INTRODUCTION

The seismic survey is a leading geophysical technique in the location of potential hydrocarbon and geothermal reservoirs beneath the Earth’s surface. However, there might be some cases, when the method is inadequate for the reflection imaging of subsurface geology. In this paper, the areas of Nyírség and Szatmár-Bereg counties are presented, where the traditional, short-offset PdP-u-reflection seismic measurement was unsuccessful because of the lithological character and spatial position of the geological formations. All this is due to a thick buried Miocene igneous complex, which forms a strong barrier for wave propagation and causes uncertainties during the interpretation of the pre-Neogene basement.

The primary purpose of the study is to summarize and introduce the regional deep geology, to construct multi-layered, complex geological-geophysical models based on the available dataset and to evaluate the possibilities of their seismic reflection imaging. In course of this procedure, forward modeling is utilized to reveal the reasons behind the weak subvolcanic amplitudes and which results allow to propose a new strategy for measurement design.

1. SEISMIC POTENTIAL OF VOLCANIC AREAS

The seismic exploration of Nyírség and Szatmár-Bereg counties (northeast Hungary) has been started in the late 1950’s. Afterwards, two other reflection seismic campaigns were done in 1969 (ELGI) and between 2001-2004 (GES Ltd.). In 2016, some archive seismic records were re-processed by the Common Reflection Surface (CRS) stacking method, but it did not result a much better solution for mapping of pre-Neogene basement structures. The complicacy of the Pannonian clastic sedimentary layer with thickness of 500 to 1500 m and the underlying, inhomogeneous Miocene igneous-volcanoclastic unit with thickness of 1000 to 3000 m are forming an obstacle in the way of conventional seismic survey to map deep geological structures. Sharp reflections are available only from the Pannonian layers and from the top of the igneous complex. This volcanic sequence can be recognized as a chaotic reflection pattern on the seismic section (Fig. 1.).

If an irregular, undulating volcanic surface associated with high acoustic impedance and structural heterogeneity is able to result high reflection and low transmission coefficients, backscattering of the incident wave and energy in all of the directions (reducing the coherency of reflections), multiples in short-offset or even extreme ray bends (possibility for shadow zones). A multi-layered, sequentially changing volcanic complex characterized by relatively lower and higher velocities acts as a high-cut filter for seismic wave.

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Part of a seismic section showing the uncertain interpretation of pre-Cenozoic basement, as a target interface. The volcanic sequence appears as a chaotic reflection pattern on it.
(solid blue - faults, solid red - top of vulcanite, dashed purple - basement)

The exploration of volcanic areas is challenging from the point of view of seismic; published papers about the successful identification of volcanic reflectors are rare. Some authors [4], [5], [9] suggest the implementation of long-offset acquisition geometry of pure P-wave (PP) for imaging sedimentary horizons lying beneath a high-velocity layer, because far-offset wave-field is free from multiples and the reflection coefficient has a maximum value around the critical distance. Other papers recommend the long-offset acquisition geometry to utilize a greater part of the converted wave (PS) energy [9]. One of the benefits of the converted waves is their maximum amplitude at mid-to far-offset, by avoiding the severe multiples in near-offsets. According to [10], the use of low-frequency source (sweep starts at 1-2 Hz) with spectral whitening in tau-p domain is preferred, since the low-frequency components of the wave are less sensitive for attenuation and scattering. However, the application of the long-offset is not easy at all. Although, the far-offset range is free from multiples and ground roll; different noises, refractions and linear ringing might influence the quality of the records. Due to the spherical divergence and the anelastic property of rocks, the absorption rate and energy loss of the wave could be significant. Note that, the long-offset range is normally muted during conventional data processing; therefore, it needs unconventional data processing applying non-stretch stack and higher order NMO-correction [5].

2. GEOLOGICAL BACKGROUND

The areas of Nyírség and Szatmár-Bereg counties are lesser known and poorly explored in terms of hydrocarbon occurrences. Their subsurface geological structures are revealed only by some exploratory boreholes. In the constitution of the sub-basins and their wider surroundings the thousands meter thick Neogene formations play the
dominant roles. The buried paleovolcanic series are very thick and horizontally extended; exploitable hydrocarbon discovery has never been made [3]. The boreholes revealed Pleistocene sand, gravelly sand and clay deposits in thickness of 100 to 200 m; Pannonian-age, fluvial and lacustrine succession of porous, siliciclastic rocks and Miocene sedimentary and volcanic rocks. The last consists of Sarmathian and Badenian dacite, andesite and ignimbrite rocks referring to multi-stage, explosive volcanic eruptions formed stratovolcanoes and lava plateaus. In the calm period of the volcanism, thin-layered, fine-grained pelitic and calcareous sedimentary intercalation was deposited in neritic province. In course of the Pannonian, the volcanic activity was rejuvenated in Nyírség and Tokaj Mts. [2], [3].

Carpathian pelagic Garáb Schlier composed of sand, silt, clay and marl was explored by Baktalóránháza-1 [8]. The Eocene-Oligocene sandstones, clayey marls and conglomerates are the part of the Szolnok-Máramaros flysch belt reached by boreholes Gelénes-1, Nyírmártonfalva-1 and Nyírlugos-1 [3], [8], [11]. The Nyirábrány-1 penetrated low-grade metamorphic diabase representing a Mesozoic (Cretaceous?) formation; while the borehole Nagyecsédi-1 crossed Cretaceous submarine diorite. Lower Triassic epimetamorphic, grey, fractured dolomitic limestone, dolomite and Upper Carboniferous dark grey quartziferous shale (as Paleozoic basement) are described in the mud log of Komoró-1 [2], [7].

Based on the regional geology and the complex geophysical measurements, more than 3000 meter troughs and horst-graben structures may be found below the surface [1]. Presumably, the formations between the Triassic and Miocene might be eroded [2]. In spite of it, the geology and tectonics of the basement is still lesser known. The expected lithostratigraphy model of the studied area is illustrated in Fig. 2. After [6], the Košice Basin (SK) and the Nyírség show good correlation in their lithological characteristics.

Figure 2
Lithostratigraphy model of the studied area (5x vertical exaggeration)
3. SEISMIC FORWARD MODELING

In course of the seismic forward modeling, 4 geo-models were constructed on the basis of the available mud logs and specialized literature. The interval velocity and bulk density values were picked from the averaging of well-logs. In case of Model-1, four-layered geological models were created referring to a continuously increasing velocity field. In case of Model-2, six-layered geological models were made, whereas the previous second layer is subdivided by a high-velocity – high-density sequence demonstrating an igneous interbedding. Their common features are the next: the uppermost layer is the Pannonian sedimentary; the second last is the Badenian / Carpathian sedimentary or Paleogene flysch bed; while the last is the Paleozoic basement. The interval velocity, bulk density and thickness of them were kept constant. In the case of the vulcanite unit, a relatively thinner (A) and a thicker (B) beddings were also assumed to study the changes in wave responses (Fig. 3.). Because of the lack of direct S-wave velocity measurement, \( \frac{v_P}{v_S}=\sqrt{3}=1.732 \) ratio was used.

According to [2], recording strong basement reflection events cannot be expected, owing to the similar interval velocities of Badenian / Carpathian formation and the basement, the multi-layered structure of vulcanite and the high acoustic impedance contrast of Pannonian-vulcanite interface. During the seismic acquisition, the following questions should be answered:

- Can the wide-angle PP or PS-seismic survey provide significant reflections from the subvolcanic area or the wave absorption masks the basically stronger reflections at far-offset?
- What is the role of the high velocity contrast in the total energy loss? How can the interbedded igneous stratum or strata (characterized by high acoustic impedance) affect the strength of the amplitudes originated from greater depths?
- Is the seismic method suitable in any way for imaging the basement surface?
  
  To investigate in details the “real” behaviour of the different wave types, ray tracing synthetic seismograms were made based on model parameters above. The major properties of the resulting seismograms (Fig. 4.) are the next:
- isotropic, horizontal and homogeneous layered medium,
- Q factor is 100 for each layer,
- Ricker wavelet; dominant frequency is 20 Hz; initial amplitude is 1,
- AGC, NMO, noise, filter, refractions and multiples are inactive,
- reflection-transmission and absorption losses are active.

  The evaluation of the reflections strength on the different horizons is summarized in Table 1.

![Figure 4](image-url)  
Original and interpreted synthetic seismograms of Model-1 and Model-2 without amplitude manipulation

(XY1= X: downgoing wave, Y: upcoming wave, 1: reflecting horizon)
Table 1
Summary about the reflectivity of the different horizons
(R: reflective surface, NR: non-reflective surface)

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As the table indicates, the pure P-mode has still the best chance for mapping the most of the horizons compared to the other wave types. In case of the P-wave, only the short- to mid-offset range (except the PP1) can provide the strongest responses. Amplitudes of the converted waves are generally far too weak to be recognized due to the quick energy attenuation of S-wave and the generally lower reflection coefficients of PS-waves. Mark “NR” means a non-reflective interface neither in the near-, nor mid- to far-offset cases (amplitudes have $\sim 10^{-6}$ order of magnitude). Note that, the top of vulcanite is a distinct reflector. The imaging of deeper horizons significantly depends on the wave attenuation and the high energy backscattering of the first horizon or the high velocity igneous layer. Presumably, Model-2 / B is closest to the real geological settings; however, more high-velocity layers might be present in the real geological environment. Besides these, the noise can easily overprint the signal coming from deeper parts (S/N ratio) and the additional igneous interbedded layers may even more degrade the received amplitudes.

SUMMARY, CONCLUSION

The primary objective of this paper was to examine the impact of sub-volcanic formations on seismic wave propagation and the consistent imaging potentials of sedimentary and basement structures below it. Significant basement reflections cannot be expected in neither cases, because the imaging of deeper horizons simultaneously depends on the thicknesses of the Pannonian and volcanic deposits and the high AI contrast of the first horizon or the igneous interbedded layer. The study showed that, the pure P-mode has far the strongest response; the use of mode converted or pure S-wave is not viable. The noise and additional high-velocity layers can efficiently decrease and mask the amplitudes coming from deeper zones.

Based on the results, the future seismic exploration of Nyírség is questionable. Even with the application of low-frequency source (with 4+ vibroseis trucks) and 4.5 Hz / 3-components / 128 dB geophones with long-offset spread within the framework
of a 3D survey, the adequate and satisfactory results are not guaranteed. Explosive source would be also favorable, but due to the environmental protection laws, it cannot be implemented. Furthermore, this type of seismic survey involves very high costs and the hydrocarbon exploration has serious risk factors in this paleovolcanic area.

REFERENCES


