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Geological Setting of the Geothermal Water in the Łódź Trough (Central Poland)

Janusz Trzepierczyński

University of Silesia, Chair of Fundamental Geology, 41-200 Sosnowiec, Będzińska 60, Poland

jtrzepie@wnoz.us.edu.pl

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ABSTRACT

The Łódź Trough is one of the Laramian structures parallel to the Trans – European Suture Zone (TESZ) of the Alpine foreland developed during the epivariscan stage of the development of the West – European Palaeozoic Platform. Geothermal waters with temperatures between 20^0 C to 100^0 C occur in sandstones and carbonates of the Mesozoic and Permian. Geothermal waters with temperatures of 60^oC and efficiencies of 65 – 300 m^3/h from Lower Cretaceous sandstones have been exploited by geothermal heating plants in Uniejów (the Łódź Trough) and Mszczonów (The Warsaw Trough) since 2002. However, the most favourable geothermal parameters have been found in Lower Jurassic sandstones. Perspective resources of geothermal water with temperatures exceeding 100^oC occur in limestones of the Middle Triassic at depths of 3000 – 5000 m, and could be utilized by a geothermal heating plant of 20 Mw capacity. Geothermal waters also occur in limestones and dolomites of the Upper Permian at the Łódź Trough flanks. Surficial heat flow increases from 50 to 90 W/m^2 in the northern part of the Łódź Trough. In author's opinion, suitable geothermal conditions in the Łódź Trough are related to geological development during pre-inversion and inversion stages. In the deep basement at the eastern side of the trough, global geotectonic units, the East European and the West European Platforms, adjoin and the Moho is lowered to 50 km.

During the pre – inversion stage, the development of the Mid – Polish Trough on the Caledonian and Variscan basements and sedimentation of the Permian and Cretaceous deposits took place. Subsidence and sedimentation in a marine basin caused lowering of the Moho with subsequently occurrence of halokinetical processes as well as a temperature raise in the Permian and Mesozoic. Transformation of the Mid – Polish Trough into the Mid – Polish Swell and adjoined troughs caused suitable hydrogeological and structural conditions.

1. INTRODUCTION

The Łódź Trough is one of the Laramian structures that formed during the epivariscan development of the Middle Europe (Pożaryski 1979, Dadlez et al. 2000, Dadlez 2001). In the territory of Poland, the Laramian structures run parallel to the deep Trans – European Suture Zone (TESZ) and diagonally at the foreland to the margin of the Carpathian overthrust. In the Polish Lowlands they are covered by 200 m thick Cenozoic deposits. The Łódź Trough is filled with Permian and Mesozoic rocks in which geothermal water reservoirs occur (fig. 1). Intensive sedimentation of Permian and Mesozoic rocks is observed in the Mid-Polish Trough, which formed at the foredeep of the Variscan orogene. 700 km long and 100 km wide, the Mid-Polish Trough during the Permian and Mesozoic was subjected to subsidence and sedimentation, that resulted in 10 km thick deposits. Thickness analysis of the Permian and Mesozoic rocks has indicated an increasing rate of subsidence during the following episodes: Zechstein - Early Triassic, Oxfordian - Kimmeridgian and Early Cenomanien (Dadlez at al.,1995). From the Early Triassic until the Middle Jurassic the thickness gradient about 100m/km , whereas from the Late Jurassic to the Early Cretaceous it was 20 m/km. In the Upper Cretaceous (Coniacian) and in the Paleogene, the Mid-Polish Trough was transformed into the Mid-Polish Swell along the axis of the most intensive subsidence. The structural shape of the Łódź Trough was formed between the Fore-Sudetic Monocline and Mid-Polish Swell (fig. 1, 2) in the Late Cretaceous. In the Łódź Trough, which is part of a geotectonic structure in the Danish-German-Polish Trough, large resources of geothermal energy have been discovered (Sokołowski, 2000). In Denmark, Germany and Poland, geothermal heating plants have been successfully working with no damage for several years. Detailed studies of the geological setting of 16 cities in the Polish Lowlands, conducted by Department of Geology and Geological Concessions Ministry of the Environment, have proved their suitable geothermal conditions. The purpose of this paper is to describe these economic geothermal water horizons and genesis of thermal conditions in the Łódz Trough, their geological setting, and relationships between geology and the efficiency of prospective geothermal heating plants.

2. GEOTHERMAL WATER HORIZONS

In the Łódz Trough, geothermal water occurs in the Permian and Mesozoic reservoir rocks at a depth of 1000 to 4500 metres. The following horizons have been distinguished:

The Upper Cretaceous - 1700 metres thick marine suite of carbonate rocks consisted of marls, limestones and gaizes (Trzepierczyński 2002a). Rocks of porosity over 20% and dense fissuring contain geothermal water of temperature 50°-60°C in the lower horizon. Geothermal energy resources were estimated at 400 mln toe. These deposits also contain–economic drinking water for the Łódz Province.

The Lower Cretaceous extend down to a depth of 2000 metres and consist of marine and brackish of limestones , mudstones and sandstones, 100 – 300 metres thick in the eastern part of the Łódź Trough. Sandstones of the Valanginian, Valanginian – Hauterivian , Barremian – Middle Albian with porosities of 5-27 % contain 60º C geothermal waters 60º C with efficiencies from 65 m^3/h to 300 m^3/h (Trzepierczyński 2002b), that is utilized by geothermal heating plants in Uniejów (fig. 1) and Mszczonów in the Warsaw Trough.

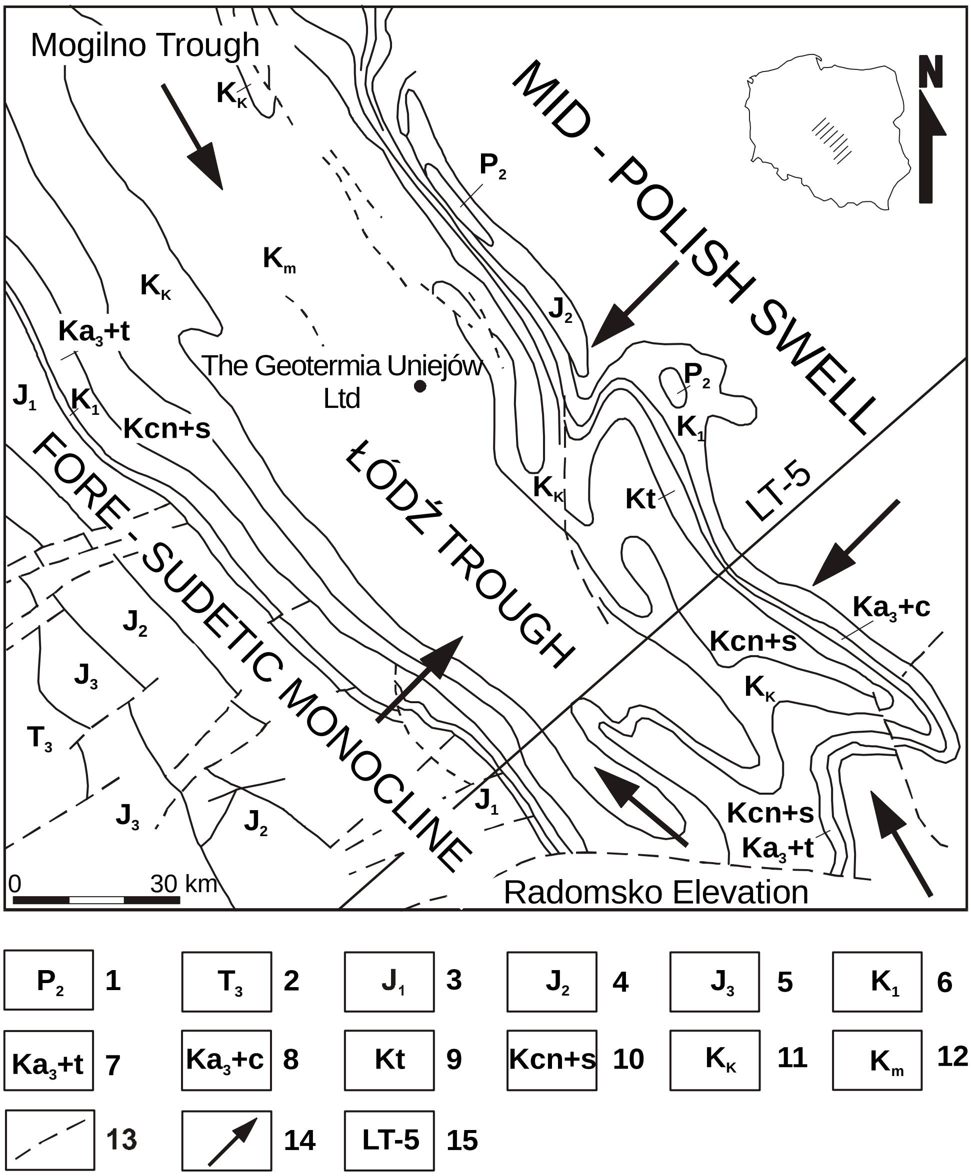

Figure 1: Geological Map of Łódź Trough without Cainozoic deposits.

1 – Upper Permian, 2 – Upper Triassic, 3 – Lower Jurassic, 4 – Middle Jurassic, 5 – Upper Jurassic, 6 – Lower Cretaceous; Upper Cretacous: 7 – Upper Albian – Turonian, 8 – Upper Albian - Cenomanian, 9 – Turonian, 10 – Coniacian - Santonian, 11 – Campanian, 12 – Maastrichtian, 13 – faults, 14 – groundwater recharge directions of geothermal reservoirs, 15 – line of GSS profile.

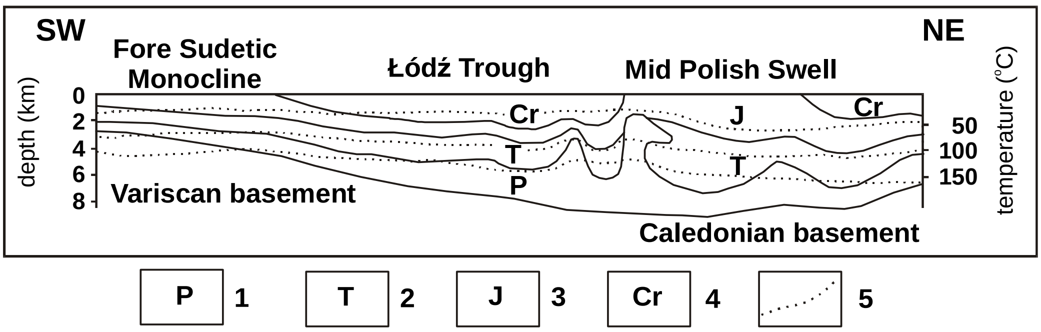

Figure 2: Geothermal – geological cross – section across Łódź Trough and adjacent areas.

1 – Permian, 2 – Triassic, 3 – Jurassic, 4 – Cretacous, 5 – geoisotherms.

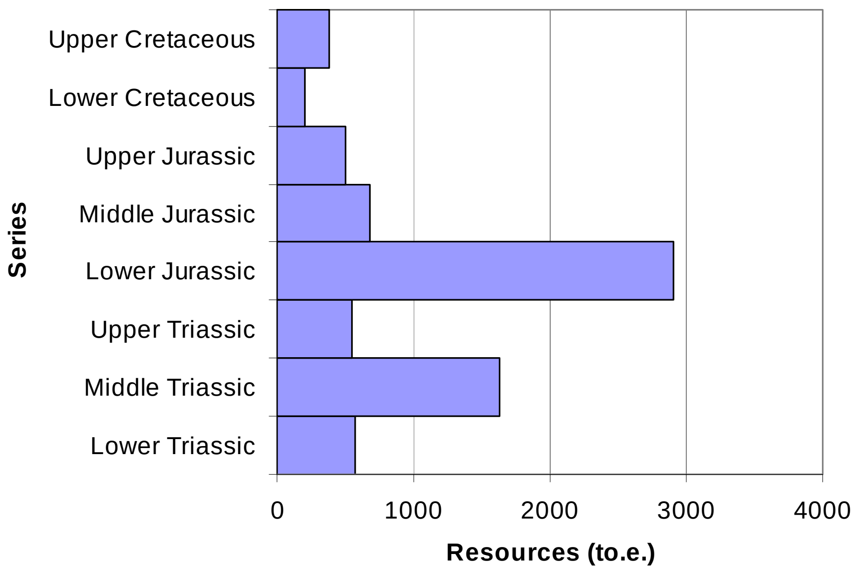

Figure 3: Mesozoic resources of geothermal energy.

The Upper Jurassic – occurs at a depth of 1500 to 2500 metres, and consists of marine and brackish carbonate rocks of the Oxfordian and Kimmeridgian and carbonate-mudstone rocks of the Thitonian, 900 metres thick in the eastern part of the trough. Oölithic and oncolithic limestones with 15-27 % porosities and permeabilities from several to 55 mD, 270 mD contain geothermal waters with temperatures 30 °C to 65º C, and even 90º C very deep in the horizon.

The Middle Jurassic – occurs at a depth of 2000 to 2600 metres and consists of claystone – mudstone deposits with sandstones and siderite concretions. The thickness of the deposits ranges from 100 – 150m. In the Mid – Polish Swell it is 1000 metres in the vicinity of Kutno. Geothermal water 50º C to 60º C and locally 90ºC occur in reservoir rocks 21% porosity and permeability of several dozen mD.

The Lower Jurassic – at a depth of 2500 to 3000 metres, a brackish suite of sandstones and mudstones, 200 metres thick occurs (Trzepierczynski 2002c). In Kalisz – Kamieńsk tectonic graben the thickness of the unit increases to 500 – 800 metres and is reduced to 100 metres at the Wielkopolska Horst and to 0 metres at the Radziątków Elevation. Geothermal water 35ºC to 90º C with resources of 2901,1 toe (fig. 3) - and efficiencies of 36 m^3/h occur in sandstones of the Hettangian, Lower Sinemurian, Domerian and Toarcian. These sandstones have porosities of 26% and permeabilities of several Darcies under subartesian pressure. The Lower Jurassic geothermal water horizon is a principle perspective for the development of geothermy of the Polish Lowlands. Since 1996 geothermal water has been utilized by a 50 Mw geothermal heating plant in Pyrzyce and it will also be utilized by another 14 Mw geothermal plant of in Stargard Szczeciński.

The Upper Triassic – down to a depth of 4000 this 1000 metres thick unit consisted of claystones, mudstones, sandstones and gypsum that formed a deltaic – lagoonal, ingressive – regressive suite. Geothermal waters 60º C - 120 º C with resources of 544,7 toe (fig.3) occur in sandstones with 6% to 19 % porosity and permeabilities from 5 to 51 mD and an efficiency of 90 l/h.

The Middle Triassic – down to a depth of 4500 metres this unit consisted of carbonate rocks (limestones and dolomites), 300 – 400 metres thick but in central part of the Łódź Trough exceeding 500 metres (Trzepierczyński 2003) This limestone transgressive suite and dolomite regressive suite of the Middle Triassic has proper fissuring, permeability and deep location to ensure suitable conditions for high water content and temperatures exceeding 100ºC. Carbonate rocks of the Middle Triassic are therefore good possibilities for power engineering not only in the Łódź Trough but also in the Polish Lowlands.

The Lower Triassic horizon distinguished down to a depth of 5500 metres consisted of a 1000 metres thick suite of sandstones, mudstones and limestones that has not been geothermally recognized so far because of the deep location of reservoir rocks.

The Permian horizon distinguished at a depth of 3000 to 5000 metres does not have good potential for geothermal water prospecting at the Fore-Sudetic Monocline situated at the limbs of the Łódź Trough. Carbonate deposits of the Basal Limestone and the Main Dolomite (Zechstein), which are several metres thick and are characterized by temperatures of 60º C to 100º C, certainly have potential for geothermal water prospecting. These deposits have been well documented through oil and gas drilling by the Polish Gas and Oil Company.

3. STRUCTURAL CONDITIONS AND GEOTHERMAL ENERGY EXPLOITATION

Profitable exploitation of geothermal energy and activity of a prospective geothermal heating plant in the Łódź Trough is possible due to beneficial geological conditions, which include lithology of reservoir rocks, high groundwater content, geological structure of the basin and presence of saline structures.

3.1 Lithology of reservoir rocks

In the Łódź Trough geothermal water of temperature exceeding 20º C occur in sandstones of the Lower Cretaceous, Middle and Lower Jurassic, Upper and Lower Triassic and carbonate rocks Upper Cretaceous, Upper Jurassic, Middle Triassic and Upper Permian. The most attractive lithologies are carbonate reservoirs whose efficiency could be improved by making them more permeable to increase capacity (Goldbrunner, et al. 1999, Ungemach 2004). Heat exploitation from sandstone reservoirs of the Lower Jurassic in Pyrzyce and of the Lower Cretaceous in Uniejów and Mszczonów is economical, and therefore they are good candidates for prospective geothermal heating plants in the Łódź Trough.

3.2 The Łódź Trough structure

The limbs of the Łódź Trough are declined at an angle of several grades; the axis runs from north-west to south-east and the pitch of the axis is towards north-west (fig. 1,2). The lithological structure of the trough was formed at the south-western terrace of the Mid-Polish Trough that developed on the Rothliegendes in the rift trough. During the Mesozoic subsidence and sedimentation in the Mid-Polish Trough migrated towards the East-European Platform. After the Permian and Mesozoic thalassocratic movements had stopped, the Fore-Sudetic Monocline, The Holly Cross Mts. and the Radomsko Elevation (fig. 1) were uplifted in the Paleogene. The Łódź Trough with eroded Cretaceous deposits at the limbs is situated between these uplifted units. The structure of the trough with its axis declined north-west causes the temperature of geothermal water to rise towards north-west and subartesian water to occur.

3.3 Saline structures

In the Trough saline structures occur in the shape of diapers and salt – pillows (fig. 2). The extension of the Variscan basement, especially the sub-Zechstein, and the system of faults have played a role in the development of saline tectonics. In the Zechstein Cyclothem PZ2 the Variscan structural plan was transformed into the Laramian (Trzepierczyński 1987). Evolution of saline structures has developed above the Variscan faults (Krzywiec 2004) as well. Saline tectonics are conducive to keep beneficial structural and thermal conditions in geothermal water reservoirs, especially at slopes of saline diapirs and intersaline troughs. Increased migration of geothermal heat is observed across fault zones towards saline diapirs where thermal conductivity of salt and anhydrites is 2-5 times as large as adjacent rocks (Twarogowski et al. 2002) and geothermal heat stream flow increases up to 10% (Majorowicz et al. (2002), Majorowicz (2004).

3.4 Groundwater recharge

The geological structure of the Łódź Trough is conducive to groundwater recharge into geothermal reservoirs from the Fore-Sudetic Monocline, north – western margin of the Holly Cross Mts., the Mid-Polish Swell and the Oborniki Elevation (fig. 1). The northern part of the trough is situated in the area of ascentive groundwater inflow from its deep part towards the shallow part; this is also conducive to temperature rise in the direction of water infiltration. The Upper Cretaceous water of carbonate fissured reservoirs, for example, get cool by groundwater recharge from the Cenozoic aquifers. Deep aquifers are separated from upper horizons by mudstones and claystones of the Lower Cretaceous, Middle and Upper Jurassic and vertical groundwater recharge goes through hydrogeological windows.

4. GEOTHERMAL CONDITIONS IN THE ŁÓDŹ TROUGH BASEMENT

In the Łódź Trough area the geothermal heat stream flow from the mantle ranges between 60 and 90 mW/m² and is higher than at the East-European Platform (40 mW/m²) and in the Sudety Mts. – less than 60mW/m² (Majorowicz et al. 2002, Krzywiec 2002, Majorowicz 2004). The highest value of geothermal heat flow was documented in the southern part of the Trans- European Suture Zone, at the Fore- Sudetic Monocline and in the Danish-Germany Trough. Different values of heat flow depend on intratelluric geological units. The boundary between the Variscan externides and their foredeep runs at the basement of the Łódź Trough (fig. 4). The Caledonian structures are situated beneath the foredeep at the edge of the East-European Platform. Extension of the Variscan orogene underneath the Permian and Mesozoic cover in relation to the edge of the East-European Platform is variously interpreted.

The old East-European Platform, which is 40-50 km thick, and the young Paleozoic Platform, 30-34 km thick, adjoin at the base of crystalline basement, and are locally lowered to 19 km (fig. 4). The thickness of crust underneath the Łódź Trough in the TESZ Zone increases to 40-45 km (Guterch and Grad 2002, 2004). In the TESZ Zone the crust is divided into segments of different thickness (Dadlez 1997) and heat flow. In the Łódź Trough part of the basement 90 km wide and occurs in anomalous crust of intermediate features between crust and mantle with increased values of geothermal heat flow that is characteristic of the Variscan Wielkopolska geothermal heat anomaly.

The thermal lithosphere under the Palaeozoic Platform is 90-160 km thick. Underneath the TESZ at a depth of 90 to 60 km (Guterch and Grad 2004, Guterch et al. 2004) there is the astenosphere offset (fig. 4) whose top surface corresponds to the isotherm 1300º C. Increased values of geoisotherms in the upper part of mantle and in crust above the Moho, due to astenosphere offset, were documented by thermal, rheological (Jarosiński et. al. 2002)) and geothermal heat stream flow modeling along the P4 seismic profile . The temperature at the Moho underneath the Palaeozoic Platform ranges between 600º C and 750 º C. The value of radiogenic heat generated in the crust was estimated at 2,2 x 10^{-6} W/m³ at the Palaeozoic Platform (Jarosiński et. al. 2002), 2,5 x 10^{-6} W/m^3 at the TESZ and 1,0 x 10^{-6} W/m^3 at the East-European Platform. The value of thermal conductivity was estimated at 3,2 W/mK in the mantle, 2,0 W/mK in the lower crust and 2,5 W/mK in the upper crust. It is assumed that if the astenosphere offset is of Permian age, the development of the Mid-Polish Trough could have been initiated (fig. 2,4).

5. CONCLUSIONS

Beneficial conditions for geothermal energy exploitation have been documented in the Permian and Mesozoic rocks of the Łódź Trough (fig. 1,2). Sandstone reservoirs of the Lower Cretaceous and the Lower Jurassic, as well as carbonate reservoirs of the Middle Triassic have the best potential. Regarding the latest calculations, geothermal water-bearing reservoirs of the Middle Triassic are characterized by temperatures exceeding 100°C, and efficiencies of 300 m³/h; these could be good candidates for a 20 Mw geothermal heating plant. The Upper Permian geothermal water horizons of the Basal Limestone and the Main Dolomite reservoirs, documented at slopes of the Łódź Trough, are assumed to be just as economic as the Middle Triassic ones. Mesozoic resources of geothermal energy are estimated at 7408,3 mln. toe (fig. 3).

The geological structure of the Łódź Trough has been described by lithology, petrophysical parameters of rocks, structure of the basin, saline structures, groundwater recharge, aquifer~~s~~ occurence, subartessian pressure in aquifers, and geothermal heating capability (Sokołowski 1995, 1996). Collectively the Łódź Trough is considered to be are conducive to geothermal plant construction.

Geothermal conditions of the Łódź Trough are stimulated by the deep location within the Earth`s crust; components are as follows:

- astenosphere offset and increased values of geoisotherms
- thickened crust with intermediate layer due to a labile temperature-pressure regime at the boundary between upper mantle and lower crust
- adjacency of old Precambrian East-European Platform to young Palaeozoic West-European Platform that consists of the Caledonian and Variscan crusts.

Tectonic and thermal processes inside the Earth`s crust and at their borders played a role in the development of the Mid-Polish Trough and its Laaramian transformation.

Current geothermal conditions, stabilized by emission of radiogenic heat and thermal conductivity of mantle and crust, have lasted for about 280 Ma.

Problems of internal geological structure of deep parts (=segments) of the Earth`s crust, upper mantle, and adjacency of East-European Platform to Palaeozoic Platform in the territory of Poland are currently being studied (fig. 4). Results of these studies are important to determine the geothermal setting of geological units. Current data on thermal conditions should be regarded in future studies as they are important for fundamental and applied geology. The geological structure of deep basement underneath the Mid-Polish Trough and its development during the Permian and Mesozoic episodes document the accumulation of a large amount of energy (fig. 3) along the edge of the East-European Platform that is documented by increased value of geothermal heat from the Variscan Wielkopolska geothermal heat anomaly.

Geothermal water in the Łódź Province could be utilized in geothermal heating power plants as well as health resorts (i.e.balneology) due to high content of bromide-iodide brines.

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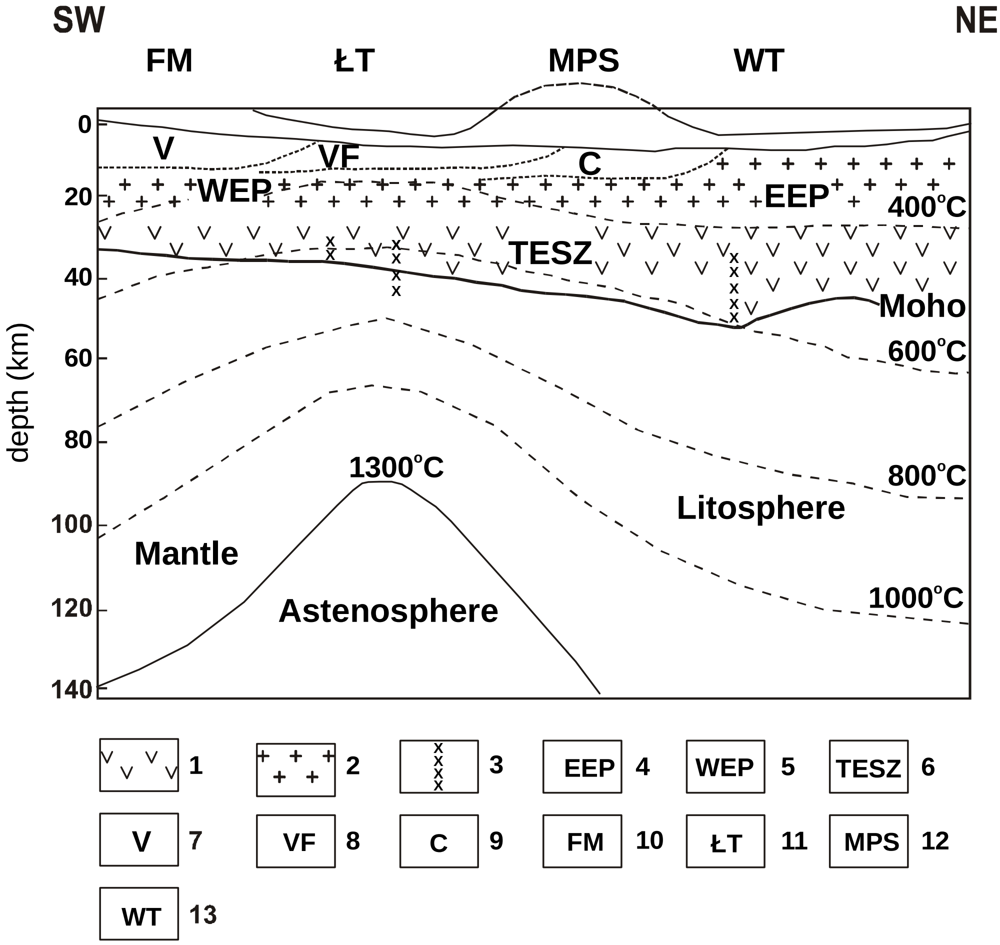

Figure 4: Crustal, upper mantel and Paleozoic basement model underneath the Łódź Trough along LT-5 profile (localization fig. 1) (Guterch et al. 1980, Trzepierczyński 1987, Guterch and Grad 2004, Jarosiński et al. 2002).

1 – lower crust, 2 – upper crust, 3 – deep fractures and tectonic disturbances, 4 – East European Platform, 5 – West European Platform, 6 – Trans European Suture Zone, 7 – Variscans, 8 – Variscan Foredeep, 9 – Caledonides, 10 – Fore-Sudetic Monocline, 11 – Łódź Trough, 12 – Mid Polish Swell, 13 – Warszawa Trough.