GEOTHERMAL ENERGY

SLOVAKIA

ENergy **E**fficiency and **R**enewables – **SUP**porting **P**olicies in **L**ocal level for **E**nerg**Y**

1. INTRODUTION

1.1. Geography

Slovakia is a landlocked Central European country with mountainous regions in the north and flat terrain in the south. Slovakia lies between 49°36’48’’ and 47°44’21’’ northern latitude and 16°50’56’’ and 22°33’53’’ eastern longitude. Slovakia borders Poland in the north - 547 km, Ukraine in the east - 98 km, Hungary in the south - 669 km, Austria in the south-west - 106 km, and the Czech Republic in the north-west - 252 km for a total border length of 1672 km.

Two main geographic regions define the Slovakian landscape: the Carpathian Mountains and the Pannonian Basin. Two-thirds of the country is in the Carpathians, most of it in the Western Carpathians and the rest of country extends into the Pannonian Basin.

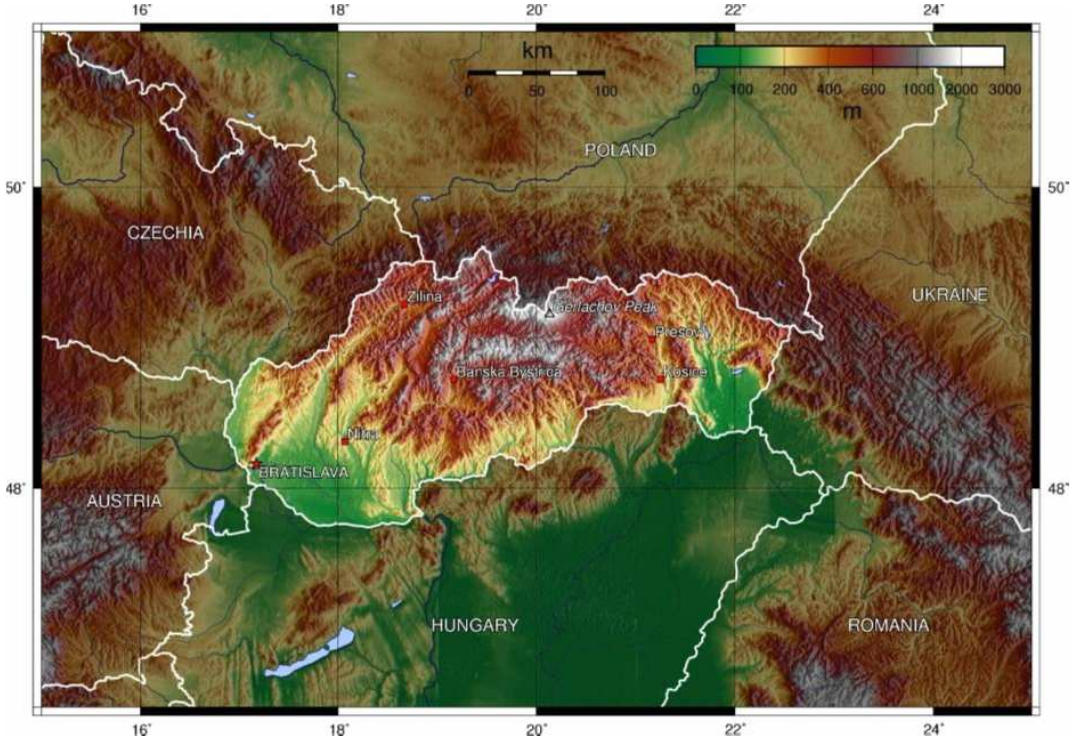

Figure 1: Position of Slovakia

1.2. Position of Slovakia in the Carpathian Mountains’ Arc

The Carpathians are an extensive range of mountains that form an arc of approximately 1500 km across Central and Eastern Europe. The chain of mountain ranges stretches in an arc from the Czech Republic in the northwest to Slovakia, Poland, Ukraine and Romania in the east, to Iron Gates on the Danube River between Romania and Serbia in the south.

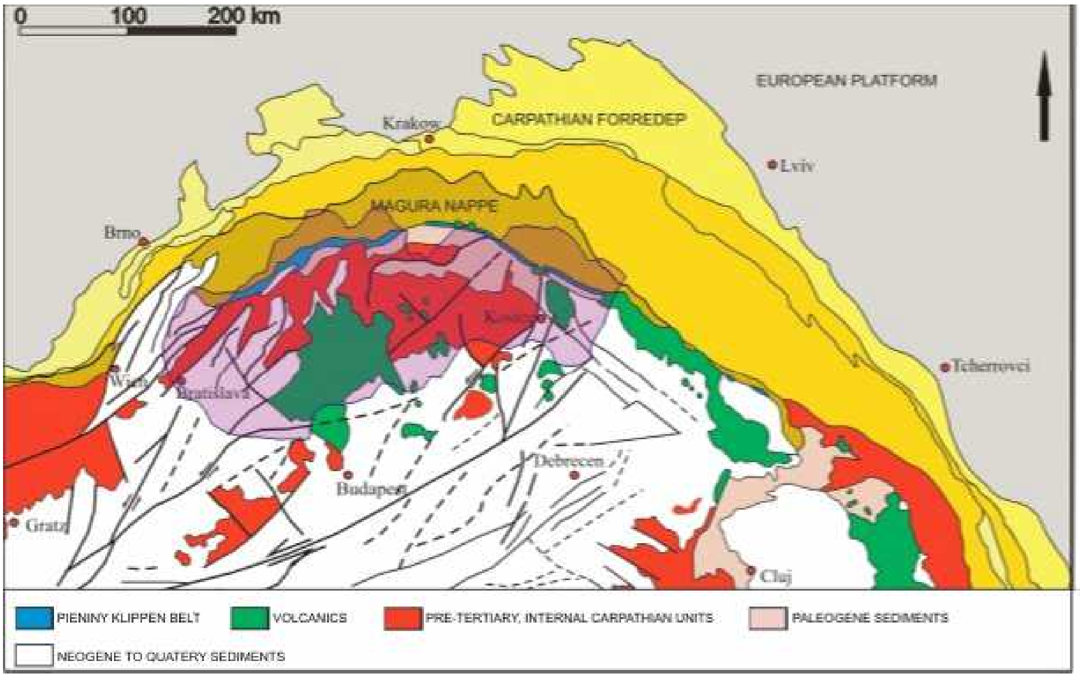

Figure 2: Structural sketch of Carpathian arc and position of Slovakia

The Carpathians extend in a geologic system of parallel structural ranges. The Outer Carpathians – whose rocks are composed of flysch – run from near Vienna, through Moravia, along the Polish-Czech-Slovak frontier, and through western Ukraine into Romania, ending in an abrupt bend of the Carpathian arc north of Bucharest. In this segment of the mountains, a number of large structural units of nappe character (vast masses of rock thrust and folded over each other) may be distinguished. The Inner Carpathians consist of a number of separate blocks. In the west lies the Central Slovakian Block; in the southeast lie the East Carpathian Block and the South Carpathian Block, including the Banat and the East Serbian Block. The isolated Bihor Massif, in the Apuseni Mountains of Romania, occupies the centre of the Carpathian arc. Among the formations building these blocks are ancient crystalline and metamorphic cores onto which younger sedimentary rocks - for the most part limestones and dolomites of the Mesozoic era (245 to 66.4 million years ago) - have been overthrust. The third and innermost range is built of young Tertiary volcanic rocks formed less than 50 million years ago, differing in extent in the western and eastern sections of the

Carpathians. In the former they extend in the shape of an arc enclosing, to the south and east, the Central Slovakian Block; in the latter they run in a practically straight line from northwest to southeast, following the line of a tectonic dislocation, or zone of shattering in the Earth's crust, parallel with this part of the mountains. Between this volcanic range and the South Carpathian Block, the Transylvanian Plateau spreads out, filled with loose rock formations of young Tertiary age. The Central Slovakian Block is dismembered by a number of minor basins into separate mountain groups built of older rocks, whereas the basins have been filled with younger Tertiary rocks.

The relief forms of the Carpathians have, in the main, developed during young Tertiary times. In the Inner Carpathians, where the folding movements ended in the Late Cretaceous epoch (97,5 to 66,4 million years ago), local traces of older Tertiary landforms have survived. Later orogenic movements repeatedly heaved up this folded mountain chain, leaving a legacy of fragmentary flat-topped relief forms situated at different altitudes and deeply incised gap valleys, which often dissect the mountain ranges.

1.3. Geothermal Sources

Slovakia is a country rich in low enthalpy geothermal sources. The potential of geothermal energy is about 21, 456 TJ/year. On the basis of distribution of the collectors of geothermal energy resources and geothermal field activity, 26 prospective areas (Fig. 3-2) or structures suitable for exploitation and energetic use were identified in Slovakia. They include above all the Tertiary basins or intermountain depressions spread in the zone of the Inner Western Carpathians. Their total area represents 34% of Slovakia’s territory. The sources of geothermal energy are represented in Slovakia above all by geothermal waters, which are linked to the Triassic dolomite and limestone rocks of the Inner Carpathian tectonic units, and, to a lesser extent, the Neogene sands, sandstone rocks, conglomerates or to the Neogene andesite rocks and their pyroclastics. These rocks, which are collectors of geothermal waters, are situated in the depth of 200 – 5,000 m and contain geothermal waters with temperatures of 15–160 °C. The overall thermal-energetic potential of the geothermal waters of Slovakia represents 5538 MWt, of which 4985 MWt is attributable to the reserves and 553 MWt to the sources. Probes carried out so far confirmed about 1200 l/s of geothermal waters, the thermal performance of which represents around 270 MWt.

1.4. Geothermal exploration

Possibilities to obtain geothermal waters, except those already used for natural springs, were discovered by drilling wells in Ganovce in 1879, in Kovacova (1899), in Dolna Strehova (1951), and in Kos and Komarno (1967). Marked progress in geothermal energy research in Slovakia started in the beginning of the seventies as a result of the oil crisis – during which the search for new, untraditional, economically profitable sources of energy was necessary. Geological exploration and research started in the Danube Basin and continued in further prospective areas of Slovakia. The first geothermal well, DS-1, was realized in 1971 in Dunajska Streda. The well was 2500 m deep and had a yield of 15 l/s with a well collar temperature of 92 °C. The distribution of aquifers with geothermal waters and the thermal manifestation of geothermal fields in Slovakia have enabled the definition of 26 prospective areas and structures with potentially exploitable geothermal energy sources. These areas and structures cover 27% of Slovakia's territorial extent. Research, prospecting and exploration of geothermal waters have so far been carried out in 13 prospective areas in Slovakia and in one non-prospective area (southern part of the Eastern Slovakian basin - an unsuccessful well). Between 1971 and 1994 a total of 61 geothermal wells were drilled (only 4 of them were unsuccessful) which verified 900 l/s of waters whose temperatures vary from 20 °C to 92 °C. The thermal capacity of these geothermal waters is around 184 MWt. Geothermal waters were captured by wells 210 to 2605 m deep, and their free outflow mostly ranged from 5 to 40 l/s (Remsik, 1993). Chemically, the waters are represented by Na-HCO3-Cl, Ca-Mg-HCO3-SO4 and Na-Cl types with mineralization of 0.7 20.0 g/l. The basic information about spatial distribution of geothermal energy sources provides an Atlas of geothermal energy of Slovakia (Franko, O., Remsik, A.,Fendek, M., eds., 1995).

2. Methodology

2.1. Phase 1. Realization of the topographic map, Digital elevation model (DEM).

Import DEM from the site http://www.gdem.aster.ersdac.or.jp/ ; log into the site; select the "Search" on the left column to search for the tile corresponding the area to be processed; choose the tile you need and to download . Obtained the DEM is imported into the GIS and can be process, by an interpolation of the shares of DEM, is realized topographic map.

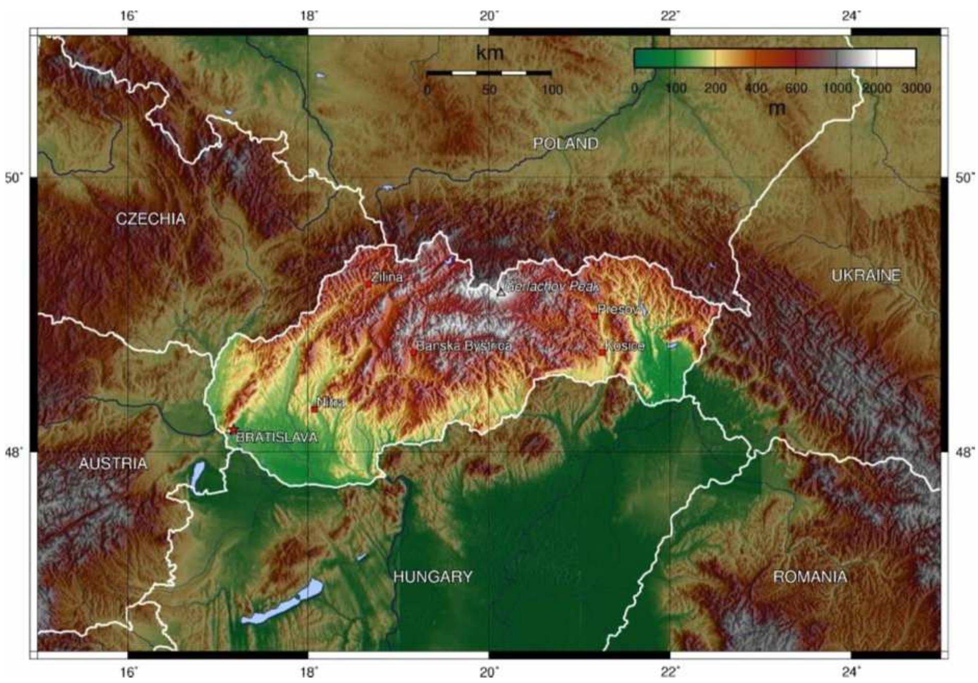

Figure 3 : DEM (Digital Elevation Model) SLOVAKIA

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2.2. Phase 2. Production of geo-referenced database (Geodatabase) through ArcCatalog (ESRI Corporation)

Attributes of wellsCopy heat flow

FID	Shape *	ID_VRTU	NAME_OF_WE	WELL_LOCAT	LATITUDE	LONGITUDE	T500	T1000	T1500	T2000	T2500	T3000	T4000	T5000	T6000	T0	DISCHARGE	HEAT_FLOW_	POWER_MW	T_D_S
0	Point	1	A-1	Albínov	48.746	21.678	39	52	84	0	0	0	0	0	0	0	0	116	0	0
1	Point	2	A-4	Albínov	48.746	21.644	38	63	84	105	126	149	185	223	254	0	0	116	0	0
2	Point	3	A-7	Albínov	48.746	21.681	39	64	88	107	128	148	186	229	258	0	0	119	0	0
3	Point	11	BN-14	Bánovce	48.665	21.83	35	62	86	105	127	143	189	233	273	46	0	112	0	0
4	Point	24	DU-1	Dunkovce	48.878	22.136	35	55	78	95	115	131	167	200	227	41	1	95	1.346	10
5	Point	28	Č-2	Čičarovce	48.559	21.949	38	61	82	102	116	128	181	231	271	50	6	121	8.793	17
6	Point	45	IU-1	ĺurkov	48.729	21.441	45	66	89	115	133	148	180	212	240	119	9	110	37.013	23
7	Point	84	GK-2	Teplička-Grét'Va	48.949	20.559	21	31	41	51	64	76	105	135	159	0	0	67	0	0
8	Point	123	KM-1	Komárovce	48.576	21.119	30	46	59	76	94	111	145	178	211	0	0	88	0	0
9	Point	149	L-1	Lastomír	48.678	21.915	39	64	86	105	128	144	189	227	265	0	0	112	0	0
10	Point	150	L-2	Lastomír	48.695	21.932	39	67	81	103	126	141	187	223	238	31	5	112	6.703	9
11	Point	177	ML-1	Malčice	48.593	21.881	36	63	90	113	139	150	191	236	262	0	0	122	0	0
12	Point	195	PT-1	Ptrukša	48.491	22.068	38	64	89	114	136	161	201	236	266	0	0	114	0	0
13	Point	196	PT-2	Ptrukša	48.474	22.085	39	67	91	115	140	163	203	237	264	0	0	114	0	0
14	Point	197	PT-7	Ptrukša	48.491	22.102	38	65	91	115	140	164	202	236	262	0	0	114	0	0
15	Point	200	PZ-1	Pozdišovce	48.763	21.884	40	67	93	119	140	155	189	223	265	0	0	120	0	0
16	Point	201	PZ-2	Pozdišovce	48.746	21.847	40	69	96	119	140	162	196	227	257	0	0	116	0	0
17	Point	225	RE-1	Rebrín	48.878	21.983	36	62	86	108	135	152	192	225	258	0	0	119	0	0
18	Point	228	RH-1	Remetské Hámre	48.868	22.189	28	44	62	78	93	108	139	170	198	0	0	73	0	0
19	Point	250	RN-1	Rozanovce	48.763	21.373	33	55	79	95	113	132	165	196	224	0	0	94	0	0
20	Point	255	S-1	Stretava	48.627	22.017	41	66	88	111	131	152	195	230	261	28	0	113	0.109	14
21	Point	256	S-5	Stretava	48.627	22.034	41	66	89	113	134	156	195	230	260	0	0	119	0	0
22	Point	257	S-7	Stretava	48.61	22.051	42	66	89	113	136	158	196	229	261	0	0	113	0	0
23	Point	258	S-21	Stretava	48.576	22.051	41	65	89	112	135	160	197	230	270	80	1	114	2.722	14
24	Point	263	SE-2	Sečovce	48.712	21.746	37	64	88	108	128	148	188	230	266	0	0	114	0	0
25	Point	264	SE-3	Sečovce	48.661	21.644	33	50	70	97	116	130	175	221	265	0	0	100	0	0
26	Point	291	T-1	Trebišov	48.61	21.763	35	63	88	114	132	150	190	228	267	0	0	112	0	0
27	Point	292	T-5	Trebišov	48.61	21.712	34	64	86	108	129	145	186	224	260	0	0	106	0	0
28	Point	293	TOS-1	Streda n/Bodrogom	48.373	21.729	44	55	83	104	116	133	167	202	233	0	0	94	0	0
29	Point	295	TMS-1	Sobrance	48.763	22.186	33	48	68	87	103	118	150	182	215	0	0	82	0	0
30	Point	296	TR-1	Trhovište	48.729	21.796	38	64	87	118	136	153	193	231	260	0	0	114	0	0
31	Point	297	TR-12	Trhovište	48.746	21.83	38	55	91	0	0	0	0	0	0	0	0	114	0	0
32	Point	298	TR-28	Trhovište	48.746	21.813	38	67	93	120	141	161	200	228	259	0	0	114	0	0
33	Point	345	Z-1	Zatín	48.491	21.932	44	70	98	115	135	154	195	230	264	0	0	114	0	0
34	Point	363	ZH-2	Záhura	48.898	20.916	17	29	44	69	72	86	115	135	165	0	0	51	0	0

2.3. Phase 3. Interpolation of Geo-database data (eg. Temperature, heat flow, etc…)

The type of interpolation is a function of data distribution in terms of geography and the physical process of study. The name of the interpolation used for create geothermal maps of Slovakia is: SPLINE INTERPOLATION.

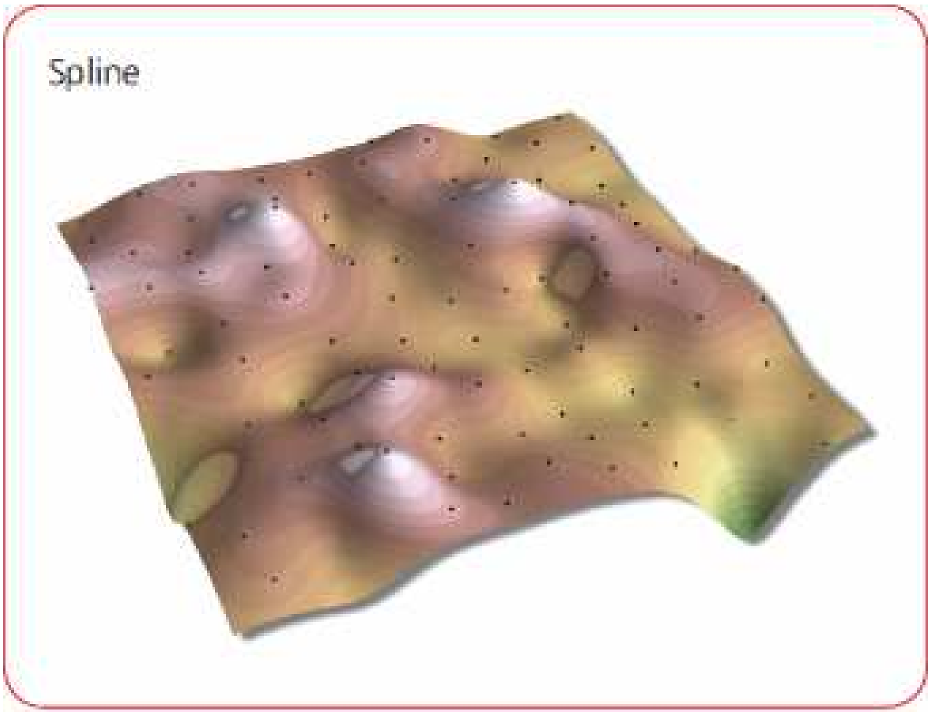

Figure 4: Spline interpolation

Spline estimates values using a mathematical function that minimizes overall surface curvature. There are two variations of spline – regularized and tension.

Tension spline uses only first and second derivates, it includes more points in the spline calculations, which usually creates smoother surface but increase computation time.

2.4. Phase 4. Overlapping levels

With use of Geographic Information System (GIS Technology), is possible to bring together different levels of information related to area in question and to geo- referenced data.

Available data:

- Wells (location and depth)

- Geomorphological units
- Basic geochemical rock types
- Heat flow

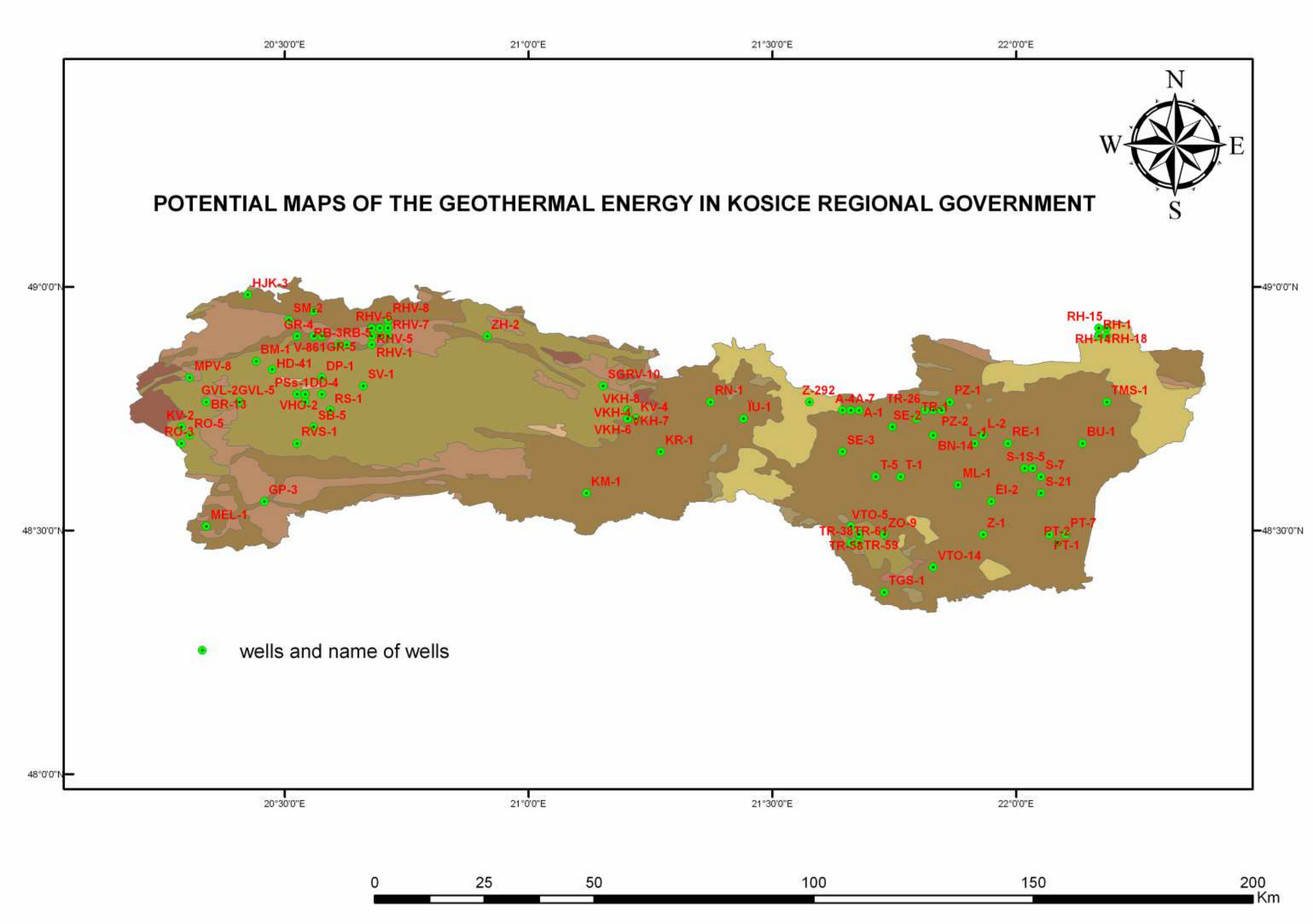

Figure 5: geo-referenced wells and Basic geochemical rock types

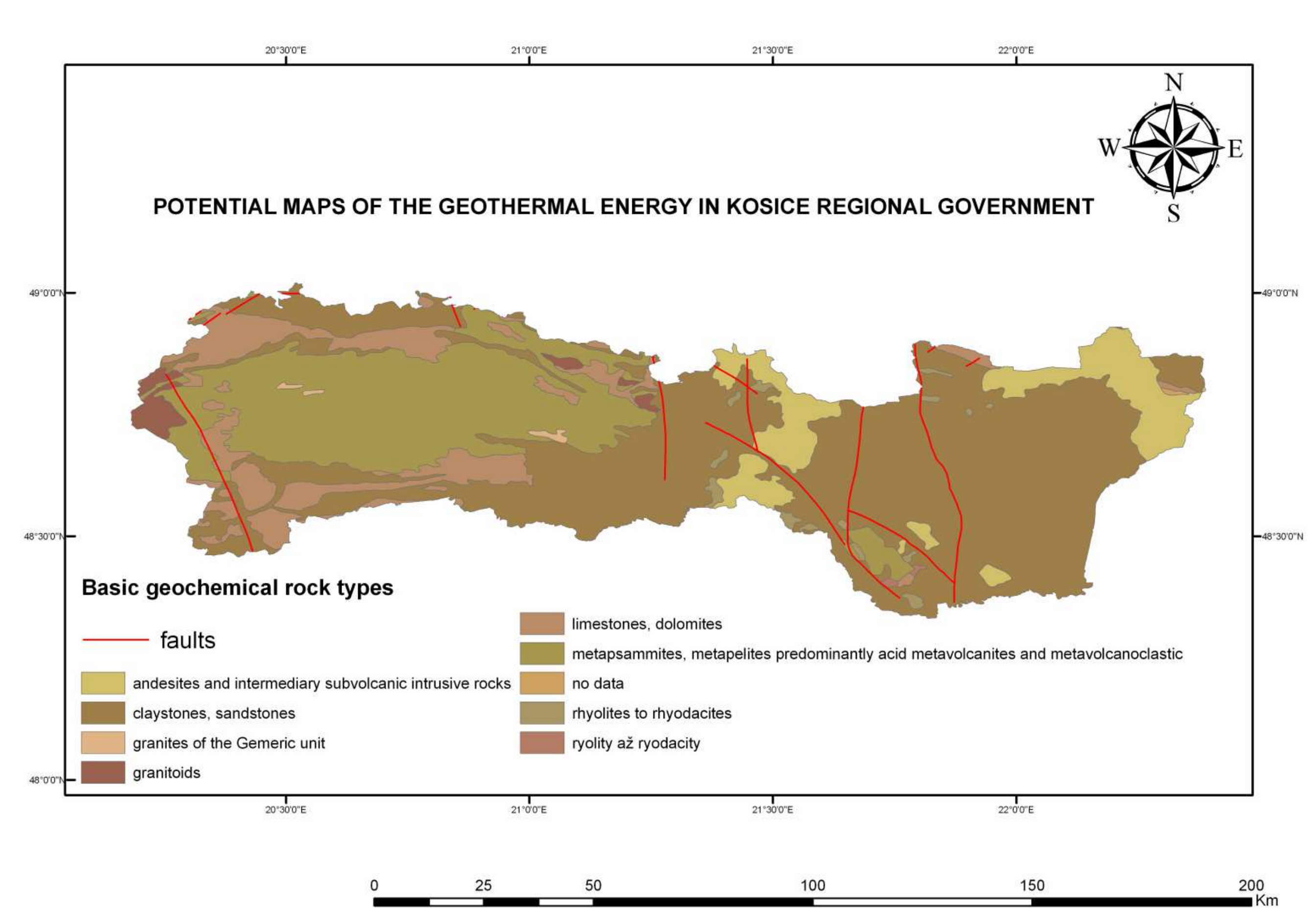

Figure 6: Basic geochemical rock types and faults

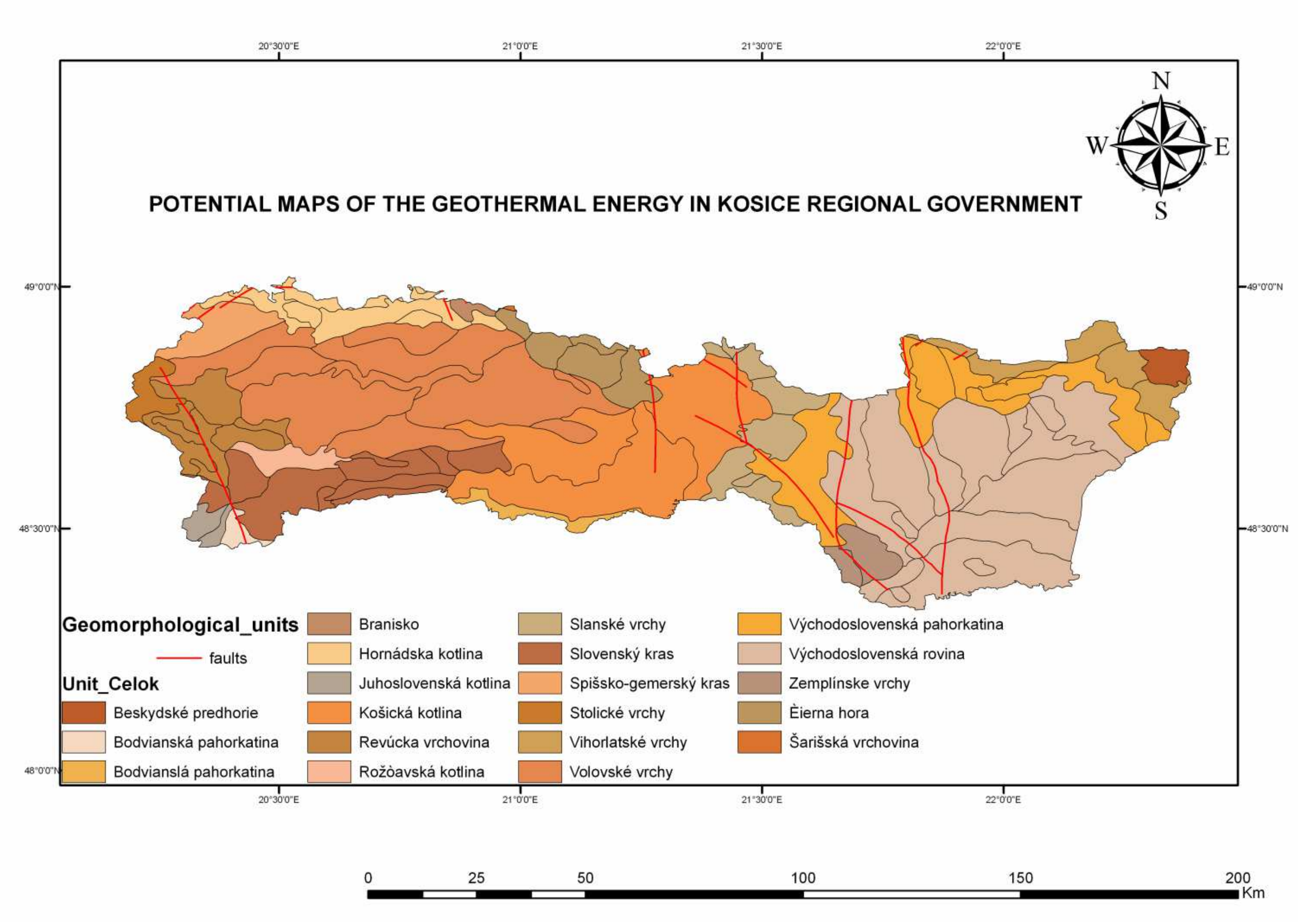

Figure 7: Geomorphological units and faults

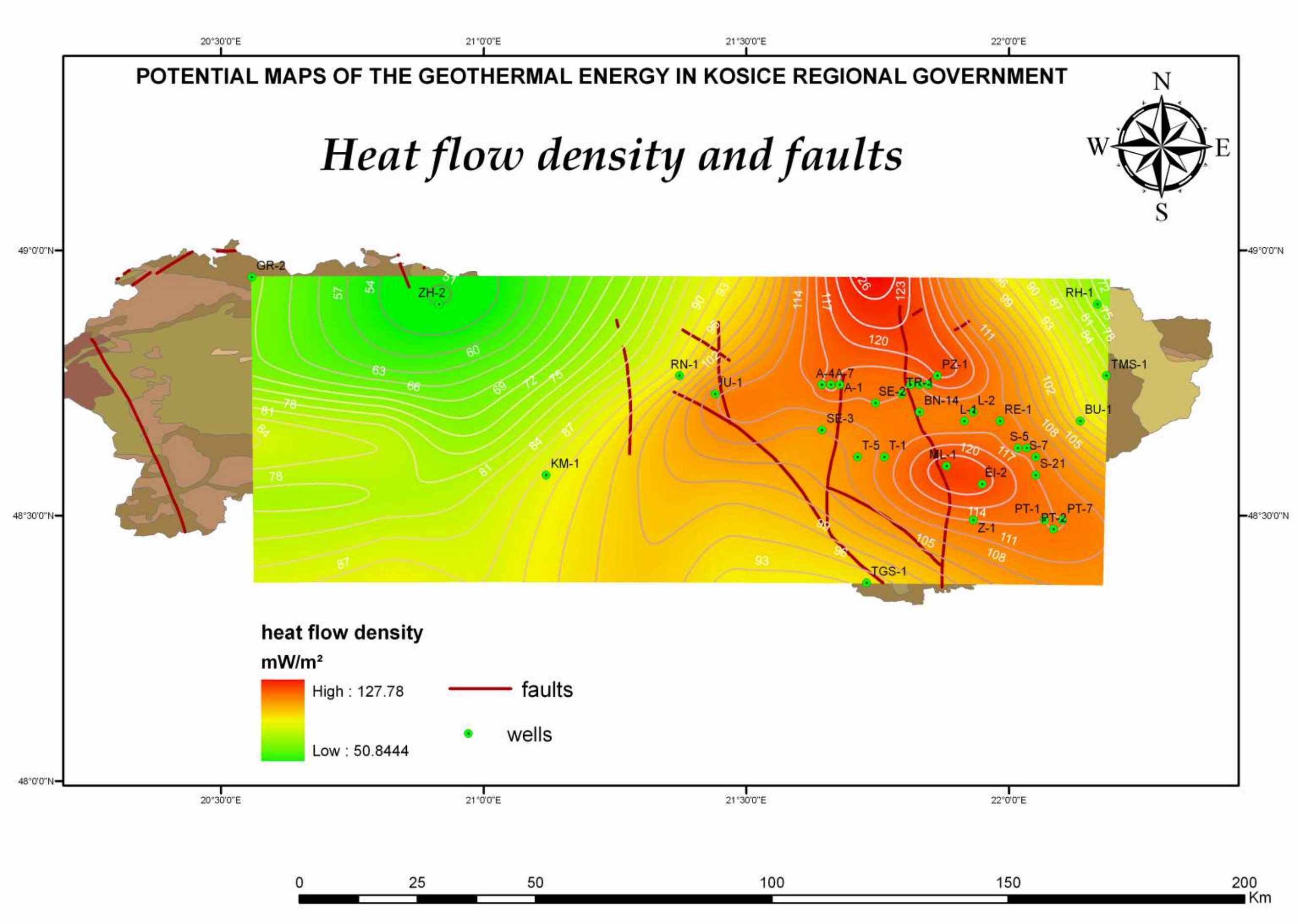

Figure 8: Heat flow density, faults and wells

2.5. Phase 5. Results and interpretation of geological and geothermal data

Geothermal maps were made using a particular type of interpolation (Spline interpolation) that can analyze the data having the slightest margin of error, so you have an excellent graphic representation of data available.

Geothermal maps shown below, represent the temperature distribution in depth throughout the area examined, starting from the exact data available within the wells, we interpolate the other data in the surrounding areas.

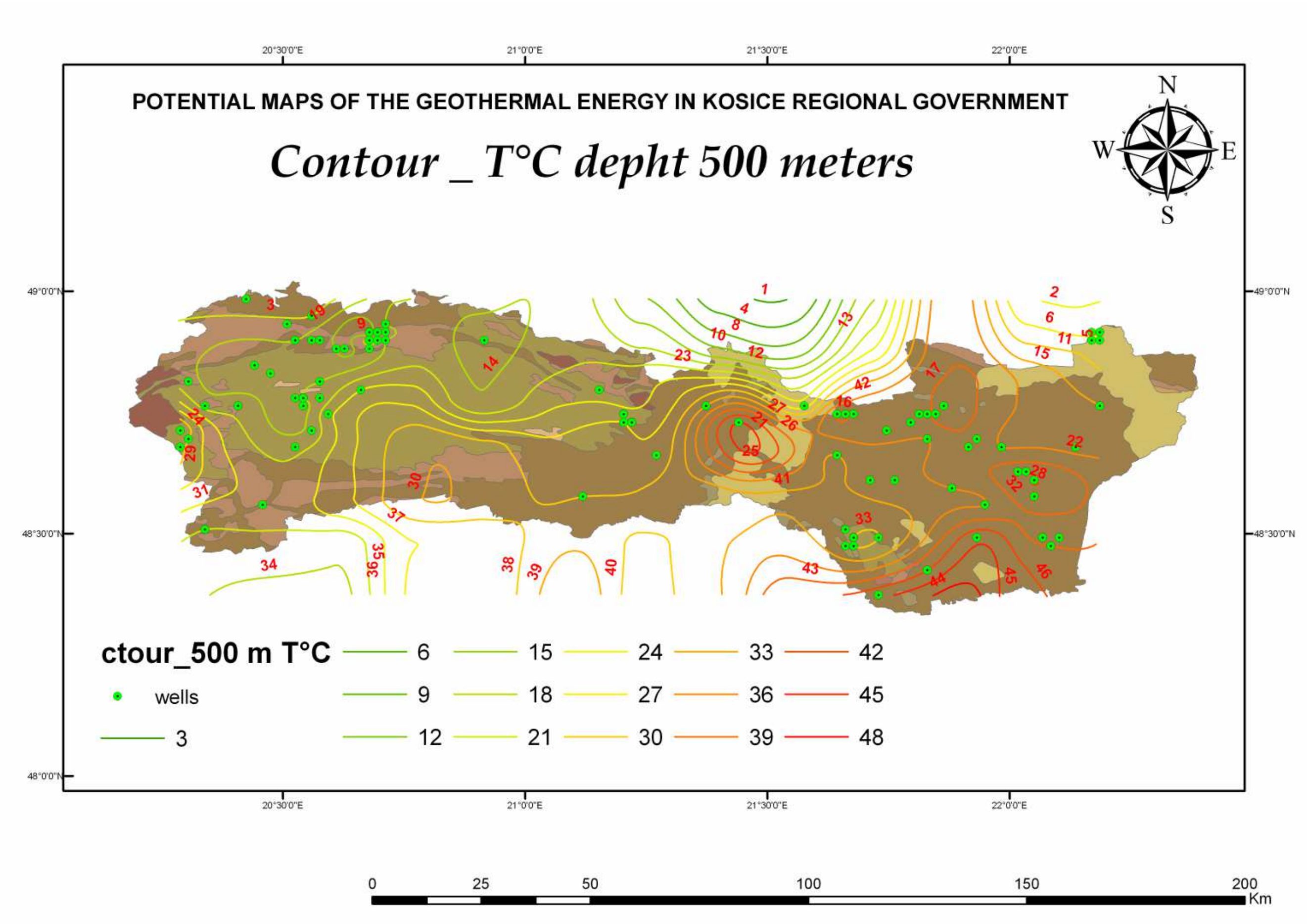

Figure 9: isotherms at a depth of 500 m - superposition of isotherms based on basic geochemical rock types –

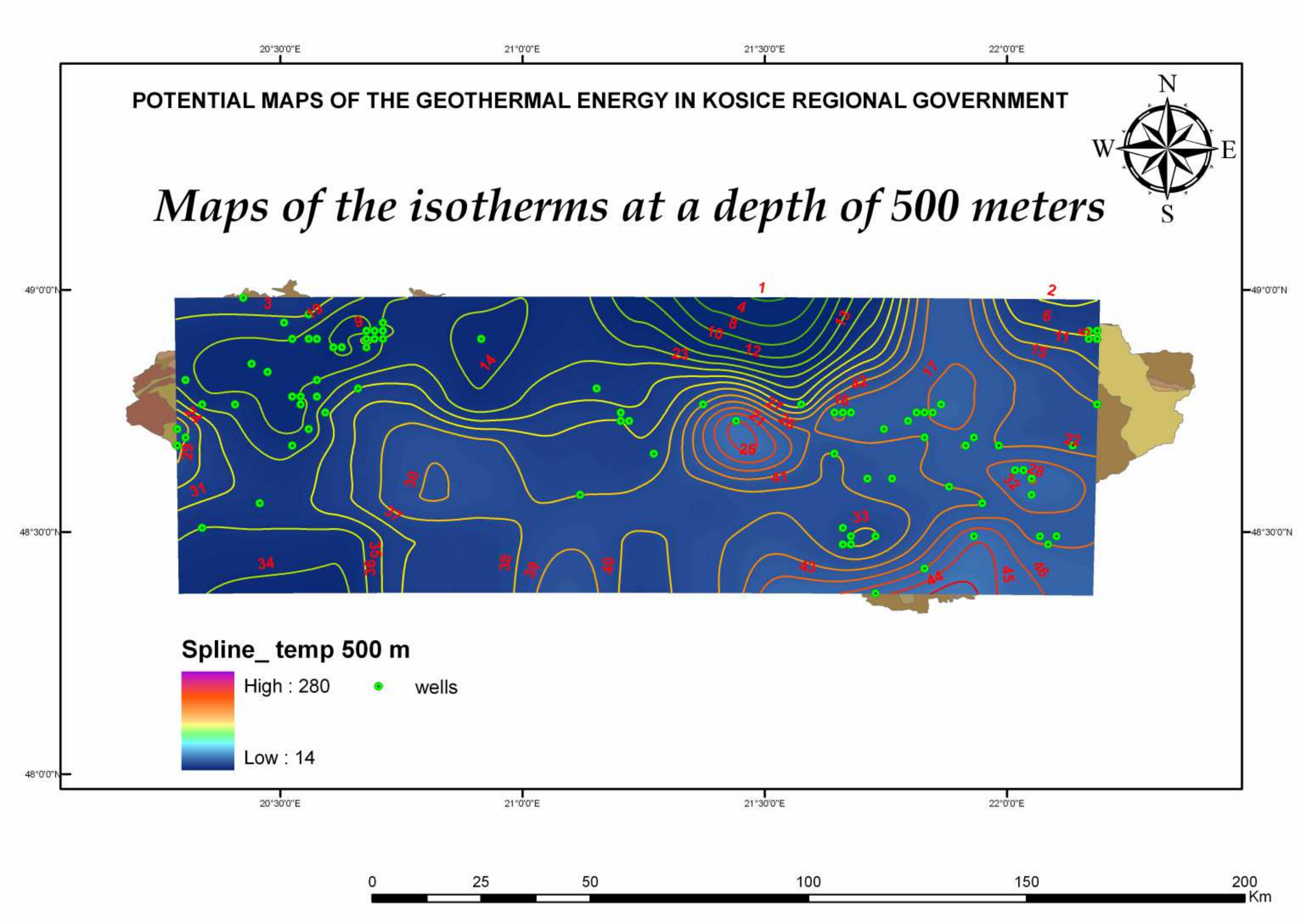

Figure 10: Map of isotherms at a depth of 500 m

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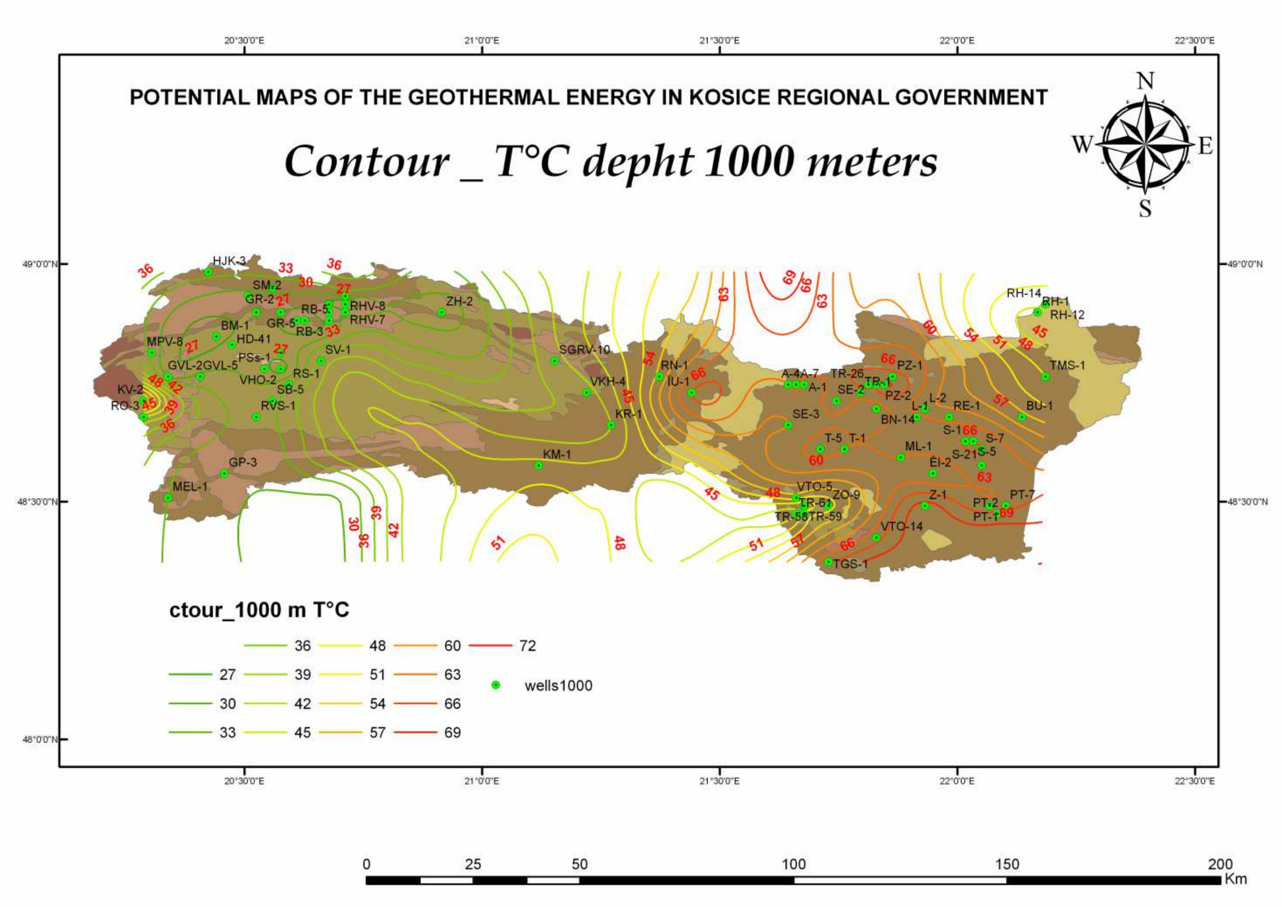

Figura 11: isotherms at a depth of 1000 m - superposition of isotherms based on basic geochemical rock types –

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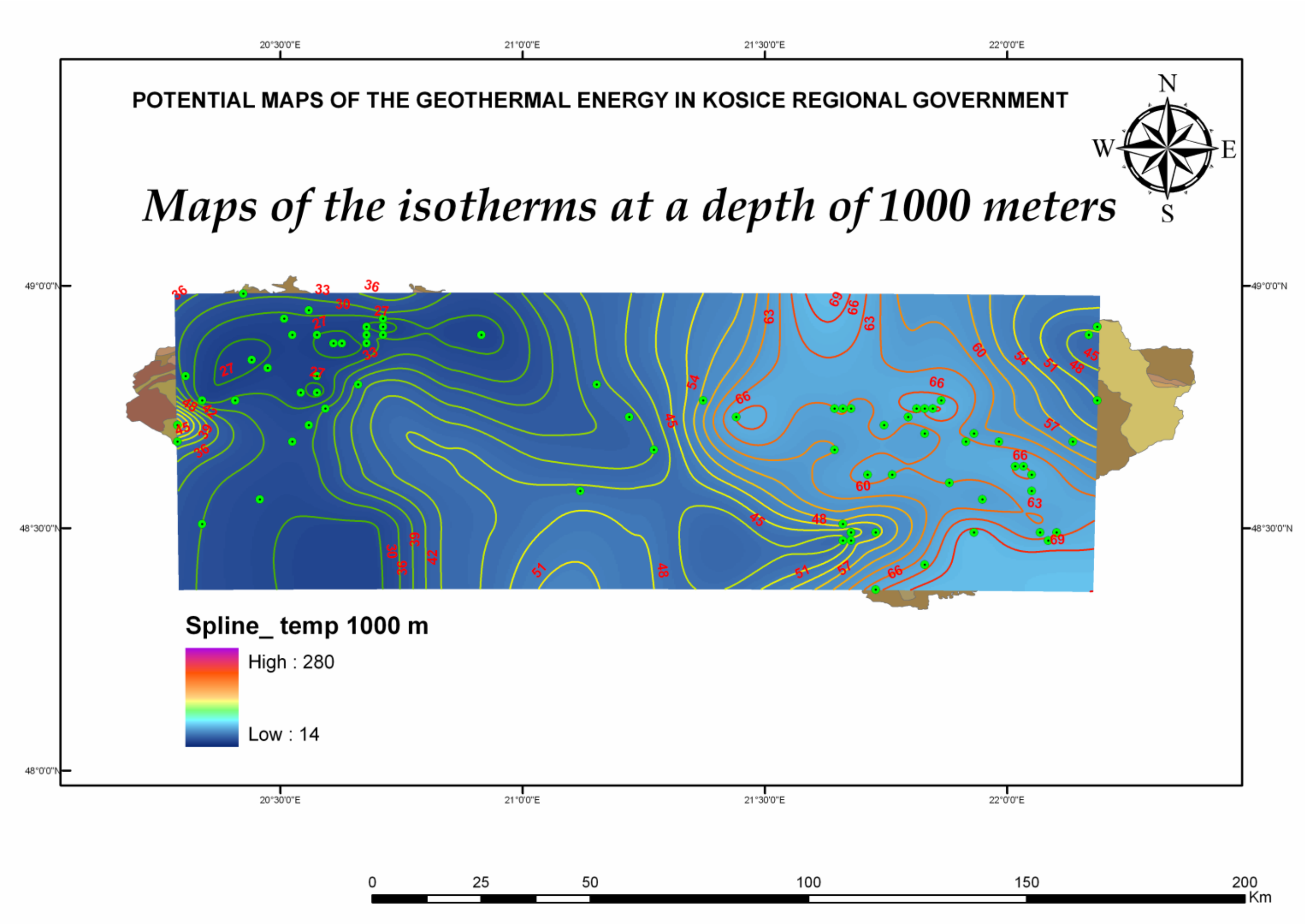

Figure 12: Map of isotherms at a depth of 1000 m

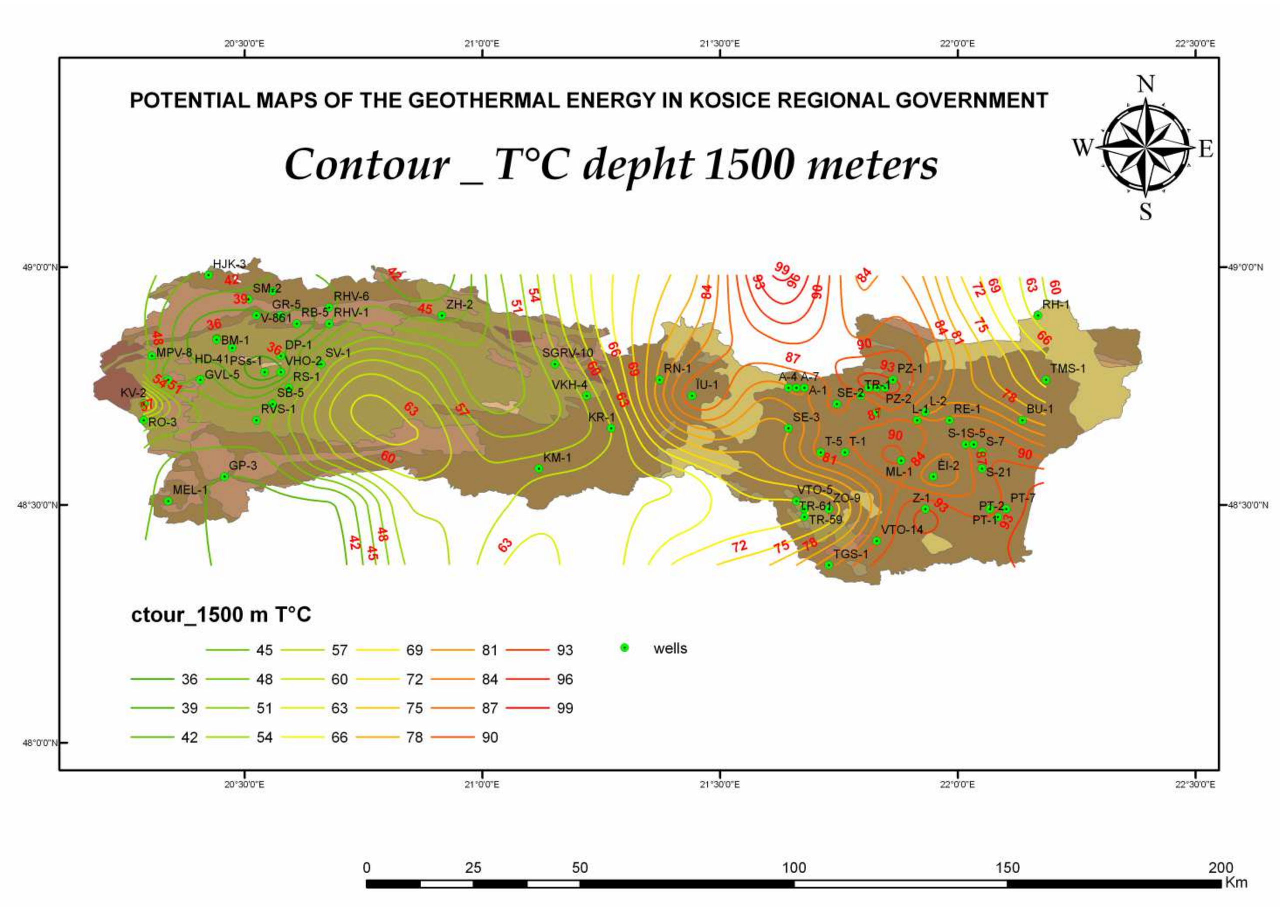

Figure 13: isotherms at a depth of 1500 m - superposition of isotherms based on basic geochemical rock types –

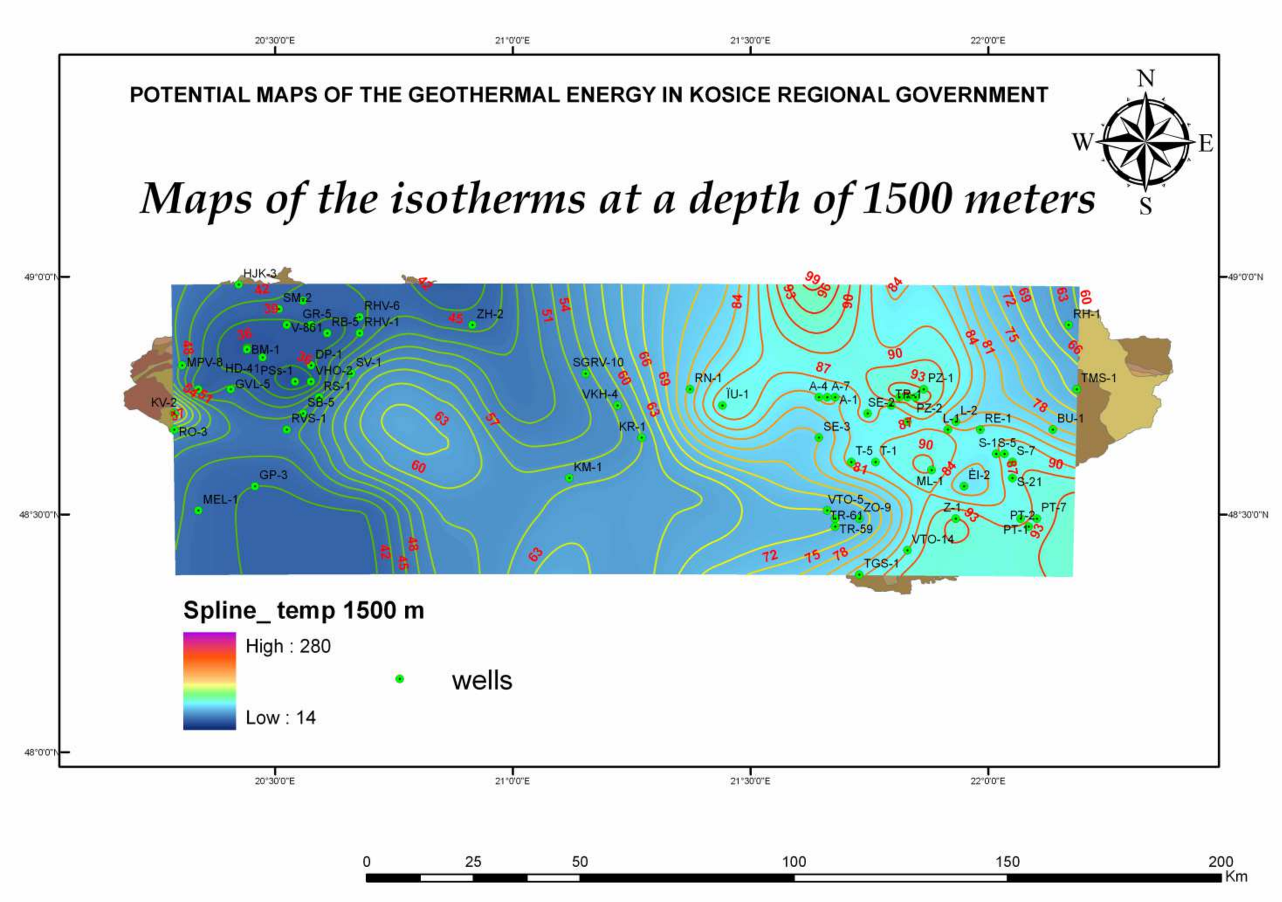

Figure 14: Map of isotherms at a depth of 1500 m

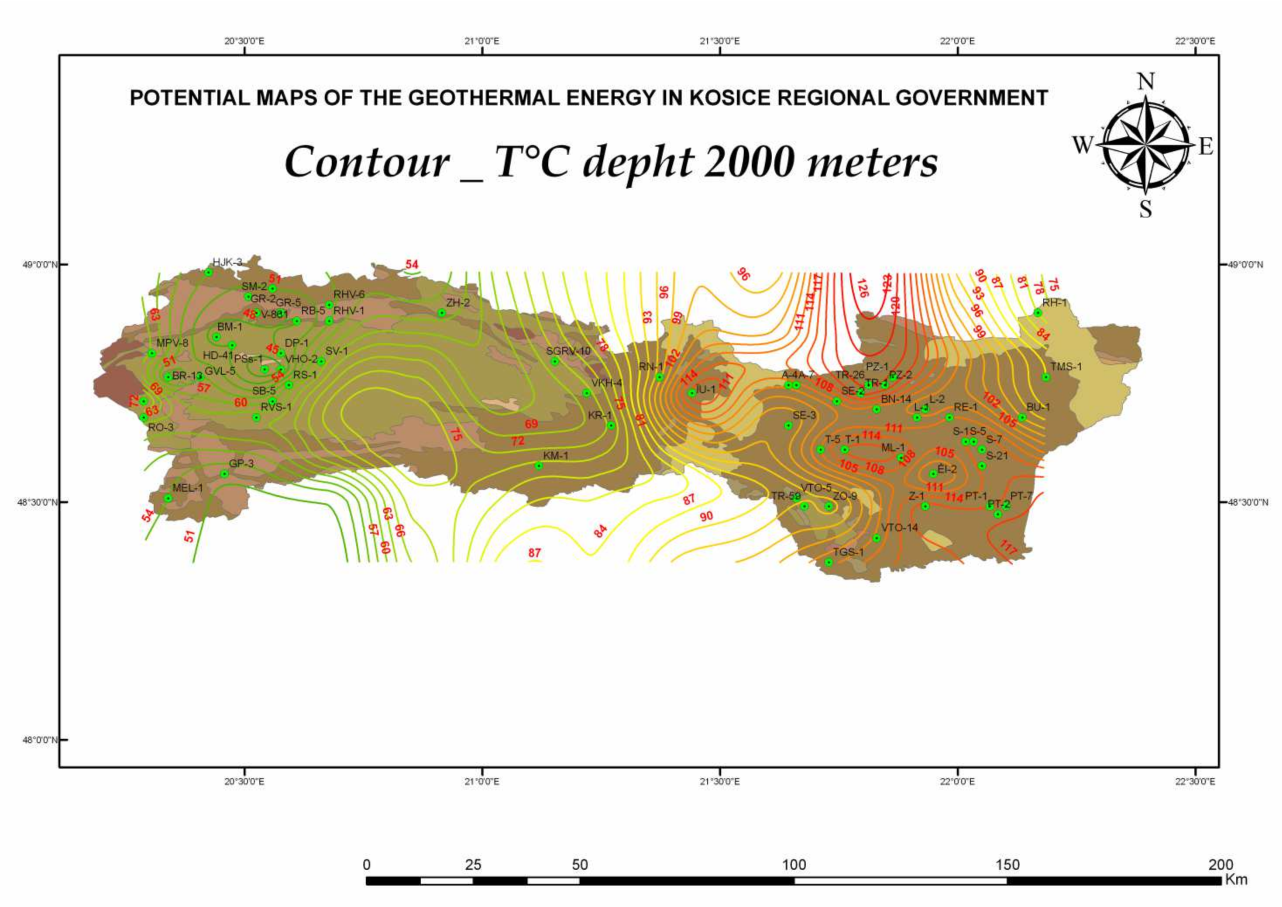

Figure 15: isotherms at a depth of 2000 m - superposition of isotherms based on basic geochemical rock types –

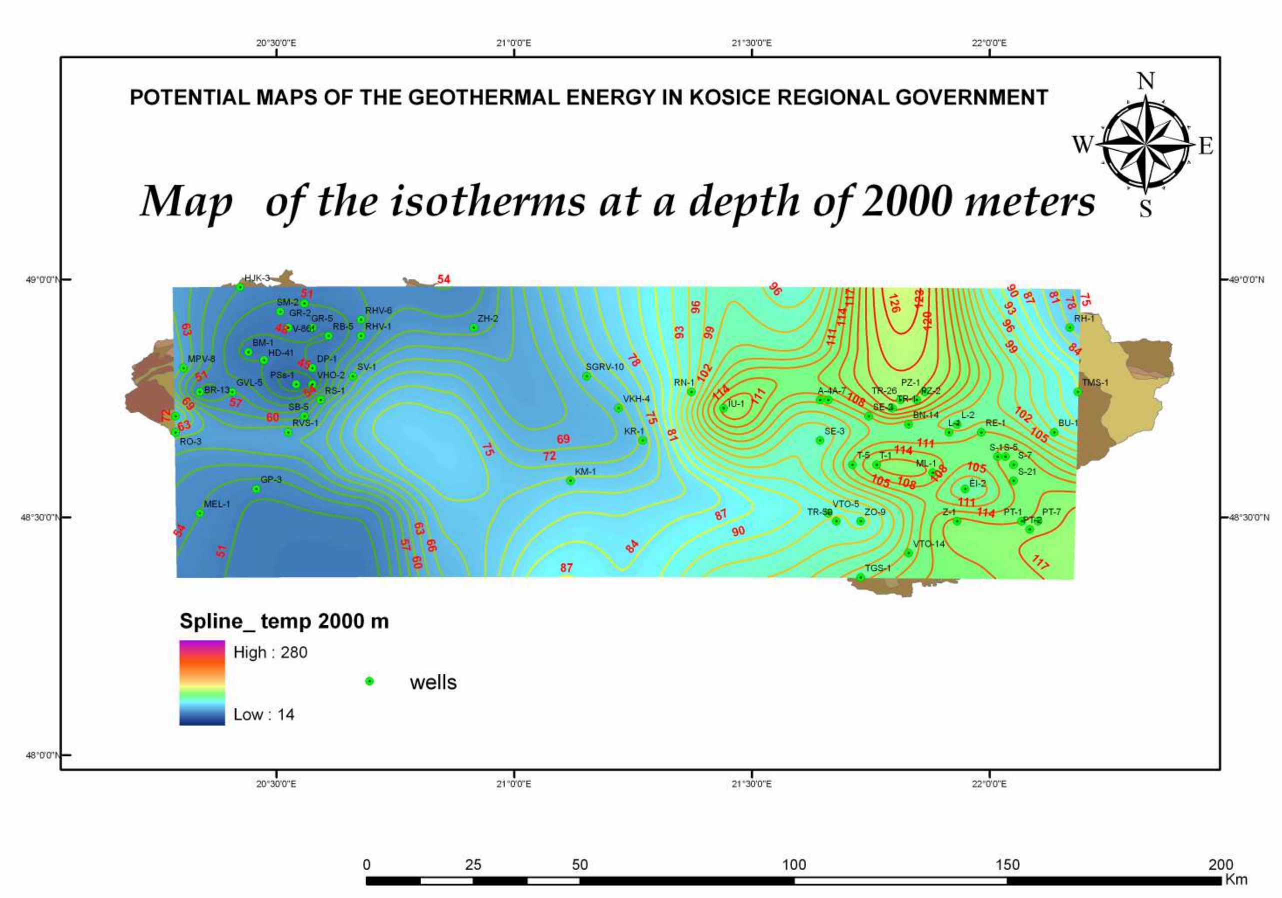

Figure 16: Map of isotherms at a depth of 2000 m

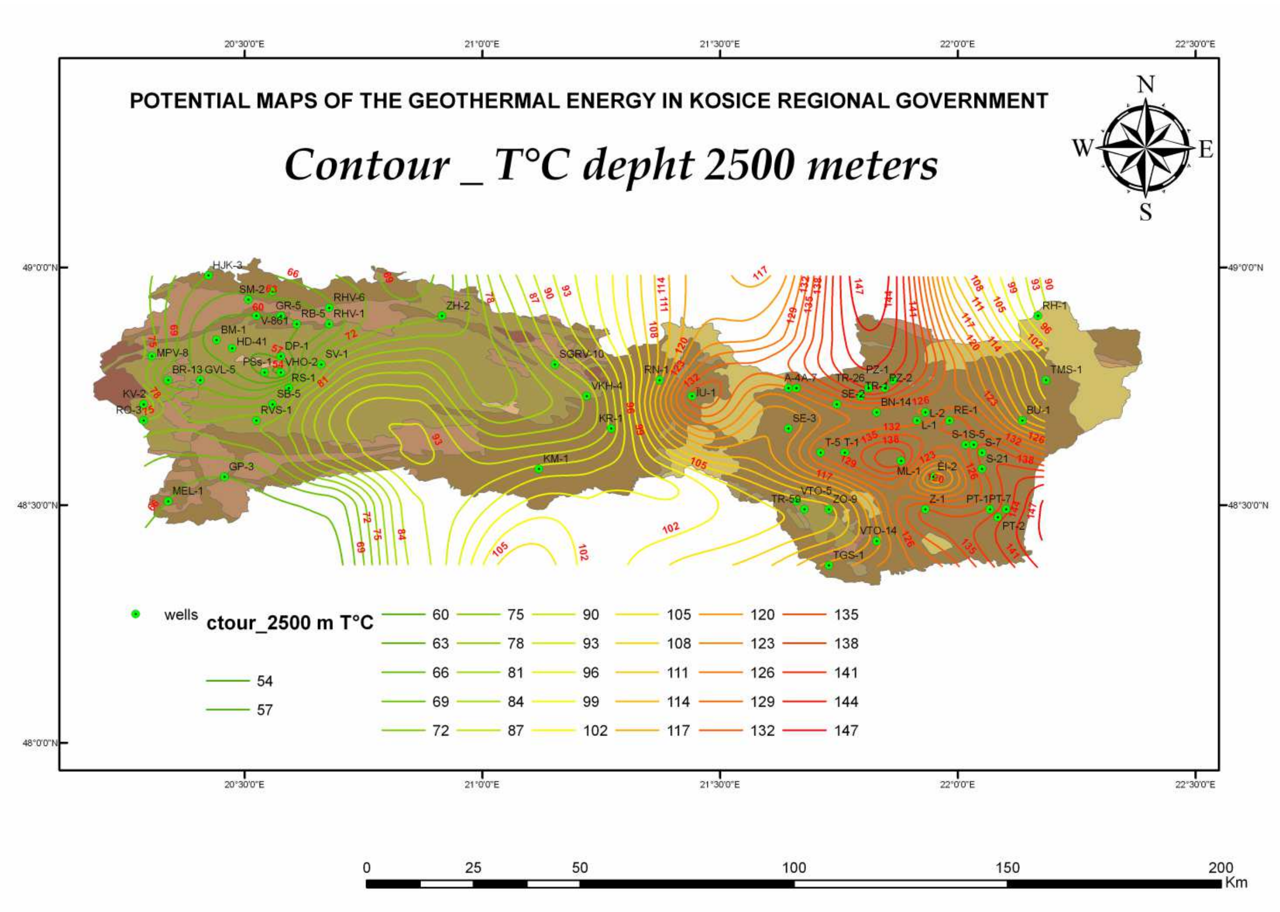

Figure 17: isotherms at a depth of 2500 m - superposition of isotherms based on basic geochemical rock types –

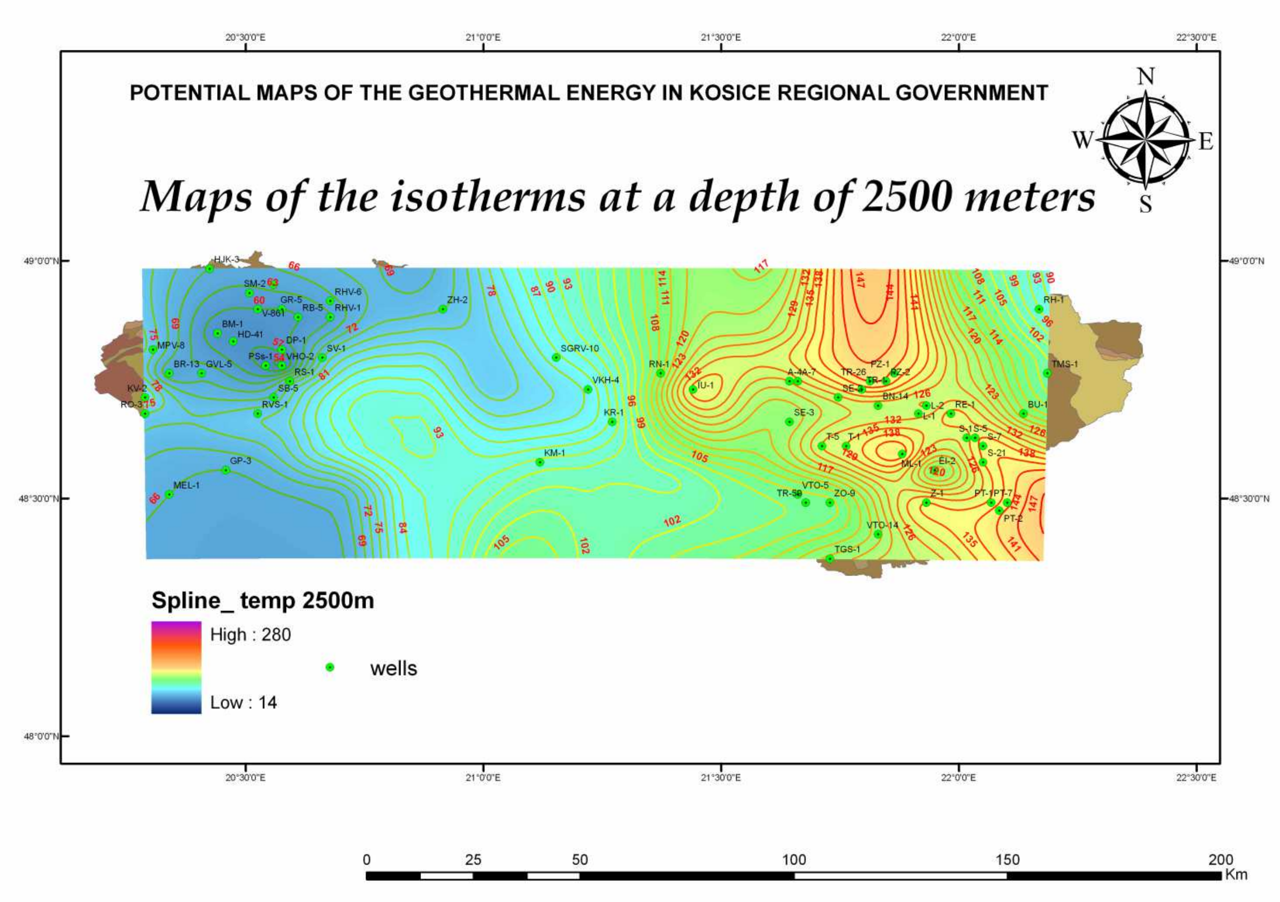

Figure 18: Map of isotherms at a depth of 2500 m

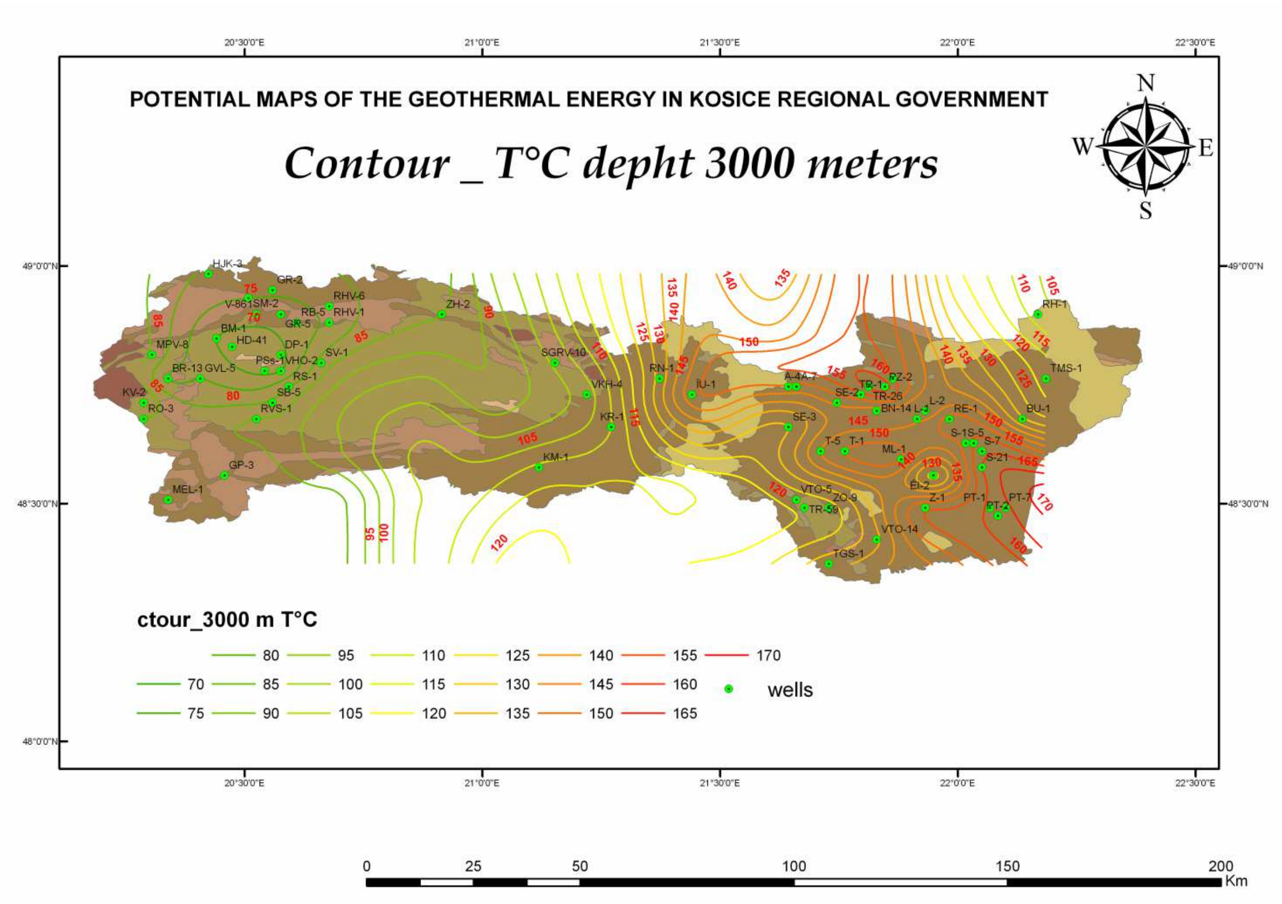

Figure 19: isotherms at a depth of 3000 m - superposition of isotherms based on basic geochemical rock types –

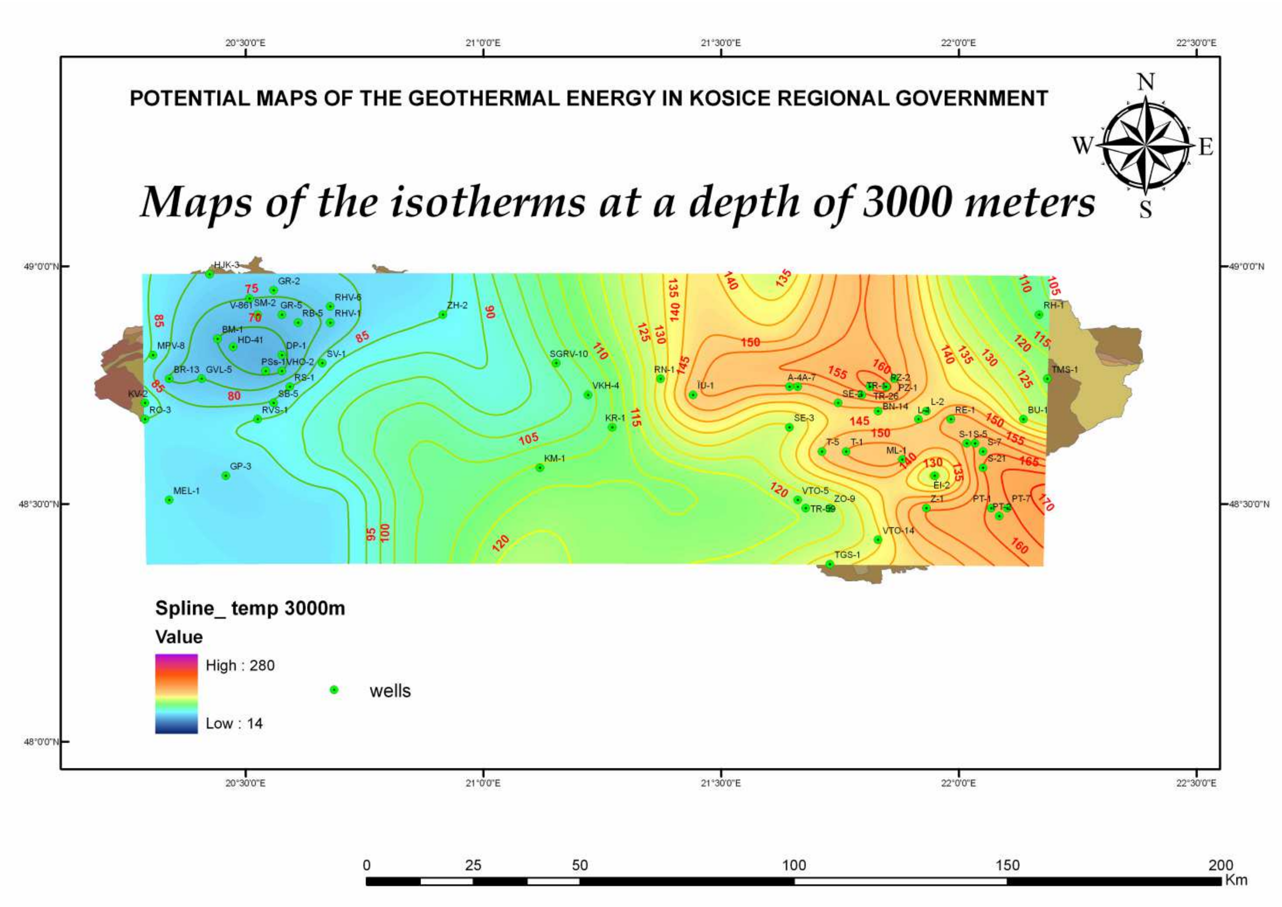

Figure 20: Map of isotherms at a depth of 3000 m

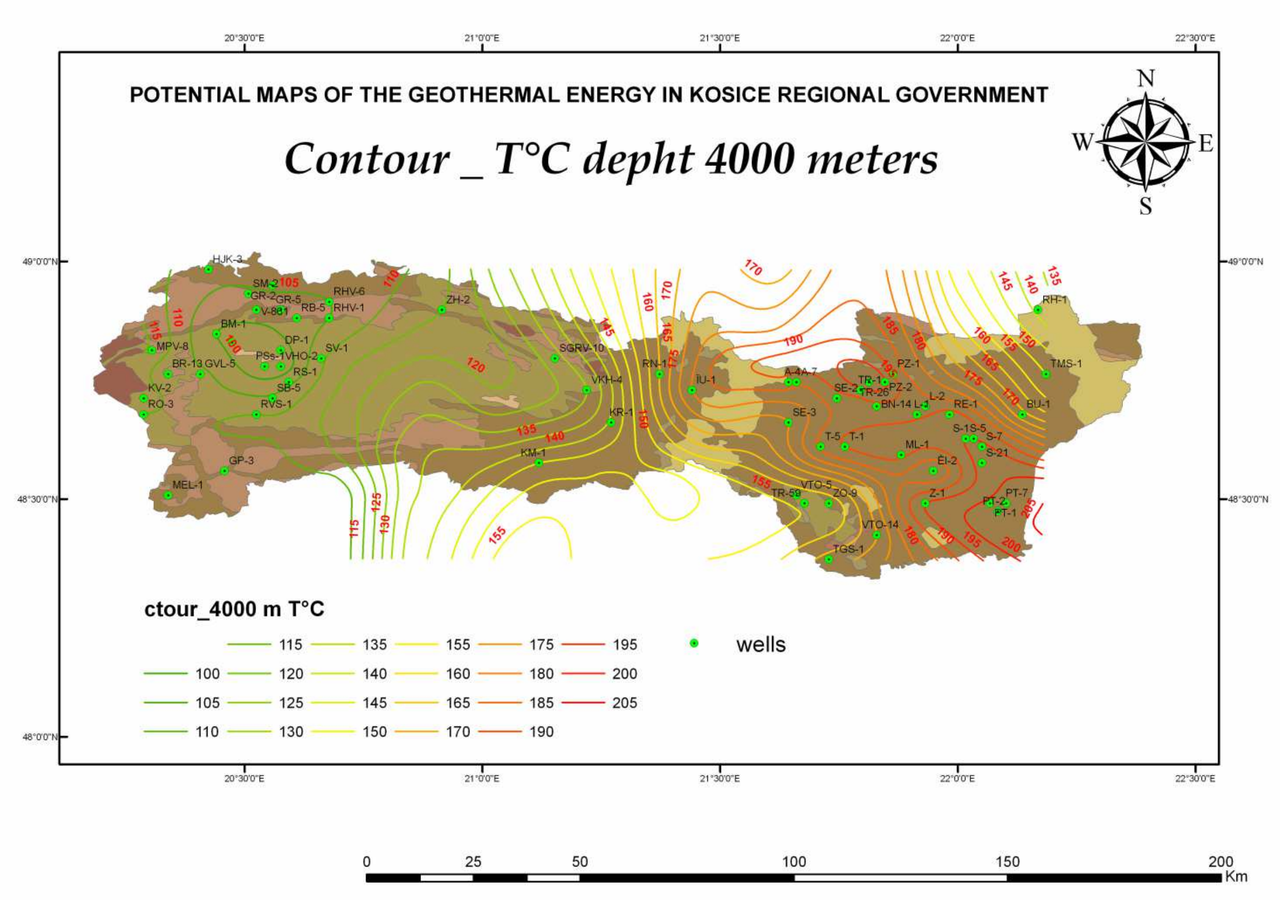

Figure 21: isotherms at a depth of 4000 m - superposition of isotherms based on basic geochemical rock types –

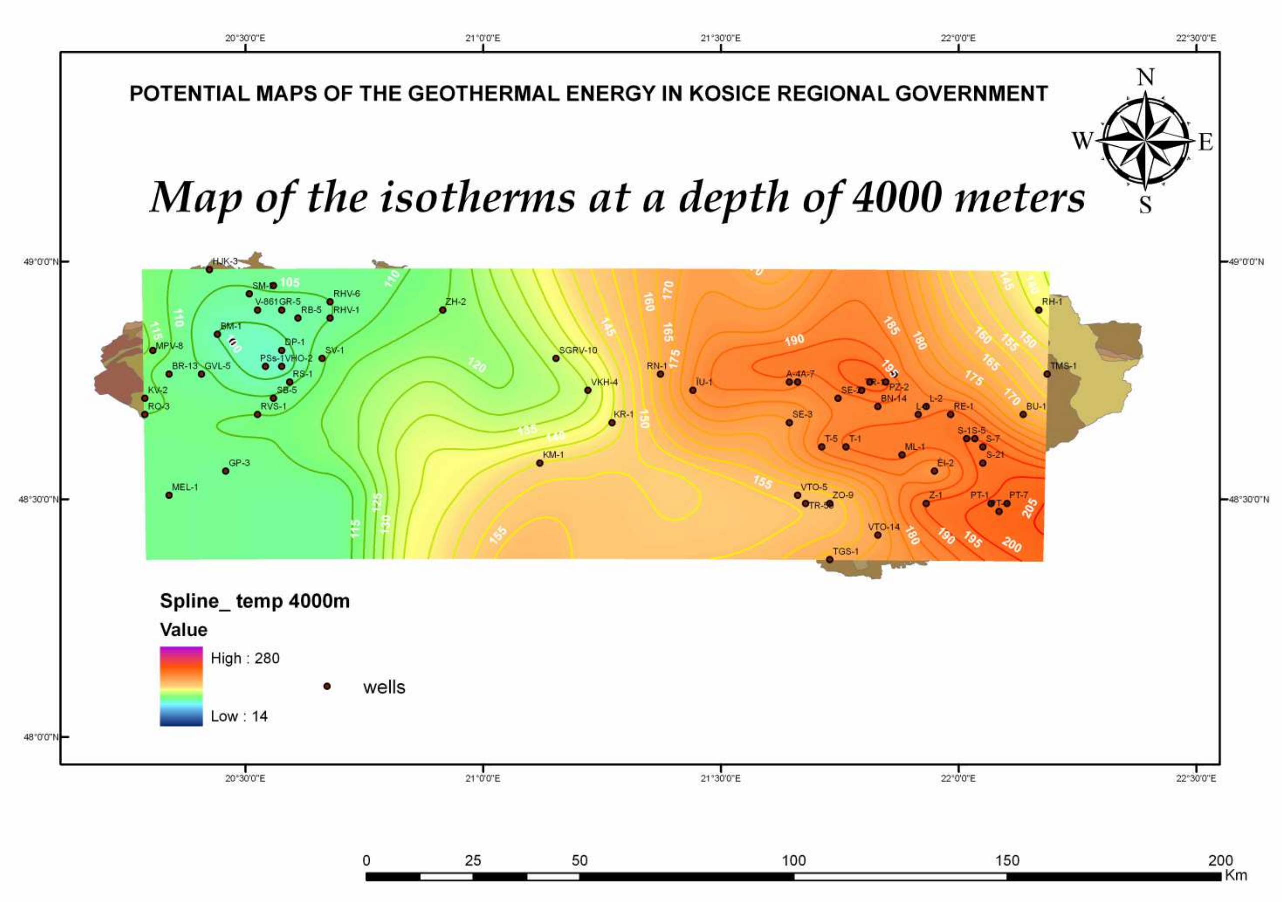

Figure 22: Map of isotherms at a depth of 4000 m

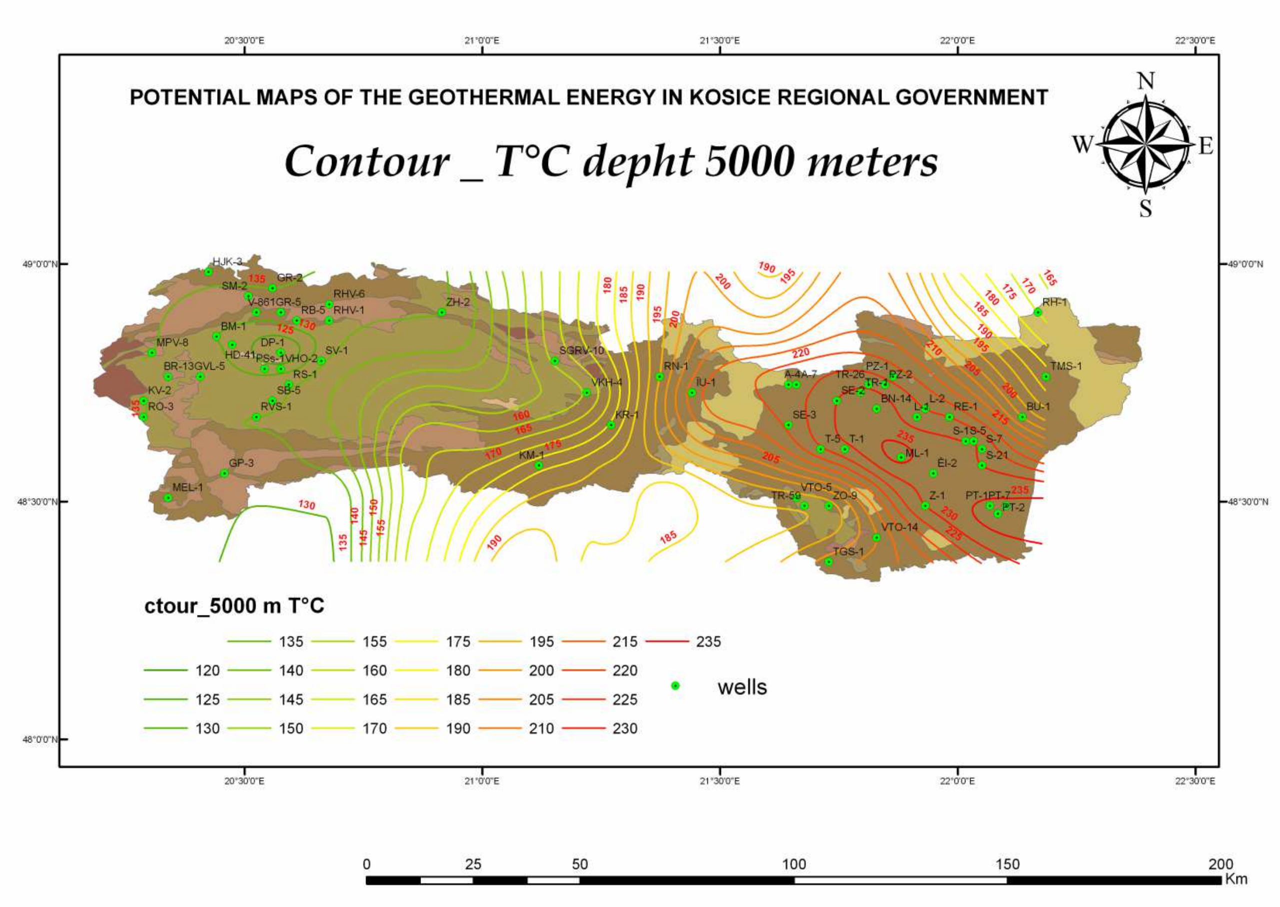

Figure 23: isotherms at a depth of 5000 m - superposition of isotherms based on basic geochemical rock types –

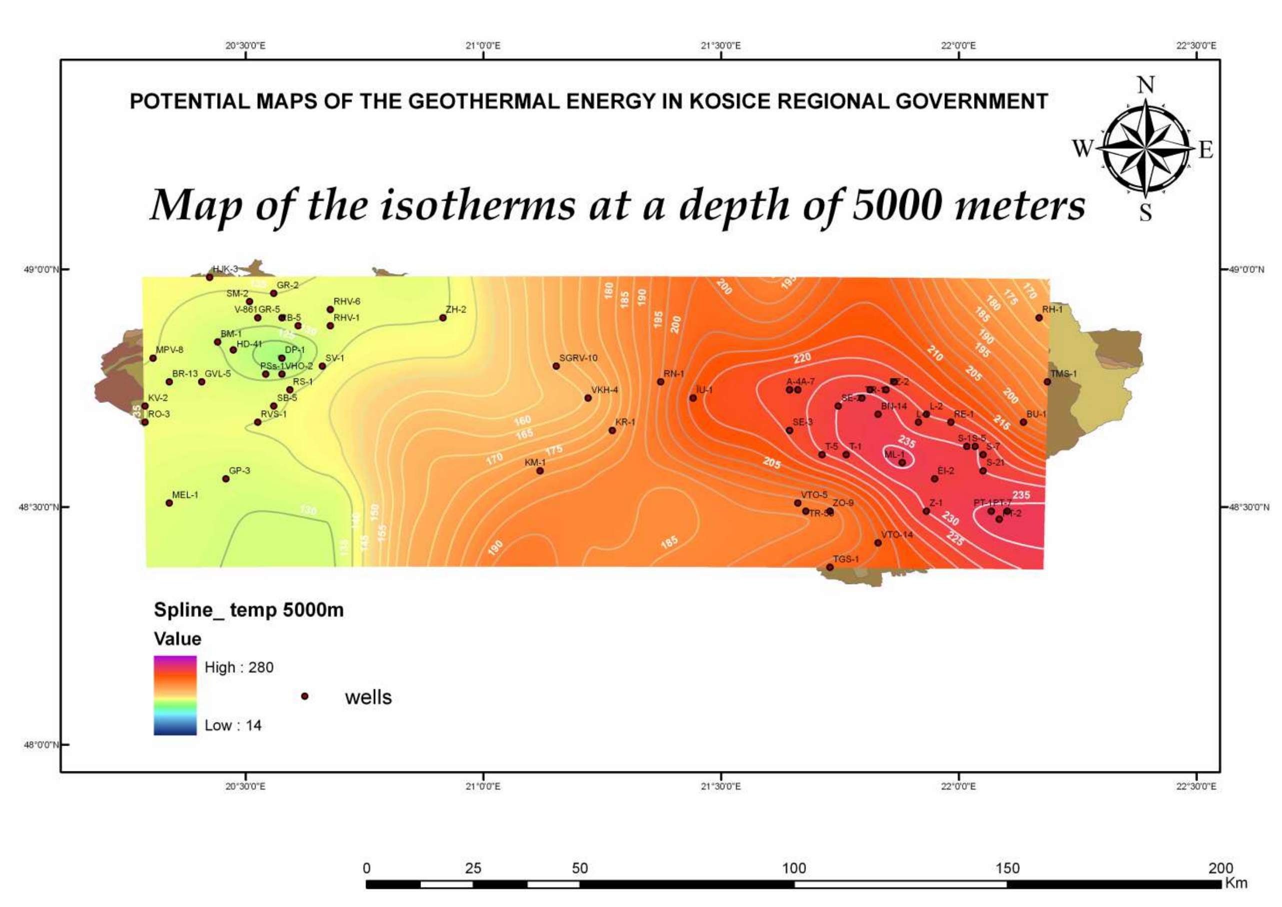

Figura 24: Map of isotherms at a depth of 5000 m

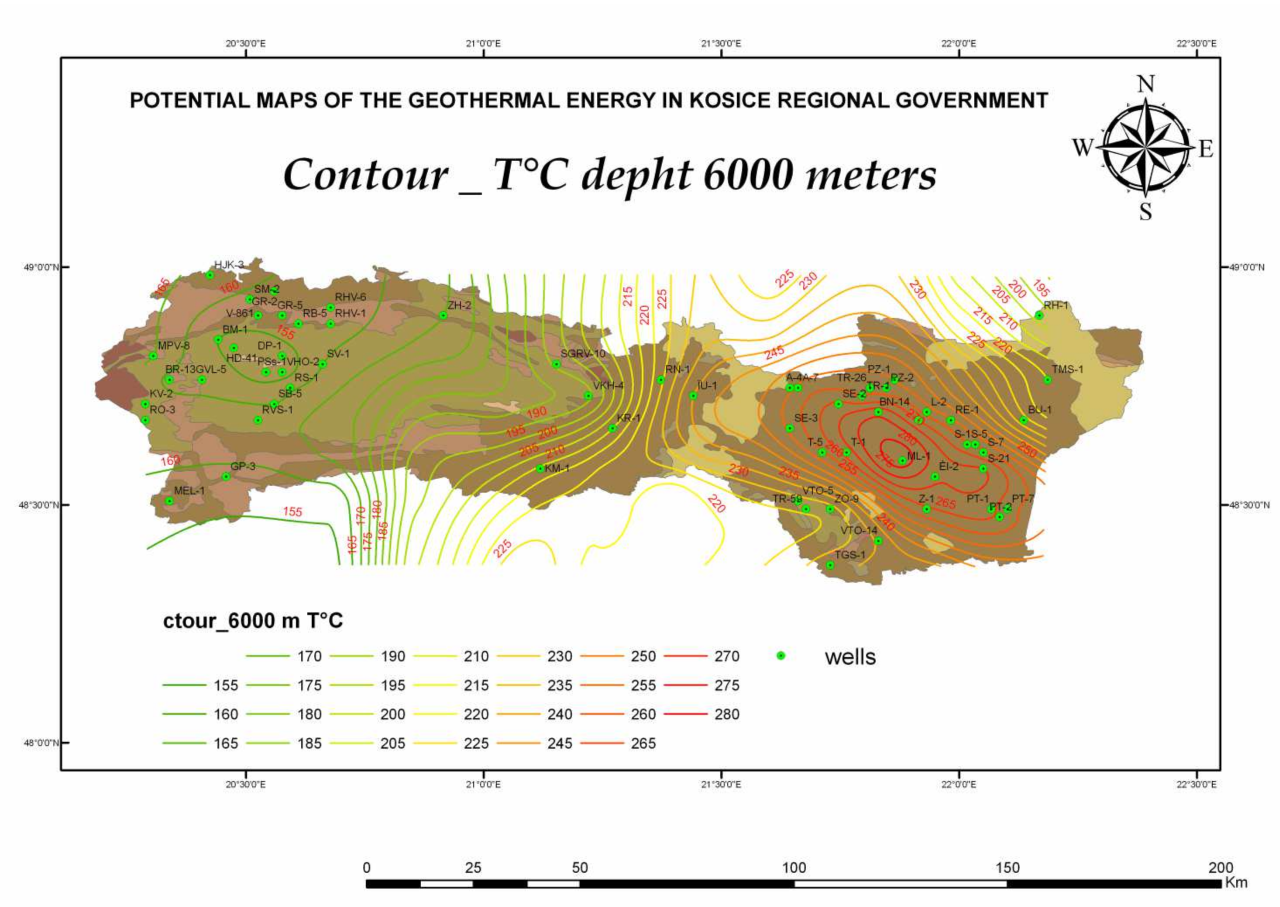

Figure 25: isotherms at a depth of 6000 m - superposition of isotherms based on basic geochemical rock types –

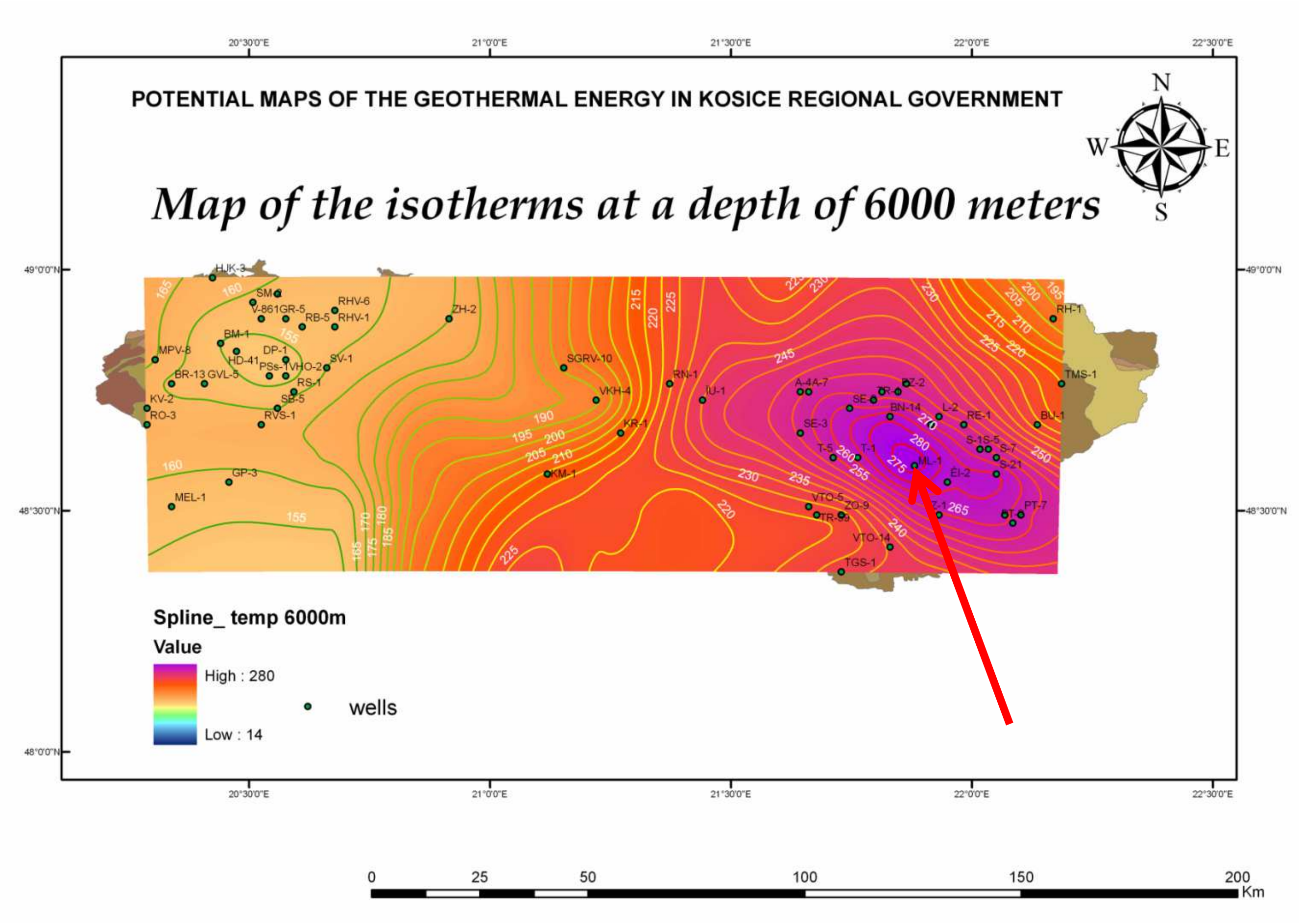

Figure 26. Map of isotherms at a depth of 6000 m

The area indicated by the arrow represents an area with high enough temperatures (280 °C), this situation was highlighted at all depths. In this area are already located more than twenty wells, from the qualitative evaluation of the graphical representation of the map is possible to move to a quantitative estimate of the geothermal resource by performing in situ analysis of existing wells.

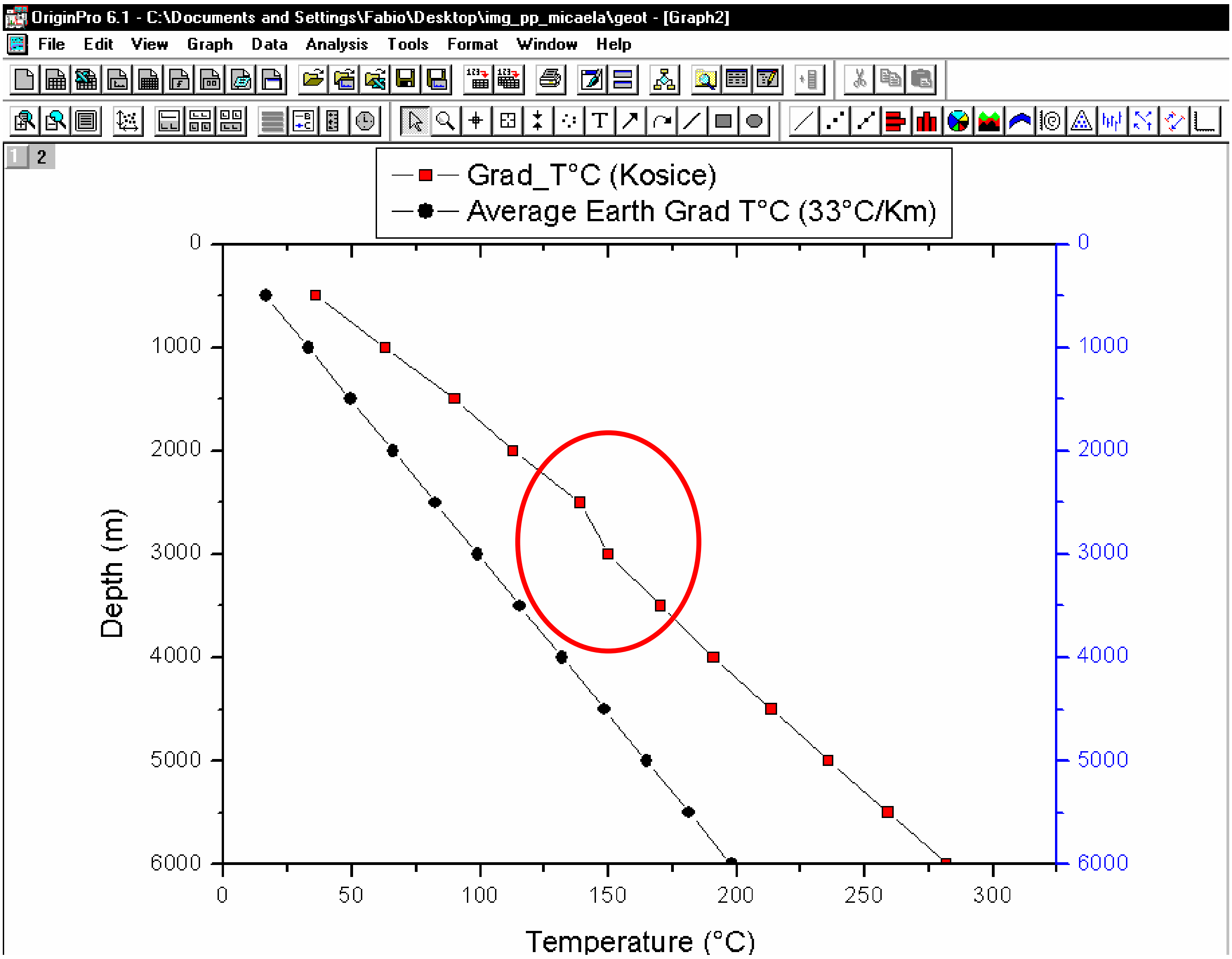

Figure 27: gradient

The chart above shows the comparison between the average gradient of the earth and the gradient of one of the wells in the area indicated in the previous map.

Within the oval can be seen that the straight line assumes a different trend, with increasing depth, the temperature remains constant and assuming that the flow of heat is high. This situation represents the ideal condition for the exploitation of geothermal resources, means that this area has a high geothermal potential, with a constant charge.

The map of the heat flow shows that the area indicated by the arrow is characterized by a high flow, confirming that it has been assumed by the graph of the gradient

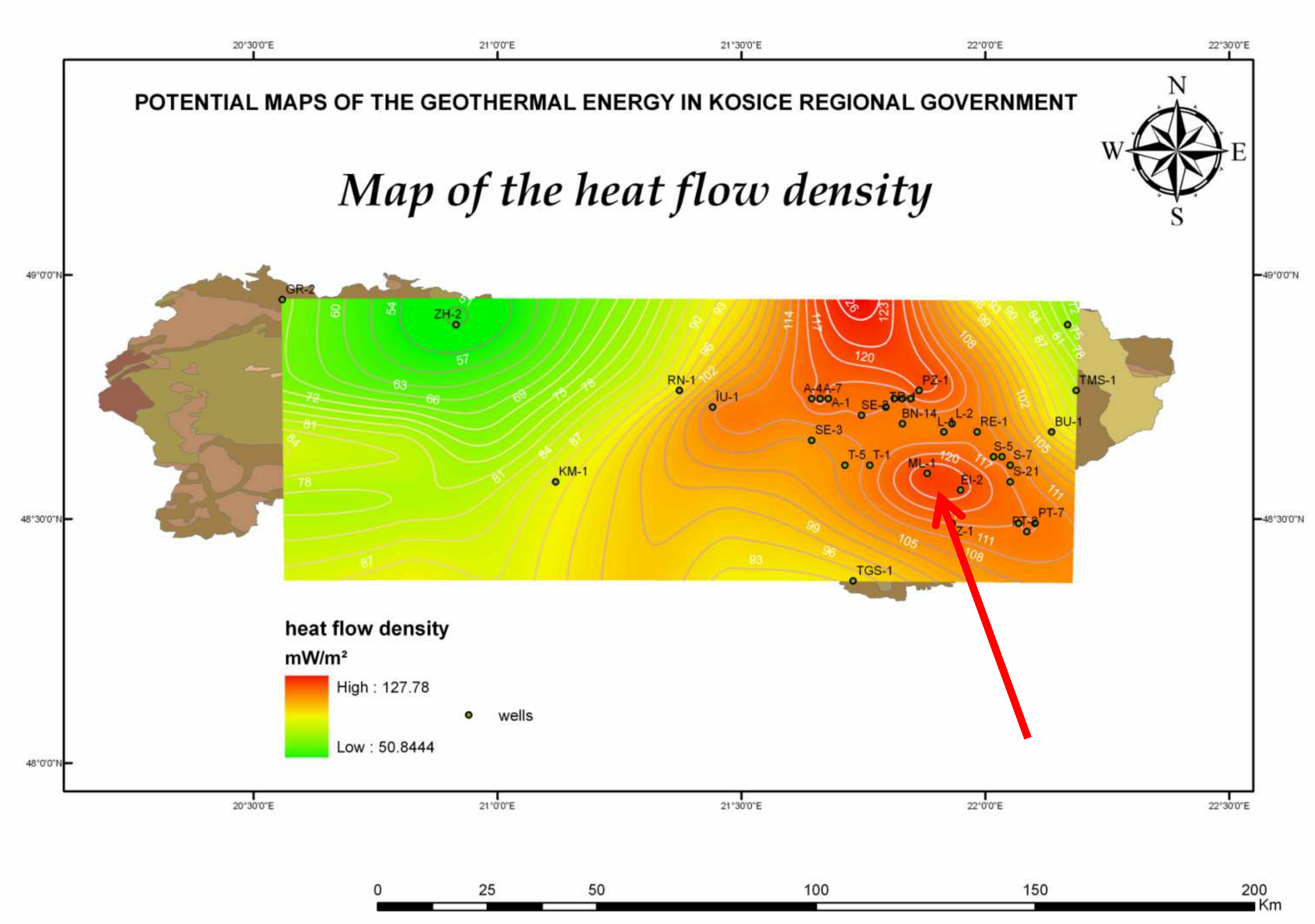

Figure 28: heat flow density

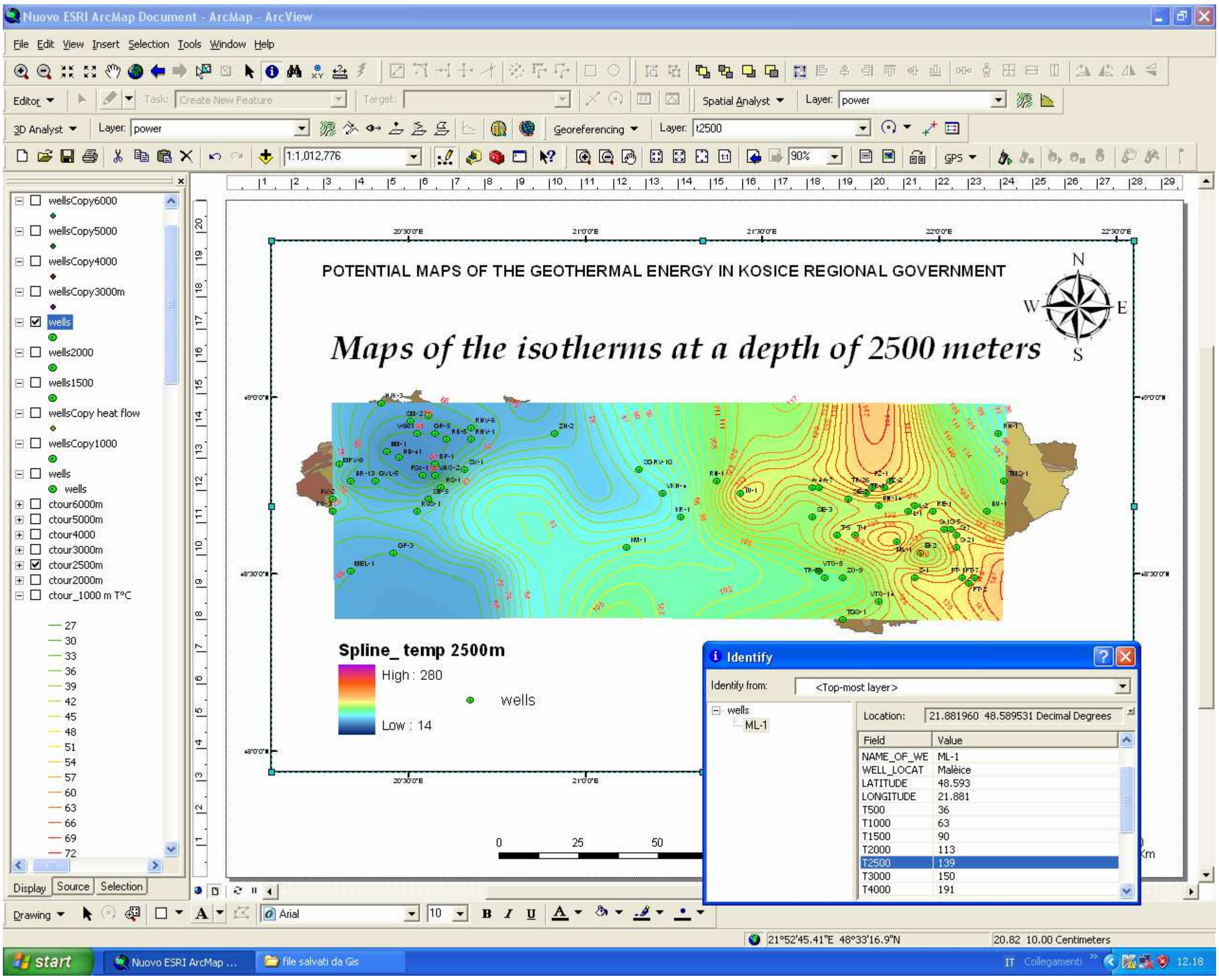

Figure 29: well ML1

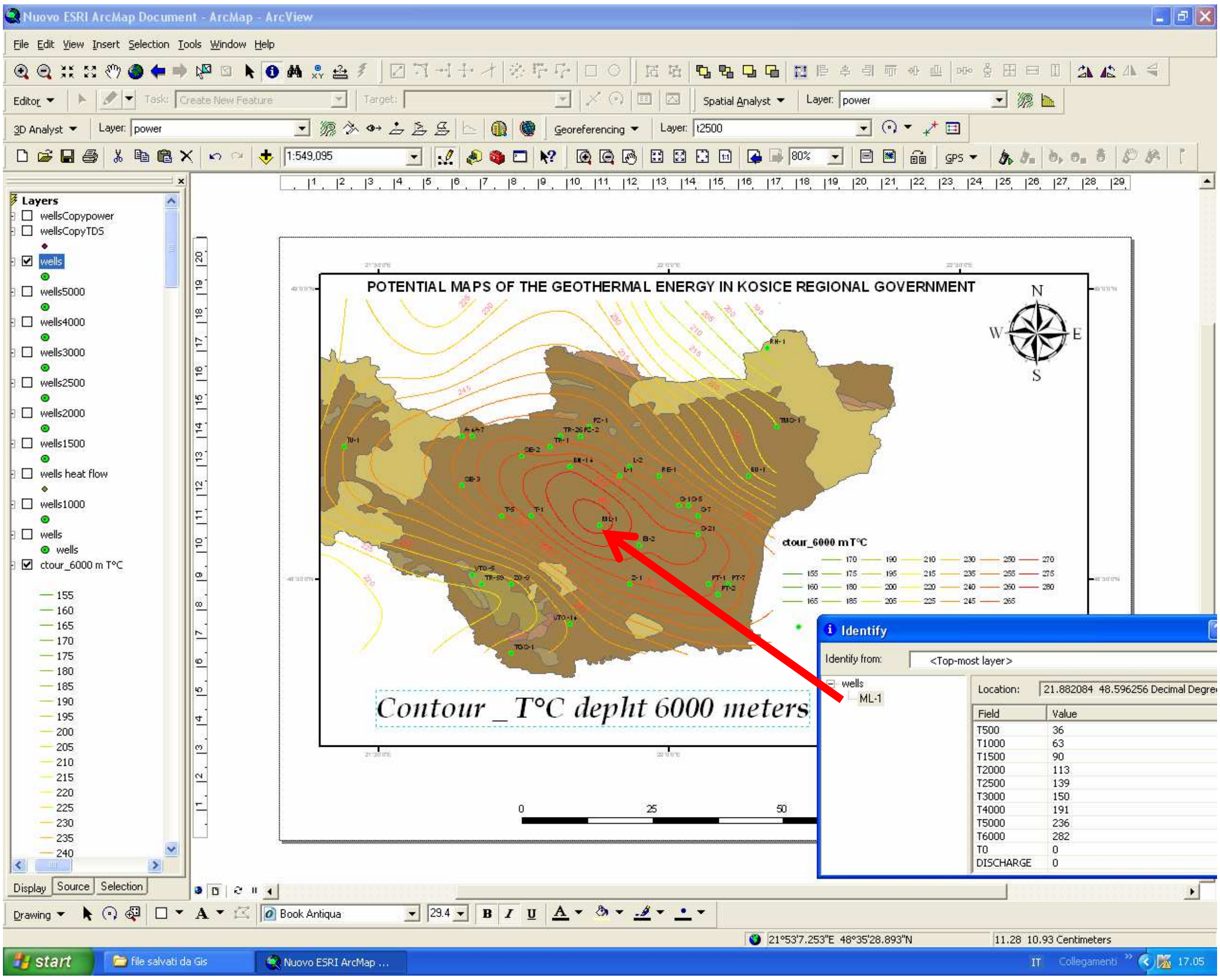

Figure 30: power

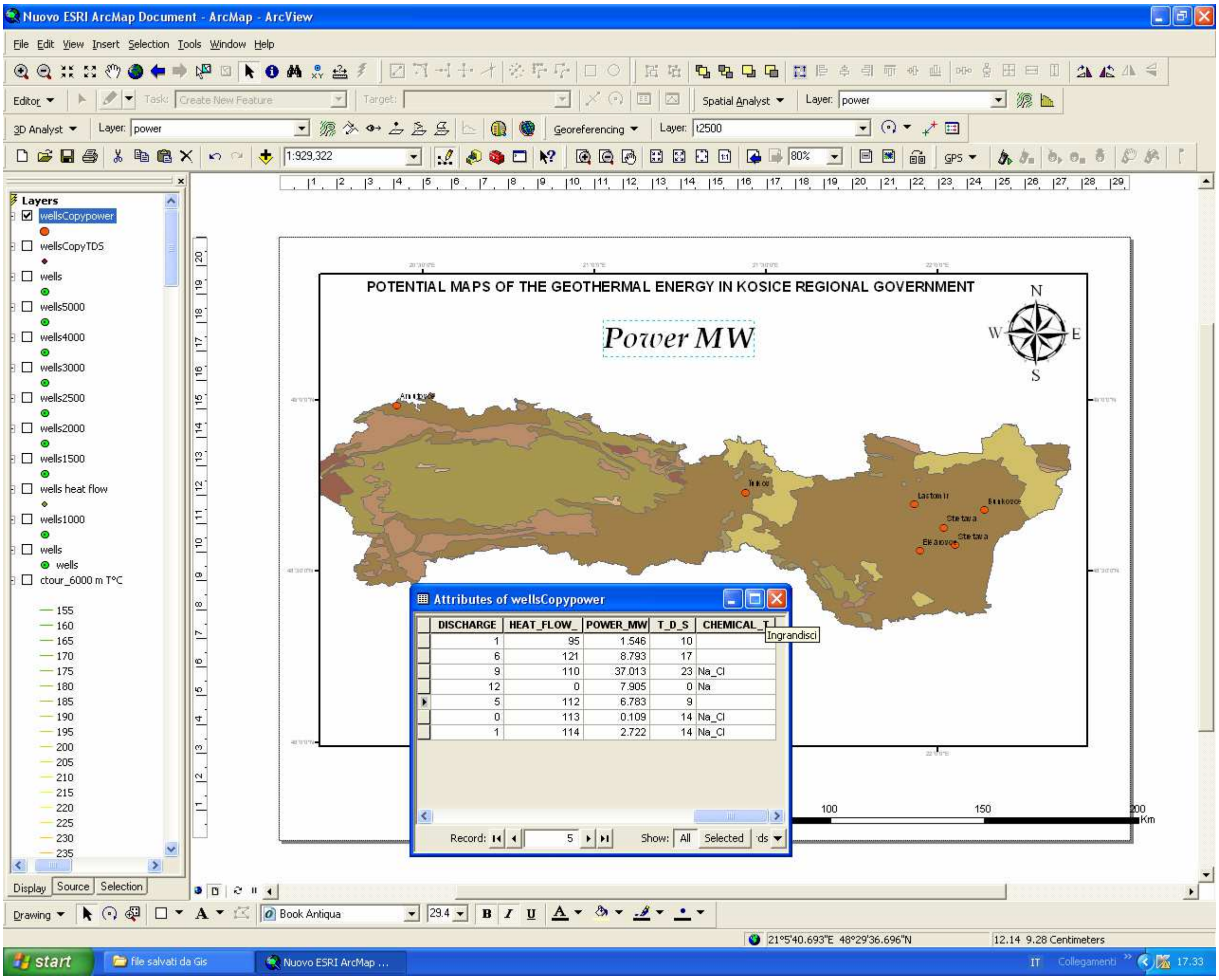

Figure 31:

3. Conclusion

Graphical representation of the geothermal maps set out above allows a direct evaluation of areas most important from the point of view of the geothermal resource.

In the case of maps of isotherms at various depths, the temperature is the most important data, these maps show what is the temperature gradient in the study area.
Using the GIS program, is possible to press a button on a selected area (eg a well) and consult all the data available from the table attributes, such as temperature data at various depths.
Another peculiarity of the GIS is that allowing to continually add new information to the maps already made in order to make more precise the qualitative estimation of data.