Application of shallow reflection seismics for identifying geological structures of potential geothermal areas

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Abstract

Geological structure of the area at the boundary between Nízke Tatry Mts. and Liptov Depression was investigated by reflection seismic methods. The seismic record and following processing showed three different lithological units steeply dipping northward from the Nízke Tatry Mts. The lowermost unit is composed of Mesozoic dolomites representing a potential source of geothermal water. Such source may be used for touristic activities in the investigated area.

Key words: shallow reflection seismics, processing, geology, geothermal energy

INTRODUCTION

The Nízke Tatry Mts. undoubtedly belong to the touristically most attractive regions in the Slovakia. The nature of the area, declared a national park in 1978, is fascinating during both winter and summer. In the larger surroundings of the Chopok ski center the best Slovak ski slopes occur with parameters suitable for organizing international competitions. Recently, there is a boom of Alpine skiing when tourists overcome difficults slopes and ridges of the mountain. During summer the region the region is especially well known by its hiking trails. Evaluating different parts of the Nízke Tatry Mts., it is clear that the most visited part is a deep and long Demänova valley. The valley is an entrance road to the main ski resort of the mountain and to the most attractive caves in the mountains originated in Mesozoic dolomites. The Demänova valley is interesting not only from the touristic viewpoint, but also by its geological structure. The valley is formed by Mesozoic carbonates (limestones and dolomites) abruptly cut by a normal fault at its outlet to the Liptov Depression (Fig. 1). The normal fault makes a distinct boundary between the Mesozoic carbonates and Paleogene mudstones and sandstones. There is also an important change – the „Liptov side“ of the fault (Liptov Depression) has a high geothermal potential due to its high heat flow. This, together with a fact that there is an extreme concentration of hotels and other lodging facilities in Demänova valley that could utilize the geothemal sources for heating purpose, led us to a geologic research focused on the potential of the area close to the valley outlet from the viewpoint of geothermal properties. Secondly, our research tried to explain the type of boundary between the Mesozoic unit of the Nízke Tatry Mts. and Paleogene unit of the Liptov Depression.

GEOLOGICAL BACKGROUND

The study area extends at the area of Demänova valley outlet at the boundary between the Nízke Tatry Mts. to the Liptov

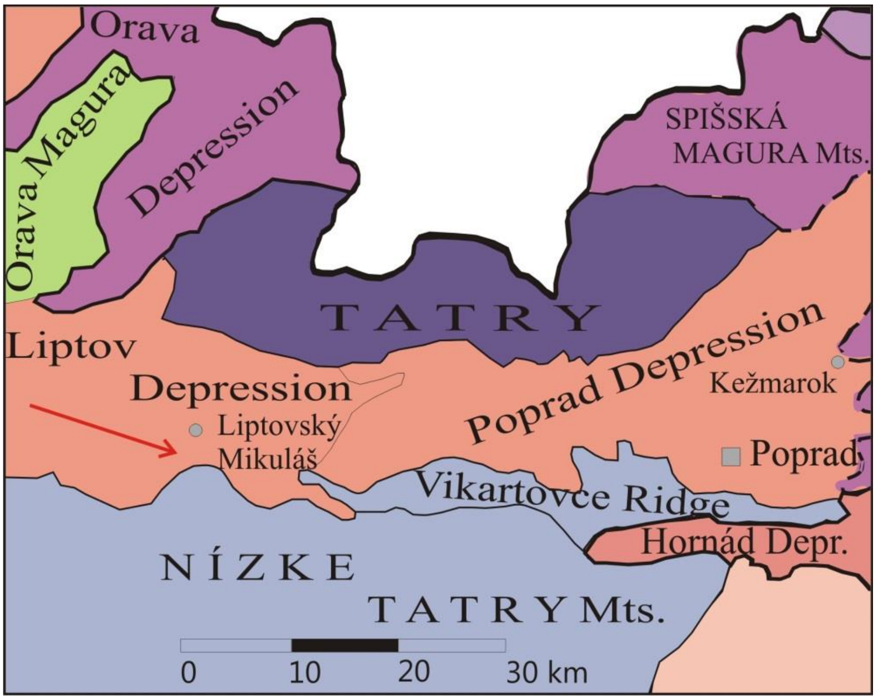

Fig. 1 Location of the study area (red arrow).

Depression (Fig. 1). The Nízke Tatry belong to the Tatra-veporicum unit composed of Paleozoic crystalline rocks and overlying Mesozoic rocks with complicated tectonic structure. All these units were penetrated by a well FGL-1 drilled in surroundins of Liptovský Mikuláš (Fig. 1).

Crystaline rocks of tatraveporicum unit are represented by several tectonic complexes termed according to their stratigraphic position. The lowemost unit is composed of mica schists and gneisses underlying migmatits and granitoids. The higher tectonic unit is a complex of granitoids and tonalits overlying migmatits and amphibolites and/or migmatitized gneisses. The autonomous unit is made by granitoids with frequent xenoliths of gneisses and overlying gneissic-amphibolitic mantle.

The Mesozoic rocks are predominantly represented by carbonates assigned to three tectonic units: Choč, and Krížna Nappes, which play a major role in the area studied, and Mesozoic envelope. The rocks of the Krížna Nappe with stratigraphic range from the Upper Hoterivian to Lower Aptian, are composed of shales (Verfen Formation?) underlying Middle to Upper Triassic dolomites occasionally interbedded with anhydrites. The Choč Nappe is the highest Mesozoic unit represented in the study area by Middle Triassic Ramsau Dolomites. The dolomites may be brecciated in their lower part. Occasionally, cherts occur in the upper part. The uppermost part of the dolomitic interval may consist of Wetterstein Dolomite (Ladinian – Lower Karnian) typical by brecciation.

The Paleogene rocks belong to the Sub-Tatric Group filling the Inner-Carpathian Paleogene Basin. They may be thick up to several hundred meters in the study area. Based on their lithology, they are subdivided into four formations. The profile of the FGL-1 well penetrated only three of them: the Borové, Huty and Zuberec Formations. The lowermost Borové Formation (Middle and Late Eocene) is represented by subaerial and shallow marine, coarse-grained sediments and nummulitic limestones. This is overlain by the Huty Formation (Late Eocene – Oligocene) composed of dark mudstones and occasional thin layers of sandstones. The uppermost formation in the area is Zuberec Formation (Oligocene). It is composed of alternating beds of sandstones and mudstones.

METHODS

Geological structure was investigated by reflection seismic method. We used the seismic device Terraloc Mk8 (ABEM company) with 24 channels connected to geophones SM-4B (10 Hz). The basic set up of the Terraloc during the measurements is shown in the table 1.

The recorded field data were stored in the SeisTW software. Later, they were processed in the Reflex W programme. The processing included filtering, time analysis, pre-stack and post-stack migration, velocity analysis and final stack of the obtained seismic section. The section was further interpreted following conventional methods used for interpretion.

ANALYSES AND INTERPRETATIONS

The profiles shoot in the field were generally set out along south – north lines perpendiculary to the assumed boundaries of geological units belonging to the Nizke Tatry Mts. and Liptov Depression. In order to test the reliability of the seismic device and to find the boundaries between the geological units as precise as possible, we shoot several lines long from 125 to 287.5 m. The time delay of the first seismic response was determined directly in the field in SeisTW (Fig. 2).

The data stored in SeisTW programme were later imported to the Reflex W programme used for their processing. The processing consists of several mathematical operations modifying the seismic reflection signal in order to select individual types of signals and reflexes pointing at the seismic boundaries, which may be considered as lithological boundaries. The seismic boundaries occur at sites between rock units with different acoustic impedance. One of the most important steps in the processing is velocity analysis revealing the velocities of seismic wave in different lithological units (Fig. 3). A precise estimation of this parameters influences correct definition of the depth of the boundary between two different lithological units.

The result of the processing is final version of the seismic picture after final stack (Fig. 4). This profile is further analysed and interpreted in order to change the seismic to geological picture. The measurements along the different seismic profiles generally showed similar pictures with possibility to recognize three basic seismic units (Fig. 4).

Seismic unit 1 is typical by laterally consistent reflexes with a big amplitude and small frequency. This unit demonstrates the alternating sandstone and mudstone beds and we thought it represents the Paleogene Zuberec Formation. The unit thickness is up to 200 m.

Tab.1 Set up of the seismic device Terraloc durig the field measurements.

Sampling interval	500μs
Sampling step	8192
Source	mechanical hammer ESS - 100
Stack	1
No. of stacks	auto
Setting up of the transmitter	strike
Setting up of the transmitter´s level	95%
Starting of the record	auto
Setting up of the record	manual
Distance between geophones	12.5 m
Datum level for seismic section	650 m.n.m.

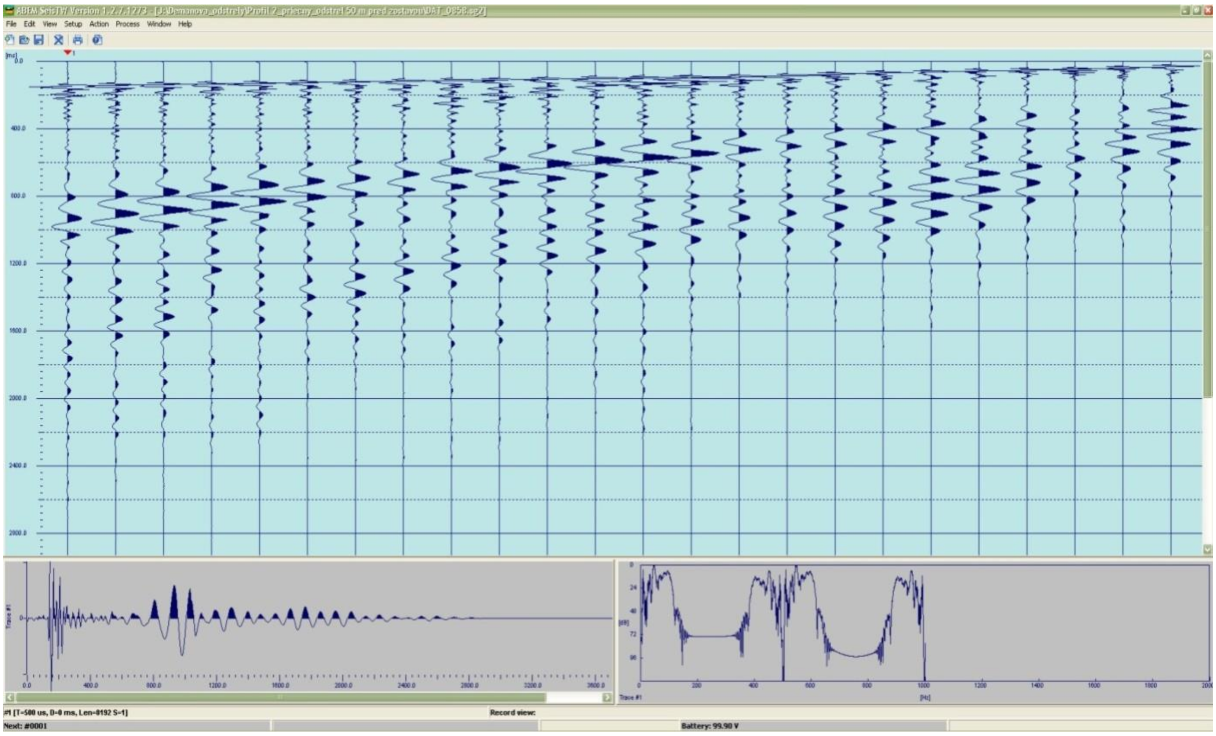

Fig. 2 The example of measured record of seismic signal on the point 858, profile D-1, 24 channels. In a grey field on the bottom – the detail of record on No.1 channel. The left window shows time delay of the arrival of the first seismic wave to geophon.

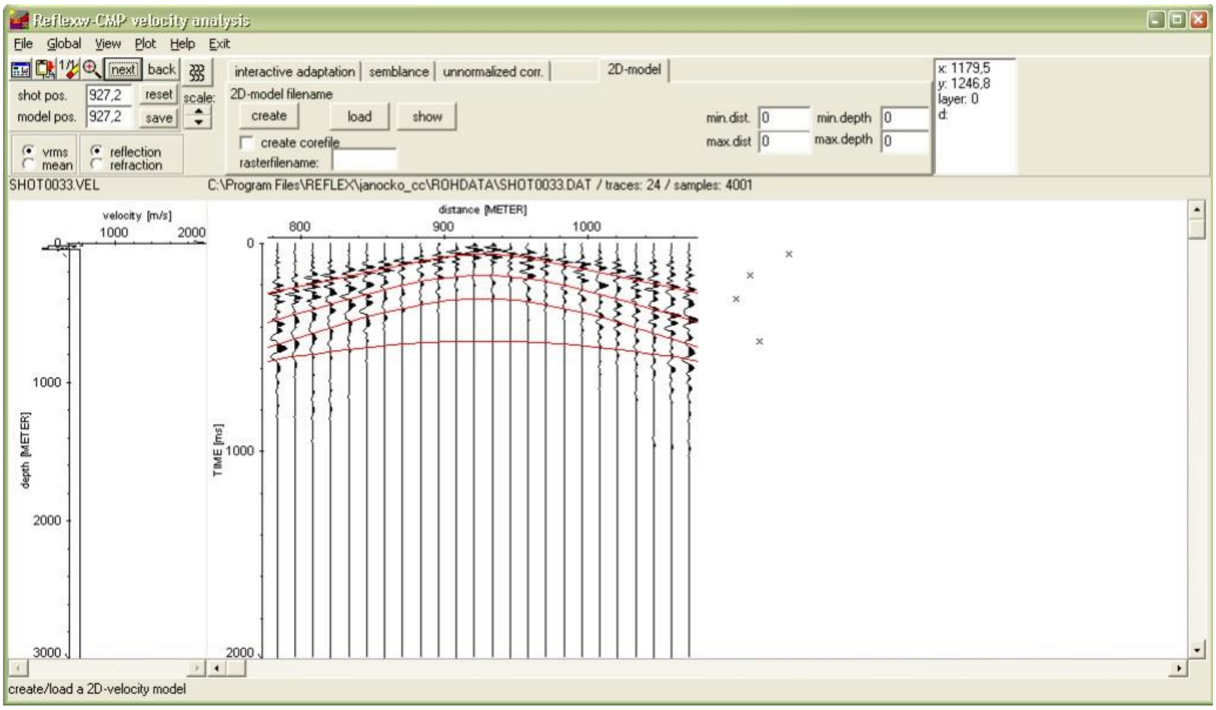

Fig. 3 Velocity analysis during processing of seismic signal.

Seismic unit 2 is created by the discontinuous reflexes with a smaller amplitude than in the previous unit. The unit represents the predominant mudstones and probably represents the Huty Formation underlying the Zuberec Formation. The base of the unit is about 400 m below surface.

Seismic unit 3 is again created by more distinct, laterally often consistent reflexes

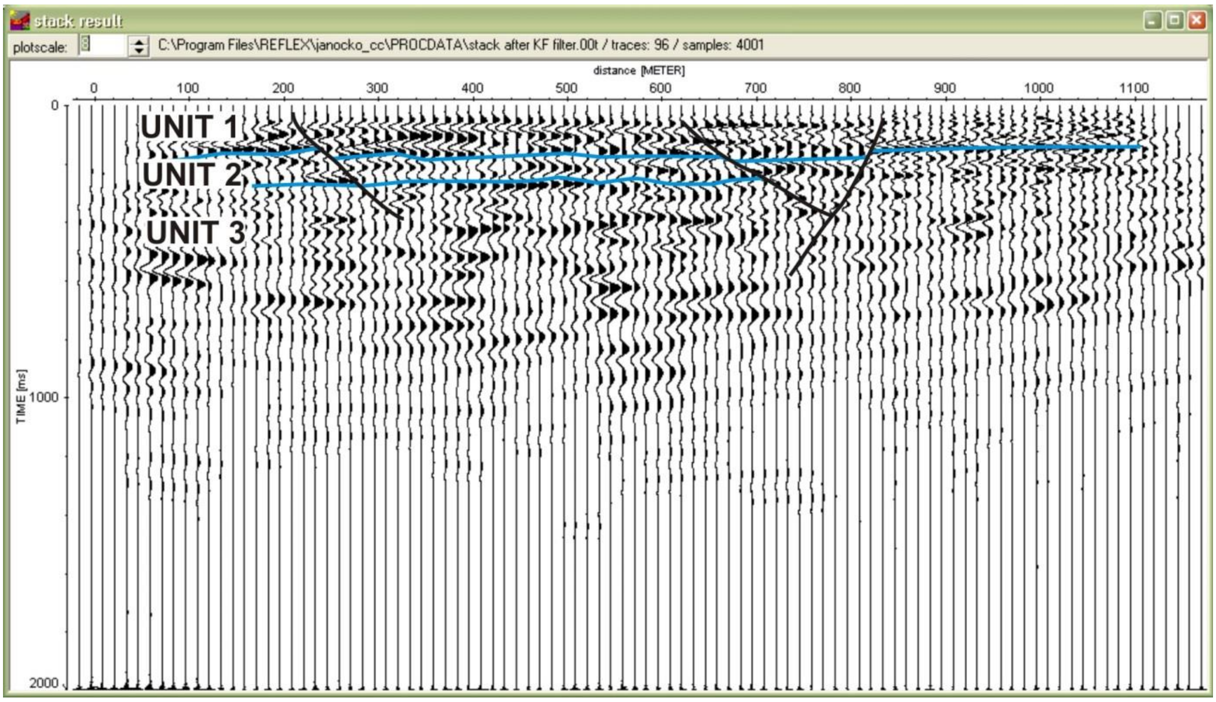

Fig. 4 Seismic profile after a final stack. Note different types of reflexes subdivided into three units. Three normal faults are also depicted.

with bigger amplitudes and smaller frequency compared to the previous unit. This unit is interpreted Mesozoic dolomites and dolomitic limestones. The dolomites are assigned to the Mesozoic unit of Choč Nappe overlying rocks of the Krížna Nappe.

The geologic interpretation of seismic profiles suggests dipping of the Mesozoic rocks northward. The dipping is intensified by normal faults dipping toward north (Fig. 5). The steep sinking of the Mesozoic carbonates, which are good groundwater aquifers, results in water temperature increase close beyond the boundary separating the Nízke Tatry Mts. from the Liptov Depression. This makes the area flanking the Nízke Tatry Mts. from the north potential from the viewpoint of geothermal energy source occurrence.

CONCLUSION

Reflection seismic methods belong to the most efficient methods mostly used for hydrocarbon prospection. New technologies provided small, portable seismic devices with simple manipulation, having sufficient vertical resolution reaching several hundred meters. Such devices may be used in numerous basic and applied geological disciplines (engineering geology, hydrogeology etc.). In this study, we used the seismic device Terraloc to investigate the geological structure at the boundary between the Mesozoic complexes of the Nízke Tatry Mts. and adjacent Paleogene rocks of the Liptov Depression. The obtained seismic profiles showed three distinct seismic units dipping from the Nízke Tatry Mts. northward. Each of the unit represents different lithological package. The unit 1 represents Paleogene Zuberec Formation consisting of alternating beds of sanstones and mudstones. The unit 2 is interpreted as mudstones of Huty Formation. The unit 3 represents Mesozoic dolomites cropping out in the region of the Nízke Tatry Mts. All the units are deformed by normal faults, which steepen their dip toward the centre of the Liptov Depression.

The interpreted geological structure suggest high geothermal potential of the area investigated; the karstified and fissured dolomites are a good groundwater aquifer.

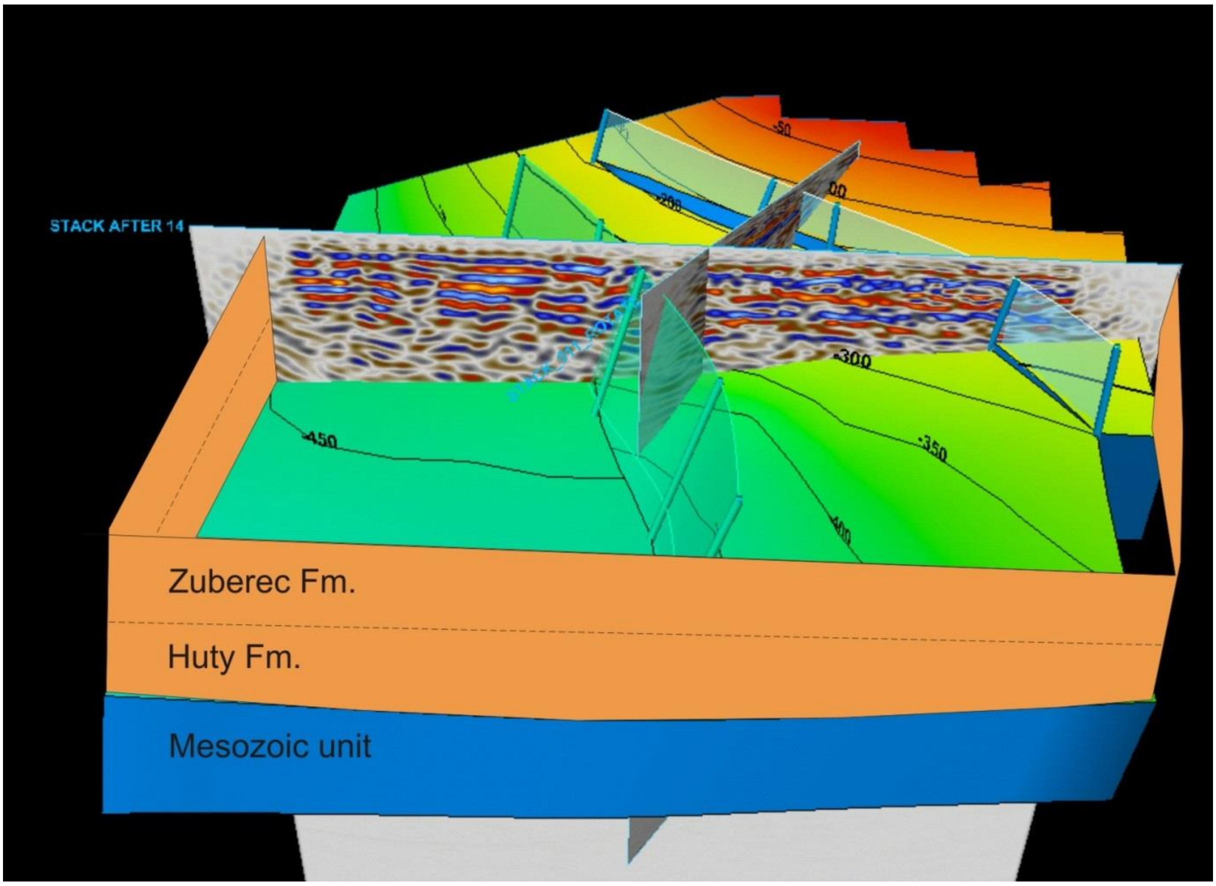

Fig. 5 Interpretation of geologic structure close to the boundary between the Nízke Tatry Mts. and Liptov Depression based on the seismic reflection profiles. The Mesozoic unit is overlain by Paleogene Huty and Zuberec Formations. The unit steeply dips northward that is also intensified by normal faults (transparent planes shown in the figure).

Because of their steep dip they occur relatively close to the Nízke Tatry Mts. deep under the surface covered by thick mudstones and sandstones of Paleogene rocks. This favours their high temperature and possible use for wide range of activities from recreational purpose to heating. Because the study area occurs in the centre of the touristic activities, such knowledge surely may be used for development of tourism.

Acknowledgment

The paper was written thanks to the support of the Operation Program Research and Development for the Project 26220220031 co-financed from the resources of the European Foundation of Regional Development.