GEOTHERMAL ENERGY POSSIBILITIES OF LITHUANIA

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ABSTRACT

We present a survey of geothermal resources in Lithuania. It evaluates its amount, distribution over the area, possibilities of extraction and consumption, and tentative economical study.
Reasonably available geothermal sources are found in three hydrogeothermal complexes and crystalline basement rocks, i.e. petrogeothermal massif. We present maps of geothermal resource in the layers of sedimentary cover and of the crystal rock, and a cross-section view of the geologic and geothermal objects around Klaipėda. A schematic representation of a prospective geothermal power plant is included and supplied with tentative economic data.
The following distribution of prognostic P_1 resources was found in the hydrothermal complexes and crystalline basement rocks:

- Upper/Middle Devonian - 36.45 mln. t. CF over 13284 km^2
- Middle/Lower Devonian - 120.1 mln. t. CF over 22626 km^2
- Cambrian - 122.2 mln. t. CF over 42444 km^2
- petrogeothermal massif - 298·10^3 mln. t. CF at the consumers temperature regime 70/20 °C or 168·10^3 mln. t CF at the consumers temperature regime 90/40 °C over the area of 65 200 km^2.

West Lithuania has most promising conditions for the exploitation of geothermal power. Closed geothermal circulation systems, say around Klaipėda, could produce power at the price below 5 USD/GJ.

1. INTRODUCTION

Development of geothermal (hydrogeothermal and petrogeothermal) energy resources is one of the greatest concerns in the world. Lithuania is located at the Western margin of the East European pre-Riphean platform with a high potential of geothermal energy. Optimal conditions for utilization of the thermal energy are found to be in the Western regions of Lithuania in the coastal area of the Baltic Sea. These conditions *can* be characterized by three basic parameters: geothermal gradient (an increment of rock temperature for each 100 m layer, starting from the zone of stable temperatures (in Celsium degrees per 100 m)), heat flow density (mount of heal per *square* unit (in W/m^2)) and resources density (the amount of conventional fuel (CF) per square unit (m^2). The conventional fuel is a standard of fuel which being burnt releases 7000 kCal/kg). In West Lithuania maximum values of geothermal gradient exceed 4 °C per 100 m, and heat flow density reaches 108 mW/m^2. The resources density is greatly varying, therefore it is discussed in detail this paper.

In the optimal area of the West Lithuanian Geothermal Field *(anomaly),* several cities and towns (Klaipėda, Palanga, Kretinga, Plungė, Gargždai, Nida, Šilutė and Šilalė) and numerous settlements are situated. They arc potential consumers of the Earth's thermal energy.

In West Lithuania hot ground water *can* he used for municipal heating systems from *three* water-bearing complexes called in this paper as the hydrothermal complexes: i.e. (a) Upper an middle Devonian, (b) Middle and Lower Devonian, and (c) Cambrian. Moreover. heat can be extracted from hot waterless rocks of crystalline basement called here as the petrogeothermal massif.

In order to utilize any of the above-mentioned heat sources, closed geothermal circulation systems (GCS) should be arranged. The GCSs can he arranged applying natural collectors (aquifers) or crealing artificial working zone in the natural collector in order to improve extraction of thermal water.

Not every collecting rock layer with proper temperature is suitable for the first case. French experience has show that the debit (30-50 lis) providing efficient operation of geothermal circular system can he obtained only by creating artificial working zone. These are the combined GCSs with improved features of a natural collector (aquifer). They are more universal and can be arranged almost everywhere required. However, economically, they are not always profitable. To create artificial collector is a very difficult technical task. Most realistic way would be to apply the hydrowedge method in the drilled wells, although there are some other possibilities as well.

At present in Vydmantai - not far from Palanga - the project of arranging GCS in the natural collector - the Cambrian hydrothermal complex - is being implemented.

The reality and expedience of this pmject on the ecological and social ground is already proved. Under similar hydrogcological and economic conditions, geothermal power plants are already in operation in Waren and Neubranderburg (Germany, Schulz et al., 1992). Thisted (Denmark, Dansk Olie og Naturgas A/S, 1993), will be in Pyrzyce (Poland, Sobanski and Meyer, 1993).

When the first geothermal power plant in Lithuania is built and the experience is gained, the geothermal energetic is planned to develop further. Water with lower temperature (up to 60 °C) is expected to be used from the Devonian aquifers. Exploitation of low temperature geothermal water is connected with development of the heat pump installations (Lund, 1993). Later GCSs are planned to be arranged in the collector of the crystalline basement rocks at 3-4 km depths, where temperature reaches 100-120 °C.

From the economic point. view, the latter option seems to be the best one.

In order that geothermal energetic were developed in an optimal way, it is necessary to have confident information about the geothermal resources in Lithuania. The paper deals with this problem.

2. AREA AND METHODS

The study covers the whole area of Lithuania about 65200 km^2 and includes the optimal area of 42444 km^2 and the central part of the anomaly of 2500 km^2.

The heat field resources of Earth's entrails in Lithuania have been calculated according to the methods worked out by Dyadkin (1985) and Boguslavskij (1984) - the scientists of the St. Pelerburg Mining Institute. Geothermal resources divided into (a) prognostic P_1 category and (b) perspective (of C_2 category) resources.

The prognostic P_1 resources are calculated for the depths being reached practically by drillings, i.e. 6 km; at the same time, the heat obtained by consumer and given back, as well as heat extraction coefficient are determined. These resources characterize real possibilities to supply underground heat to comers and to obtain electric energy.

Perspective resources of C, stands for the amount which can be reasonably extracted in present economical situation. This evaluation covers only such areas, where technical and economical parameters of GCS could exceed those of organic fuel powered plants.

3. GEOTHERMAL RESOURCES OF SEDIMENTARY COVER AND CRYSTALLINE BASEMENT

Groundwater fitting for extraction of geothermal energy is most often related to the zones with slow or very slow exchange in the Baltic artesian basin. There are three hydrogeothermal complexes in it: UpperMiddle Devonian - nearest to the surface, Middle/Lower Devonian - below the latter, and Cambrian - the deepest one. Hydrogeological stratification data show that these are: Upper/Middle Devonian, Middle/Lower Devonian and Ordovician/Cambrian water-bearing complexes. These complexes are separated from each other by practically impermeable aquicludes and make up independent hydraulically separate aquifers. Therefore, composition and temperature of heat carrier (groundwater), as well as thermal resources are evaluated without taking into hydrodynamic interaction of the above mentioned systems. Such interaction takes place only in the zones of tectonic fractures.

For evaluation of resources, the drilled well data on temperature and thickness of a layer have been used. Prognostic and perspective resources were calculated for each horizon and each drilled well, where roof temperature exceeded +20 °C. Simple interpolation between the wells enabled to draw corresponding maps (Suveizdis and Rasteniene, 1993).

3.1 Upper/Middle Devonian Water-Bearing Hydrothermal Complex

The Upper/Middle Devonian (Šventoji-Upninkai) hydrogeothermal complex consists of two stratigraphy isolated, but hydraulically related terrigenous variegated rock horizons. Their total (nondenudated) thickness ranges in 170-200 m. From Central Lithuania it is deepening South-Westwards from - 100 to 600 m (absolute height).

Rock Lithology and Collector Features

Collecting layers are represented by weakly cemented aleuritic sandstones with lenses and interlayers of fine and very fine sand. These deposits accumulated rather high quantities of geothermal water. Aquifers (1-25 m thick) are alternating with impermeable layers (3-25 m thick). The Šventoji - Upninkai geothermal complex is not sufficiently supported by core material.

The described water-bearing (hydrothermal) complex is overlain by impermeable marls, dolomites and clays of Pliavina formation, from above, and isolated by Narva formation rocks (110 m thick) from below. The bottom is made of impermeable lime and clay rocks.

Geothermal Hydrogeochemical Conditions

The Upper/Middle hydrogeothermal complex is a constituent part of the water-bearing complex of the *same* stratigraphic size, and it is spread in the South-Western part of Lithuania (as far as +20 °C isotherm). This conventional temperature line surrounds the complex along the Telšiai fracture in the North, state border in the South and line Jurbarkas - Užventis in the east. This hydrothermal complex is covered by rather numerous boreholes. Only boreholes with temperature measurements and roof temperature exceeding +20 °C have been analyzed. There are 45 such boreholes.

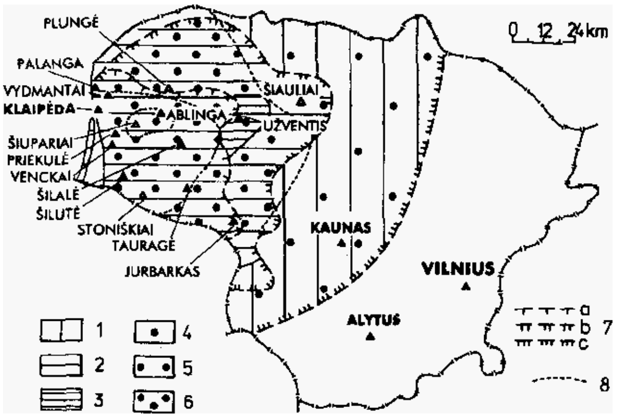
The Middle/Upper hydrogeothermal complex is a constituent part of the Baltic artesian basis therefore groundwater is confined here. Piezometric level measured in the boreholes of Palanga environs reaches 0.6 - 8.1 above the land surface. In Stoniškiai borehole, hydraulic test was done in the perforated column in the range of 645 - 680 m. After the perforation, water fountain sprang from the borehole and reached 14 m height over the borehole opening. The debit was 864 m³/h.

Water in the complex is of calcium chloride type with excreting gases. Water mineralization is 27.3 g/l, specific weight 1.02. temperature +30 43 (when air temperature +25 °C). Contents of dissolved salts (in %) are as follows: NaCl 8.6, $CaCl_2$ 8.4, $MgCl_2$ 1.1, Ca SO_4 11.3, NaBr 0.2, $Ca(HCO_3)$ 0.4. The hydrogeothermal complex is spread in that part of the area where water mineralization ranges in 5 - 15 g/l for the upper part and 15 - 35 g/l for the lower part.

Thermal Resources

Their quantity depends directly on temperature and thickness. The temperature of Upper Middle Devonian hydrogeothermal complex is rater low and weakly differentiated ranging from +20 °C tu +35.5 °C. Total thickness of the complex varies from 131 m to 222 m.

Two fields of prognostic resources (Figure 1) are singled out in the described hydrogeothermal complex. The largest area (10044 km²) corresponds to the density of resources equal to 0.2 - 0.3 t CF per m². Significantly smaller area (3240 km²) is occupied by resources with density exceeding 0.3 t of CF per m² and quantity equal to 11.34 million tons of CF.



1-3 – thickness of complexes, in m, 1 – to 100, 2 – from 100 to 300, 3 – more than 300, 4-6 – density of resources, in tons of CF per m², 4 – to 0,2, 5 – from 0,2 to 1,0, 6 – from 1,0 to 1,2, 7 – 20°C isotherm of hydrogeothermal complex (a) Middle/Upper Devonian (b) Lower/Middle Devonian, (c) Cambrian, 8 – isolines of the resources density, in tons of CF per m².

Figure 1. Summarized map of geothermal resources in the hydrogeothermal complexes of sedimentary cover (P_1 category).

Summing up it can be stated that the UpperMiddle Devonian hydrogeothermal complex is spread in the area of 13284 km². Here the prognostic (of P, category) thermal resources up 36.45 million tons of CF.

3.2 The Middle/Lower Devonian Water-Bearing Hydrothermal Complex

The thickness of this hydrothermal complex in West Lithuania exceeds 400 m in some places. However, usually, the thickness varies within the 200-300 m range. This complex, especially in the Gargždai series, is affected by tectonics: there is a large number of tectonic fractures cutting the complex or complicating *it* by flexures. Moreover, due to tectonic uplifts this horizon experienced rather significant denudation as well. Clearly seen denudation section is in characteristic at the South-Eastern limits, from which the thickness abruptly decreases southwards.

The depths of occurrence in Central and West Lithuania are 200 - 500 and 600 - 900 m below sea level, correspondingly. Nowhere Lithuania, this complex ris[redacted]l of Quaternary.

Rock Lithology and call

In profiles of Parnu layers, the sandstone, (cemented by gypsum of basal type), aleurolite, clay with interlayers of dolomitic marl are found The Kemeri layers are composed of rhythmic laminated fine-gained sandstone (feldspar and quartz and fine mica cemented by clayey siliceous rocks), aleurolite, clayey aleurolite and clay. The Gargždai series are composed of clayey aleurolite and clay with coarse-grained aleurolite and sandstone interbreeds. All the rocks in the complex are mainly variegated of continental type. This is confirmed by high variations of rocks both in the horizontal and vertical directions.

Collecting features of rocks are investigated only in the Western part of Lithuania, whereas the Eastern part remains unexplored, although the latter is characteristic of higher sand content in the sections. This hydrogeothermal complex in the Westem part is covered with a significant number of boreholes. The geophysical measurements have been done, and cores from some horizons, contact zones or aquifers sampled. Interval prospect for oil extraction have been tested by a layer and prober and perforating column (47 cases).

Kemeri formation is expressed mainly by sandstonc, which is interbedded with locally spread aleuritic-clayey deposits with interlayers 6 m in thickness. The profile is divided into layers-collectors (reaching 14 m in thickness). Therefore, sand content is significantly higher than forthe Gargždai series. Sandstone is fine or medium -grained, cemented by clayey, sometimes dolomithic, ferruginous clayey, sometimes siliceous cement. Cementation usually is of a contact type, sometimes basal, till the absolute filling of pores. This affects permeability of rocks. In most cases, the permeability is high and very high, reaching hundreds or often exceeding 1000 mD. For example, in the Šilutė area, it exceeds 7300, in Tauragė area - even 12000 mD.

According lo geophysical curves, efficient aquifers have been distinguished and their porosity coefficient determined for some boreholes (all in all for 50 ones). Mean porosity coefficient varies from 15 % to 25 %. Results of hydraulic test confirm the laboratory and geophysical data.

The rocks of the Gargždai series are significantly more clayey, but there also are separate 2-7 m thick sand and sandstone ranges having rather high collecting features. The laboratory analyses of deposits from core samples of the Gargždai series show that in some interlayers permeability and porosity are rather high (400-500 mD, or even over 1000 mD)

Summarizing data on collecting capacity of the complex it can be stated that, in the area of its spreading, there are quite a few interlayers with rather high collecting features: hence, this will enable to obtain necessary volumes of water. to satisfy demands of heat consumers and to return cooled water back into the aquifers complex.

Geothermal Hydrogeochemical Conditions

The hydrogeothermal complex under description has its highest heat potential m the Western part of Lilhuania. Conventional limit of the complex in the East is + 20 43 roof temperature isotherm. In the North this line goes not far from the state border with Latvia, in the South - practically coincides with the state border and the boundary of wedging-out of these deposits. Since this area is perspective for hydrocarbon accumulation, the prospecting boreholes (deep and structural) have becn drilled here. The boreholes having temperature measurements an with temperature of the roof exceeding t 2 0 °C have been analyzed. In the boreholes drilled in the maritime area (war to the Baltic Sea), the roof temperature of the Parnu horizon exceeds +40 °C ant at the foot of Lower Devonian it even cxcceds t 5 0 °C.

From hydrochemical point of view, the upper part of the complex is clearly seen in the Parnu-Kemeri rocks, and the lower part is in the Gargždai series. They differ not only in waler mineralization, but also in piezometric levels and content of micro elements. Mineralization gradually increases going deeper. 58 boreholes of this aquifer are analyzed by hydraulic trial method. 43 ones from Parnu-Kemeri layers and 35 ones from Gargždai series. Water mineralization is varying in the lower part of the complex from 10.8 g/l to 110 g/l. In the upper part - Parnu-Kemeri layers - the variations are from 6.6 g/l to 85.4 g/l.

Water of this complcx is of calcium chloride type. Moreover. this water is rich in other elements, e.g. bromine (from 2.6 mg/l I to 576 mg/l). Small amounts of iodine, boron, manganese, copper, zinc. molybdenum and cobalt are also determined in this waler. The hydrogeochemical characterization shows that entrails arc isolated from influence of surface water and allows to assume about the direct relationship between hydrogeothermical and geothermal indices. The pressure of the layer in this water-bearing complex is higher than hydrostatic one.

Thermal Resources

The second - Middle/Lower Devonian complex is notable for its thickness varying from 145 m. to 442 m. As a rule, quantity of thermal resources depends directly on thickness of a layer.

Within the limits of the described geothermal complex. three fields are singled out, according to the density of prognostic resources (Figure I). The Eastern and Northern parts of the complex are occupied by a field (15732 km²), where density of thermal resources reaches from 0.2 to 0.6 tons of conventional fuel per square meter. The quantity of resources is calculated to 62.9 million tons of CF. In the other, smaller field (5904 km²), density of thermal resources varies from 0.6 to 1.0 t of CF. with the quantity of resources equal to 47.2 million t of CF. One more field (990 km²) with density of resources exceeding 1.0 t of CF per m² has the resources evaluated by 10.0 million t of CF.

3.3 The Cambrian Water-Bearing Hydrogeothermal Complex

Stratigraphical size of the Gegė and Virbalis layers of the Middle Cambrian complex is rather large, but its thickness is not the highest. reaching 40 m in the Eastern part and 170 m in the Western part.

In West Lithuania this hydrogeothermal complex consists of rocks belonging lo the Deimena series and Kybartai lavers. with lower occurring layers of Virbalis and Gėgė. All their sections are composed of sandy and aleuritic deposits. In Central and East Lithuania its upper pan becomes thinner and total thickness smaller.

Occurrence depth ranges from -600 m in the East to -2100 m in the West. Conditions of occurrence arc complicated by tectonic fractures, mainly normal faults.

Rock Lithology and Collecting Features

Quartz sandstones with scarce aleurolite or aleurolitic clay interlayers prevail in the section of the Deimena series. Eastwards and Northwards, the quartzification disappears. The lower occurring layers of Kybartai formation have prevailing aleurolites with lenses of fine -grained sandstone. The sections of Gegė and Virbalis formations are notable for rhythmic lamination of fine and medium sandstone with aleurite and argillite interlayers. which in some places have a disturbuted ("kraksten"). It should also be noted that ferruginous oolites (with interlayers 10-20 cm thick) are often detected in the lower parts of the sections. There is a general tendency for all the Cambrian layers - the increase in sand content Eastwards (shorewards).

The efficient thickness varies from 13 m to 67.5 m. Open porosity gradually decreases Westwards from 6.5 % lo 19.6%. Lower values of mean porosity (10 %) is thought to be related less to primary sedimentation conditions, but more to diagenesis caused sandstone quartzification which is especially often in the upper pari of the Deimena series - the oil-bearing horizon.

One of the best ways to determine collecting features is to apply hydraulic test for promising horizons and to calculate the layer permeability from the fluid inflow. Analysis of over 100 test results, mainly from Upper/Middle Cambrian Deimena series, has been done. Maximum permeability (1100 μD) is determined in the borehole of Ablinga-4 after the tests in the range of **2130-2134** m. Such a permeability is typical of various-grained quartz sandstone of the Upper Cambrian Salantai member. Permeability ratio of these rocks is always high. In all other cases, it varies from **3.5** μD to **380** μD.

Water debits obtained during hydraulic tests in South an Central Lithuania are rather high. e.g. in the borehole of Graužai-105, the **debit obtained at free flow was 764.6 m^3/h. Lower debits were obtained** in West Lithuania It should be noted that the results of the analyses characterize one or two ranges investigated for oil. As for the thermal resources, all the effieient ranges can be used and layer volumes of geothermal water extracted.

Geothermal Hydrogeochemical Conditions

Conventional "geothermal" boundary of this complex in East Lithuania is the roof isotherm of **+20 °C**. In the North, it coincides with the state border, and in the south it goes along the state border and is limited by the zone of the Cambrian rocks.

It should be emphasised that till now special geothennal investigations were not performed. Temperature was measured only as a part of geological studies. Thermometry done in the districts of Klaipėda, Šilutė, Plunge, Šilalė and Jurbarkas comprises about *58* % of all boreholes. Here, the characterization of the Cambrian hydro-geothermal complex is based on the data from **73** boreholes. The "honest" entrails with temperatures over +80 °C were determined in the Kuršiai depression - on the Baltic Sea coast.

Heat carrier - groundwater in the Cambrian hydrogeothermal complex was tested almost in all boreholes by layer probes and perforating column, during the oil prospects. In this paper, more than 100 test cases are analyzed. Most general hydrochemical index water mineralization varies from **109 g/l** to **203 g/l**. Water mineralization is increasing going deeper.

The water described is attributed to the calcium chloride type. This water type is characteristic of deep (closed. isolated) medium. According to prevailing anion Cl^- (over **95%** e.q.), this water belongs to the chloride type. Of cations, Na* is prevailing, therefore this water is attributed to the sodium subgroup. The exception is ma& for the areas of Purmaliai, Šiupariai, Pietų Šiupariai, Degliai and Traubai, where Ca^{++} prevails over Na^+.

Rather large quantities of bromine are detected in the Cambrian groundwater. Its contents varies in a rather wide range: from **258 mg/l** to **1138 mg/l**. Most often **700-800** mg/l concentrations are found, thus exceeding the condition standard by 3-3.5 times. Thus, the Cambrian **groundwater can be attributed to the industrial bromine water category.** High salt contents in this complex is, by no doubt, related with its high temperatures.

Thermal Resources

Prognostic resources of P_1 category are evaluated for two thirds of Lithuania's area Conventional zero-line almost coincides with **+20 °C** isotherm. The boundary doesn't mean that eastwards beyond it there are no resources. Of course, there are thermal resources in the rest area as well, but having in mind present level of technologies, they are not expedient to be utilized

In this paper, there fields of prognostic resources are distinguished. The largest field is in the Eastern part, it occupies area of **19548** km^2, the density of resources ranges from **0.0** to **0.2** tons of CF per square meter, and the quantity reaches **19.5** million tons of CF. The second field in size (**17388** km^2), but with large density (**0.2-0.6** CF t/m^2), has the resources about **69.6** million tons of CF. The density of resources in the Western field (**5508** km^2) exceeds **0.6** with their quantity reaching **33.1** million tons of CF (Figure I). Total thermal resources are evaluated in the area of **42444** km^2, where prognostic resources of P_1 category make up **269.4** million tons of CF, and perspective resources of C_3 category make up **163.9** million tons of CF (Table 1).

Total geothcnnal resources of the Upper/Middle, and Middle/Lower Devonian and Cambrian hydrogeothermal complexes

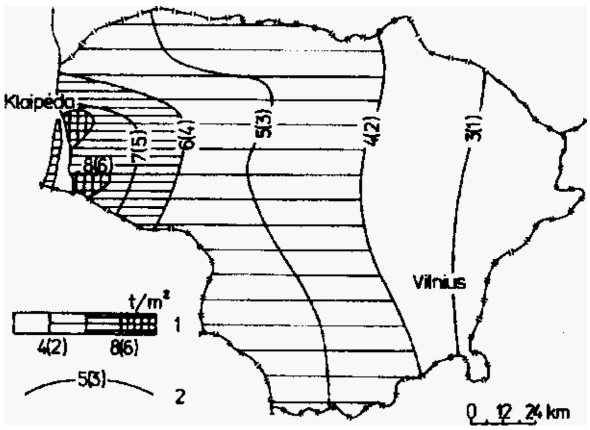
Table I

Density of resources, (CF* t/m^2)	Area, (km^2)	Quantity of resources, (mln. tons CF*)
Category P_1		
<0.2	16398	16.4
0.2-1.0	17604	105.6
1.0-2.0	h312	95.6
>2.0	2070	51.8
In all:	*42444*	*269.4*
Category C_3		
0.2	24930	24.9
0.2-1.0	11592	69.0
0.9	540	4.9
I.2	5382	64.6
In all:	*42444*	*163.9*

CF* - a conventional fuel unit

3.4 The Petrogeothermal Massif of Crystalline Basement

The geothermal resources have been calculated for the petro-geothermal complex of the Baltic syneclise at two temperature regimes **70/20** and **90/40 °C**, when the **first number** is ground water temperature in situ, and second one is temperature of water returned to the aquifer. The schematic map reflects densities of prognostic resources of P_1 category given in isolines (Figure **2**). The isolines are drawn for **I, 2. 3...** I of CF per m^2. Four density ranges are distinguished, and for each o m the resources are calculated (Table **2**). The perspective resources of C_3 category are given in Table **3.**



1 – density of resources, in tons of CF per m² fa two consumption regimes 70/20°C and 90/40°C, 2 – isolines of resources density, in tons of CF per m², for two consumption regimes 70/20°C and 90/40°C.

Figure **2.** Map showing distribution of prognostic petrogeothermal resources (P_1 category).

The evaluated resources present in the layer reaching **6 km** depths make up $298.5 \cdot 10^3$, and $168.0 \cdot 10^3$ million tons of CF for consumption regimes **70120 °C** and **90140 °C**, correspondingly. The resources of higher (C_3) category in this layer make up respectively $248.5 \cdot 10^3$ and

$115.8 \cdot 10^3$ million tons of CF. Resources of the hydrothermal complexes in the sedimentary cover represent a constituent part of total **geothermal** resources, however, not a largest *one,* as the above data **show.**

Petrogeothermal prognostic resources of P, **category** in Lithuania

Table 2

Density of **resources**, (CF* t/m²)	Area, (km²)	Quantity of resources, (mln.·10³ tons CF*)
Consumers temperature regime 70120 4:		
2-4	20625	61.9
4-6	39185	190.9
6-8	5950	41.6
8-10	450	4.1
In all:	***65200***	***298.5***
Consumers temperature regime 90140 °C		
0-2	20625	20.6
2-4	38175	114.5
4-6	5950	29.8
6-8	450	3.1
In all:	***65200***	***168.0***

Petrogeothermal perspective prognostic **resources** of *C,* **category in** Lithuania

Table 3

Density of resources, (CF* t/m²)	*Area* (km²)		Quantity of resources. (mln.·10³ tons CF*)	
	70120 °C	90/40 4:	70/20 °C	90/40 °C
1-2	**8463**	-	12.7	
2-3	**12308**	6232	30.8	15.6
3-4	16744	**5360**	58.6	**18.8**
4-5	15259	5240	68.7	23.6
5-6	6540	4360	36.0	24.0
6-7	3052	**2924**	19.8	19.0
7-8	**2180**	**1744**	16.35	**13.1**
8-9	654	200	5.6	1.7
In all:	***65200***	***26060***	***248.5***	***115.8***

4. RESOURCE EXPLOTATION

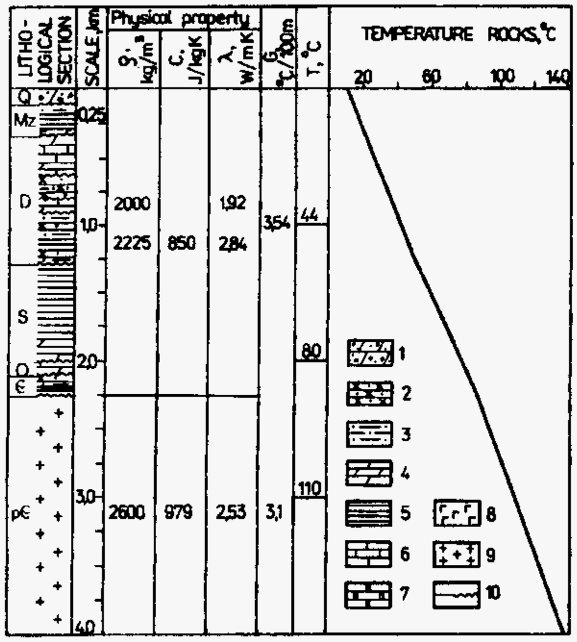
4.1 Possibilities

Comparative technical and economical **calculations of geothermal circulation systems using** artificial **(hydrofracture** at deep **depths) and** natural **(pumping** only *at* shallow depths) resource exploitation were carried **out** for Lithuanian **geologic-geothermal** conditions in the *central* part of the anomaly (2500 **km²).** The artificial exploitation was shown to **be** the **most** advantageous. This method transported **heat from the depth of 3 - 4.3 km, yielding 240 - 500 m³/h, temperature** of **100 -** 140 °C, thermal productivity of 15 · 346 MW, electrical consumption of **13.1 - 44.8 kWh/GJ, and would save up to** 12.5-2% **·10³** tons of CF per year (Suveizdis et al., **1993).**

The natural exploitation **(0.1 · 0.5** darcy), transported heat from a **depth of 1.8 - 2.2 km, yielding 100 -** 300 m³/h, temperahue of 70 - **90 °C, thermal productivity of 7 - 10 MW, electrical consumption of 31.6** · 326 **kWh/GJ,** and would save up to 6.6 **· 81.3·10³ t CF** per year. Utilizing geothermal *energy* in **this region** would save **more than** 700·10³ tons of CF per year.

Even though technical **and** economical calculations showed the superiority of **the** artificial exploitation, putting this into **practice** in the near **future** in Lithuania is **rather** difficult **as** hydrofracturing for **artificial** exploitation in **the USA,** Great Britain France, Japan and Germany are still in the developing **stage.**

However, projects are now being out in **Bad** Urach, Germany based **on a depth of 4.5 km and with very favorable** hot rock temperature of **180 °C (geothermal gradient of 4.0 °C/100 m), and in Cornwall, Great** Britain with a geothermal gradient of **3.4 °C/100 m. Comparing these** data with the Lithuanian **ones** (geothermal **gradient** in the Klaipėda (Figure 3) **and** Šilale zones **are** respectively **3.5** and 4.0 **°C/100** m), **we** can conclude that Lithuania might apply **for** the European Community subsidy for a demonstration project.



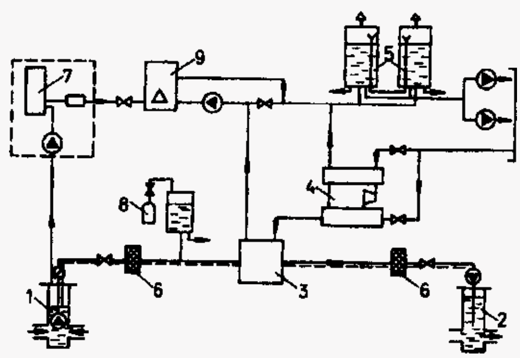
1 — morainic clay, sandy loam; 2 — sandstone; 3 — aleurolite; 4 — marl; 5 — argillite; 6 — limestone; 7 — dolomitic; 8 — anhydrite; 9 — granite gneisse; 10 — geological border

Figure 3. Klaipėda geological · geothermal section.

Artificial exploitation will **he** implemented in Lithuania **at** a later date; but at the present, our aim, even though not **as** effective, **should be for the more** simpler natural exploitation.

4.2 The Projects of GCS

The first to be mentioned is the construction of GCS in Vydmantai *on* the natural collector of Cambrium. Here **4 km deep** layers carry **water** of *up* **to** 13.3 **°C,** containing 162 g of salts and **1 l of gas** **(**CH_4 - 62.25%, C_2H_6 - 4.29%, C_3H_8 - 1.87%, He - 1.61%, N_2 - 27,1%, CO_2 - 1.33%, H_2 · 0.6% and **others · 0.35%)** per 1 l. Preliminary studies for several projects have been completed, see one of them in Figure 4. Its construction depends on the overall **economic** situation in the state. Itenvisagesa 100 to **170 m³/h yield, a 7.9 Gcal/h power, a** 12.9 mln. Lt. cost.



1. **Production well**
2. **Reinjection well**
3. **Heat exchanger**
4. **Heat pump**
5. **Settling tank**
6. **Geothermal water filters**
7. **Gas reservoir**
8. **Nitrogen reservoir**
9. **Utilization boiler**

Figure **4.** Principal technological scheme of Vydmantai experimental geothermal circulation plant.

Ways of reducing the cost and increasing the power to supply heat also to the town of Palanga are sought. The technology is based on an absorption heat pump (Dansk Ole og Naturgas (1994) calculations during a feasibility *study)*:

costs for geothermal plants

Table 4

City	Heat demand (TJ/year)	Reservoir temp., (°C)	Costs. (USD/GJ) repay-after
Klaipėda-D	5280	42	4.1-1.7
Palanga-D	578	37	6.8-2.7
Palanga-C	578	77	5.1-3.0
Šiauliai-C	4292	54	5.0-2.8
Šilalė-C	164	76	5.9-3.0
Šilutė-D	464	41	6.4-2.1

The -D and C after the city names denotes calculations based on the Devonian or Cambrian reservoir. TJ/year = million Joule per year.

The following heat production costs were calculated assuming a loan with 4.88% real interest (7.5% nominal interest at 2.5% inflation). Heat production costs includes costs while repaying a 25 year plant loan and costs after repayment of loan.

construction of pilot GCS in Klaipėda is under consideration. The next plant could be in Priekulė.

Calculations performed at LEI in prices of 1993 refer to existing well in Venckai near Priekulė. It's water comes from devon layer and is of 43 °C, so that it *can* be used as a source of heat. Three approach of supplying thermal power to a settlement of living houses were studed: a) M heat-pump, extended heating surfaces in individual houses; b) a heat pump in each individual house; c) a central heat-pump power plant for the settlement (Figure 5).

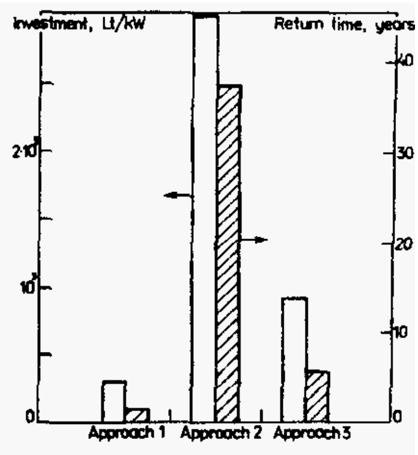


Figure 5. Three approaches of supplying thermal power to a settlement Venckai near Priekulė.

It was concluded, that heat carriers of low potential heat can be applied in standard houses of the Construction Plant in Alytus (panel walls and floors) only after improving thermal insulation of the houses. The project of a central heat-pump power plant requires minor reconstructions of the houses. It is more expensive than approach a), but cheaper than approach b).

The settlement Venckai can consume just 1/10 of the power of such thermal plant.

In spite of the cheap power from the Ignalina Nuclear Power Plant (Almenas at al., 1994), we in Lithuania seek for alternative safe, pollution - free and cheap local *source* of power. The optimistical prognoses of geothermal power in Europe (Cataldi, 1993) encourage our hopes of including geothermal power in the fuel budget of Lithuania.

5. CONCLUSIONS

1. Geothermal power in *the* territory of Lithuania comes from Upper/Middle Devonian, Middle/Lower Devonian, Cambrian hydrogeothermal complexes and from petrogeothermal massif. Prognostic P, resources from the sedimentary cover amounts to 269.4 mln. t CF and are distributed over the area 24444 km², that of *petrogeothermal* massif *amounts* to $168 \cdot 10^3$ or $298 \cdot 10^3$ mln. t. CF, depending on the consumers temperature regime and are scattered over the area of 65200 km².

2. Largest amounts were found in the 2500 km² anomalous area in West Lithuania, where the resources density more than 8 t/m² geothermal gradient - 4 °C/100 m, heat flow density - 108 mW/m² are obtained.

3. Potential geothermal power in the 42444 km² area of West and Central Lithuania is sufficient for its industrial exploitation, first of all for domestic heating systems.

4. The most promising technology is that of closed GCS. Heat can be extracted from natural collectors of the sedimentary cover at a price below 5 USD/GJ in the nearest future. With such a favorable geological situation in Lithuania, extraction of heat using artificial exploitation is equally promising.

5. Utilization of geothermal power from low-temperature water (of 43 °C) is possible in the climate of Lithuania with special low - *potential house heating* systems, (panel walls and floors) after improving thermal insulation of the houses.

REFERENCES

Almenas, K., Kaliatka, A., Ušpuras, E. (1994). *Ignalina RBMK-1500.* Literae Universitatis Vytauti Magni, Kaunas. 132 pp.

Boguslavskij, E. (1984). Technical *Economic Evaluation of Geothermal Resources.* S.P.G.I., St. Petersburg. 168 pp., (in Russian).

Cataldi. R. (1993). Environment-related problems and costs of geothermal development. *Exploration Technology, Geosynoptics and Geothermal Energy.* NO 5-6(167), Krakow, pp. 175-204.

Dansk Olie og Naturgas AIS. (1994). *Baltic Geothermal Energy Project* Final Report, Copenhagean. 93 pp.

Dansk Olie og Naturgas *AIS.* (1993). *Geothermal Energy.* 25/6 pp.

Dyadkin, Y. (1985). *Fundamentals of Geothermal Technology.* S.P.G.J., St. Petersburg. 176 pp., (in Russian).

Lund. J.W. (1993). Direct utilization of geothermal energy. *International Geothermal Conference.* St. Petersburg. (in press).

Shulz, R., Werner, R., Ruhland, J., Bußmann W. (1992). *Geothermische Energie: Forschung und Anwendung in Deutschland.* Muller, Krlsruhe. 216 pp.

Sobanski, R., Meyer, Z. (1993). The first Polish geothermal district beating plant in Pyrzyce. *International Seminar on Environmental Protection by rhe use of Georhem l Energy,* Zakopane-Koscielisko, pp. 1-10.

Suveizdis, P., Rastenienė, V. (1993). *The Geothermal Resources in Lithuania.* NO 4, Geological Society of Lithuania, Scientific Papers. 26 pp.

Suveizdis. P., Rastenienė, V., Makarevičius, V., Zinevičius, F. (1993). Geothermal Energy in Lithuania. *Geo-Heat Center Quarterly Bulletin.* Oregon Institute of Technology, Vol. 15, NO 2, pp. 26-27.