Log drop down box select Create new. In the adjacent text field type in Shmin calibration – EMW for the name of the calibration log you will create.

12. Ensure that Property type is set to EMW Stress. In the Scaling section, select Normal scale, set the Left scale to 0 ppg and the Right scale to 20 ppg.

13. In the Properties table specify the following rows of data:

MD(m)	Value(ppg)
820	12.30
925	12.80
1025	13.60

14. Click Apply at the bottom of the view to create the Shmin calibration - EMW log. This action creates the new points on the wellbore. They are now available in the JewelExplorer under Well Data > Log Types >EMW Stress.

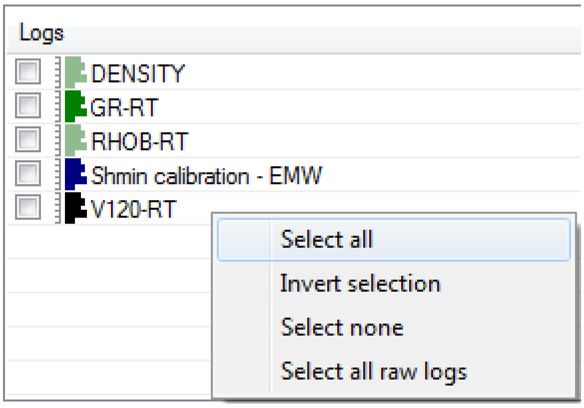


15. Close the Logs and Calibration Data forms. At this point you may also have many view tabs open. Close all tabs except for the Well Correlation view.

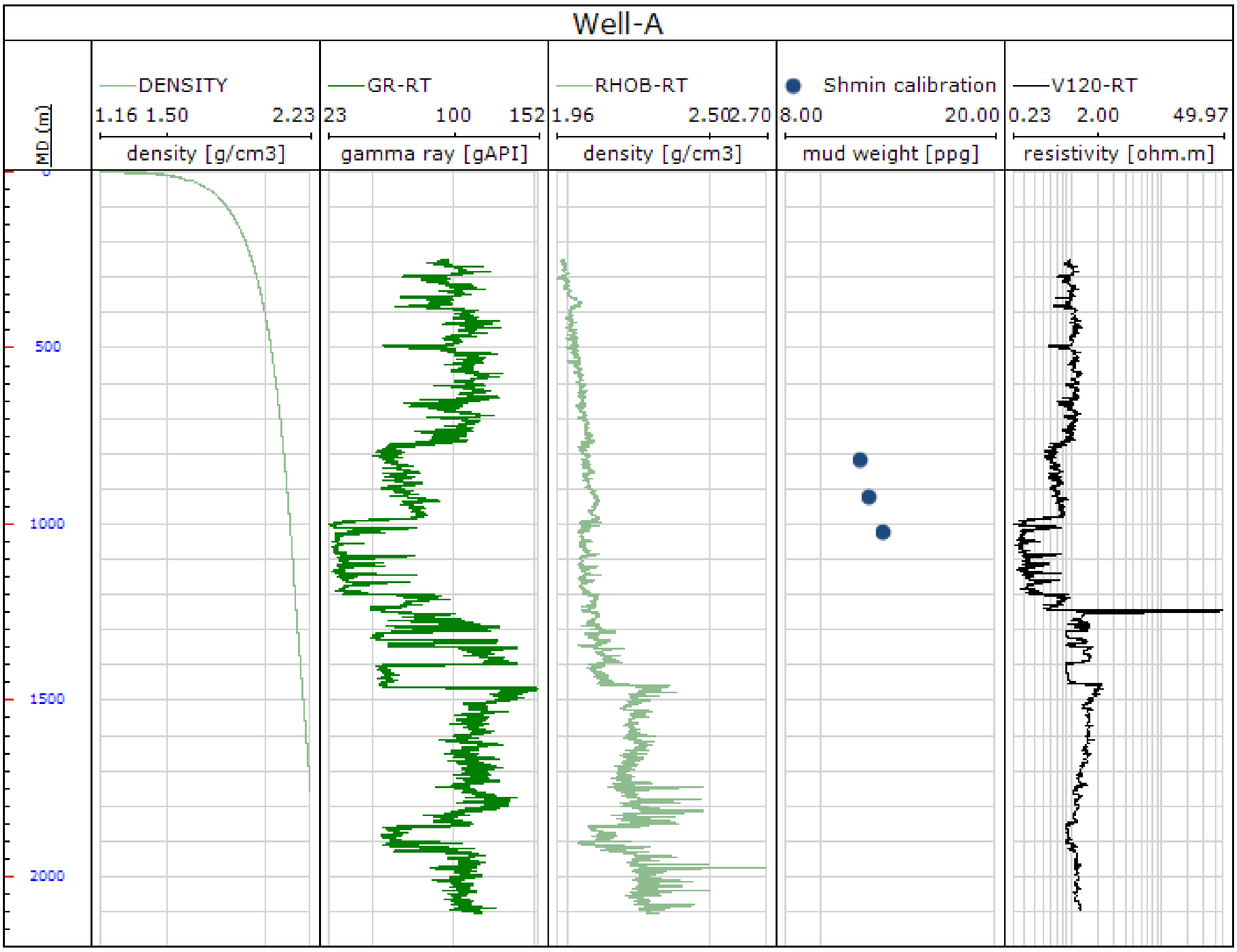
Now that all of the initial data has been imported or created, you can perform a QC before moving to the 1D modeling workflow.

Validating data

1. In the DATA > Static Data sub-strip open the Check Logs form. This form allows you to quickly show and check all the well data you created or imported. Right-click the list box and choose Select all.



2. Click Show to open a new view with all the imported and created log data. Observe that the newly created Shmin calibration - EMW log represents the data points defined during the creation process in the previous section. All other data appears correct.



3. Close the Check Logs form.

You have now successfully added additional static well data that will you will use in the remainder of the tutorial. In the next section you will create and assign this data to a case so that you can start the 1D model workflow.

Self-Test Questions:

1. What are the parameters required to define a well?
2. What are the well markers? How to set new ones?

References:

1. Ahmed, B.I., Al-Jawad, M.S. Geomechanical modelling and two-way coupling simulation for carbonate gas reservoir. *J Petrol Explor Prod Technol* **10,** 3619–3648 (2020). https://doi.org/10.1007/s13202-020-00965-7

2. https://petrowiki.spe.org/Geomechanics_in_reservoir_simulation

3.https://www.bakerhughes.com/integrated-well-services/integrated-well-construction/evaluation/reservoir-modeling/jewelsuite-subsurface-modeling-software/jewelsuite-geomechanics

4. Dataset location: C:\Users\Public\Public Documents\Baker Hughes\JewelSuite 6.2 GeoMechanics

5. Tutorials\Tutorial 1 - Full Pore Pressure Prediction Workflow