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3D Modeling of a Geothermal Reservoir in the Central Part of Kosice Basin in Eastern Slovakia

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3D MODELING OF A GEOTHERMAL RESERVOIR IN THE CENTRAL PART OF KOSICE BASIN IN EASTERN SLOVAKIA

Katarína Kamenská

A 30 credit units Master’s thesis

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A Master’s thesis done at
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ABSTRACT

The question of energy needed for enhancing human comfort has recently become very popular and geothermal energy, as one of the most promising renewable energy sources, has started to be utilized not only for recreation purposes, but also for heating and probably electricity generation in Slovakia. Slovakia is a country which has proper geological conditions for geothermal source occurrence. Kosice Basin seems to be the most prospective geothermal area – the reservoir rocks are Middle Triassic dolomites with fissure karstic permeability and basal Karpathian clastic rocks at the depth of 2100 – 2600 m, with an average temperature around 135 °C. Seismic data from the central part of Kosice basin enabled the demonstration of position, spatial distribution, morphology and tectonic structure of reservoir rocks and their Neogene overlier as an insulator. Based on a 3D tectonic model, reservoir rocks are segmented into individual blocks which probably do not communicate with surrounding blocks in terms of geothermal water flow. Tectonic and geologic aspects affect the thickness of sedimentary sequences, which is demonstrated by variable thickness in the whole space of the modeled area. The model showed at least one potential geothermal area, but for further evaluation detailed geophysical measurements are needed. Geothermal sources in central Kosice Basin as a home source can reduce dependence on gas and other fossil fuels. Utilization of geothermal sources can secure energy supply for Kosice town and prevent future shortages in energy as happened in January 2008 when Russia cut gas supply to part of Europe, including Slovakia. Geothermal utilization produces much less greenhouse gasses as conventional fossil fuel plants and in the case of reinjection there is no emission to the atmosphere. Probably the biggest disadvantage of geothermal utilization in the area of interest is high capital cost.

PREFACE

RES | the School for Renewable Energy Science in Iceland provided me with the opportunity to write a Master thesis on a geothermal topic connected to Slovakia. Project work took place mainly in Slovakia at the Technical University of Kosice in cooperation with my supervisor, Dr. Stanislav Jacko.

This project is related to the 3D modeling of subsurface bodies, especially geothermal reservoir rocks in Schlumberger's Petrel software. The area of interest is in the Eastern part of Slovakia, in the central part of Kosice Basin. Slovakia is a country with favorable geological conditions for geothermal utilization. Geothermal water sources occur mainly in Tertiary basins, volcanic mountain ranges and intra – mountain depressions. Kosice Basin, as a Tertiary Basin, is one of the prospective geothermal areas of Slovakia. Evidence revealing the existence of convenient reservoir rocks was detected by petroleum research in the late sixties and early seventies. The first geothermal research in the studied area was conducted in 1998 – 1999 in the Durkov area, where three geothermal wells were drilled and favorable geothermal conditions were verified. For the creation of a 3D model, seismic sections from a geophysical survey in 1992 were used. The 3D model is supposed to show the spatial distribution of reservoir rocks, their thicknesses and tectonic rupture and other potential areas where geothermal water could be expected.

This paper was created with great support from my family, friends and Rasťo. Special acknowledgement belongs to Dr. Stanislav Jacko, Michał Pachocki and Dr. Björg. I dedicate my thesis report to Samko Dudáš, Veronika and Radko.

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1 INTRODUCTION

Recently, geothermal energy has become a very attractive source of energy all around the world, and Slovakia is no exception. Owing to favorable geological conditions Slovakia is a country abundant in low-enthalpy sources. Geothermal water sources are related to Tertiary basins, volcanic mountain ranges and intra–mountain depressions. In these geologic units there are 26 potential areas that constitute 34% of the total territory of Slovakia. The main reservoir rocks are Triassic dolomite and limestone rocks of the Inner Carpathian tectonic units and less common Neogene sands, sandstone rocks, conglomerates and the Neogene andesite rocks and their pyroclastics. Kosice basin – with its Mesozoic dolomites containing fissure and karstic permeability and basal Karpathian clastic rocks as reservoir rocks – is the most perspective area for geothermal utilization. The existence of geothermal water sources was determined by petroleum wells in late sixties and early seventies. The first geothermal research conducted in the central part of Kosice basin was realized in 1998 – 1999. Three geothermal wells GTD -1, 2, and 3 were drilled in Durkov for purpose of utilization in Kosice town. Results from hydrodynamic tests confirmed convenient conditions from a geothermal point of view. The Middle Triassic dolomites with fissure and karstic permeability together with basal clastic rocks of Karpathian are considered as reservoir rocks in the whole modeled area. The presence of the same reservoir rocks and results from geothermal research from the Durkov area could indicate other potential hydrogeothermal structures in the rest of the modeled area. Seismic measurements, which were realized in the central part of Kosice basin, were basic data for the modeling of the subsurface – which includes reservoir rocks and insulator rocks. Kosice basin, as a part of the Eastern Slovakia basin, did undergo complicated tectonic events during Neogene, which could also have an impact on the pre-Tertiary underlier created by reservoir rocks. The model is intended to show the spatial distribution of reservoir rocks and tectonic influence on them and to assume next potential structures favorable for geothermal energy.

2 GEOGRAPHICAL AND GEOLOGICAL INTEGRATION OF SLOVAKIA

2.1 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.

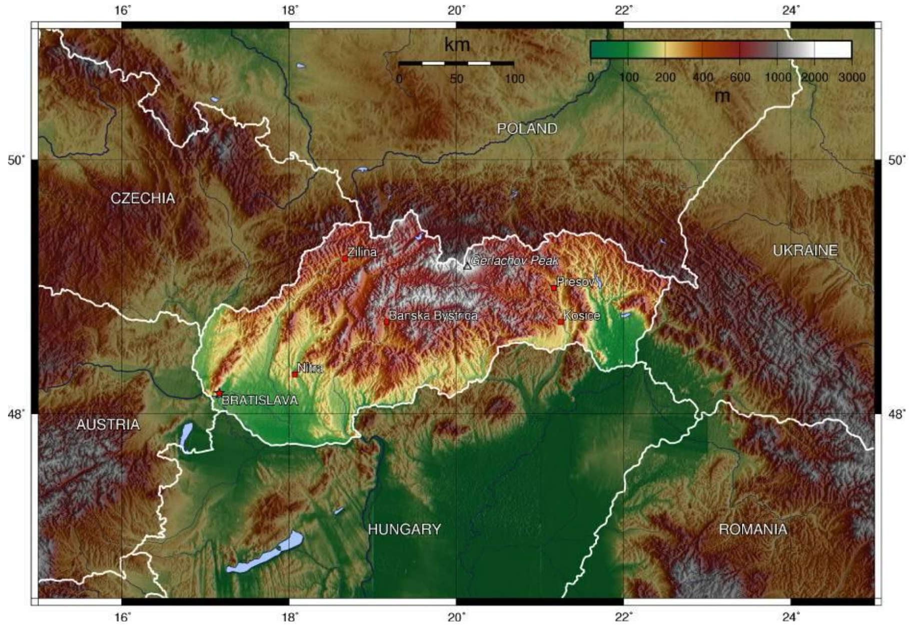


Fig. 2-1Position of Slovakia (httpgeology.comworldslovakia-satellite-image.shtml#satellite.jp)

2.2 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.

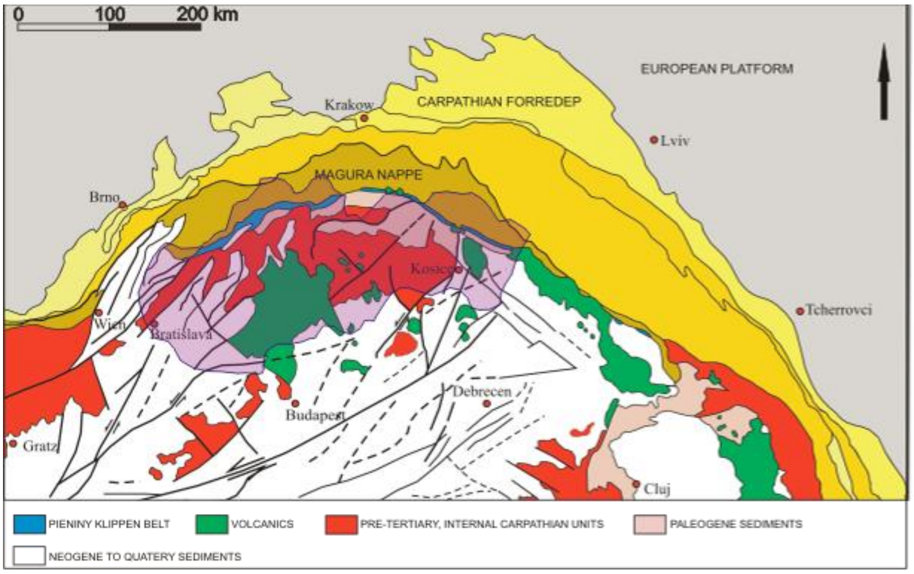


Fig. 2-2 Structural sketch of Carpathian arc and position of Slovakia

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.

2.2.1 Slovakia as part of the Western Carpathians

Generally, the Carpathians have been divided into the Western (Czech Republic, Poland, Slovakia, Hungary), the Eastern Carpathians (South-eastern Poland, North-eastern Slovakia, Ukraine, Romania) and South-eastern Carpathians (Romania, Serbia).

The Western Carpathians are a large mountain province in western part of Carpathians. The West Carpathians extend to areas of Slovakia, Moravia, Poland (minor northern part), Hungary (south-eastern part) and Austria (south-western headlands). The total extent of Western Carpathians is approximately 70 000 km2 and they originated during the Alpine orogene by progressive closing of Tethys ocean.

The Western Carpathians are part of the Alpine – Himalayan system. They join Alps from the west and Eastern Carpathians from the east. The Eastern European platform and Bohemian massive on the west represent the northern boundary. The southern boundary is indistinct due to deep penetration of lowlands into the mountain system. The Western Carpathians' structure is characterized by zoning. The Mesozoic and Tertiary formations, arrayed in a series of arcuate belts, have been tectonically transformed from qualitatively and temporally different sedimentary basins into the foldnappe ranges, which are either composed of sedimentary filling alone or include the original basement. Variscian consolidated Carpathian foreland and Tertiary Carpathians foredeep do nor crop out in Slovak territory – they do, however, occur in the tectonic basement of the Outer Carpathians units.

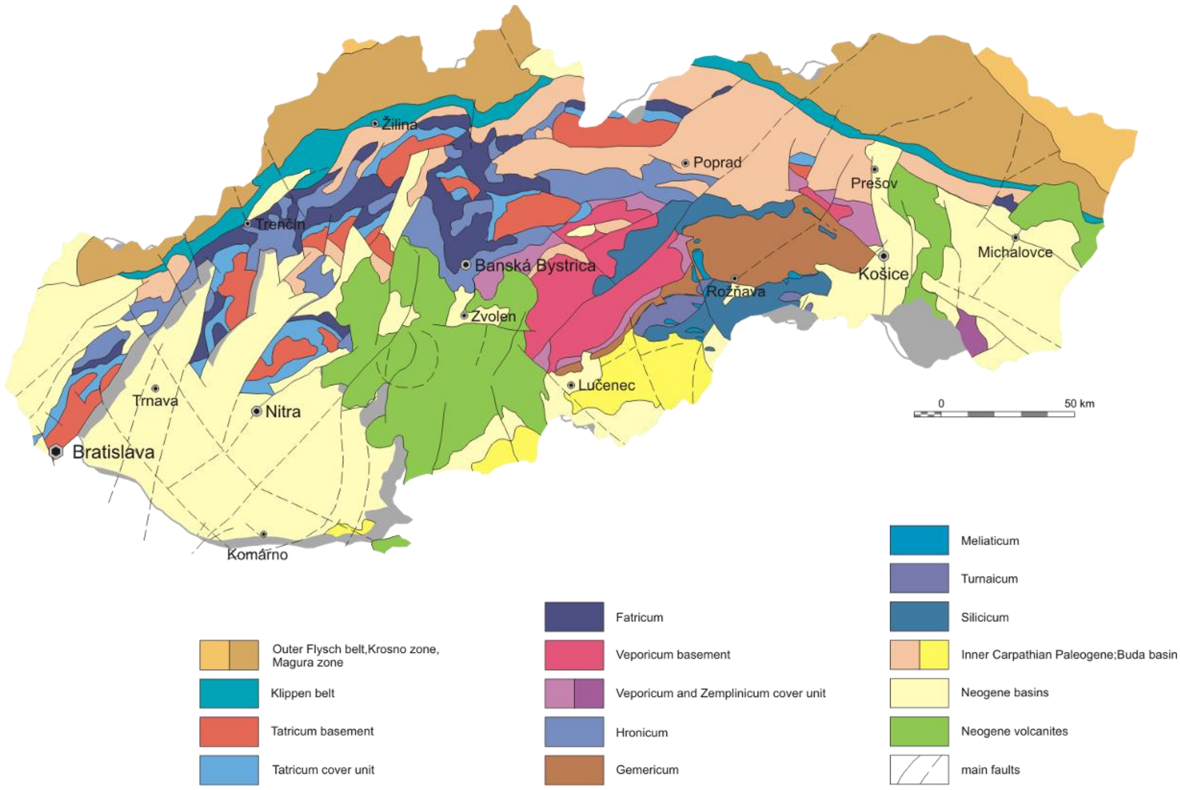


Fig. 2-3 Tectonic sketch of Slovak part of Western Carpathians (Biely Ed., 1996)

The Western Carpathians are classified according to the age of development of the Alpine nappe structure as an Outer with Neo–Alpine nappes and the Inner with Paleo – Alpine – Pre – Paleogene nappe structure. The Klippen belt marks the boundary between the Outer and Inner Western Carpathians.

The *Outer Carpathians* (Flysch belt) represent an external part of the Western Carpathians, which arose by tectonogenesis between the Upper Cretaceous period (Senon) and Miocene epoch. They are made up of the Tertiary series of rootless nappes, i.e. of the sedimentary sequences detached from their basement and thrusted over the North–European platform. The origin of these sequences is not known. Typical features are:

a) predominately flysch–like character of the Mesozoic and Paleogene formations

b) a total absence of the Pre-Mesozoic formations

c) negligible distribution of the post nappe cover

The elements of this belt are in Moravia and in Western Slovakia – below the Vienna Basin Neogene linked with the Alpine Rheno-Danubian flysch. They expand further eastward into the Eastern Carpathians. The Flysch belt is composed of three groups of nappes. While the marginal group has an affinity to the frontal foredeep, it is totally absent in Slovakia. The central group – the Silesian Unit – crops out in the Western Beskydes, representing the Krosno-menilite Group. Exposures of the Dukla Group in NE Slovakia represent a complicated fold-nappe structure composed of the Cretaceous – Paleogene predominately flysch formation. In the Polish territory this unit is thrust over the Silesian nappe. The Inner-Magura group of nappes predominates in Slovakia. Its links with the elements of the Rheno-Danubian flysch in the Vienna Forest are masked by postnappe Neogene sediments of the Vienna Basin. The Magura group of nappes is made up mainly of Paleogene flysch formations. Cretaceous sediments are scarcely exposed at the surface. This group is composed of five nappes. These are thrust northward as a group over the central group of the flysch belt. The partial nappes in the western section are diagonally truncated against the Pieniny Klippen belt, whereas in some sectors (e.g. Orava) they are backthrust over it or locally folded and scaled together.

The Pieniny Klippen Belt is a tectonically and orthographically significant zone of the Western Carpathians with a very complicated geological structure. It is a narrow (0,5 to 15 km) and long (about 600 km) north banded zone of extreme shortening, after subduction of Piemont-Liguria Ocean (which is called Vahic or Pieninic ocean in Western Carpathians), where only fragments of strata and facies are preserved. The Pieniny Klippen Belt is considered as one of the main tectonic sutures of Carpathians and a boundary between the Outer and Inner Carpathians. Tertiary destruction of a Lamarian fold-nappe system is responsible for most of its recent shape. Particular features of the Klippen belt are as follows:

a) absence of Pre-Mesozoic rocks

b) fluvial variability during the Jurassic and Cretaceous period

c) flysch development of Paleogene

d) characteristic klippen-fashioned tectonic pattern represented by lenses of Jurassic-Early Cretaceous limestone in a form of Pieniny-type klippen which penetrates the Cretaceous and Paleogene marlstones and flysches.

The Pieniny Klippen Belt is divided into numerous tectonic units, but only a few of them occur in the entire belt. The oldest rocks of the Klippen Belt are known only since the Middle Jurassic to upper Cretaceous, which are in normal stratigraphical position with minor hiatus. Enormous shortening has caused rocks of different tectonic units and origins to occur close to each other, or to be pushed up and over another. At present these tectonic units are known as the Czorsztyn unit, the Kysuca unit, the Pruske unit, the Klape unit, the Orava unit and the Manín unit.

The *Inner Western Carpathians* are also called Slovakides or Slovakocarpathian Units. The Unit is a pre-gossau fold nappe complex, which formed between the Kimerian and Mediterranean phases as a result of the structuring of the basins irrespective of their type and post-nappe deformations. They are vertically stratified into nappe complexes overlain by post-nappe Late Cretaceous to Neogene sedimentary and volcanic complexes. The Pre-Gossau nappe complex made up of Alpine tectonic units incorporates the crystalline rock basements and late Paleozoic formations. The following tectonic units have been distinguished to compose the Inner western Carpathians:

a) Tatricum Unit – crops out in the mountains and represents the crystalline rocks and Upper Paleozoic and Mesozoic cover. In some core mountains the Tatricum crystalline basement has some specific features. Generally, most of it is made up of medium to high-grade metamorphic rocks and granitoids. High-pressure relicts are also reported. In some core mountains low-grade assemblages occur. Most contacts between the variously metamorphosed assemblages are tectonic and probably Hercynian. The Late Paleozoic and Mesozoic sediments spanning the time from Permian to Lower Turonian unconformably overlie the crystalline rocks that represent their allochtonous envelopes. An assemblage of clastic rocks represents the Late Paleozoic sedimentation, which continued to form the basis of Lower Triassic. Platform carbonates, limestones and dolomites represent middle Triassic rocks. Clastic sedimentation prevailed during the Upper Triassic period. The sedimentary area became differentiated during the Jurassic period. Basin sedimentation is represented by the Algau Formation and by radiolarian limestones and radiolarites. The Lower Cretaceous times were characterized by the development of pelagic, cherty limestone. Between Albian and Middle Turonian stages the sedimentary cycles ended by the development of a flysch formation. The Tatricum has the lowermost provenance of the tectonic units cropping out within the Inner Carpathians and represents a relative autochthon to all overlying units. It should be noted that the potential basement for the Tatricum Unit (the probable equivalent of the Lower Austroalpine Unit of the Eastern Alps) is the Penninicum.

b) The Veporicum tectonic unit comprises: i) Crystalline basement of the western part of Slovak Ore Mountains, Kralovoholske Tatry Mts. and Cierna Hora Mts. and its Early Paleozoic and Mesozoic envelopment; ii) Series of nappes made up by Mesozoic complexes in a tectonic superposition over the Tatricum in Core Mountain belt.

i. Complicated internal structure of the Veporicum comprises several lithotectonic units (complexes). The results of the latest research show that tectonic superposition of the crystalline rock complex was already fixed during the Hercynian tectonic events, though a great deal of rejuvenisation or destruction took place during the Alpine processes. The Veporicum had two facial areas of Triassic sedimentation. The first (northern) is Veporicum, which includes Carpathian Keuper, and the second (southern) is Veporicum without Carpathian Keuper.

ii. The Veporicum represented by a group of flat-lying nappes (Fatricum) above the Tatricum in all Core Mts. had a uniform development during the Triassic but different development during the Jurassic and partly during the early Cretaceous periods.

c) Hronicum is represented by a serious of nappes conspicuous by their uniform development of Permian-Carboniferous sedimentary-volcanic formations by differentiated development of Triassic and by local preservation of Jurassic-Early Cretaceous formations. The Hronicum crops out mainly in the Core Mountain belt.

d) Gemericum is a Pre-Gossau tectonic unit exposed in the Volovske Hills and in the so called West-gemericum salient which has been extensively thrust over the northerly lying Veporicum. It consists of two subunits: the northern and southern Gemericum that differ by their lithological composition, dynamomethamorphic development of the pre-Carboniferous flysch and their Upper Carboniferous (marine) and Permian-Lower Triassic (continental-lagoonal/sabcha) cover. Most of the southern Gemericum is composed of a Hercynian lowgrade metamorphosed, Early Paleozoic, volcano-sedimentary, flysch sequence that is unconformably overlain by the Permian-Lower Triassic, continental-logoonal formations.

e) Meliaticum originated from an oceanic or paraoceanic domain, which closed during the Late Jurassic. The tectonic unit is represented by a series of dark clay-like shales of Jurassic age intercalated with thin layers of dark and greenish-red radiolarites, sandstones and marlstones, and numerous olistolits and olistostromes of Triassic predominately basinal limestones.

f) Turnaicum is represented by a group of nappes whose lithological filling corresponds to the original position between the Silicikum and Meliaticum sedimentation zones, i.e. it is related to a slope or to a basin environment (Upper Carboniferous-? Jurassic).

g) Silicikum. Tectonic outliers lie above the main mentioned tectonic units. They are composed mainly from Triassic carbonates, which were considered as a part of Gemericum.

Postnappe formation of Inner Carpathians. Development of the Inner-Carpathian area during the Late Cretaceous period is not very well known. The sediments lie in transgressive and unconformable positions on the basement. Their thickness is less than 100 m. A broader distribution and larger thickness (up to 1500) attain Cretaceous sediments is Brezovske Carpathians Mts. which are equivalent of the Gossau Cretaceous of the Eastern Alps. Conglomerate flysch beds including Campanian variegated red marlstones and Orbitoid limestones make up succession. Presumably the dry land conditions prevailed in the Inner Carpathians during the Paleocene period. The Paleocene formations are preserved in tectonically delineated belts along the inner margin of the Klippen belt and in a more extensive area situated within the Brezovske Carpathian Mts. During the Paleocene and Early Eocene times the Inner Carpathian Pre-Gossau structure was subjected to deformations.

Basins and grabens are distinct morphostructural features in the Western Carpathians and combined with the Core Mountains represents a typical pattern of the Western Carpathians scenery. Development of basins and grabens in the western Carpathian falls into the framework of the geodynamic processes which controlled the development of the Carpathian arc at the end of the Paleogene and during the Neogene period. The current scene is the result of development during the Middle Miocene period, during which the pre-arc basins (Vienna Basin), inter-arc basins (intermontane depressions, East Slovakia Basin) and back-arc basins (Danube and Southern Slovakian Basins) formed. The prevailing sediments are siliciclastic evaporates (which may contain coal eventually). Oroganogenic carbonates are rare. Detritic material was splashed from the uplifting mountains or from contemporary volcanic. Sediments in larger basins create accumulations reaching thicknesses of several thousand meters. The sedimentation developed mainly in a marine environment that changed progressively over to marine-brackish, lacustrine or fluvial conditions.

Neogene volcanics cropping out mainly in the central, southern and eastern Slovakia are part of an extensive volcanic region of the Carpathian arc and Pannonian Basin. Their formation is associated with subduction processes and back-arc extension during the Neogene evolution of the Carpathian arc. Al-Ca volcanics of orogenic type (Middle to Late Miocene) are represented by multimodal association ranging from basalts to rhyolites. Volcanics evolved in terrestrial and/or shallow marine environments. Andesites build up stratovulcanoes formed of alternating lava flows, hyaloclastite breccias, pyroclastic breccias, tuffs and epiclastic breccias grade outwards into complexes of epiclastic conglomerates and sandstones. Subvolcanic intrusions of diorites, granodiorites and diorite to granodiorite porphyry are associated with hydrothermal alternation and mineralization. Alcalic volcanic (Pliocenne – Quaternary) in southern and central Slovakia are represented by alkali olivine basalts and nepheline basanites forming dykes, necks, maars, diatremes, cinder cones and lava flows.

3 GEOTHERMAL SOURCES AND UTILIZATOIN IN SLOVAKIA

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.

3.1 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).

3.2 Publications about geothermal potential

A basic publication about geothermal waters was written by Mahel (1952). This publication deals with the relationship between geological structures and their spring distribution. A work by Hynie (1963) deals with a detailed description of geothermal water localities. Franko O. (1964) analyses the problems of geothermal waters research.

In subsequent publications, Franko, O. (1971, 1972) highlights new geothermic information and its importance in the evaluation of deep geological structures and geothermal waters as well as possible methods for their exploitation. The exploitation of hyperthermal waters was assessed from all aspects by Pápež et al. (1974). The formation and classification of mineral waters, which broadly speaking also includes thermal waters, are dealt with in a monograph by Franko O., Gazda, Michalíček (1975). Essential data to assess geothermal aquifers by pumping tests are given by Mucha (1976). A geothermal field in Slovakia was outlined for the first time by Marušiak, Lizoň (1976). Hydrogeologic structures of geothermal waters in Slovakia and geothermal activity of territories were assessed by Franko (1979, 1980).

The results of gradual and systematic regional drilling investigations of geothermal energy in the Komárno block were described by Remšík, Franko O. et. al. (1979) and Remšík et. al. (1992), in Danube Basin central depression by Franko O., et. al. (1984, 1989), in Vienna Basin by Remšík et. al. (1985, 1989), in Topolcany embayment by Fendek et.al. (1985), in Levice block by Remšík (1985), in Poprad Basin by Fendek et. al. (1992) and in Liptov Basin by Remšík et. al.. (1993, 1994). All these publications give a complex hydrogeothermal evaluation of a given area, delineate structures with geothermal waters, determine spatial distribution of geothermal waters, their chemical composition and hydraulic as well as geothermic parameters and assess renewable and non-renewable recoverable amounts of geothermal energy.

Techniques of geothermal energy exploration and utilization are dealt with fairly comprehensively by Roľko et. al.. (1985). A comprehensive review of the complex exploration and utilization techniques of low-temperature geothermal sources in Slovakia and abroad was given by Remšík (1987). The relationship between hydrostatic pressures of geothermal waters at well head and at certain depth on the one hand and water temperature, TDS and gases on the other hand were described by Franko O., Fendek (1993). Newer views on geothermal field were represented by Kral (1986). The thermal potential of Slovakia‘s geothermal sources and their prospects for the future are discussed by Franko O (1977, 1987, 1987a).

Areas geologically evaluated from a point of view of further reconnaissance and regional investigations of geothermal energy include the Kosice Basin (Remšík, Fendek 1992; Remšík 1993). Remšík (1993) noted that electricity can be generated in the Kosice basin using geothermal waters whose aquifer temperatures attain 115-165 °C. Geothermal issues in eastern Slovakia are dealt with by Remšík, Fendek (1994). The paleohydrogeology of mineral waters in a broad sense in the Inner western Carpathians was first outlined by Franko, Bodiš (1989). The characteristics of Slovakia's geothermal areas explored by wells were presented by Franko et. al.. (1992). Procedures applied to compile a geothermal map of the Czech-Slovak Socialistic Republic at scale 1: 500 000 (Franko, Hazdrova et. al. 1989) were described by Franko O. (1991). Renewable and non-renewable amounts of geothermal energy in all determined areas were given in Explanations to geothermal map of Czech-Slovak Federal Republic at scale 1: 500 000 (Fendek, Franko, O., Remšík 1990 in Franko, O. et.al. 1990a). Zembjak (1989) noted possible exploitation of dry-rock heat and Vranovská (1993) determined principles to select localizations suitable for such exploitation.

3.3 Geothermal field

The geothermic field is distinctly variable on the territory of the West Carpathians. Its regional character and spatial distribution of geothermal activity are mainly determined by Franko et al. (1995):

- different depth structure of neotectonic blocks of the West Carpathians, mainly manifested by different thickness of Earth's crust and non-uniform contribution of the Earth's mantle
- the course of the main disconformities and fault lines deep-seated in the earth crust
- spatial distribution of Neogene volcanism
- distribution of radioactive resources in the upper parts of the Earth's crust
- hydrogeological conditions

3.4 Temperature

The temperature field at depths to 3000 m is mainly formed in dependence on hydrogeological conditions. Its local variability is also conditioned by the geomorphology of the terrain, local manifestations of natural outflows of geothermal waters and Neogene volcanism and representation of rocks with various heat conductances. The temperature field at depths below 3000 m is, however, a reflection of geothermal activity of deeper morphological structures of the Earth's crust. From a geothermal point of view the West Carpathians may be dividing into two parts. The relatively low temperatures and values of surface heat flow density are characteristic of the central and northern parts of the Inner Carpathians and of the western part of the Outer Flysch Belt. High temperatures and a high heat flow are typical of Neogene basins and volcanic mountain ranges of the Inner West Carpathians.

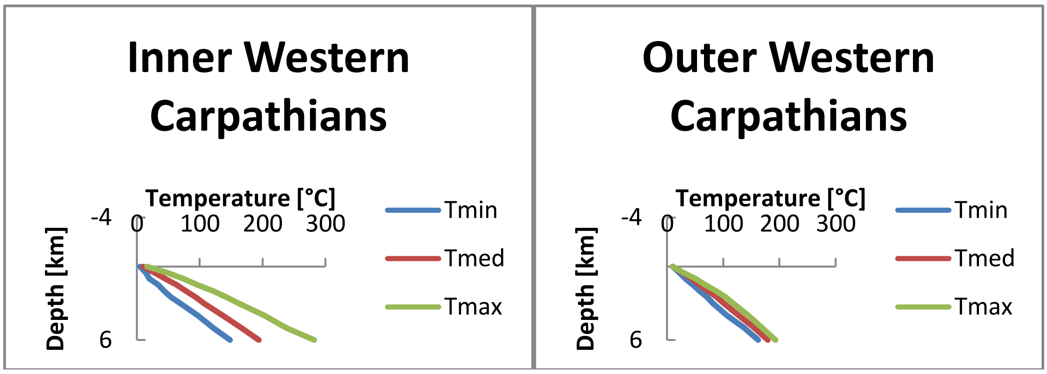


Fig. 3-1 Geothermograms – Inner and Outer Western Carpathians (Kral, 1996)

The boundary between these geothermally different regions is formed by the zone of intense horizontal temperature gradients, mainly at the contact of the volcanic-sedimentary complex with pre-Neogene units of the West Carpathians. A transitional geothermal activity is in the Inner Carpathian Paleogene and in the eastern part of the Outer Flysch Belt. Vertical distribution of temperatures indicates distinct differences of temperature between these regions and their increase with depth. Maximum temperature differences at a depth of 1000 m are around 50 °C, at a depth of 6000 m, however, the temperature difference reaches 130 to 140 °C. According to regional measurements the geothermal activity of the West Carpathians sinks in the direction from the inner structures towards the outer margin of the Carpathian arc. The temperature field at depths up to 3000 m is controlled by hydrogeological and structural conditions. The biggest low-temperature anomalies were noted in hydrogeological structures whose temperature field is affected by percolating cold surface waters. This is largely the case at the margins of inter-montane basins where carbonatic rocks are exposed at foothills of adjacent mountains. A hydrogeologic setting is a principal phenomenon controlling the formation of temperature fields in intra-montane basins.

The Outer West Carpathians mostly have a monotonous temperature field. The only major high-temperature anomaly of regional importance was noted in the eastern part of the Flysch Belt (confirmed by well ZB-1).

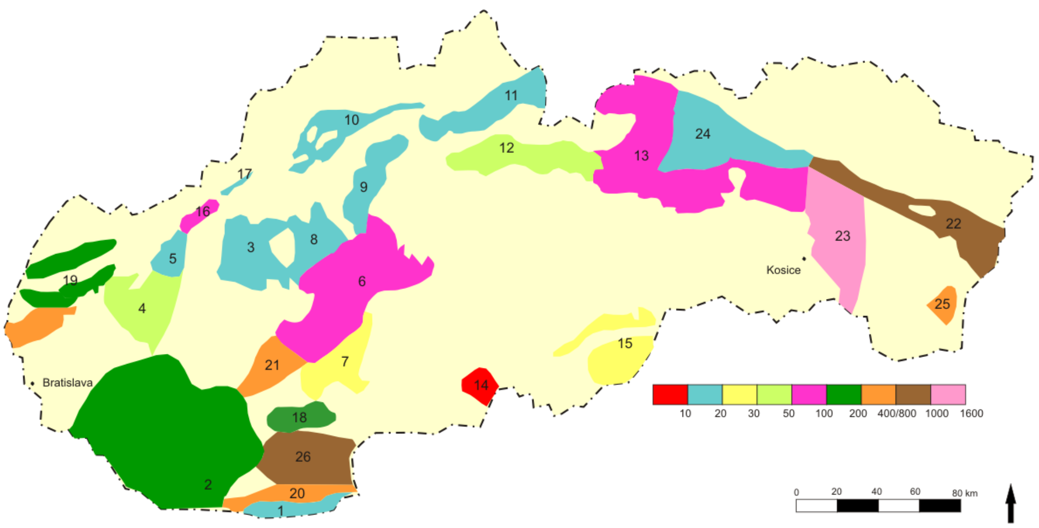
Temperature conditions in the Inner West Carpathians vary considerably from one structural-tectonic unit to another. Low temperatures are characteristic of Core Mountains in the central and northern Inner West Carpathians and Slovakian Ore Mts. Increased anomaly in this area is caused by extremely radioactive granites whose heat generation is 4,5 μW/m3 , i.e. twice the average heat generation of west Carpathians granites. The Neogene volcanic mountains and southern part of the Inner West Carpathians are characterized by increased but fairly variable geothermic activity and complex spatial distribution of the temperature field. The West Carpathian intra-montane basins are characterized by considerable dispersion of their temperature field. Great differences in thermal activity were noted not only between individual basins but also within a single basin between wells situated close to each other.

The highest geothermal activity occurs in Neogene volcanic mountains and Neogene basins. The Central Slovakian Neogene volcanic is characterized by increased geothermal activity and a very variable temperature field chiefly at shallow depths, which results from their morphology.

In the Vienna Basin, temperature-field character changes with depth. Up to 2000-3000 m the field is dominated by two major high-temperature anomalies in the Lab and Laksarska Nova Ves elevated zones. Higher temperatures in the near-surface zone were caused by ground waters ascending along the fault zones. At depths below 3000-4000 m the temperature field is fairly stable, the highest temperature being in the centre of the basin.

The temperature field in the Danube Basin has similar characteristics. At depths up to 3000 m it is dominated by two major regional low-temperature anomalies situated in the centre of the basin and in the Komarno high block. The temperature field in this area was hydrogeologically affected by cold waters. In contrast, substantially increased temperatures are typical in the eastern section of the basin. Similarly, at 3000 m the temperature-field character changes, the temperature pattern being controlled by the basin’s deep structure rather than by the hydrogeologic conditions present in the upper part. The highest temperatures were noted in the centre of the basin when Neogene sediments reach their maximum thicknesses.

From a geothermal point of view the most active unit in the Western Carpathians is the Eastern Slovakian Basin where temperature conditions are analogous to those in the hyperthermal Pannonian Basin. The highest temperatures occur in the central and southeastern parts. Increased temperatures correspond to the occurrences of the buried igneous bodies. Lower temperatures noted in the southwestern part of the basin in the Zemplin island area are associated with an elevation of the pre-Neogene substratum. An extensive lower-temperature zone in the Besa-Cicarovce hydrogeothermal structure at depths between 1500 and 4000 m is a noteworthy phenomenon. It reflects hydrogeological settings in this structure. At 4000 m it gradually comes to an end and does not affect the temperature field at greater depths. Decreased temperatures were noted throughout the northern and northeastern section of the basin and also at its contact with the Klippen Belt. The Eastern Slovakian Neogene volcanic and Kosice Basin are transient areas between the high temperature Eastern Slovakian Basin and much colder Outer Flysch, Inner Carpathian Paleogene and Slovakian Ore Mts. Temperatures drop abruptly towards the Outer Flysch Belt and horizontal temperature gradients. The highest temperatures can be found in the Western Carpathians region, and occur at its contact with the Eastern Slovakian Basin as well as at the contact between the Kosice Basin and Slovakian Ore Mts. This is not only related with differences in the geological structure but also different geothermal settings in adjacent units. The high geothermal activity in the Eastern Slovakian Neogene Basin is directly related to the geodynamic history and deep structure including an elevation in the Mohorovicic discontinuity and an intrusion of mantle material into the Earth's crust.



1- Komarno high block; 2- central depression; 3- Banovce depression; 4- Trnava bay; 5- Piestany bay;
6- central Slovakian neovolcanics (NW part)7- central Slovakian neovolcanics (SE part); 8- Horna Nitra depression;
9- Turiec depression; 10- Zilina depression; 11 - Skorusina depression; 12- Liptov depression; 13- Levoca Basin;
14- Horne Strhare; 15- Rimava depression; 16- Trencin depression; 17- Ilava depression; 18- Levice block;
19-Vienna Basin; 20- Komarno marginal basin, 21- Komjatice depression; 22- Humenne ridge; 23- Kosice depression,
24- Levoca depresion;25-structure Besa-Cicarovce; 26- Dubnica depression

Fig. 3-2 Potential geothermal areas and structures in the territory of the Slovak Republic

3.5 Heat flow

Extremely high values around 115 mW/m^2 are characteristic of the Eastern Slovakia Neogene Basin, along with the central and southern expanses of the Central Slovakian Neogene volcanic. The heat flow density in the West Carpathians is distinctly variable and, from a regional point of view, similar to the temperature, we record its decrease from the Inner Carpathians towards the outer arc. According to the average value of heat flow density (q = about 82 mW/m2) and the geothermal gradient (Gg = about 39°C/km) the territory of Slovakia has quite a raised geothermal activity (Franko et al. 1995). Maximum differences in mean surface heat flow density in individual Western Carpathian structural-tectonic units reach as much as 55 mW/m2. The differences in geothermal activity are caused by the different structure and dynamics of the basic neotectonic blocks. High heat flows are associated with weakened areas of the Earth's crust whereas low heat flows typically occur in thick crust.

3.6 Aquifers

Thermal springs as manifestation of geothermal energy can occur outside of active volcanic zones (seismic zones). These waters also occur in young orogenic belts (Alps, Carpathians, etc.) (Franko, 1990). The main geothermal aquifers are Triassic dolomites and limestones of Inner Carpathian nappes and envelope units as well as Eastern Alpine nappes (Vienna Basin). Thermal springs are associated with these carbonates. They are widespread in the intermontane depression, northern embayments of the Danube Basin, Central Hungarian Mountains and in the northern part of the Eastern Slovakian Basin below Tertiary sediments. Their thickness varies from one nappe or envelope unit to another. The aquifers have fissure and fissure-karst permeability. The relationship between geothermal waters and aquifers is best indicated by natural geothermal springs. The springs result from the fold-nappe structure of Mesozoic formations with extensive folds plunging from mountain slopes to substantial depths and from longitudinal and transverse faulting. Geothermal waters are also bound to aquifers without natural springs, as is the case in the hydrogeothermal structure of the Danube Basin central depression.

Prospecting for geothermal waters is focused mainly on aquifers without natural springs. Further, significant, although less widely distributed, aquifers are Miocene and Pliocene sands (Danube and South Slovakian basins). The aquifers have intergranular permeability. Andesites and related pyroclastic in the Eastern Slovakian Basin are less important geothermal aquifers. These Miocene aquifers contain geothermal waters because they are at substantial depth and are faulted (Rudinec, 1989).

In compliance with worldwide trends (e.g. Sine, 1983), three types of geothermal waters have been distinguished in Slovakia (Franko, 1985, Franko et.al. 1986, Remsik, 1987a):

1. high-temperature waters whose surface temperature exceeds 150 °C (aquifer temperature exceeds 180 °C)
2. medium-temperature waters whose surface temperature is 100-150 °C (aquifer temperature exceeds 130- 180 °C)
3. low temperature waters whose surface temperature is less than 100 °C

   (aquifer temperature is below 130 °C)

3.7 Hydrogeochemistry

Geothermal waters of the Western Carpathians are, in relation to total mineralization, divided into four types: (Franko et al. 1975):

1. low mineralized (up to 5 g/l)
2. medium mineralized (5-10 g/l)
3. high mineralized (10-35 g/l)
4. very high mineralized (more than 35 g/l)

From a geochemical point of view the chemical composition of geothermal waters in Slovakia, three basic genetic types have been distinguished (Bodis – Franko, 1986):

1. Geothermal waters with marinogene mineralization, which include:
   - Connate waters whose mineralization corresponds to the paleosalinity of their aquifers and which were metamorphosed only in the water-rock system and/or by CO2 addition.
   - Connate waters infiltration-, biogenic- or petrogenic- degraded to various degrees and at different periods.
   - Highly mineralized geothermal waters formed through halite dissolution by sea water or through local thickening of sea water
2. Geothermal waters with petrogene mineralization whose T.D.S. does not exceed 5 g/l exemplified by meteoric waters of fairly deep or deep circulation
3. Geothermal waters of mixed origin and complex chemistry

Connate waters are characteristic of a whole investigated section in Pannonian in the Danube Basin central depression (Franko et.al., 1989), subjacent Triassic carbonates in the Laksarska Nova Ves elevation (Remsik et. al., 1989), Levice block, southern part of Kosice Basin, andesites and related pyroclastics in the Besa-Cicarovce structure and deeper Miocene sediments of Komarno block. The chemical composition of connate waters is typically Na-Cl type with a minimum presence of sodium–hydrogencarbonate component. The waters were metamorphosed only in the water-rock system. The metamorphism of connate waters results in lower concentrations of Mg2+ ions and higher concentrations of Ca2+ ions in comparison with their original chemistry. These changes are probably the result of cation exchange of Mg2+, 2Na+ ions in solution by Ca2+ from rock or by the reaction:

$$MgCl_2 + 2\,CaCO_3 \rightarrow CaMg\,(CO_3)_2 + CaCl_2$$

The infiltration degraded water occurs in the Mesozoic basement of the middle part of Vienna Basin. High content of sulphates in this water comes from the dissolution of gypsum (anhydrite) and also very high hydrogen sulphide values occur (200-400 mg/l). Similar geothermal waters are genetically associated with Triassic carbonates of Kosice Basin and Levoca Basin.

High mineralized geothermal waters of marked Na-Cl type, with Cl mineralization 50 g/l, occur in the Danube, Vienna and Trebisov Basins. It is assumed that in the Danube and

Vienna Basins the so-called connate saline occurs. They originated by the thickening of basin waters under a critical point of NaCl solubility. In East Slovakia Basin are concerned waters, which originated from the sea water dissolution of halite.

Petrogene mineralization is characteristic for the central and eastern parts of the Komarno block. The waters are Ca-(Mg)-HCO3 chemical type with temperatures of 20-30 °C and mineralization around 0, 7 g/l and associated with Triassic carbonates of Hungarian Upland.

Carbonate-sulphate geothermal waters occur in the Mesozoic basement of Liptov Basin and in Mesozoic carbonates of Central Slovakian Neovolcanics.

3.8 Utilization of Geothermal energy

Based on geological exploration, in 1993 it was determined that 26 perspective areas held Slovakia's total potential of renewable sources, which was estimated at 5200 MW. Geothermal waters with temperature 75-95 °C can be used for heating buildings with performance around 200 MWt (Böszörményi, 2001). In the past the thermal springs of Slovakia were used in agriculture. Now geothermal waters are utilized in swimming pools and aquaparks. In Galanta town thermal water is used for the heating of 1236 flats, a retirement home and a hospital. Energy potential of 8 MWt is delivered from two geothermal wells. In Podhajska town geothermal energy is used for greenhouse heating with thermal performance of 12 MWt and for a geothermal swimming pool. The most prospective area in Slovakia is Kosice Basin where geothermal waters have temperatures in the range of 120–160 °C at depths above 3000m. At present the biggest geothermal heating project in Central Europe with an installed heat output of 110 MW will be situated in Eastern Slovakia – Kosice basin. The area was investigated by three investigative oil drills – Durkov 1, 2, 3 drilled 1968 – 1972. Geothermal water inflows were confirmed by DST (drillsteam testing) (Benovsky et.al. 2000).

4 GEOPHYSICAL EXPLORATION TECHNIQUES

Geothermal water is accumulated in geothermal water reservoirs. Geothermal water reservoirs are hydrogeothermal units created by hydrogeothermal aquifers or systems of hydrogeothermal aquifers where the substantial volume of geothermal water is accumulated and preserved after interruption of the water supply. The most important geometric attributes of geothermal reservoirs are shape, area, spatial distribution and hydrothermal aquifer thickness. From the viewpoint of utilization of geothermal water, the depth of the top and base of aquifers under the subsurface, types, origin and age of the rocks, chemical composition of the water, gas content, hydraulic and thermophysical properties of geothermal water aquifers are important. The basic tool to obtain information about rock composition and water in hydrogeothermal structure or in geothermal water reservoirs is the geothermal well. Geothermal wells are instruments which transport geothermal water from the reservoir to the surface (exploitative well), and in some cases back to the reservoir (reinjection well).

Geophysical methods like gravimetric, seismic and geoelectric represent the basic methods used for geothermal water reservoir exploitation. Using these methods, based on indirect measurements of various physical parameters in the depth (e.g. rock environment density, seismic waves propagation velocity, electric conductivity, electric resistance and magnetic susceptibility), it is possible to delimitate geothermal water reservoirs. Supplementary information can be obtained by the results of magnetic and radiometric methods. (Fendek et. al., 2005)

Discovery and definition of the hydrogeothermal structures is a task similar to those which are routinely solved by petroleum geologists and geophysicists at the exploration of the promising accumulation structures of hydrocarbons. The main difference is only in the medium that is in the scope of exploration. The main interest is to find the accumulation structure and determine its type (anticline, thinning out of the beds, reservoir determinate by lithofacial changes, etc.), scale, presence of suitable aquifer within the structure and petrophysical properties (porosity, permeability, etc.) of potential reservoir.

It is coessential to predict temperature, pressure and hydrodynamic conditions of potential reservoir in a specific depth and also if it is possible to expect the thermal water to have the needed derived value and sufficient reserves for long-term exploitation. Most of these claims can be solved by reflection seismic (by its modern software interpretation tools) or by creating a real interpretation base from seismic data for the following wider considerations and evaluations. However, the key problem is to discover promising accumulation structures containing reservoirs.

Reflection seismic is not a suitable exploratory technique in volcanic areas because the interpretation of reflections is uncertain (Hersir, Bjornsson 1991). The geological structure of the Western Carpathians is complicated and diversified with a relatively wide scale of the hydrogeothermal types of structures.

The following types of potential geothermal reservoirs are expected in Slovakia:

- less compacted different types of sandstones with sufficient porosity and high – porous reservoirs of biohermic type within the Tertiary basin filling
- high-porous dolomites and limestones in the pre-Tertiary formations

According to the Atlas of deep reflection-seismic profiles of the Western Carpathian and their interpretation compiled by Vozar et.al. (1999) Slovakia is among the countries having the most dense network of deep reflection seismic sections. More than 1 250 km of profiles were shot over a 49 030 km2 area of the Slovak Republic starting in 1971.

Currently, reflection seismic is the most important of geophysical methods for defining hydrothermal structures and prospective reservoirs. Reflection seismic is, in comparison to other geophysical methods, more expensive; but on the other hand it belongs to so called "high resolution geophysical methods" — the geophysical methods with high resolution ability and efficiency that allow the attainment of high quality data for solving problems (Hrusecky, Fejdi 2005). The reflection seismic method has much higher resolving power than other exploratory techniques. It delivers a detailed picture of a layer, depth and slope of faults and displacements as well as folding structures in sediments (Hersir, Bjornsson 1991).

For modeling, output data from geophysical measurements, namely reflection seismic represented by seismic sections was available. After the analysis of seismic sections from the studied area it was possible to continue the modeling process in Schlumberger's Petrel software. Petrel is the one of the different 3D geological modeling software programs with which it is possible to interpret subsurface structures based on reflection seismic.

Petrel is a Windows PC software application intended to aggregate reservoir data from multiple sources. It allows the user to interpret seismic data, build reservoir models suitable for simulation, submit and visualize simulation results, and design development strategies to maximize reservoir exploitation. Geological models are created for many different purposes, but common to all of them is a request to build a representation of the subsurface. Depending on the purposes, different aspects of the model may be important. In the case of a regional exploration model, the shape of the structures may be most important. Geological models may be used to achieve accurate volume calculations or to test the effect of different depositional regimes against observed data. Petrel uses a 3D grid to supply the building blocks with representations of reality, which the user can recreate.

5 METHODOLOGY OF WORK

Geothermal water aquifers are Triassic karscificated carbonates, mainly dolomites with dolomite breccias and basal clastic rocks of Karpathian. The goal of this work is to create a 3D model of the central part of Kosice Basin that shows the spatial distribution of the aquifer and overlying Neogene sequences like insulator rocks, to show how the thickness is changing and to indicate tectonic structure.

This report presents a final description and valuation of background information and obtained results. The work required a few individual steps in order to do so.

The first step was to obtain the required information about studied area. That information included geological and tectonic background, a valuation of Kosice Basin from geothermal point of view, an overview of works (reports) concerning geothermal possibilities and utilization in the studied area and geophysical works.

The next step was to extract coordinates in the space of seismic profiles and then coordinates of individual stratigraphic sequences and wells situated in the profiles from geophysical 2D seismic sections 700/92, 702/92, 703/92, 704/92, 705/92 and 706/92 interpreted by Janocko (1999), Kamenska (2008). Some of mentioned seismic profiles have very low quality. These seismic sections are the result of a geophysical survey conducted in 1992. Seismic sections were imported as bitmaps into Petrel and the individual stratigraphic sequences were mapped. After acquiring the information from profiles the modeling process was started.

The first step in order to obtain the 3D model was to construct surfaces. Surfaces represent individual stratigraphic boundaries. There are five surfaces with their own marks and characteristics. From the bottom of modeled area:

1. Surface of Mesozoic base
2. Surface of Mesozoic top
3. Surface of Karparhian – Lower and Middle Badenian boundary
4. Surface of Lower and Middle Badeinan – Upper Badenian boundary
5. Surface of Upper Badenian - Sarmatian boundary

After surface construction, well interpretation (stratigraphy with relevant lithogy) followed, along with its implementation to the surfaces. Exact coordinates of position and depth were extracted from the seismic sections and the stratigraphy and lithology was taken from reports (Takac, 2007, Vranovska 1999). The role of the borehole data in the model is to fill up the space between the surfaces. There are four wells – Kecerovke Peklany-1, Durkov-1 and 2 and Rozhanovce-1 – in the model. According to stratigraphic profiles of these wells it was possible to spread individual stratigraphic sequences over the whole space of the model. The shape of final model was constrained by marginal points of the seismic profiles. Time – depth conversion was done based on a check – shot from well Durkov-1, which was used for conversion of all wells in studied area.

An important part of modeling is the interpretation of faults. In this point I have to emphasize that the available data was not 3D seismic but 2D, and because of that the ability to accurately model the faults was limited. It was a complicated task to make a 3D tectonic model because of the approximately 5–7 km distance between the 2D seismic profiles. In the 'gaps' individual faults could change their length, depth and direction or completely disappear and a new fault could start. The final 3D tectonic model presents a simplified tectonic structure in the modeled area but its size is smaller than the model where tectonics are not included due to the lack of required quality seismic data (Fig. 7-20B).

After the connection of surfaces and well profiles in the 3D grid it was possible to obtain a final 3D model with individual stratigraphic sequences distinguishable in color. The 3D model prepared in this way was used for interpretation.

In the interpretation section it is shown how the whole model and the model of Mesozoic reservoir rocks look and how the thickness, spatial distribution and tectonic rupture of Neogene sediments and carbonate rocks changes in space. The model of reservoir rocks is cut into small slices to demonstrate changes of thickness and spatial distribution in the model's interior.

After the interpretation overview, a summarization and evaluation of results obtained from modeling follows.

6 GEOLOGICAL AND GEOTHERMAL CONDITIONS OF KOSICE BASIN

The Eastern part of Slovakia is the most prospective geothermal area – the Kosice Basin in particular. No geothermal research was realized in this area until 1998, but knowledge about the presence of geothermal water and convenient aquifers was found based on petroleum research. The main tools helping to obtain data from the subsurface were available borehole data and seismic measurements. The first geothermal research in Durkov area as a part of Kosice basin was realized. Detailed research confirmed the presence of geothermal water and information about stratigraphy and lithology, sediment physical data, geothermic data, hydrodynamic and thermodynamic parameters, parameters of geothermal reservoir, physiochemical properties of water and gases. These data were obtained from geothermal wells GTD-1, GTD-2, GTD-3.

6.1 Present exploration in Kosice Basin

Conceptions about geological structure, tectonics, strafigraphy, paleography and raw minerals in the interest area were introduced in a geological map of 1: 200 000 scale (Matějka et al., 1964, Čechovič et al., 1964). Since the 1964 extensive shallow and medium depth structural investigation with the aim to verify hydrocarbon structures was realized in Kosice Basin. The investigation produced a number of new results about the geological character of pre–Neogene underlier (wells Durkov 1, 2, 3, Rozhanovce 1, Kecerovske Peklany 1, Presov 1), lithology, stratigraphy, petrography, tectonics and geothermal water chemism. These results were evaluated by Cvercko (1973). In Kosice Basin geophysical research was realized (gravimetric, geothermic and seismic). Actual results of measurements and interpretation were associated into the structural–tectonic map including the specification of a deep subsurface structure by Šefara et al., 1987. A prominent addition to the specification of subsurface structure was seismic measurements, done in 1992, in which seven seismic sections of slalom line type were realized. 3D seismic investigation was realized in 1999. The total investigated area had 30 km^2, and at the same time three 2D profiles with total length 21 km were done. The interpretation of the seismic measurements significantly contributed to the knowledge of spatial distribution of the geothermal water Triassic aquifers. According to the seismic measurements it is possible to define depth of deposition, thickness and tectonic structure. Skvarka et al. (1976), Hanzel et al. (1975), Jetel (1996) dealt with the hydrogeological evaluation of Kosice Basin. A collective evaluation of the actual results of borehole data and seismic investigations into the possibility to obtain geothermal energy were processed by Remsik (1994), Franko J. (1996), Vranovska (1999).

6.2 Location and Geology of Kosice Basin

Kosice Basin is situated in eastern Slovakia between the Ore Mts. on the western side and the Slanske vrchy Mts. on the eastern side.

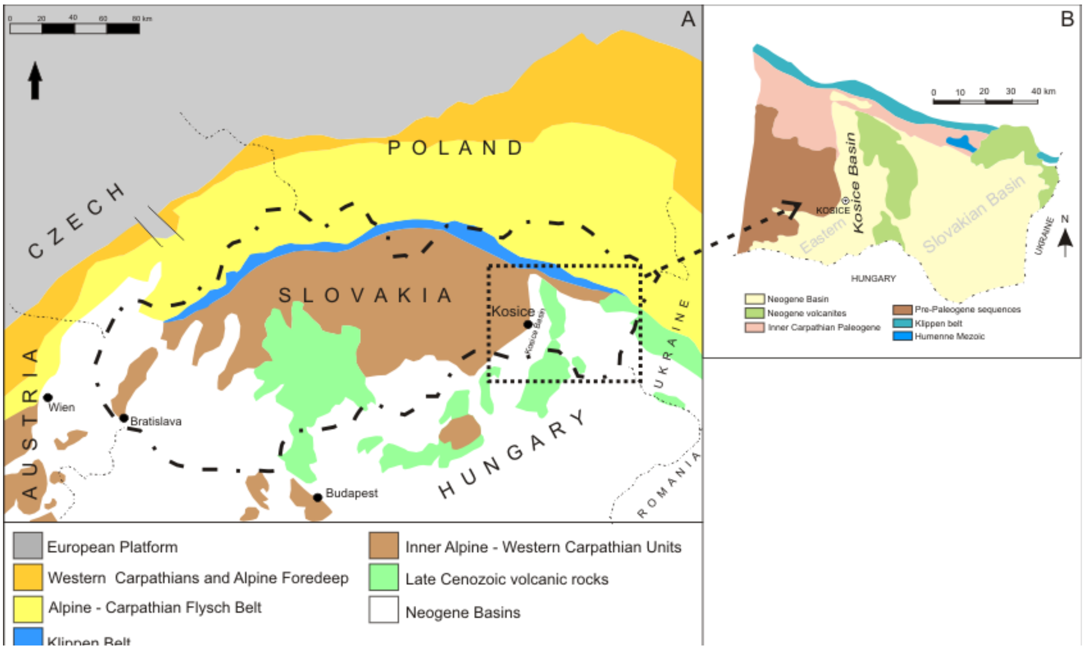


Fig. 6-1 Position of Kosice Basin within the Western Carpathians (Janku, Magyar, 2002)

The Kosice Basin, from a geological viewpoint, is part of the East Slovakia Basin and represents a north-eastern promontory of the Pannonian Basin. The Kosice Basin has a longitudinal north-south trending shape, with the southern part curved south-westwards and transiting to Hungary. The total area of the basin is approximately 900 km^2. The geological structure of the Kosice Basin is relatively complex and formed during more geological stages. Its present shape was formed during the accumulation of Neogene sedimentary formations. In the northern part of the basin the Neogene sediments are underlain by Paleogene sediments. Various types of Palaeozoic – Mesozoic rocks represent underlying pre-Tertiary complexes in the whole basin. The pre-Tertiary underlier has a brachyanticline structure and rugged topography with depression and elevation structures due to long denudation and younger tectonics. The underlier is made up of different geological Inner Western Carpathians units. A low metamorphosed Palaeozoic complex of the Gemeric Unit has the largest areal extension within the underlier of Tertiary sediments in the southern and south-western part of the Kosice Basin. An oil exploratory well penetrated through Devonian green amphibolites which are overlain by Carboniferous rocks. Above these rocks are rhythmically alternating dark phyllitic shales with light gray quartzy phyllitic shales. A few meters thick layer of coarse grained quartzites to fine grained metaconglomerates appears as an interbed in the dark monotonous quartzy phyllitic shales layer. The last sedimentary complex is represented by sandy-shaly sediments of Badenian and Sarmatian age, except a few last tens of meters of Quaternary gravels.

A Paleozoic lithological complex of the Gemeric Unit indicates low water saturation in the rocks and the low temperature results from a shallow burial depth. From a geothermal point of view the southern part of the Kosice Basin is more or less uninteresting because the Mesozoic carbonate complex of Gemericum, which could be a theoretical geothermal waters aquifer, was not determined until now.

A Palaeozoic-Mesozoic complex of the Veporic Unit represents an underlying layer of Tertiary sediments in the central part of the basin. Rocks ranging from granites and granodiorites to high metamorphosed old Paleozoic rocks are overlain by isolated remnants of Young Paleozoic – Permian sequences of violet shales and sandstones to conglomerates, probably in autochthonous position.

A Paleozoic-Mesozoic complex is overlain by a Mesozoic sedimentary sequence of Triassic age in parautochtonous position. The Triassic sequence starts with Werfenian shales and quartz sandstones, continued by dolomite limestones to dolomites of Anisian - Ladinian age and at some places preserved remnants of slaty limey claystones with layers of dolomites, evaporitic siltstones and anhydrites of Carpathian Keuper. The Mesozoic sequence was penetrated by oil exploratory Roz-1, KP-1, Dur-1, 2, 3 wells and by geothermal GTD-1, 2, 3 wells. This sequence is overlain by shaly-sandy and volcanoclastic sediments of Karpatian, Badenian and Sarmatian age. Fractured Anisian - Ladinian dolomites, reaching into the vicinity of the Slanske vrchy Mts. thickness above 1000 m, are the most important from a geothermal energy viewpoint. It is assumed that dolomites continue beneath the Slanske vrchy Mts. These dolomites are highly saturated by water and their high burial depth results in a relatively high temperature of geothermal waters.

Tab. 6-1Summary data from wells (Vranovská, 1999)

Well	***Depth (m)***	***Neogen (m)***	***Mesozoic (m)***	***Depth of Mz (m)***	***Paleozoic (m)***
Kecerovské Pekľany 1	3098	0 - 2160	2160 - 2820	660	2820 - 3098
Rozhanovce 1	1882	0 - 1525	1525 - 1710	185	1710 - 1882
Ďurkov 1	3200	16 - 2140	2140 - 3200	> 1060	-
Ďurkov 2	2230	0 - 2190	2190 - 2230	> 40	-
Ďurkov 3	2612	10 - 2475	2475 - 2612	> 137	-
GTD-1	3210	0 - 2155	2155 - 3210	> 1055	-
GTD-2	3151	0 - 2467	2467 - 3151	> 684	-
GTD-3	2625	0 - 2226	2226 - 2264	> 38	-

In the yield of Mesozoic complex loamy-sandy and volcaniclastics sediments Karpathian, Badenian and Saramtian age occurs. In keeping with the progressive north-southward trending inversion of relief during Tertiary in the northern part of the basin, Paleogene and Lower Miocene sediments are found in the central part – namely Lower and Middle Miocene sediments – while in the southem part of the basin only Middle and Upper Miocene sediments occur. Karpathian sediments (conglomerates, claystones, sandstones and thin beds of halite) are the oldest Neogene sediments, and they overlap the Mesozoic basement. Lower and Middle Badenian sediments – pelites, volcaniclastics, clays, sandy claystones – indicate rapid subsidence of the deposition area. During the Upper Badenian, basin depressions which caused changes in the topography of the coast, with the addition of clactic material by continental rivers (clays, claystones, siltstones, sandstones, conglomerates, rhyolitic volanoclastics), were found. The deposition area of Sarmatian is basically identical, with a deposition area during the Lower Badenian, but the local subsidence was in progress. The eastern margin of the basin is formed by subsequent Neogene volcanic mountain ranges of the Slanske vrchy Mts. The initial stage of the basin's evolution during the Lower Miocene was accompanied by predominantly explosive rhyolite and dacite volcanism. Major volcanic activity is represented mainly by andesite volcanism. It dominated in the advanced and final phases of the basin's development, i.e. during the Upper Badenian to Lower Pannonian. Products of this stage form in Slanske vrchy Mts., a range of morphologically separated smaller and larger andesite stratovolcanoes.

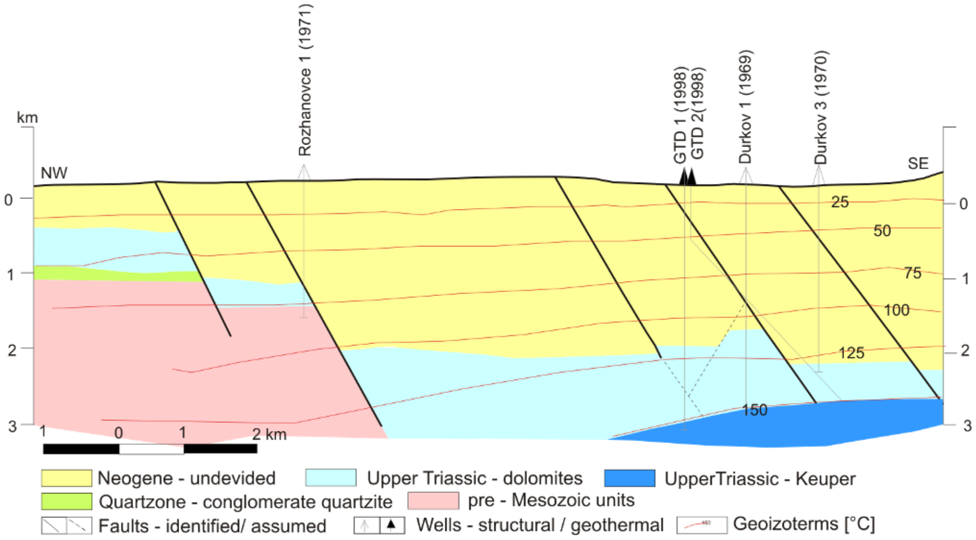


Fig. 6-2 Schematic hydrogeothermal NW – SE section through the Kosice Basin (Vranovska et. al 1999).

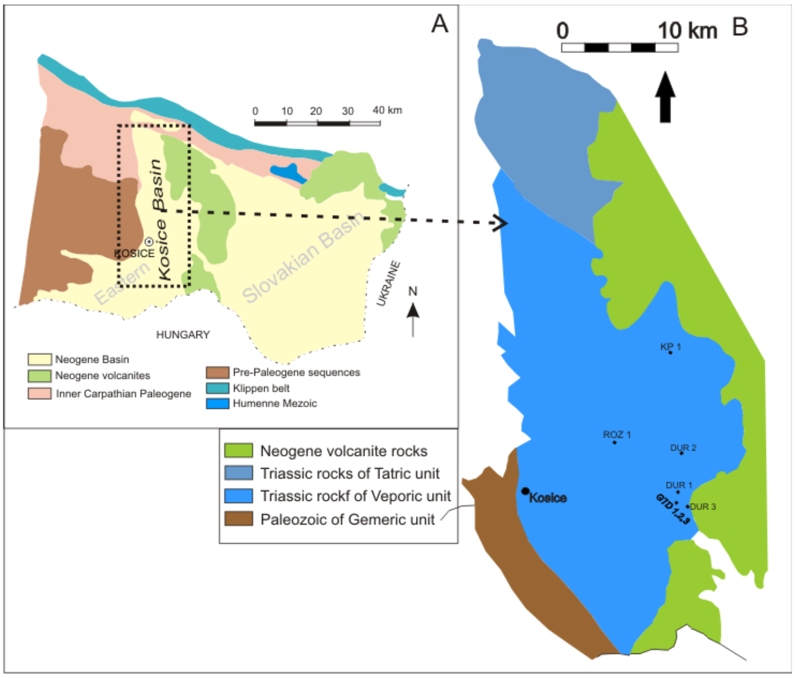


Fig. 6-3 Base Tertiary sub – crop map of Kosice Basin (Pereszlenyi et.al.1999)

6.3 Tectonics

Kosice Basin, as a part of the Eastern Slovakia Basin, has undergone complicated tectonic progress. Pre-Tertiary rocks of the Kosice Basin are folded and imbricated – frequently in a nappe position. Upper Cretaceous and Paleogene periods are the major stages of the West Carpathian folding and pre–Tertiary sediments that underwent an intensive denudation. Denudation continued in the central and southern part of the basin till to the Lower Miocene. Consequently there are no Jurassic and Lower Cretaceous sediments preserved, even though they would be undoubtedly developed here. On the other hand intensive erosion caused fracturing and weathering of 100 to 200 m thick complexes of Triassic carbonates, which constitutes an important reservoir of geothermal waters.

Lesser known Paleogene tectonics have a normal fault character, with strike-slip attributes.

Neogene tectonics are characterized by three major fault systems. The oldest fault system of NW - SE trending opened the basin during the Lower Miocene and its activity ends in the Badenian. During the Badenian discontinuous innovation happened where a marked transversal fault system of NNE – SSW direction occurs. These faults caused the characteristic block structure of the territory. By Vass in Banacky et al. (1987) the fault's origin is related to the Badenian phase of 'pull – apart' opening of the Eastern Slovakia Basin. The main tectonic activity of these faults culminated in the Upper to Lower Sarmatian. Transversal faults that breached older tectonic units are a limiting factor for sediment distribution in Kosice Basin. The youngest is a group of faults of WNW - ESE trending, which were functioning during the Upper Badenian and partly during the Upper Miocene (Eggenburgian). Their activity is connected with paleogeographical changes in Eastern Slovakia Basin, with the uplift of the pre–Neogene unit on the western edge of the basin and the subsidence of the Neogene molase basin along these faults. Tectonic activity of WNW – ESE faults persisted until the Upper Sarmatian to Pliocene. Synsedimentary and epigenetic normal faults, in some cases with strike-slip attributes, predominated during the Neogene.

Faults which originated in the Neogene are also active in the Quaternary with north to south direction. These faults delimit the Kosice Basin, Cierna Hora Mts. and Slanske vrchy Mts. and create typical horst structures. Another group of faults active from Lower Pleistocene have a north to east direction. Together with the northern-southern group of faults, they create horst – graben structures that are conditioned for sedimentary space origin.

Rotation of extensional and compression components of the paleostress field during the Neogene had a distinct effect on the development of sedimentary environments in the basin and depocenter migration from north to south. Sedimentary development and Tertiary tectonics had an effect on the burial depth of Triassic carbonate reservoir rocks. Burial depth and proximity of neovolcanics – Slanske vrchy Mts. are closely associated with geothermal water temperature (Pereszlenyi et.al. 1999).

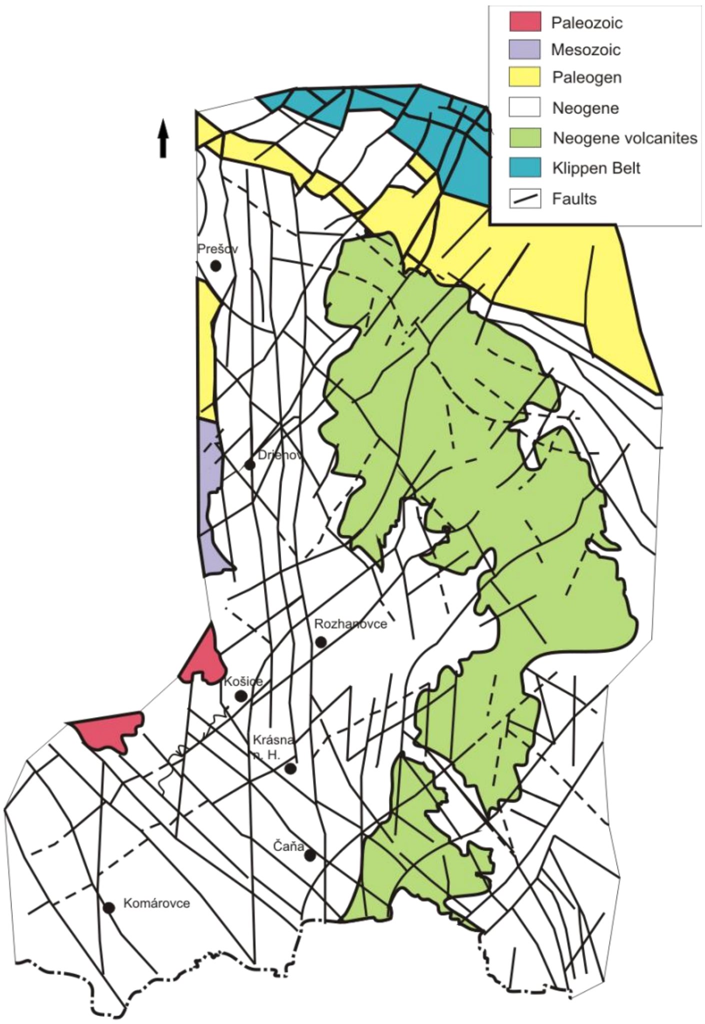


Fig. 6-4 Tectonic sketch of Base Tertiary sub – crop map of Kosice Basin (Kaliciak et al. 1991, 1996)

6.4 Geothermic conditions of Kosice Basin

Kosice Basin is one the most prospective geothermal areas in Slovakia. The geothermal water of Kosice Basin is bounded to Triassic dolomites and partly to Lower Triassic quartzites, which are situated in a Tertiary underlier, and their thickness varies from 100 to 3000 m. The Atlas of Geothermal energy of Slovakia (Franko O., et. al., 1995) provide regional characteristics of thermal fields in form of geoizotermic level maps in depths of 500 – 5000 m. Information about thermal conditions, thermal flow density, thermal conductivity and hydrochemical composition is possible to define on the basis of the results from available borehole data obtained in Kosice Basin. Geothermal waters in Triassic carbonates were found by oil wells at Durkov (D-1, D-3), Kecerovske Peklany (KP-1) and Presov (P-1) (Rudinec, 1989).

Kosice Basin is characterized by large variability of its thermal field because it is a zone between the geothermicaly active area Easternslovakian Neogene and less thermal active ambient structural – tectonic units. The low (90 °C) and medium (150 °C) temperature sources occurs. Low temperatures are characteristic for the western and southwestern parts of the basin and high temperatures are typical for the eastern part, with maximum temperature values in the Durkov area. The average thermal gradient determined until now in the sedimentary filling of Kosice Basin is within the range of 36, 5 – 50, 3 °C/km and in pre–Tertiary rocks it is between 25,0 – 32,3 °C/km (Kral, M, 1994). Such a high thermal gradient in the Neogene sequence is related to the lower thermal conductivity. Generally, the geothermal gradient increases in a south, south–east direction (Hungary) due to overheated and thinner Earth crust. Because of that a higher thermal gradient in shallower parts can be expected. Another reason for higher thermal gradient in the Neogene sequence is the tectonic rupture and inflow of hot water along the faults. At depths of 500 – 4000 m where geothermal water aquifers are assumed the temperature ranges from 27 – 182 °C (Franko, O. et. al., 1995).

An analysis of Badenian and Karpatian sediments from wells shows low thermal conductivity where Badenian has 2, 09 W/mK and Karpathian 2, 37 W/mK. In comparison with the whole Eastern Slovakian Basin, the thermal conductivity of Badenian sediments is 2, 52 W/mK and Karpathian sediments 2, 87 W/mK. The difference is almost 0, 50 W/mK (Král, M., 1994). Thermal conductivity of Sarmatian sediments in Kosice Basin is 2, 10 W/mK. Sandy clay sediments of Paleogene have characteristic thermal conductivity 2, 31 W/mK. The average thermal conductivity of Tertiary rocks is 2, 05 ± 0, 25 W/mK and of Mesozoic carbonates is 3, 46 W/mK.

Tab. 6-2 Summary of geothermic data

Stratigraphy		**Lithology**	**Thermal gradient °C/km**	**Thermal conductivity W/mK**	
NEOGENE (1,6 – 20 Ma)	Sarmatian	claystones sandstones	36,5 - 50	2,10	av. 2,05 ± 0,25
	Badenian	claystones		2,09	
	Karpathian	conglomerates		2,37	
MESOZIC (245 – 65 Ma)		dolimites limestones	25 – 32,3	3,46	

The highest values - 100 – 110 mW/m^2 of thermal flow are found in the southeastern part of the basin, in the Slanske vrchy Mts. foothills. In the central part of the basin typical values within range of 85 – 95 mW/m^2 occur, and in the western part the thermal flow values are at the interval 80 – 85 mW/m^2. The average value of thermal flow is 94, 9 ± 10, 5 mW/m^2 (Král, M., 1994).

Two different chemical types of water were identified in the deep oil wells. Na-HCO_3 type water with mineralisation of 10,9 g/l occurs in well P-1, while wells D-1 and KP-1 discharged Na-Cl type waters with mineralization 26,8-33,4 g/l. The waters contain marinogenetic mineralization which seeped into the sea floor in the third stage of the hydrogeologic evolution (Eggenburgian – Karpatian) of mineral waters in the Inner Western Carpathians (Franko. O.,Bodis, 1989). They were degraded to various degrees by infiltrating meteoric waters.

The prospective thermal – energetic potential of geothermal energy sources in Kosice Basin for reinjection exploitation is 1276, 4 MWt (Fendek,Franko,O. in Vranovska 1999) with an expected lifetime 40 years with an extraction – reinjection system.

6.5 Geophysical exploration in central part of Kosice Basin

In 1992, seismic measurements were realized in the central part of Kosice Basin (Fig. 7-1). The total measured area is approximately 187 km^2 in seven seismic profiles of north – south direction namely, 705/92 and 706/92 and west – east direction, namely 700/92, 701/92, 702/92, 703/92 and 704/92. These profiles, together with information from wells drilled in the interest area, provided needed background information for making the 3D model in Petrel, which is the result of my work. The interpretation of the seismic profiles was done by prof. Janocko (1992).

From a seismic-geologic viewpoint it can be said that the network of seismic profiles in the central part of the Kosice basin provides good data. Boundaries in the Neogene are clearly visible. From a seismic-geologic viewpoint the base of the Neogene is significant. A base of strong continuous reflections was taken as the base of the Neogene. In some of the profiles there is a doubt as to whether or not the reflection is a base of Neogene, or if the continuous reflections are related to the surface of Karpatian basal clastics and the Neogene base is deeper. The boundary of Lower Badenian - Karpatian is less significant and in some places it is more or less conventional. The boundary between the Middle and Lower Badenian is not traceable in the seismic profiles. A base of Upper Badenian is relatively traceable, but a base of Sarmatian is again uncertain.

From a facial point of view the seismic material reflects very well the different lithology of individual sedimentary complexes. The complex of Sarmatian rocks in the uppermost parts of the profiles is very difficult to identify. Upper Badenian is characterised by long and seldom interrupted reflections with "onlap", and rarely "downlap", structures that are typical for delta sediments. The complex of Middle and Lower Badenian is characterised by shorter, but in many cases very significant, reflections that are typical for sandstone lenses in claystones. Karpatian sediments have poorly traceable reflections excluding basal clastic reflections, which is typical for mainly pelitic facies. The Neovolcanic complexes have significant traces in the seismic profiles; they are characterized by chaotic arrangement of reflections and sharp boundaries against Neogene clastics.

Considering fault types, several faults can be interpreted as complicated "flower structures" – mainly those that are developed in the neighborhood of volcanic bodies. Drop faults represent another fault type and several thrust faults are the last type. Considering fault bending and the fact that some of the faults are thrust faults in one part and drop faults in another part, it can be assumed that part of the faults have character of horizontal or inclined displacements (Vozar et.al. 1999).

6.6 Hydrogeothermal structure Durkov

The Durkov structure is the most perspective geothermal area with the highest density of thermal flow in Kosice basin. The presence of geothermal waters in this area was confirmed by oil and gas wells, and on the basis of results from these wells detailed geothermal research was realized in 1998. The goal of the project was to verify sources of geothermal waters for their prospective utilization in the city of Kosice.

The Hydrogeothermal structure Durkov is located in the central part of Kosice Basin near the Slanske vrchy Mts. The pre–Tertiary underlier is created by dolomitic limestones, dolomites of Anisian – Ladinian which were penetrated by six deep wells (Durkov-1, 2, 3, GTD – 1, 2 and 3). The pre–Tertiary underlier is sinking beneath Slanske vrchy Mts. from NW to SE.

Durkov structure is one of the deepest parts of Kosice Basin. From a geological – tectonic viewpoint the Durkov hydrogeothermal structure is considered as a depression of pre–Neogene underlier with depths of Mesozoic dolomites below 2000 m. The geological structure and geochemical factors point out that it is a close structure. Its western boundary is marked by a fault line of north–south direction. The eastern boundary is specified by an extension of Mesozoic carbonates in the Slanske vrchy Mts. underlier. The northern boundary is approximately 500 m northwards from Durkov – 1 in a place marked by the beginning of a morphostructural depression of pre–Neogene underlier. At the southern boundary, the presence of massive neovolcanic complexes on the surface and in the Tertiary sedimentary filling of the basis is characteristic. It is 1000 m to the south of the 704/92 seismic profiles. Masses of neovolcanic rocks can create a natural barrier and significantly limit geothermal water flow in a hydrogeothermal reservoir. The total area of the hydrogeothermal structure Durkov is approximately 33, 6 km^2.

Geothermal waters aquifers are Mesozoic carbonates – Upper and Middle Triassic dolomites with karstic permeability and basal clastic of Karpathian. The thickness of clastic rocks of Karpathian (86 – 155 m) is, in comparison with Mesozoic carbonates thickness (220 – 2175 m), negligible. That is why basal clastic rocks of Karpathian are considered to be in one unit of the geothermal aquifer together with Mesozoic rocks.

In the Neogene, sequences of clay development were determined, also sandstones and eventually conglomerate layers of Sarmatian, Badenian and Karpathian age, with the exception of basal clastic rocks of Karpathian. Despite the fact that the Neogene filling is complex, it is regarded as an overlying insulator of the main geothermal water aquifer dolomites of Middle Triassic. The function of the insulator also has underlying complexes of Palaeozoic crystalline rocks.

On the basis of hydrodynamic tests the following hydraulic attributes of the reservoir were determined: the coefficient of flow capacity and the coefficient of filtration.

Tab. 6-3 Hydrodynamic parameters

Well	**Coefficient of flow capacity (m^2/s)**	**Coefficient of filtration (m/s)**
GTD – 1	2, 1 – 5, 7. 10^{-4}	4,471. 10^{-7}
GTD - 2	1, 6. 10^{-4} - 8, 2. 10^{-5}	9, 44. 10^{-8}

Geothermic activity in the Durkov structure is very high. Geothermic data from wells GTD – 1, 2, 3 and Durkov – 1 were used to determine the average temperatures and geothermal gradient at depths of 500 to 3000 m for the Neogene and Mesozoic complexes. On the basis of geothermic measurements, the average temperature at 500 m depth is 30 °C, at 1000 m depth it is 52 °C, at the depth of 1500 m it is almost 80 °C and at the depth of 2000 m the average temperature is close to 110 °C. All these data are for the Neogene sedimentary sequence. Average temperatures at depths of 2500 and 3000 m are 134, 1 °C and 141, 7 °C. These data are for Mesozoic carbonates. The average thermal gradient in the Neogene sequence is 51, 2° ± 1, 1 °C/km and in Mesozoic carbonates it is 29, 4 ± 0, 5 °C/km. Temperatures at the top of the geothermal water reservoir at depths of 1800 – 2600 m are within the limits 100 – 135 °C and temperatures of the base at depths of 2500 – 3200 m are within the range of 120 – 185 °C.

The average thermal conductivity coefficient of Neogene sediments is 2, 088 – 2, 414 W/m.K. Thermal conductivity changes at interval 0, 848 – 1, 027 mm^2/s and average values of specific heat are within the range 931, 4 – 1126, 1 J/kg.K. The therrmal conductivity coefficient of basal Karpathian conglomerates is 2, 757 W/m.K, thermal conductivity is 1, 192 mm^2/s and specific heat is 864, 5 J/kg.K. For Triassic carbonate rocks in the underlier of Neogene the thermal conductivity coefficient is 3, 922 W/m.K, thermal conductivity is 1, 730 mm^2/s and the average value of specific heat is 811, 4 J/kg.K.

The density of ground thermal flow is within the range 108, 4 – 114, 9 mW/m^2 with average value 112, 2 ± 2, 8 mW/m^2.

The thermal – energy potential – amount of energy accumulated in an average depth 1000 m represents 0, 714. 10^9 GJ and in minimal depth 200 m is 0, 143. 10^9 GJ. The minimum amount potentially of mined energy from the Durkov structure is 113, 4 MWt.

Hydrgeochemical conditions were determined based on chemical analyses of geothermal waters during hydrodynamic tests. The general chemical composition of geothermal waters is highly natrium – chloride type with minor a portion to absence natrium – hydrogen carbonate component. Total mineralization is 27 to 32 g/l. The characterization noted above, included with other geochemical factors (HCO_3/Cl, Na/K and relatively low content of biogenic elements), indicates a geochemical closing of the hydrogeological structure. From a genetic point of view it is assumed that waters probably originated fom the infiltration of meteoric/marinogenic (subsequently marinogenic) waters through Neogene sequences (plus saliferous formations of Karpathian) into the Mesozoic aquifer.

For hydrogeothermal structure Durkov the presence of CO_2 in geothermal waters is typical. It is relatively clean (for about 98 volume % from total gas content). The extension of CO_2 is not bound only on Durkov's surroundings, but it is a regional occurrence of CO_2 in relation to volcanic activity. CO_2 content in geothermal water can adversely affect mining conditions.

The main purpose of the research was to verify the existence of a geothermal water reservoir, to establish a utilizable amount and temperature of geothermal water, to its specify geological – tectonic structure, to find out the geothermal waters hydraulic attributes of aquifers, pressure, thermal and hydrogeochemical conditions, and technological properties of geothermal waters. A review and description of the obtained results from this research are summarized in a final report written by Vranovska (1999). Geothermal wells are situated near to the well Durkov group of wells. Fig. 6-5 shows the bending of geothermal wells in the pre–Neogene basement.

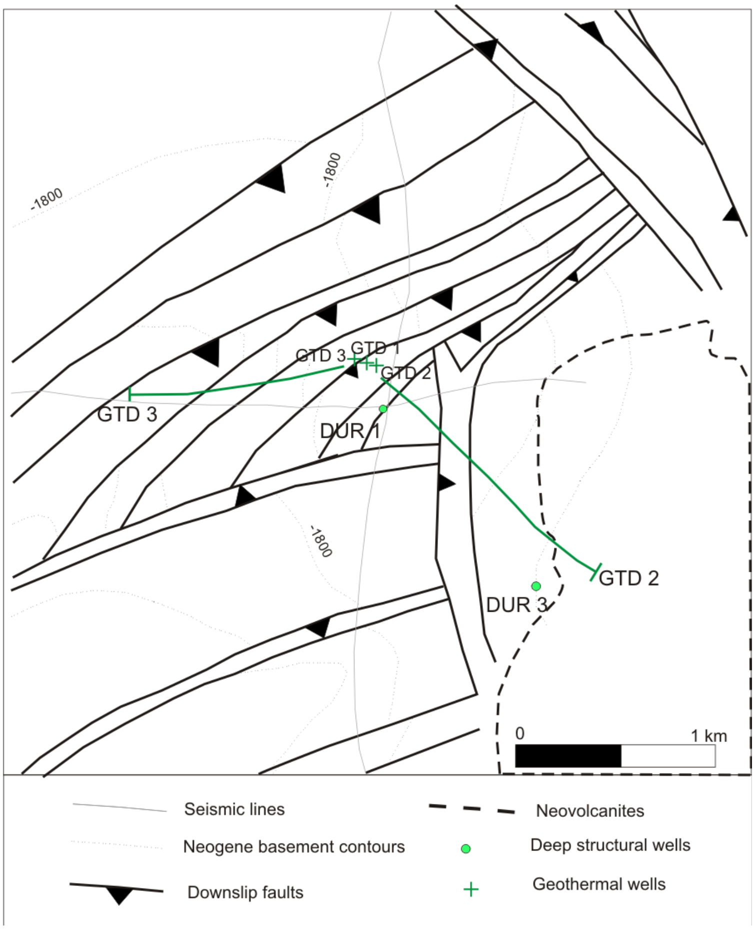


Fig. 6-5 Contours map of pre – Neogene basement and position of geothermal wells (Vranovska et.al.2000)

7 INTERPRETATION OF DEEP GEOLOGICAL STRUCTURE

The basic information and input data for modeling in Petrel were coordinates x, y and z subtracted from east - west 700/92, 702/92, 703/92, 704/92 and north – south 705/92 and 706/92 seismic profiles and import of these 2D seismic section to the Petrel. The profiles were obtained from seismic measurements in 1992 in the central part of Kosice Basin (Fig. 6-1). They are in 2D picture and this fact was the main limiting factor of my work. In the profiles are interpreted stratigraphic boundaries of the Mesozoic top boundary, the boundary between Karpathian and Lower and Middle Badenian, the Lower and Middle Badenian and Upper Badenian boundary and the boundary between the Upper Badenian and Sarmatian. Besides the boundaries faults and neovoclanic bodies of Slanske vrchy Mts. are also interpreted. All of the above mentioned attributes of seismic profiles were interpreted by Janocko (1999). My task was to interpret the Mesozoic base boundary to delimitate the geothermal waters aquifer. The interpretation was very difficult because the main data were based on the results of available borehole data from only four wells Kecerovske Peklany – 1, Rozhanovce – 1 and Durkov- 1 and 2, where Kecerovske Peklany – 1 and Rozhanovce – 1 penetrated through base of Mesozoic. In some profiles it was observed that a boundary was interpreted following seismic reflexes but in very small cases reflexes were continuously visible the whole length of the 2D profile. A brief description of seismic profiles and wells as a primary source of data for the next process (modeling and interpretation) follows.

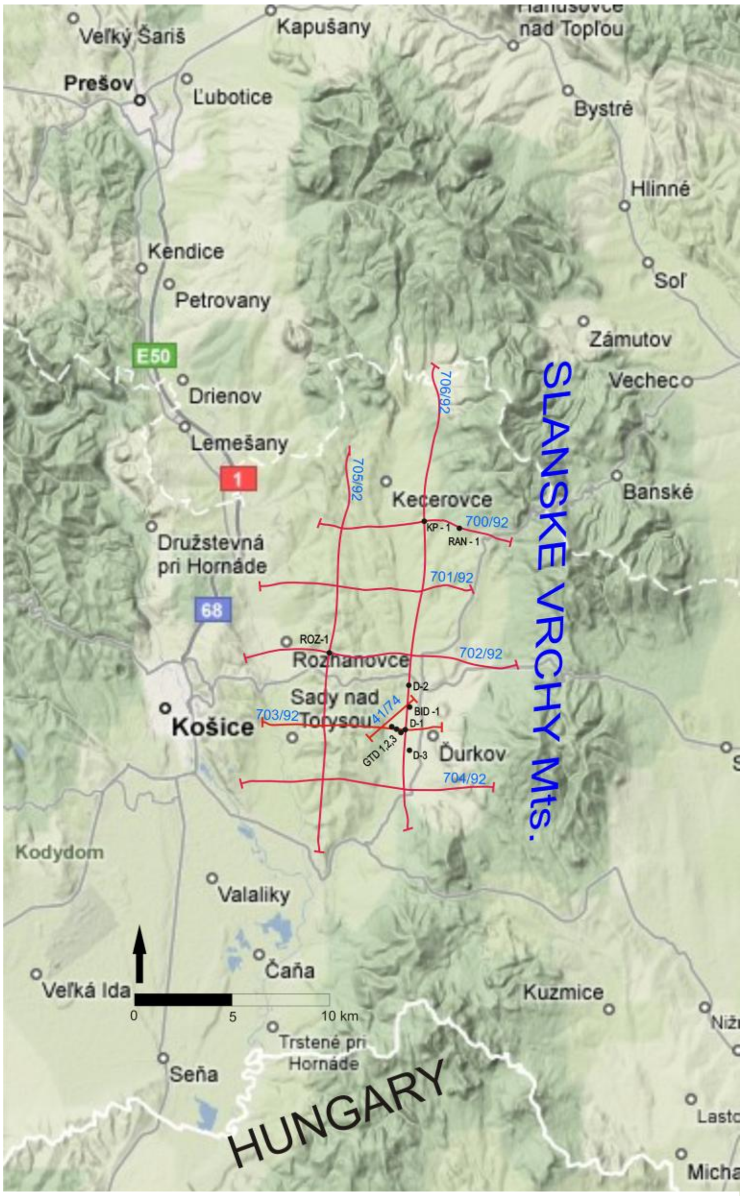


Fig. 7-1 Position of seismic profiles in central part of Kosice Basin

7.1 Characteristic of seismic profiles

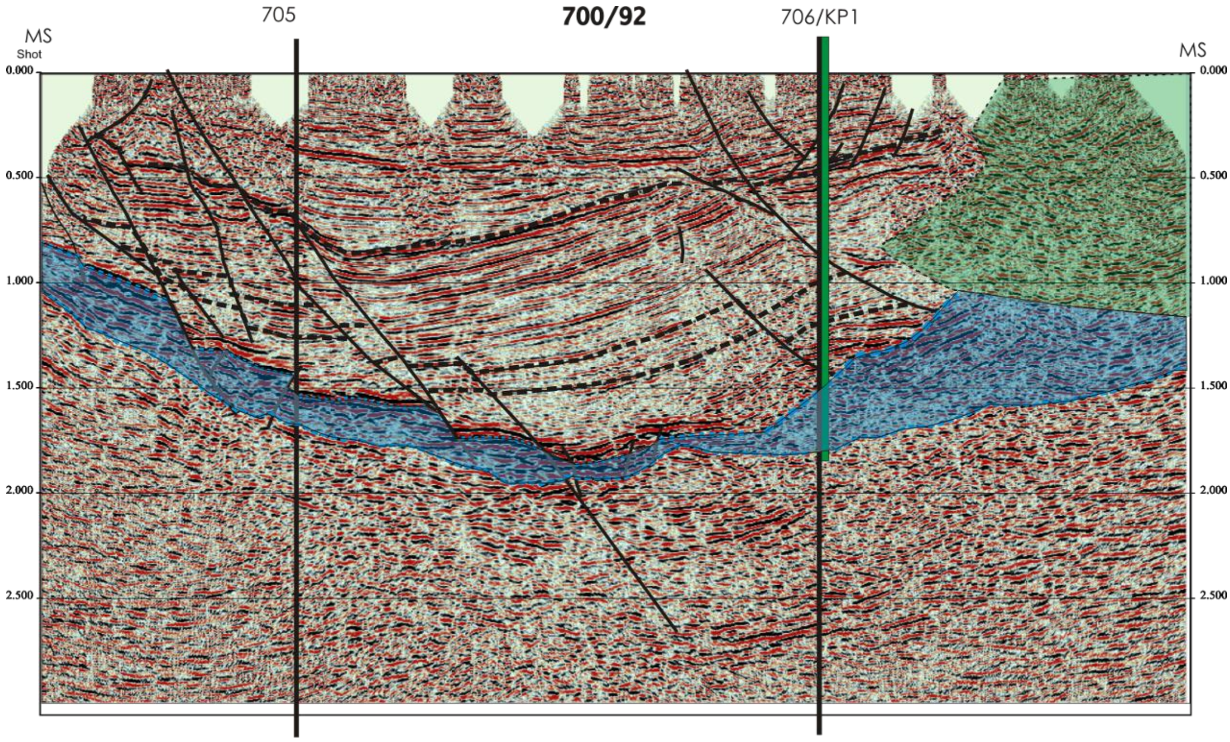


Fig. 7-2 Profile 700/92

Profile 700/92 shows a west to east direction. Seismic - geologic complexes of Neogene rocks and their clear boundaries are clearly visible in the profile. Planar normal faults and oblique - slip faults occur in profile. Planar normal faults are in the western part of the profile. These faults were active during the Miocene and they are probably the reason for the origin of a marked depression in the middle of the profile. Faults fractured geothermal water reservoir rocks. In the eastern part of the profile oblique – slip faults and their antithetic faults occur. Their origin is probably connected with the penetration of neovolcanic rock to the ground. Pressure realised from moving volcanites fractured surrounding sediments and also affected the buckling of Mesozoic carbonates and the origin of compressed structures. In the whole length of the section pre–Tertiary reservoir rocks are marked blue. Profile 700/92 is intersected by north-south profiles 705 and 706. The distance between the two N-S profiles is approximately 6 km.

Well Kecerovske Peklany KP-1with total depth of 3098 m is situated at a point of contact between profiles 700 and 706 penetrated through the Mesozoic sequence to the crystalline rocks. The Middle Triassic is represented by grey and dark grey dolomites sporadically with breccias, which merge into calcareous dolomites to dolomitic limestones in the direction of the base. In the underlier of dolomites (2705 – 2745 m) violet - brownish to violet – reddish shales of Verfen layers occur. Below them (2745 – 2820 m) are white grey, pinkish, heavy tectonically faulted quartzites which represent the base of Lower Triassic. Within the quartzites from the core at interval 2751 – 2755 m (Magyar – Voborníková, 1974) an interbed of variegated shales occurs. In the depth of 2820 – 2940 m are violet – brownish greywacke and silicious sandstones with interbeds of clay shales, probably of Permian age. Dark green chloritic, chloritic – muscovite mica schists were drilled below 2940 m. The Lower Triassic – Permian boundary is in the depth of 2840 m (Tőzser - Rudinec, 1975) and the Permian – crystalline rocks boundary is at a depth of 2925 m.

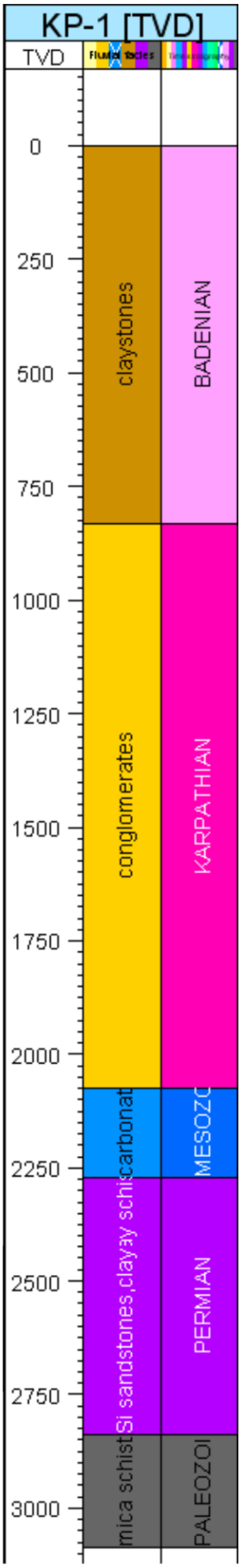


Fig. 7-3Well KP - 1

Tab. 7-1 Stratigraphic profile of well KP – 1(Biela, 1978)

Depth (m)	***Stratigraphy***
0-715	*Upper Badenian*
718-840	*Middle Badenian*
840-1751	*Upper Karpathian*
1751-2160	*Lower Karpathian*
2160-2705	*Middle Triassic*
2705-2820	*Lower Triassic*
2820-2940	*Permian*
2940-3098	*Paleozoic?*

Tab. 7-2 Character of water in well KP - 1(Biela, 1978)

Depth of the Inflow(m)	***Mineralisation (g/l)***	***Type of water***	***Gas***
1109-1114	27,5	Cl-Na	–
1191-1194	25,9	Cl-SO_4-Na	–
1351-1356	34,7	Cl-Na	–
1517-1575	48,1	Cl-Na	–
2168-2237	25,6	Cl-Na	–
2490-2565	32,2	Cl-Na	–
2594-2635	33,4	Cl-Na	N_2
2645-2706	39,2	Cl-Na	N_2
2763,5-2770	12,9	Cl-HCO_3-SO_4Na	–

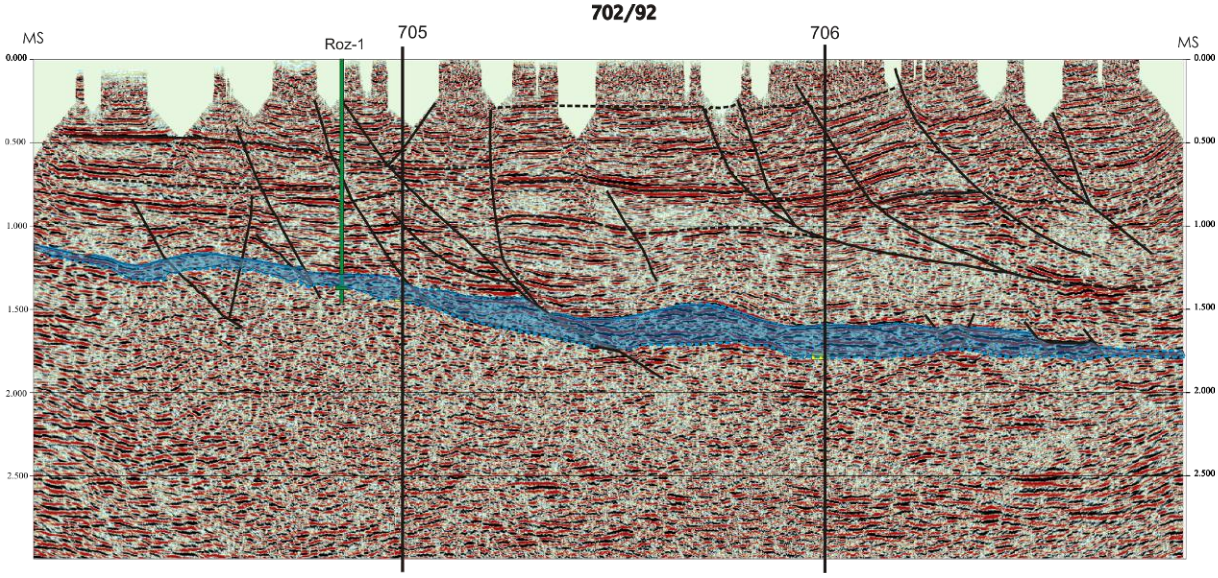


Fig. 7-4Seismic profile 702/92

Profile 702/92 lays in an east – west direction approximately 8 km from profile 700/93. The Neogene complex is easy to recognize due to discordant boundary with pre – Tertiary basement. Neogene complex is fractured by system of planar normal faults, oblique – slip faults and by some antithetic faults. Most of fault started up in Sarmatian and their activity continues to the Mesozoic. Group of oblique – slip faults in eastern part of profile ends during Karpathian and their origin is connected with processes including ascent of neovolcanites. The thickness of reservoir Mesozioc rock is controlled by mentioned faults from Neogene and increasing to the middle of the profile and then again become thinner. Also transversal profiles 705 and 706 are indicated.

Profile shows well Rozhanovce Roz-1 with total depth of 1882 m. Well Roz-1 penetrated through Mesozoic complex alike well KP-1. In the pre – Neogene underlier two different complexes of rocks exists. In the depth of 1525 – 1710 m grey to dark grey dolomites with plentiful calcite veins occur (Cvercko, 1971). Middle Triassic is represented by dolomites which is probably continuation of Cierna Hora Mts. envelope crystalline rocks. Grey to grey greenish muscovite, siliceous, chlorite – muscovite mica schists occurs in lower part of drill core profile.

Tab. 7-3 *Stratigraphic profile of well ROZ – 1 (Biela, 1978)*

Depth (m)	***Stratigraphy***
0-410	*Lower Sarmatian*
410-650	*Upper Badenian*
650-834	*Middle Badenian*
834-1002	*Lower Badenian*
1002-1153	*Upper Karpathian*
1153-1525	*Lower Karpathian*
1525-1710	*Lower Triassic*
1710-1882	*Paleozoic?*

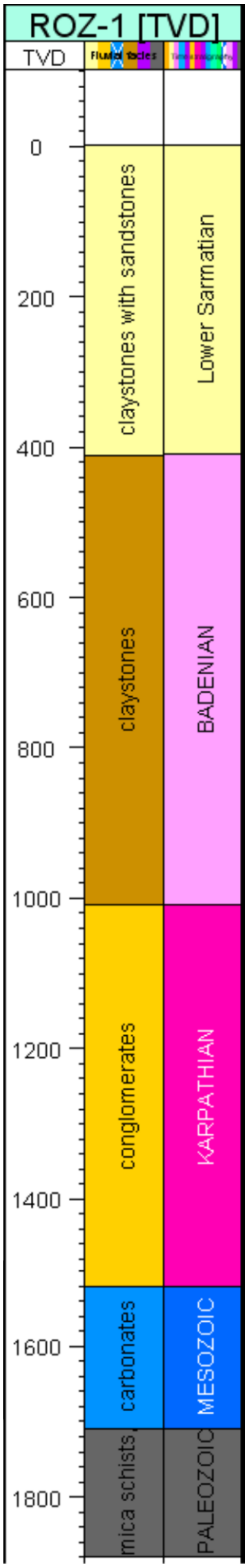


Fig. 7-5Well ROZ - 1

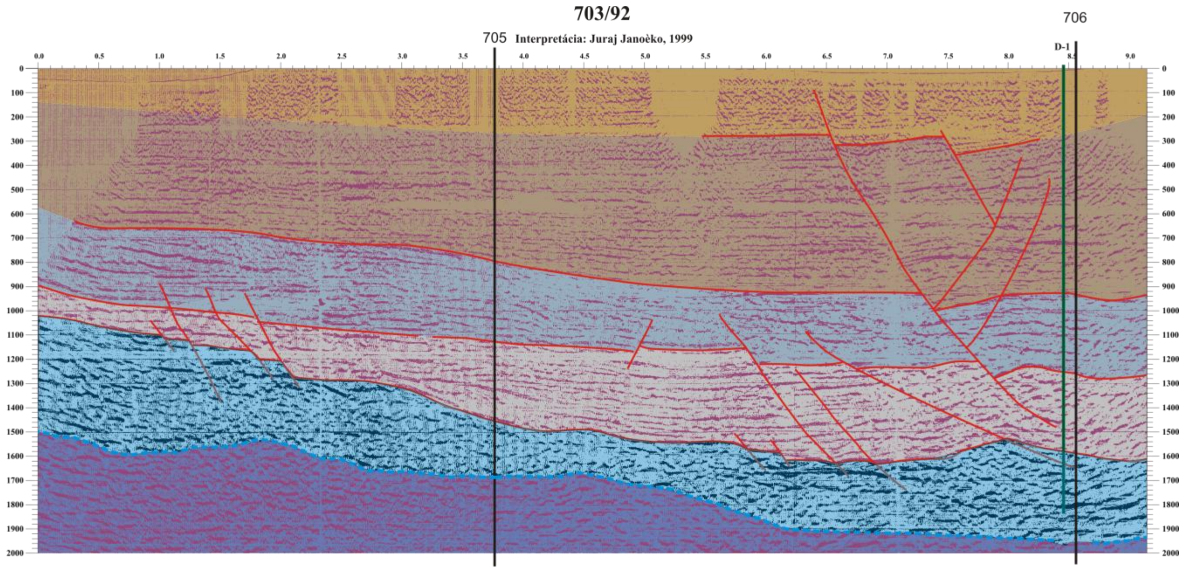


Fig. 7-6Seismic profile 703/93

Profile 703/92 is situated in a west – east direction and 4-5 km away from profile 702/92. Planar normal faults do not have as large an impact as in the previous profile. Their activity probably decreased during the Karpathian but rupture of Mesozoic rocks is still visible even if less in amplitude. On the other hand very outstanding became oblique – slip faults and antithetic faults. Their expansion is caused by the presence of a large neovolcanite body which will show the next seismic profile. These faults end their activity again during Karpathian. The thickness of the Mesozoic complex is bigger in comparison with the previous two profiles, probably due to a less striking tectonic rupture.

Well Durkov D-1 penetrated into the Mesozoic complex (Middle Triassic) where it finished at a depth of 3200 m. The underlier of Neogene sediments is created by grey – light grey compact shale dolomites with calcite veins. From a depth of approximately 2750 m the portion of $CaCO_3$ increases up to 45%, which means that they merge into dolomitic limestones (Zádrapa, 1969). Between the dolomites (2682 – 2753) were found layers of dark grey clay shales. It is assumed that the carbonate complex belongs, from tectonic point of view, to the Krizna nappe. Dolomites are probably of Upper Triassic age (Cverčko, - Rudinec, 1971).

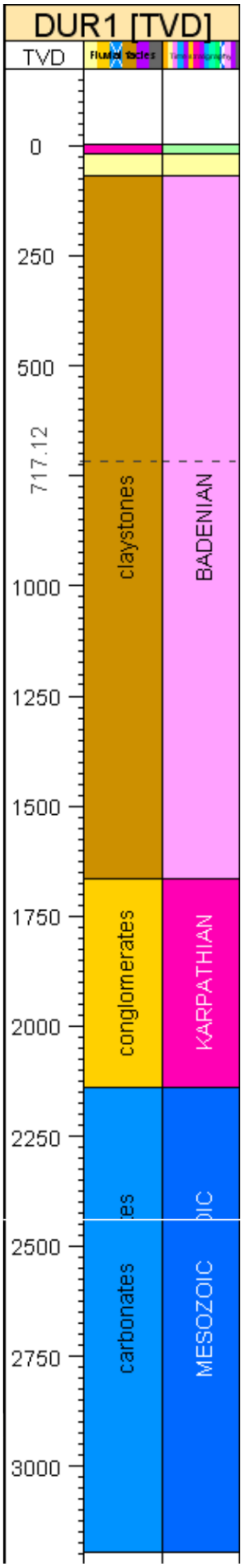


Fig. 7-7Well DUR - 1

Tab. 7-4 Stratigraphic profile of well DUR – 1(Biela, 1978)

Depth (m)	***Stratigraphy***
0-16	*Quaternary*
16-60	*Lower Sarmatian*
60-1195	*Upper Badenian*
1195-1505	*Middle Badenian*
1505-1670	*Lower Badenian*
1670-1850	*Upper Karpathian*
1850-2140	*Lower Karpathian*
2140-3200	*Lower Triassic*

Tab. 7-5 Character of water in well DUR – 1(Biela, 1978)

Depth of the Inflow(m)	***Mineralisation (g/l)***	***Type of water***	***Gas***
1060-1087	19,7	Cl	–
1140-1145	6,5	Cl	CH_4-N_2
1648-1658	18,5	Cl	N_2
2150-2176	22,8	Cl	CO_2-N_2
2302-2345	26,8	Cl	CO_2
2459-2517	18,9	Cl	CO_2
2668-2700	22,8	Cl	CO_2
2816-2817	19,3	Cl	–
2971-3102	22,9	Cl	CO_2-N_2

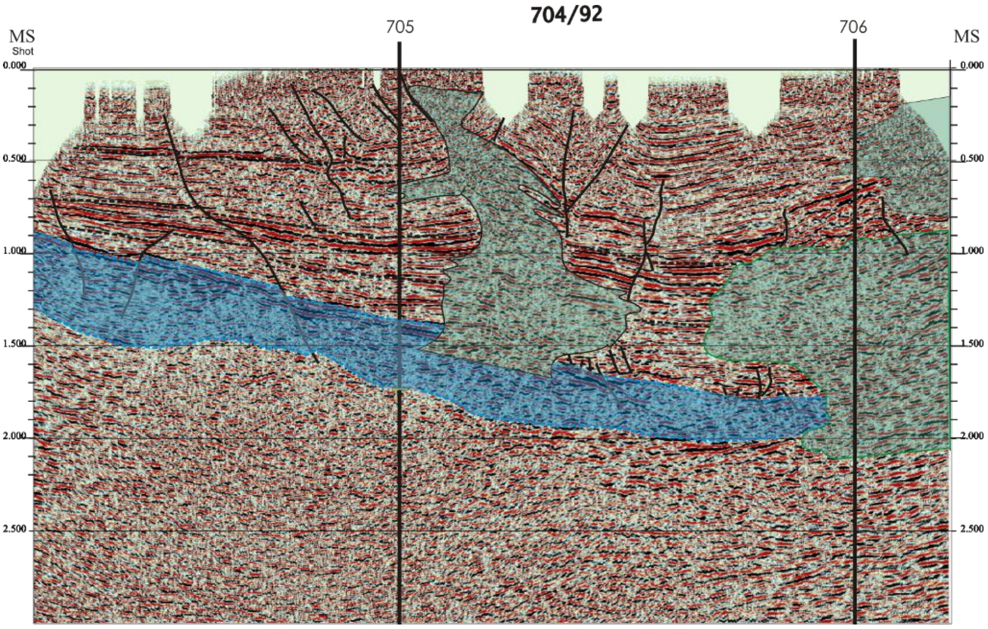


Fig. 7-8Seismic profile 704/92

Profile 704/92 has an east-west direction, which is parallel to profiles 700,702, 703/92 but 4 km south of profile 703/92. The profile is important for the fact that it uncovered a buried columnar body of neovolcanic rocks in its center. And these neovolcanic bodies caused rupturation of the surrounded sedimentary sequences. Tension cracks occur in nearby bodies. Lifting of reflexes is caused by penetration of neovolcanites. Except for tension cracks normal faults fracture sediments of the Neogene and Mesozoic sequence. The thickness of Mesozoic reservoir rocks thins out to the east.

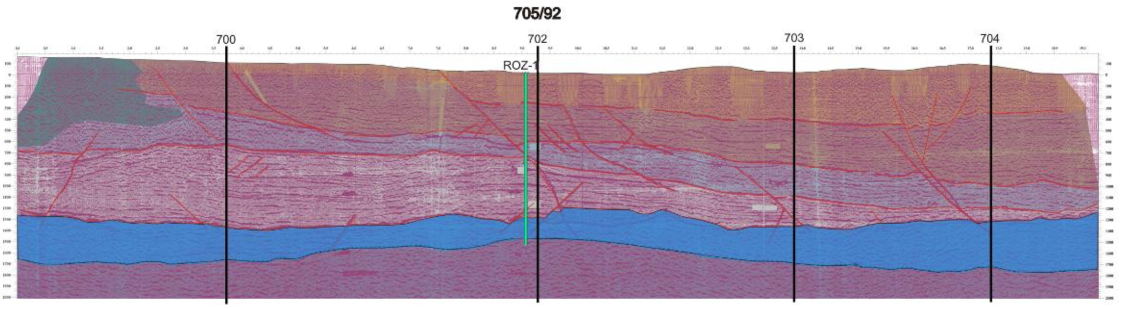


Fig. 7-9Seismic profile 705/92

Profile 705/92 lays in a north–south direction. It is a transverse profile to all previous profiles. It is the farthest profile from neovolcanites. A small segment of neovolcanites occurs on the west in the upper part of the profile. Faults connected with neovolcanites still occur but their activity is visibly lower. Normal faults are still active and it is represented by the rupturation of Neogene sequences. The Mesozoic sequence is almost homogenous – only a few tectonic effects occur and they affect the thickness of Mesozoic reservoir rocks in the middle of the profile.

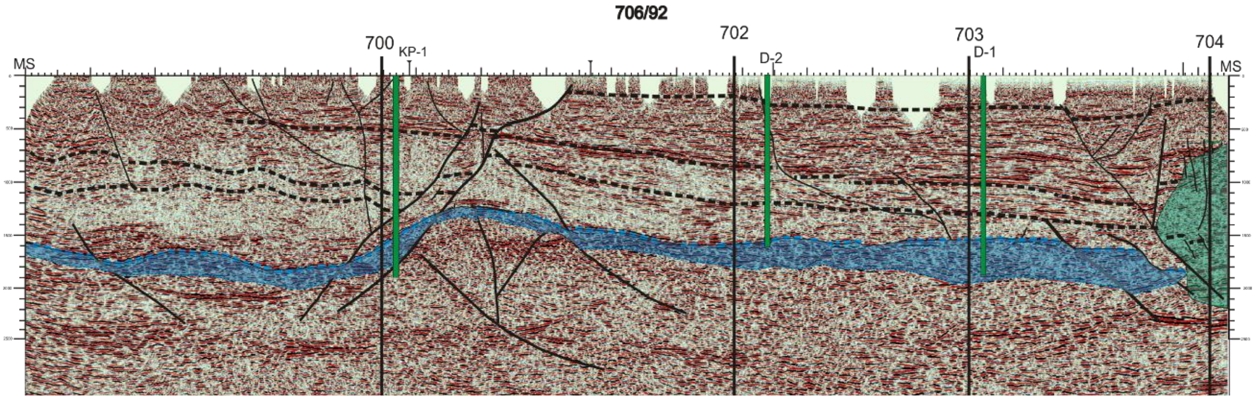


Fig. 7-10Seismic profile 706/92

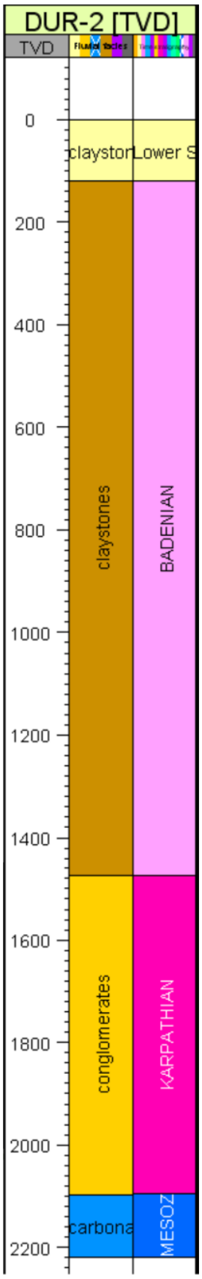


Fig. 7-11 Well DUR - 2

Profile 706/92 has a north-south direction along neovolcanics of the Slánske vrchy Mts and it is the second transverse profile. Practically the same Neogene sediments are recorded in the Tertiary basement as in previous profiles. The Mesozoic complex of carbonates is interpreted in the basement. In middle of the profile there is significant elevation of the pre-Tertiary basement. The outstanding elevation in the middle of the profile is probably the effect of movements caused by ascending neovolcanites during the Sarmatian. These faults reduce sediments and very markedly rupture Mesozoic sequences.

Profile 706 is the only profile in which it is possible to see three wells: KP-1, D-1 and Durkov D-2. The last mentioned well penetrated into the Mesozoic complex and finished at a depth 2230 m. In the easternmost part the neovolcanites occur. In well Durkov – 2 is a pre–Neogene underlier represented by heavily fissured dolomites of Middle and probably Upper Triassic. (Cverčko, 1970).

Tab. 7-6 Stratigraphic profile of well DUR 2(Biela, 1978)

Depth (m)	***Stratigraphy***
0-120	*Lowe Sarmatian*
120-1030	*Upper Badenian*
1030-1320	*Middle Badenian*
1320-1475	*Lower Badenian*
1475-1882	*Upper Karpathian*
1882-2190	*Lower Karpathian*
2190-2230	*Middle Triassic*

The wells characterized above were not focused on geothermal research. These are wells realized for oil and gas research and were drilled in the late sixties and early seventies together with geophysics measurements. After 20 years it was discovered that thermal water appeared in these wells, and geothermal research started after its discovery. The first geothermal water sources prospecting research in Kosice Basin started in 1998(GTD – 1, 2) and beginning of 1999 (GTD – 3). Three geothermal wells GTD – 1, 2 and 3 were drilled.

Wells GTD - 1 and GTD - 2 were projected as a doublet system for geothermal waters exploitation and reinjection. GTD – 1 is a vertical exploitation well with a total depth of 3210 m. GTD – 2 is a reinjection well with a bend depth of 600 m, azimuth 138°, deviation 36 – 40° and total length of 3730 m. GTD – 3 well was drilled as the next reinjection well. It has a deviation with a length of about 2620 m in a north-western direction. For research in Durkov area more detailed seismic measurements were realized but these data were not available to use for this thesis work. Based on sedimentological, petrography – lithological and biostratigraphycal analyze the following profiles were established. (Kovac et al., 1998):

GTD - 1

Sarmatian and Upper Badenian sediments are characterized by calcareous clays with variable content of silt, siltstones and bodies of fine to coarse-grained sandstones, fine-grained conglomerates with pebbles of volcanic rocks–andesites and tuffs. Grey calcareous clays, siltstones with variable content of sandy and volcanodetritic components belong to the Middle and Lower Badenian. The Karpathian is created by grey to red–violet clays, siltstones and conglomerates. Sediments of the Middle – Upper Triassic are represented by dark grey breccias, dolomites with white secondary dolomite veins and dark grey tectonic breccias in a fine–grained matrix. Frequent occurrence of dolomite breccias means that the complex of Mesozoic rocks was exposed to intensive deformation processes.

GTD - 2

Loams, gravels and sands belong to Quarternary. Grey calcareous claystones and siltstones and sporadically fine–grained sandstones represent the deltaic sequence; pebbles of andesites are sediments of the Lower Sarmatian to Badenian. Carbon vegetation is also present. Light grey siltstones represent the Upper Badenian and light violet siltstones with variable content of greenish clay and carbon vegetation are of Middle – Lower Badenian age. Grey–violet clay shales create a boundary base of Badenian and Upper Karpathian. Cuts of granitic, metamorphic and sedimentary rocks are sediments of Karpathian. It is assumed that these sediments were penetrated to the Karpathian by a dyke during the Sarmatian. Dominant rocks in the Mesozoic complex are dolomite fragments, grains of quartz from granitoide rocks and crystallic shales, claystones, siltstones and infrequent neovolcanites.

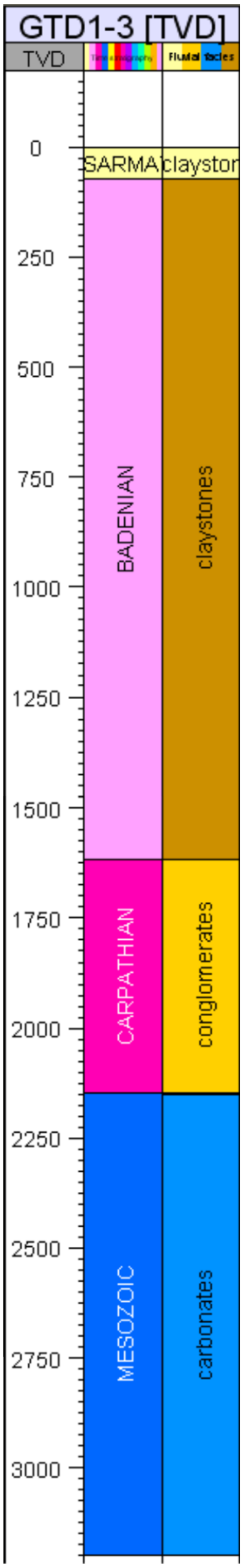


Fig. 7-12Wells GTD 1, 2, 3

Tab. 7-7 Stragraphic profiles of GTD -1 and GTD – 2 (Vranovska, 1999)

GTD-1		***GTD-2***	
Depth(m)	***Stratigraphy***	***Depth (m)***	***Stratigraphy***
0 - 70	Sarmatian	0 - 70	Sarmatian
70 - 1080	Upper Badenian	70 - 1080	Upper Badenian
1080 - 1480	Middle Badenian	1080 - 1500	Middle Badenian
1480 - 1620	Lower Badenian	1500 - 1720	Lower Badenian
1620 - 2155	Karpathian	1720 - 2467	Karpathian
2155 - 3210	Middle – Upper Triassic	2467 – 3151	Middle – Upper Triassic

7.2 Characteristics of surfaces

Construction of surfaces was the first step in the modeling process. They are boundaries which selected individual sequences of Mesozoic rocks and Neogene sediments. The depths are determined by colorful distinction. The value of depth is in milliseconds and approximate values in meters are mentioned in gaps. Time – Depth conversions for all four wells were based on only one available check – shot from oil well Durkov – 1 and therefore its values in meters are mentioned as an approximate value.

7.2.1 Surface of Mesozoic base

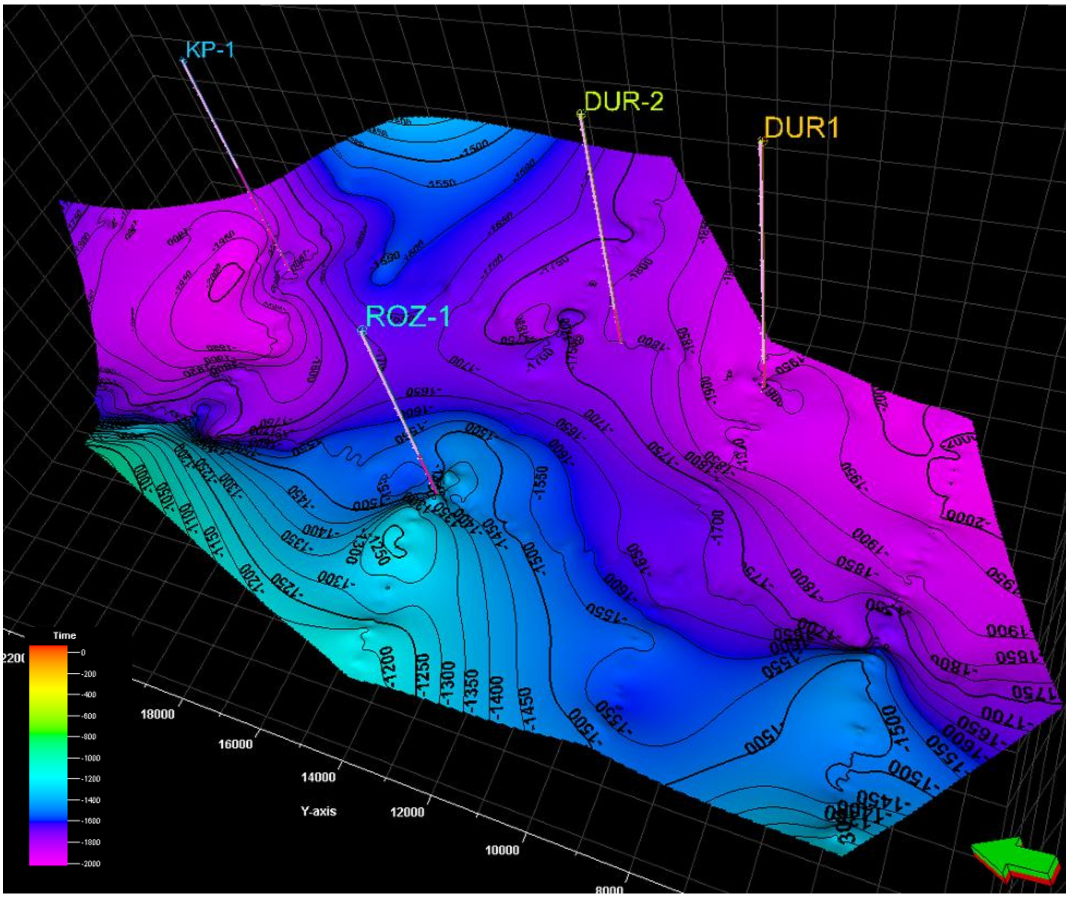


Fig. 7-13Surface of Mesozoic base

The surface of the Mesozoic base is the lowermost surface of the model and it delimitated a geothermal water aquifer from the bottom. The deepest part is marked in violet color and it represents a depth of about 2000ms (approx.2600 m) and the uppermost point of this surface is at a depth of about 1250 ms (approx.1380 m). The difference in depths shows that the Mesozoic complex has rugged topography due to younger tectonics and a denudation processes. In the central part of the surface an outstanding elevation occurs (blue). The elevation separates the depression in the Durkov area on the SE edge of the surface and the depression in the Cizatice area on the western edge of the surface. Depressions are probably the result of NE – SW Neogene normal faults. Striking N-S faults in the western part occur. From the displayed wells only two of them penetrated through the base of Mesozoic, namely Kecerovke Peklany – 1 (KP – 1) and Rozhanovce – 1 (ROZ – 1).

7.2.2 Surface of Mesozoic top

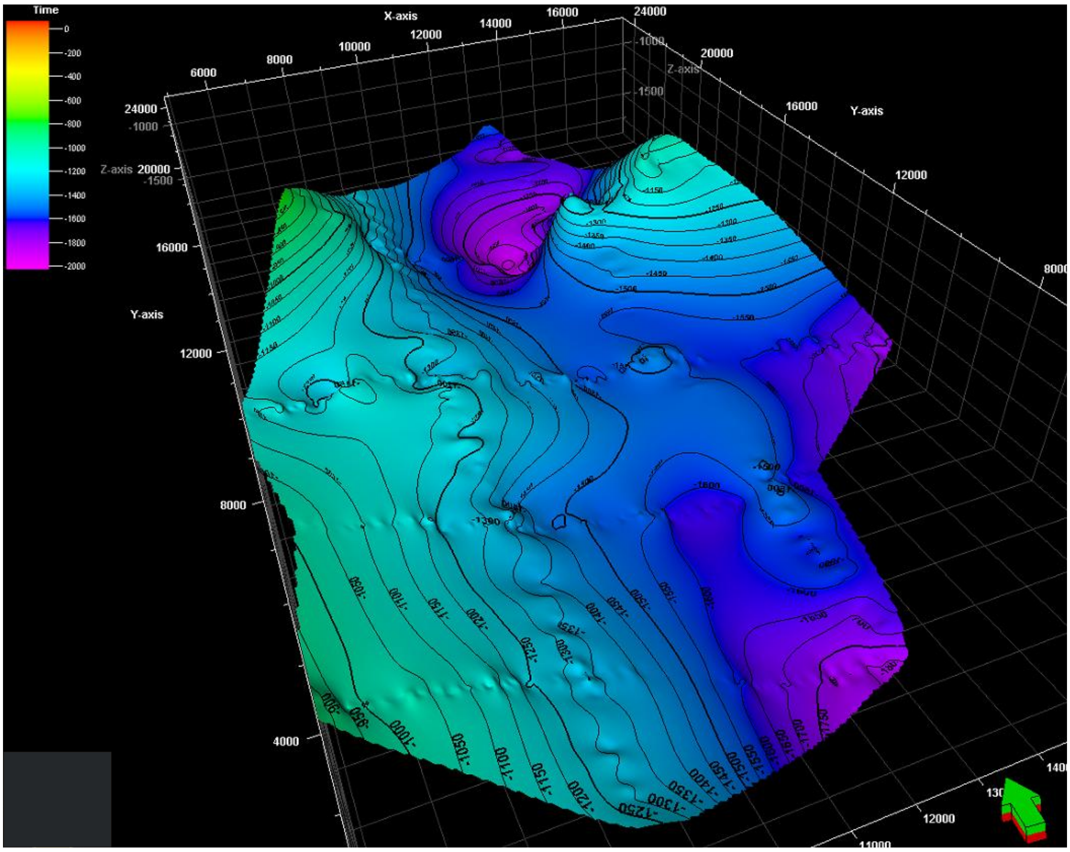
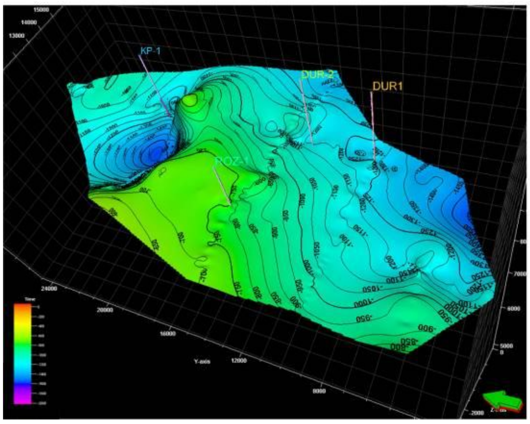


Fig. 7-14 Surface of Mesozoic top

The geothermal waters aquifer is delimitated by this surface from the top. The surface also has rugged topography with the deepest part at a depth of around 1800 ms (approx. 2270 m) and the highest part at 800 ms (approx.850 m). The depth difference is bigger than in the previous surface probably due to the effects of tectonics. This elevation is more outstanding and delimitates two depressions. The depression in the Durkov area is not as large as in the previous surface but the depression in the Cizatice area is still very outstanding. It is because of the increasing activity of the Neogene N – S or NE – SW faults. All of the wells – Kecerovke Peklany – 1 (KP – 1), Rozhanovce – 1 (ROZ – 1), Durkov – 1 (DUR – 1) and Durkov – 2 (DUR – 2) – penetrated through the top boundary of the Mesozoic sequence. This surface is also the boundary where rocks of Karpathian started to occur.

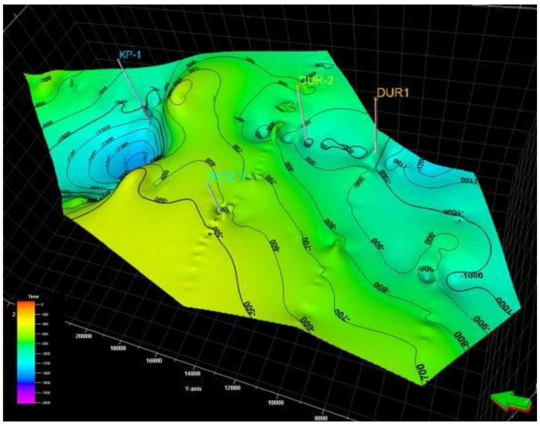
These two surfaces delimitate Triassic carbonate rocks and, on the basis of course and topography, the thickness variability can be assumed.

7.2.3 Surfaces of Neogene sequences



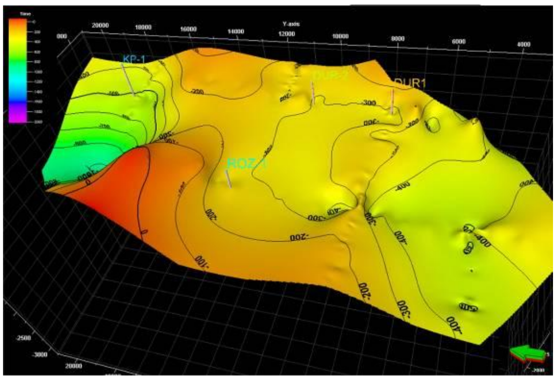
The topography of this surface is not as rugged as in the previous two surfaces. The depth difference is 260 ms (approx. 220 m) with the deepest part about 1550 ms (approx. 1850 m) and highest part about 600 ms (approx. 570 m). The activity of massive faults in N – S direction is decreasing but the system of northern east – southwest faults is still very outstanding .

Fig. 7-15 Surface of Karparhian – Lower and Middle Badenian boundary



The surface of Lower and Middle Badeinan – Upper Badenian boundary shows more moderate topography but the striking depression in the western part of the surface is still visible. The depth in the depression is approx. 1530 m where at the lowest point of the surface. The uppermost point is at a depth of approx. 450 m. The north-eastern – south-western fault is slowly losing its intensity. The more active fault is the north-west – south-eastern fault.

Fig. 7-16 Surface of Lower and Middle Badeinan – Upper Badenian boundary



The surface of the Upper Badenian - Sarmatian boundary is the uppermost surface of the model. Its topography is moderate with one outstanding depression and a depth around approx. 910 m. Sediment of Sarmatian outcrops to the surface.

Fig. 7-17 Surface of Upper Badenian - Sarmatian boundary

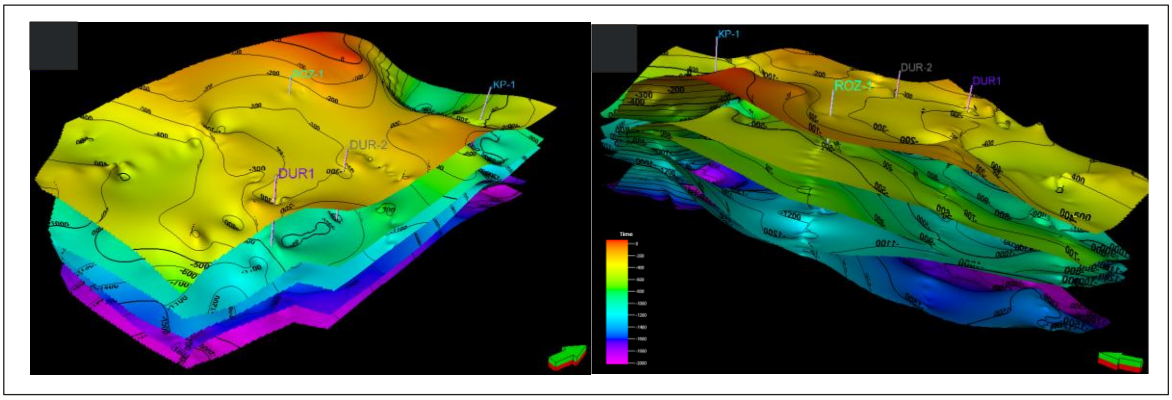


Fig. 7-18Space position of all surfaces

From the general trend and shape of all the surfaces it is visible that they are controlled by Neogene tectonics, which has a very intensive influence on the morphology of sedimentary sequences. The largest tectonic activity was during the Karpathian and Badenian where strike – slip faults predominated. In the Sarmatian these faults changed to similar extension faults.

7.3 Characteristics of tectonic structure

Following facts obtained from the display of these surfaces, a very intensive interaction between tectonic and reservoir rocks was determined. Due to a lack of 3D seismic data it was possible to construct only a simplified tectonic model from the studied area. The model was constructed based on the combination of the surface trends described above and the interpretation of faults from a few seismic sections in Petrel. The tectonic model demonstrates the course of individual fault systems and their effect on the geothermal reservoir. The tectonic structure in the central part of Kosice Basin includes several fault systems.

In seismic profiles faults have sharp edges showing seismic reflexes - a 'cut – off' or an abrupt change of reflexes visible in a dip. The most significant rupture of sedimentary filling is a nearby neovolcanic intrusion in the eastern part of the studied area. During the ascension of neovolcanites to the ground stress was generated, which caused several tectonic structure systems to form. These tectonic structures have minor length and regional range and they do not have a significant effect on the segmentation of the underground geothermal reservoir, i.e. fissured carbonates. The faults tend to be very irregular and difficult to interpret due to a lack of other seismic sections, and for that reason these faults are not incorporated into the tectonic model.

The tectonic model involves two significant fault systems where the first group of faults have a regional trend and it was possible to interpret these important faults in seismic sections and integrate to the tectonic model of the studied area. Normal faults predominate and generate ''growth fault'' types of faults of NE – SW direction (Fig. 7-19A). 'Growth faults' are growing faults that are shown by sediment thickness changes at the border of faults.

NE- SW faults were generated during the development of the Eastern Slovakian Neogene Basin. Faults have mainly oblique – slip or planar form. Their concave trend and depth of disposition shows that these faults were generated first of all during the Badenian and

Sarmatian. It is related to the largest sedimentation in the Eastern Slovakia Basin caused by massive subsidence near near the south-eastern edge of the basin. Some of them, mainly planar faults, have deep impact, which is the reason for the segmentation of the underlier carbonates of the Mesozoic. The fault's importance affects morphology, which is obviously visible on surfaces described above. By analyzing the selected horizons (surfaces) two outstanding depressions are evident. In the north it is the Cizatice depression (Fig. 7-19C) and in the south it is the Durkov depression. Both of them are controlled by NE – SW faults and separated by the elevation of the nearby well Kecerovske Peklany – 1. Both structures were created during the Neogene sedimentation, which was affected by the intrusion of neovolcanites. The intrusion probably caused nipping of the underlier and at the same time elevations originated.

The next group of faults are faults of N – S direction (Fig. 7-19B). This fault system is interpreted in the western part of the studied area. A planar normal fault with amplitude of drop around 150 ms (approx. 120 m) is visible. This fault caused significant morphologic bending. The generation of this fault happened during the Paleogene and it is an old deep fault structure which is evident both above ground and in the whole underlier of the East Slovakian Basin, where it significantly segments the geothermal reservoir carbonates.

The pictures below show tectonic segmentations of the model (Fig. 7-19D), the main (possible to interpret) faults (yellow) and faults which affect the tectonic structure of the area but are impossible to interpret and integrate into the model (white).

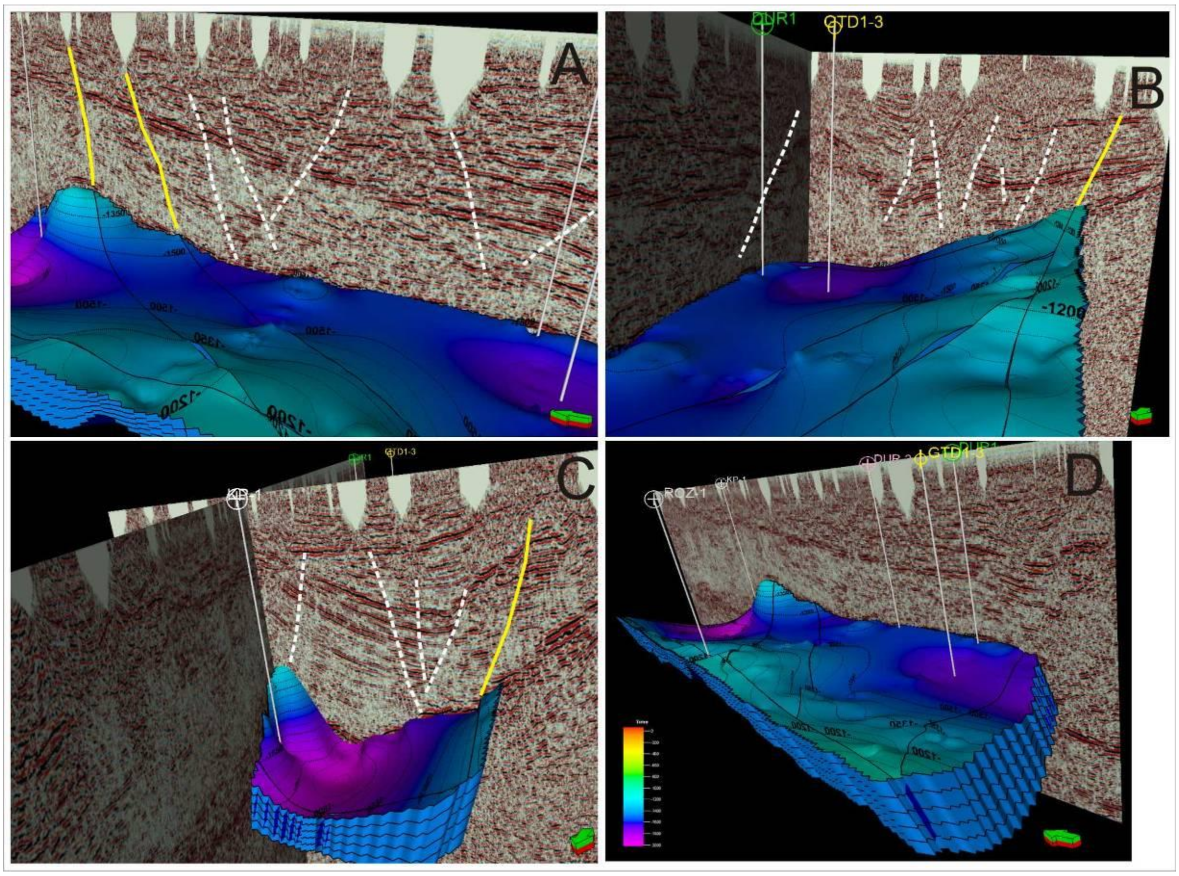


Fig. 7-19 Simplified 3D tectonic model

7.4 3D reservoir model interpretation

Based on the interpretation of seismic profiles, deep wells and 3D modeling, it can be assumed that the Triassic dolomites that form the main geothermal water reservoir are not one homogenous body. Carbonates are not appropriate reservoir rocks but the fact that carbonates in Kosice basin were uplifted above sea level, eroded and underwent karsification made them convenient reservoir rocks with fissure permeability. Sediments of Neoogene (clays with sandstones and conglomerate layers) are considered to be insulator rocks.

7.4.1 Interaction between tectonics and geothermal water reservoir

Tectonics affected the segmentation of the geothermal reservoir in the whole modeled area and created several individual blocks. As it was mentioned above, the main role in the segmentation of the reservoir is carried out by faults of NE – SW and N – S direction. The non-homogenous structure of the reservoir is apparent both from the tectonic model (Fig. 7-20, Fig. 7-21) and also the general course of the model (Fig. 8-1) and slices (Fig. 7-22, Fig. 7-23) done for demonstration of the internal structure of the reservoir body. In the following tectonic interpretation at least four individual hydrogeothermal tectonically delimited structures can be assumed.

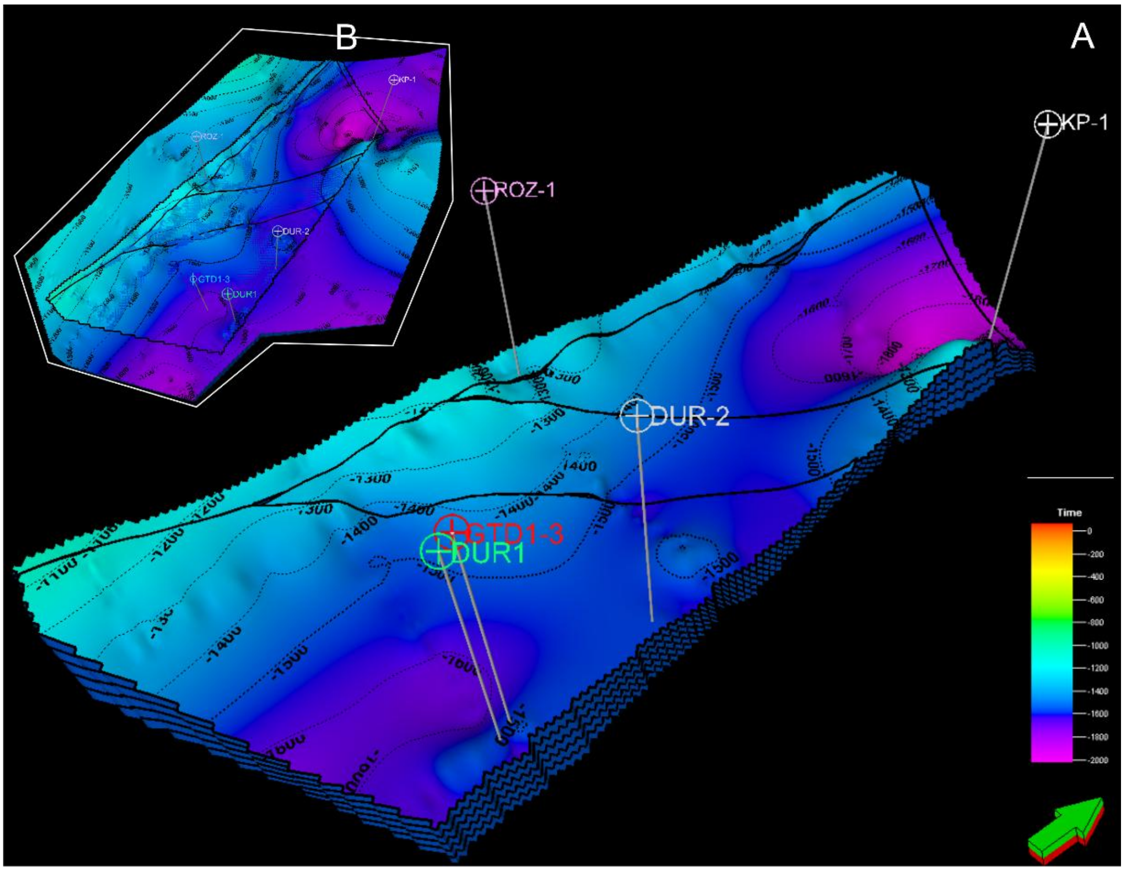


Fig. 7-20 Block structure of reservoir rocks (A) and its limitation due to a lack of seismic data (B)

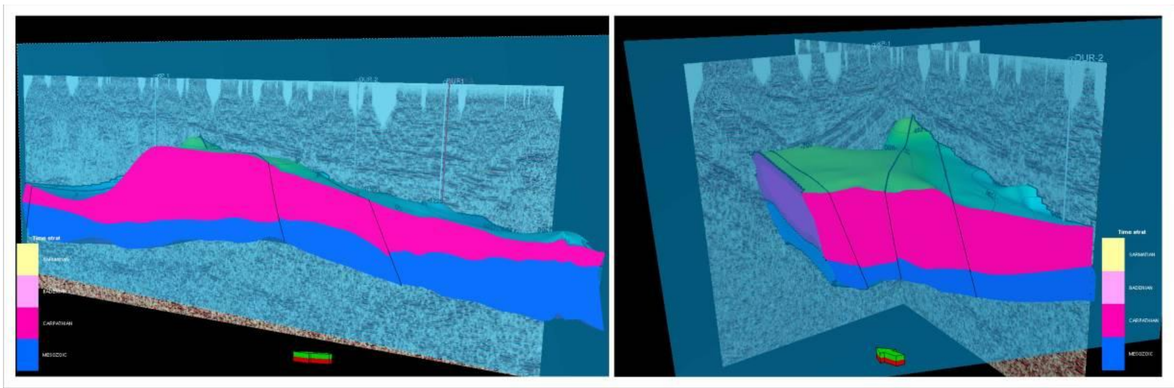


Fig. 7-21General fault intersection of Mesozoic and Karpathian overlying rocks

In the south it is the hydrogeothermal structure Durkov that is delimited from the north by the elevation of the nearby well Kecerovske Peklany – 1 and by NE – SW a fault system. This fault system is delimited from the south-north structure called Cizatice depression. Cizatice depression probably represents graben structure. In the depression higher temperature water can be found. The third individual structure is the western structure delimited by a north–south system of faults. A Smaller structure between the two NE – SW faults is probable. In the central part of Kosice Basin more fault systems occur which caused more detailed segmentation, but geophysical data limitations prevented their interpretation and visualization in the tectonic model. Pressure and inflow conditions within the individual blocks are not very clear and further exploration and tests (response tests) should be conducted to investigate this particular problem.

Tectonics' effect on the reservoir is characterized by the general trend of the model. The internal structure of the reservoir is demonstrated by cutting the model into a few slices in S – N and W – E directions. The thickness of reservoir rocks varies in the whole course of the model. The most outstanding structure in the whole model is Cizatice depression in the western part of the area, which was created due to NE – SW fault activity during the Neogene, which was probably connected with the ascension of neovolcanites to the ground. The reservoir rocks are generally pitched in a south-southeastern direction, in the direction of the Durkov hydrogeothermal structure, where the largest thickness of reservoir rocks occurs. This means that geothermal water has a natural ground slope. The downward slope of the reservoir rocks is verified by drilling. The biggest thickness of reservoir rocks, more than 1060 m, was confirmed by the oil well Durkov - 1(Vranovska, 1999). Geothermal wells GTD – 1, 2 and 3 did not penetrate through the whole Mesozoic sequence but did punch through the biggest thickness of carbonate rocks (1055 m) (GTD-1). Well Kecerovkse Peklany – 1, situated more to the north, proved thicknesses around 660 m. The thinnest part was determined to be in the vicinity of well Rozhanovce – 1 in the northwestern part of studied area, which penetrated through the Mesozoic sequence, and its thickness is 185 m. It is probably related to the upper position compared with the rest of the area due to the uplift of the pre–Mesozoic underlier. It appears from this that the thicknesses of reservoir rocks are tectonically reduced toward the western edge of the area.

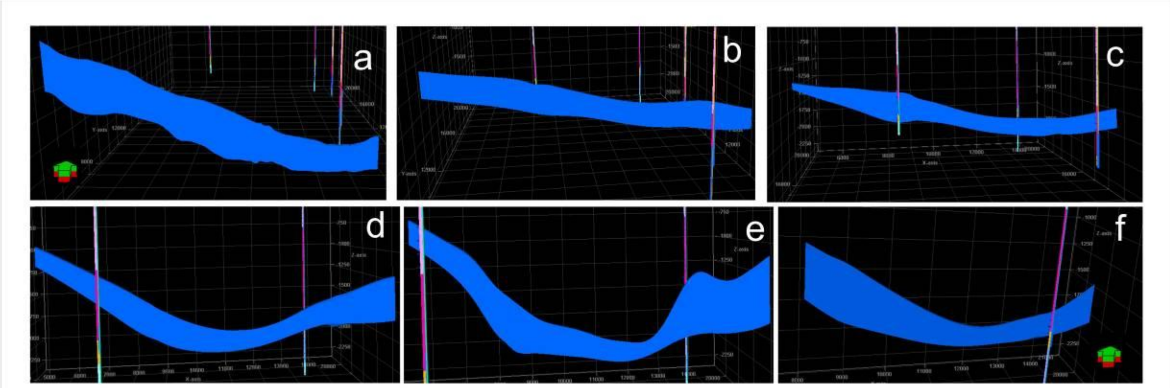


Fig. 7-22 Internal structure of reservoir rocks in S (a) – N (f) direction

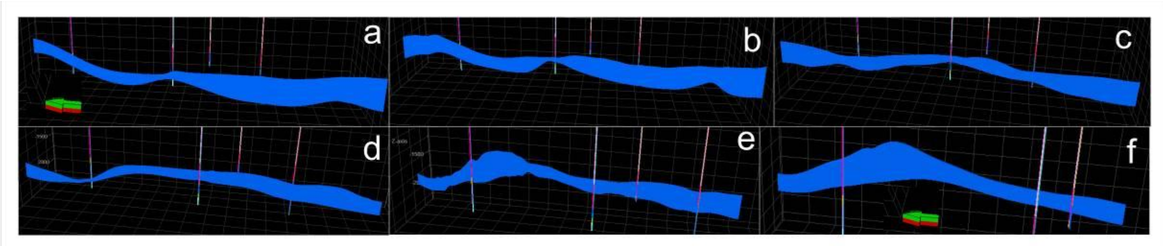


Fig. 7-23 Internal structure of reservoir rocks in W (a) – E (f) direction

8 INTERPRETATION OF RESULTS AND DISCUSSION

Slovakia is a country with proper geological conditions for geothermal energy sources and utilization. The geological structure of Slovakia has zonal settings and it is created by two individual geologic units – the Inner and Outer Western Carpathians. The most significant areas with high temperatures and high values of surface heat density from a geothermal point of view are Tertiary basins, volcanic mountain ranges and intermountain depressions of the Inner western Carpathians. These geologic units are based on 26 potential areas in Slovakia, which constitutes 34% of the total territory of Slovakia. Geothermal water is accumulated mostly in fissured dolomites and dolomite limestones of Anisian and Ladinian ages (Middle Triassic). Less abundant geothermal water reservoirs are Neogene sands, sandstone rocks, conglomerates and Neogene andesites and their pyroclastics. The occurrence of reservoir rocks happens within the depth range of 200 – 5000 m. The average temperature of geothermal waters in all types of reservoirs is 15 – 160 °C. The geothermal waters probably have meteoric/marine origin which saturated through the Neogene formation (plus saliferous sediments of Karpathian) to the Mesozoic reservoir.

Among 26 perspective geothermal areas, the fissured dolomite rocks of Kosice Basin are considered to be the most prospective geothermal reservoirs. The source of heat is a near-surface thermal anomaly with its beginnings in the Pannonian Basin (Hungary). This anomaly causes relatively high heat flow, which is explained by a Middle Miocene extension and thinning of the lithosphere (e.g. Royden et al., 1983). The East Slovakia Basin, as a northern promontory of the Pannonian Basin, is the hottest area of the anomaly, with heat flow above 100 mW/m^2. The first results concerning geology and thermal conditions were obtained during petroleum exploration in late the sixties and early seventies. The first special geothermal research in Kosice Basin was realized in 1998 when three geothermal wells – GTD – 1, 2, 3 – were drilled. Research took place in the southern part of Kosice Basin near to Slanske vrchy Mts. in the Durkov area.

Seismic measurements realized in 1992 in the central part of Kosice Basin provided the basic data needed for the construction of the 3D model. The total area in which the seismic measurements were done is 187 km^2. The 3D model shows the spatial distribution, thickness and influence of tectonics on reservoir rocks and the Neogene overlying rocks. Neogene rocks, as a unit, except for basal breccias of Karpathian age are considered to be a relatively impermeable top of the main geothermal water reservoir dolomites and have an insulating function. The contact zone between Mesozoic and Karpathian sediments is considered to be the most permeable feed zone. According to Cvercko(1969) permeability decreases with depth, but considering fissure permeability and tectonic rupture it is not a rule for the whole area of interest. From the model (Fig. 8-1) it is visible that the course of the Mesozoic sequence is different than course of the Neogene sequence. In the case of carbonates, the sedimentary conditions and processes after sedimentation are different. Dolomites were accumulated in the space of the neritic (shallow environment) sea during the Middle Triassic. During the main folding stage in the Inner Western Carpathians, probably between the Upper Cretaceous and Paleocene epochs, the rocks of the pre–Tertiary underlier were affected by very strong denudation, which persisted until the Lower Miocene. This is the reason why Jurassic and Lower Cretaceous complexes do not occur. Strong erosion caused that surface of Triassic carbonates to be fissured and weathered to the depth of 100 – 200 m, which makes carbonates an appropriate geothermal water reservoir (Vranovska, 1999). After the uplift and denudation of the Mesozoic sequence sediments of Neogene started their deposition. The thickness of Neogene sediments is changing in connection with tectonic and sedimentary conditions. In the direction of the Eastern Slovakia basin (east) the thicknesses of Neogene and Mesozoic sediments are increasing. This is related to the opening of the basin in a southeastern direction. According to Rudinec (1989) the Mesozoic complex probably continues deeper under the Slanske vrchy Mts. Currently, inactive intermediate neovolcanites with large amounts of quartz (a good thermal conductor) can represent a local heat source for the surrounding deep embedded Mesozoic rocks. Neovolcanics are a natural barrier for geothermal water flow.

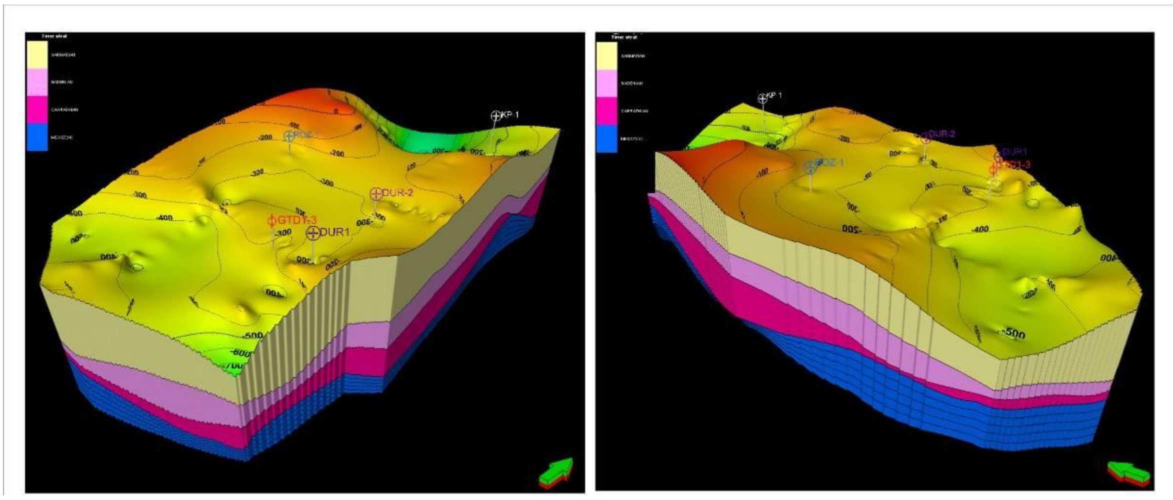


Fig. 8-1 3D model of Mesozoic and Neogene sequences

Analysis of the model shape (Fig. 8-1, Fig. 7-21) can lead to conclusions about the general structure. It can be assumed that the studied area was tectonically ruptured, which has an effect on spatial distribution and thickness changes. The territory of Kosice Basin as a part of the Eastern Slovakian basin has a complicated tectonic structure (Fig. 6-4). The main tectonic effect was caused during the Miocene and especially during the Badenian and Sarmatian subsidence and extension of the Eastern Slovakian Basin. A simplified tectonic model from part of the study area demonstrates the effect of tectonic activity on the pre–Tertiary underlie, ergo Mesozoic dolomites. The general course and spatial distribution of reservoir carbonates shows that the thickness is changing in the whole space. Based on the tectonic model and interpreted seismic sections it is possible to assume that the reservoir rocks are not one homogenous body but, due to tectonic effects, they are segmented into at least four individual blocks. The most morphologically outstanding block, including the Cizatice depression, is in the western part of the model. The Cizatice depression is probably graben structure and its origin was controlled by the activity of NE – SW faults during Sarmatian. Less morphologically outstanding is the Durkov depression, where the hydrogeothermal structure was determined. The Durkov structure is also delimited from the north by a NE – SW fault system and from the west by a N – S system of faults. The last mentioned fault system delimits the western individual block. The fourth individual block is located between two NE – SW fault systems, which are antithetic to each other. The temperature of geothermal water depends on the depth of deposition of the reservoir rocks, and therefore on the geothermal gradient. The two mentioned depressions (Cizatice on the west and Durkov on the southeast) represent places where higher temperatures are more likely to occur, especially if neovolcanic rocks occur nearby. Places with lower temperatures can be assumed in elevated parts of the model that are in the western part delimited by N – S fault and in the elevation between the two antithetic NE – SW faults. Carbonates are pitched in a south – southeast direction with the biggest thickness in the Durkov hydrogeothermal structure area. In the northwest the thickness of the reservoir is decreasing (185 m) and the reservoir was reached at a very small depth of 1500 m under the ground (well Rozhanovce 1). The biggest thickness - more than 1060 m - was verified by Durkov – 1 oil well. As it was mentioned above, the Durkov area was explored to assess geothermal water sources for utilization in Kosice town. The Durkov hydrogeothermal structure is considered as the most perspective geothermal area in Kosice Basin based on quality seismic data, borehole data and hydrodynamic tests. In the rest of the central part of Kosice Basin geothermal research was not realized and the existence of geothermal waters reservoir rock was documented by petroleum research wells.

The Durkov hydrogeothermal structure confirmed the existence of geothermal reservoir rocks and based on hydrodynamic tests the geothermic data, hydrodynamic and thermodynamic parameters, parameters of the geothermal reservoir, physiochemical properties of the water and gases were determined. The geological structure and geochemical factors point out that it is an enclosed structure with very small or no recharge of its geothermal water. The evidence is isotope analyses and geochemical settings of geothermal waters from geothermal wells. According to the facts mentioned above and a simplified tectonic model, the existence of another individual block without the potential effect from the surroundings in this area can be assumed, for example, in the Cizatice depression in the west part of the model. Another proof is the fact that three geothermal wells (GTD 1, 2, 3) did not affect each others' yields (average yield is 50 – 60 l/s), which is caused most probably by tectonic closing. (Fig. 6-5)

The total modeled area is 187 km^2, from which 33, 6 km^2 constitutes the Durkov hydrogeothermal structure. The thickness of the reservoir rocks from exploration data in Durkov area is in the range of 50 – 1100 m and the thickness measured in 3D model is within the range of 45 – 525 m. Such a big difference is caused by the availability of the data from which the model was constructed. It was based only on six 2D seismic profiles compared to a very detailed seismic data and borehole data realized in the Durkov area. Mesozoic carbonates in the Durkov structure have temperatures of 100 – 135 °C at depths of 1800 – 2600 m and 120 – 185 °C at depths of 2500 – 3200. The average temperature at a depth of 2300 m is 135 °C. The average thermal gradient is 29, 4 °C/km for Mesozoic rocks and 51, 2 °C/km for the Neogene sequence. Without any geothermal research and hydrodynamic tests in the rest of the modeled area it is difficult to predict the main geothermic conditions, but based on the morphology of reservoir dolomites it is possible to assume that similar geothermic conditions could be found in the Cizatice depression. Comparing the positions of the Durkov and Cizatice depressions the temperature in the last mentioned depression could be similar. Lower temperatures could be expected in elevated parts of the model, in well Kecerovske Peklany 1 and well Rozhanovce 1, surrounding and also in the elevation between these two wells.

Evidently, to confirm this hypothesis it is necessary to do very detailed geophysical research with a dense network of seismic lines to determine the thickness and position of reservoir rocks and tectonics in the area north and west of the Durkov hydrogeothermal structure. The proximity of neovolcanites causes risks from a drilling point of view. It is very important to detect the position of volcanic bodies before drilling in order to ensure the proper localization of wells. It is important to detect volcanic intrusions to avoid reaching them during drilling. Seismic profiles – in particular seismic profile 704/92 – with buried intrusions are examples of the existence of volcanic bodies in the area.

CONCLUSIONS

In the first section, the report presented a general overview of the geology and geothermal potential in Slovakia. In the second part detailed geology and geothermal conditions and exploration in central part of Kosice basin were documented. In Kosice Basin, geothermal research was realized in 1998 and three geothermal wells – GTD 1, 2, 3 – in the Durkov area confirmed the existence of geothermal water, which was known from petroleum research realized in Kosice basin in the nineteen-sixties and seventies. Geothermal water existence verification was done for its prospective utilization in the city of Kosice. Well head temperatures ranging between 123 – 129 °C and approximately 170 l/s total flow from the three geothermal wells seem to be promising for the development of a low temperature binary geothermal power plant with combined heat and electricity production. For example, ORC binary power plants are designed for temperatures ranging from 45 °C (Alaska) to 225 °C (Hawaii) and are built in a variety of sizes (Bronicki, 2007).

Based on seismic measurements realized in Kosice basin in 1992, a 3D model of the central part of Kosice Basin was constructed in Petrel software. The model was created based on six 2D seismic sections. The amount and quality of 2D seismic sections was the biggest limitation. This vantage occurred mainly during the modeling of the tectonic structure. The result is two models. The first shows the tectonic structure spatial distribution of Triassic dolomites as a reservoir of geothermal waters in the studied area and Neogene sediments as an insulator rocks and their morphology. The second model shows simplified tectonics, the area of which is smaller due to a lack of quality data.

The morphology of individual sequences and the simplified tectonic model indicate that the studied area is tectonically ruptured, which attests to the position of the Eastern Slovakia basin within a complicated tectonic structure. Mainly Neogene tectonics affected the insulator and reservoir rocks. Middle Triassic dolomites with fissure and karstic permeability and basal Karpathian clastic rocks are considered to be reservoir rocks. According to the results of hydrodynamic tests from three geothermal wells, the contact zone of Mesozoic and Karpathian in depths of 2000 – 2600 m rocks is considered as the main inflow zone (Vranovska, 1999). Based on the simplified tectonic model at least four individual blocks can be assumed in the central part of Kosice Basin, which should not affect the amount of water and hydrogeothermal conditions of the surrounding blocks. Tectonic rupture and denudation processes during the Paleogene had an impact on the spatial distribution of reservoir rocks, which is demonstrated by irregular distribution of carbonates. The biggest thickness of more than 1060 m was verified by drilling in the area of the Durkov hydrogeothermal structure and the smallest thicknesses were defined in the vicinity of well Rozhanovce 1. This could be related to an elevation in the pre – Tertiary underlier.

The model showed that there are convenient reservoir rocks in the central part of Kosice Basin and their geothermal potential was verified by geothermal research in the Durkov area. Tectonic segmentation could be a positive factor because it separates individual blocks from each other and extraction from one block shouldn’t be affected by extraction from another. Geothermal research in the northern part of the modeled area in the Cizatice depression could give very similar results. Before drilling, detailed geophysical measurements are needed for the precise localization of wells.

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