EFFICIENCY OF INTEGRATED SEISMIC METHODS APPROACH TO NEAR-SURFACE CHARACTERIZATION

Authors:

Irena GJORGJESKA[1*], Vlatko SESOV[1], Kemal EDIP[1], Dragi DOJCINOVSKI[1]

[1]Institute of Earthquake Engineering and Engineering Seismology (IZIIS),
Ss. Cyril and Methodius University in Skopje, Republic of North Macedonia

*email: gj_irena@iziis.ukim.edu.mk

Geophysical survey by use of combined active seismic methods at three characteristic locations in R. North Macedonia were performed

Locations and applied methods

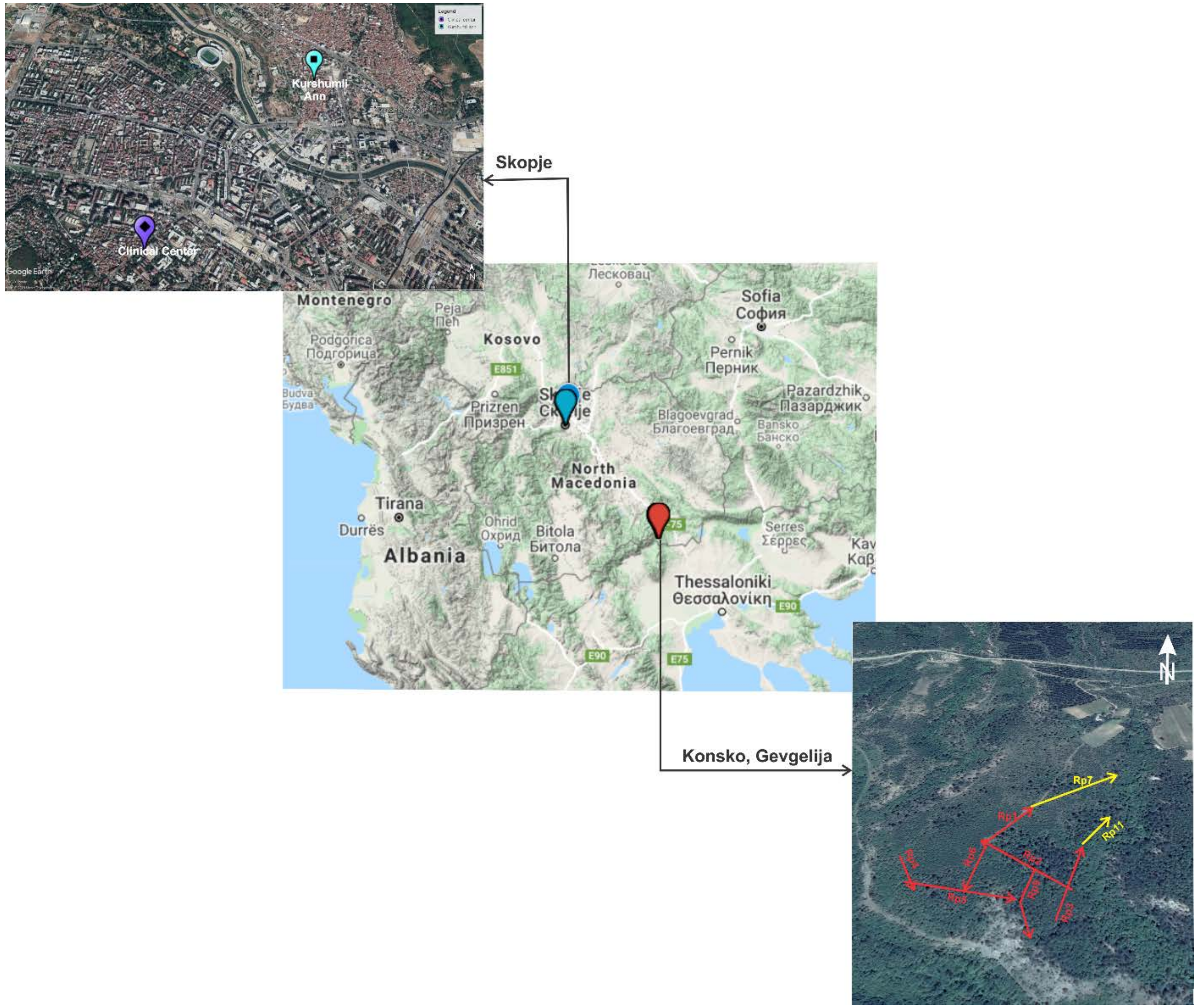
Clinical Center, Skopje
Seismic Refraction vs 2D MASW

Kurshumli Ann Skopje
Seismic Refraction vs Reflection & 2D MASW

Konsko, Gevgelija
Seismic Refraction vs 1D MASW

The main objective of this study is to show the advantages and efficiency of using an integrated seismic methods approach to subsurface modeling.

Fig.1. Regional and local maps of the study locations

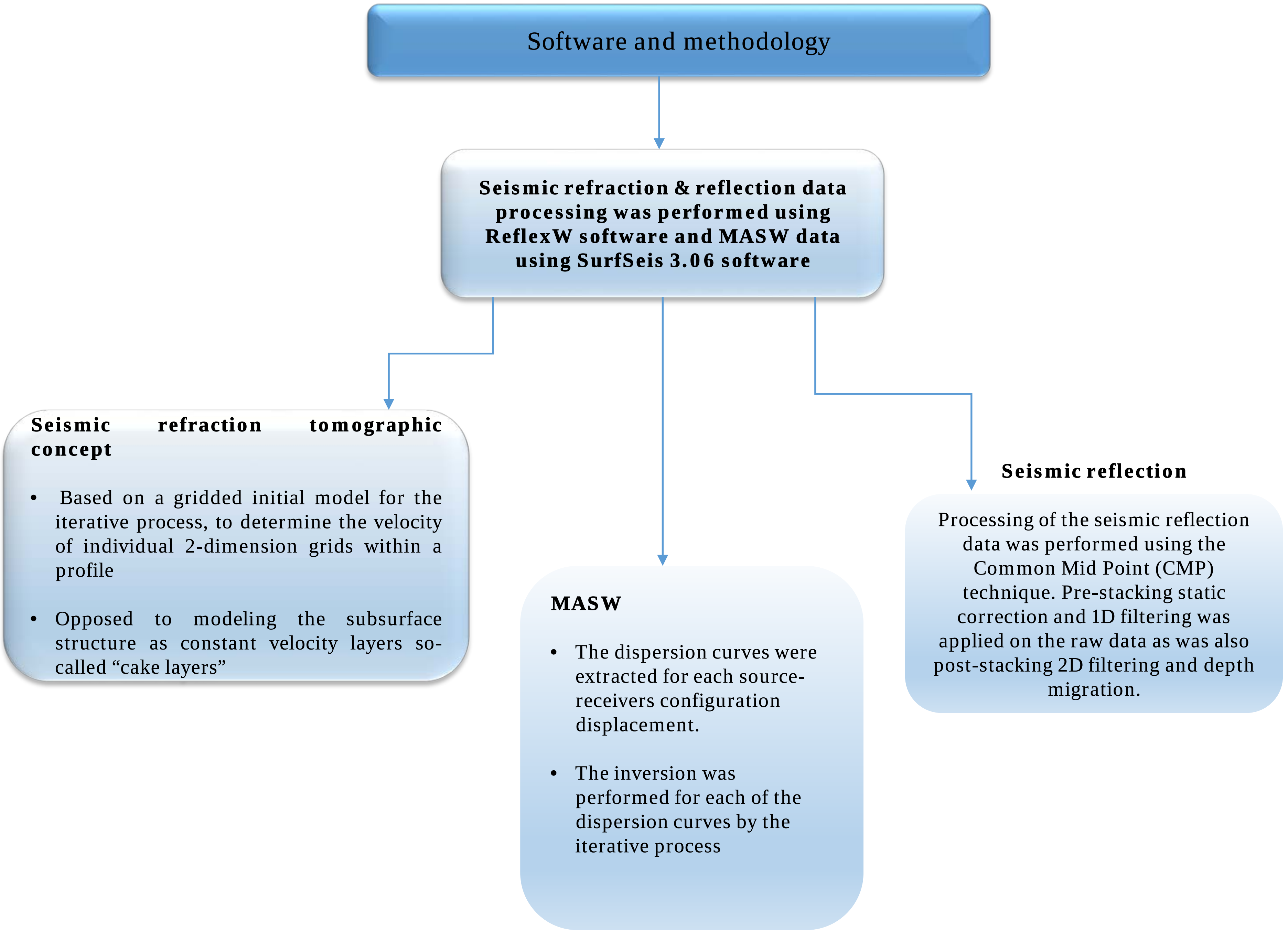


Location	Coordinates (UTM WGS 84)	
Kurshumli Ann, Skopje	7 536 195.00 E	4 650 211.00 N
Clinical Center, Skopje	7 534 817.00 E	4 648 702.00 N
Konsko, Gevgelija	7 611 555.03 E	4 559 616.76 N

- The same seismic equipment and, in most of the cases, the same acquisition parameters were used for the surveys

Fig.2. Photos of the survey locations

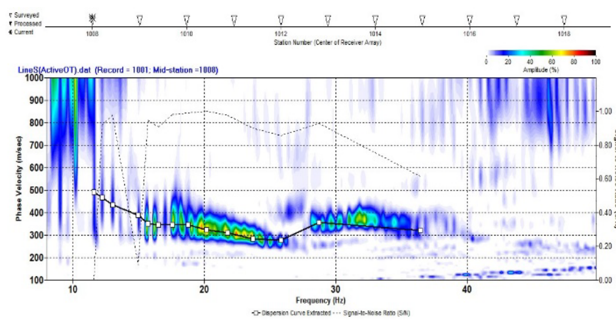
- The measurements were performed using the SoilSpy Rosina multichannel digital seismograph (MoHo - Science & Technology, Italy).
- The seismic energy was generated with vertical impacts by a 10 kg sledge hammer on an aluminum plate and was recorded by 4.5 Hz vertical geophones.


Software and methodology
Seismic refraction & reflection data processing was performed using ReflexW software and MASW data using SurfSeis 3.06 software
Seismic refraction tomographic concept
• Based on a gridded initial model for the iterative process, to determine the velocity of individual 2-dimension grids within a profile
• Opposed to modeling the subsurface structure as constant velocity layers so-called "cake layers"
MASW
• The dispersion curves were extracted for each source-receivers configuration displacement.
• The inversion was performed for each of the dispersion curves by the iterative process
Seismic reflection
Processing of the seismic reflection data was performed using the Common Mid Point (CMP) technique. Pre-stacking static correction and 1D filtering was applied on the raw data as was also post-stacking 2D filtering and depth migration.

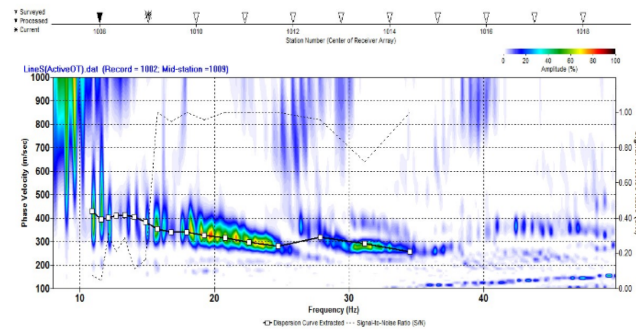
Location: Clinical center, Skopje

- Preliminary MASW surveys were first conducted to optimize the field acquisition parameters, such as the offset of the seismic array, the receiver spacing and the length of the record
- The surveys were performed varying the acquisition parameters in order to determine their respective influence on the dispersion image resolution

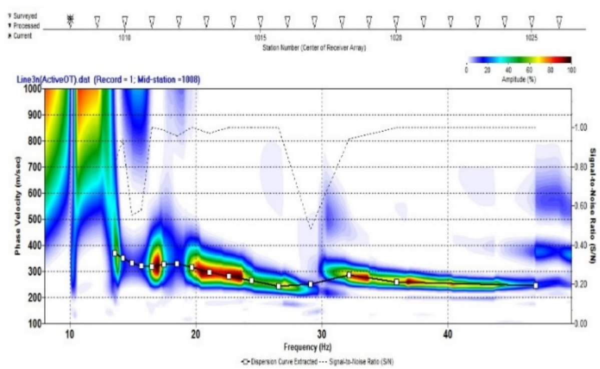
a) 1st source-receiver configuration displacement



b) 2nd source-receiver configuration displacement



c) 1st source-receiver configuration displacement



d) 2nd source-receiver configuration displacement

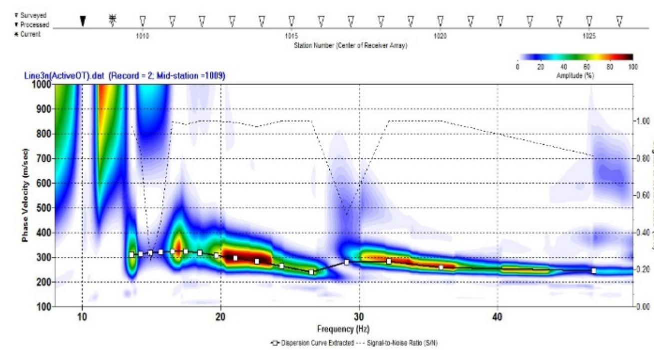


Fig3. Dispersion images with extracted effective dispersion curves (white dots)

a) and b) 1st seismic array design: 16 channels, distance between geophones of 3m, minimum off-set of 15m and recording length duration of 1.5s, with a sampling frequency of 1024 Hz, 11 SR displacement in total, 3m excitation step

c) and d) 2nd seismic array design: 16 channels distance between geophones of 2m, minimum off-set of 5m and recording length duration of 0.3s, with a sampling frequency of 1024 Hz, 19 SR displacement in total, 2m excitation step

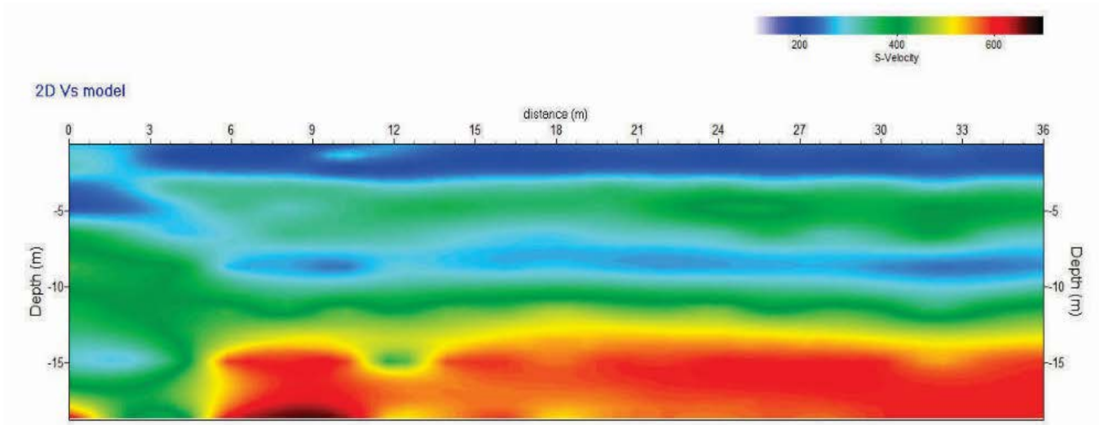
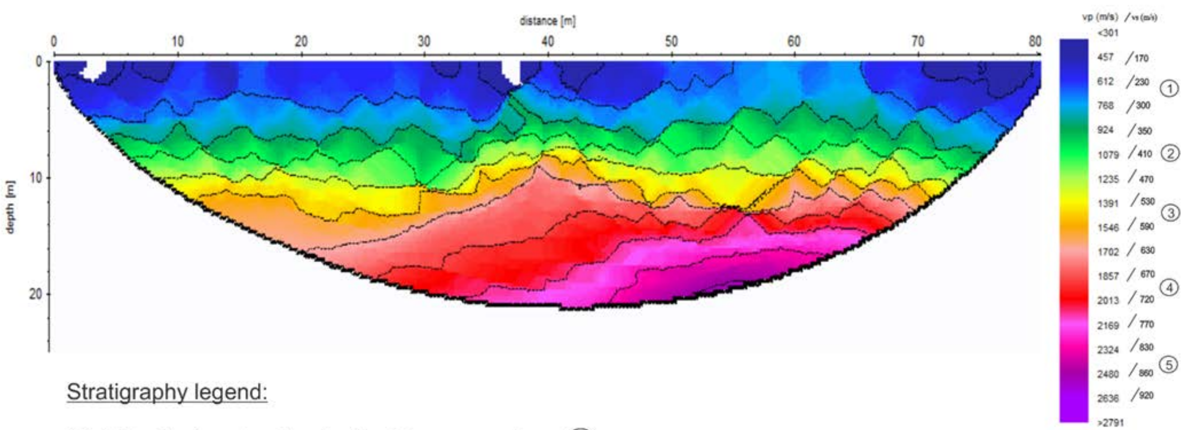


Fig.4 2D Vs model – Multichannel Analysis of Surface Waves (MASW). Generated using the data from the 2nd seismic array design.



Stratigraphy legend:

1. fill (embankment) and sandy silt with some gravel (Vp=350-750 m/s and Vs=130-300 m/s)
2. Gravel (Vp=800-1250 m/s and Vs=310-470 m/s)
3. Gravel (Vp=1350-1700 m/s and Vs=500-630 m/s)
4. Marl (Vp=1800-2200 m/s and Vs=680-830 m/s)
5. Marl (Vp >2200 m/s and Vs>830 m/s)

Fig.5. Seismic refraction tomography 2D Vp and Vs model. The surveys were conducted along 17 channels seismic spread with receiver distance of 5m, near offset of 5m and recording length of 0.5s

- Data analysis with the 2nd configuration of seismic array with 5m minimum offset and 0.3s recorded signal length (unconventional for this kind of surveys) provided a better quality dispersion image.
- The effective dispersion curves were extracted from the dispersion images as a combination of the fundamental and higher modes of the Rayleigh waves.
- The generated 2D MASW Vs model (Fig.4) is a result from the survey using 2nd seismic array design.
- According to the results from MASW and seismic refraction survey, the surface layers of the terrain are characterized by seismic velocities in the range of Vp=350-1700 m/s, and Vs=130-620m/s
- They are composed of quaternary deposits, overlying Mio-Pliocene sediments, characterized by Vp>1800m/s, Vs>680 m/s.
- Both, the seismic refraction and MASW 2D model clearly mapped the seismic bedrock topography i.e the max. thickness of the quarternary deposits in this part of the location is approximately 10-15 m
- The velocity inversion is mapped at 7 m in the 2D Vs MASW model and indicates a groundwater level

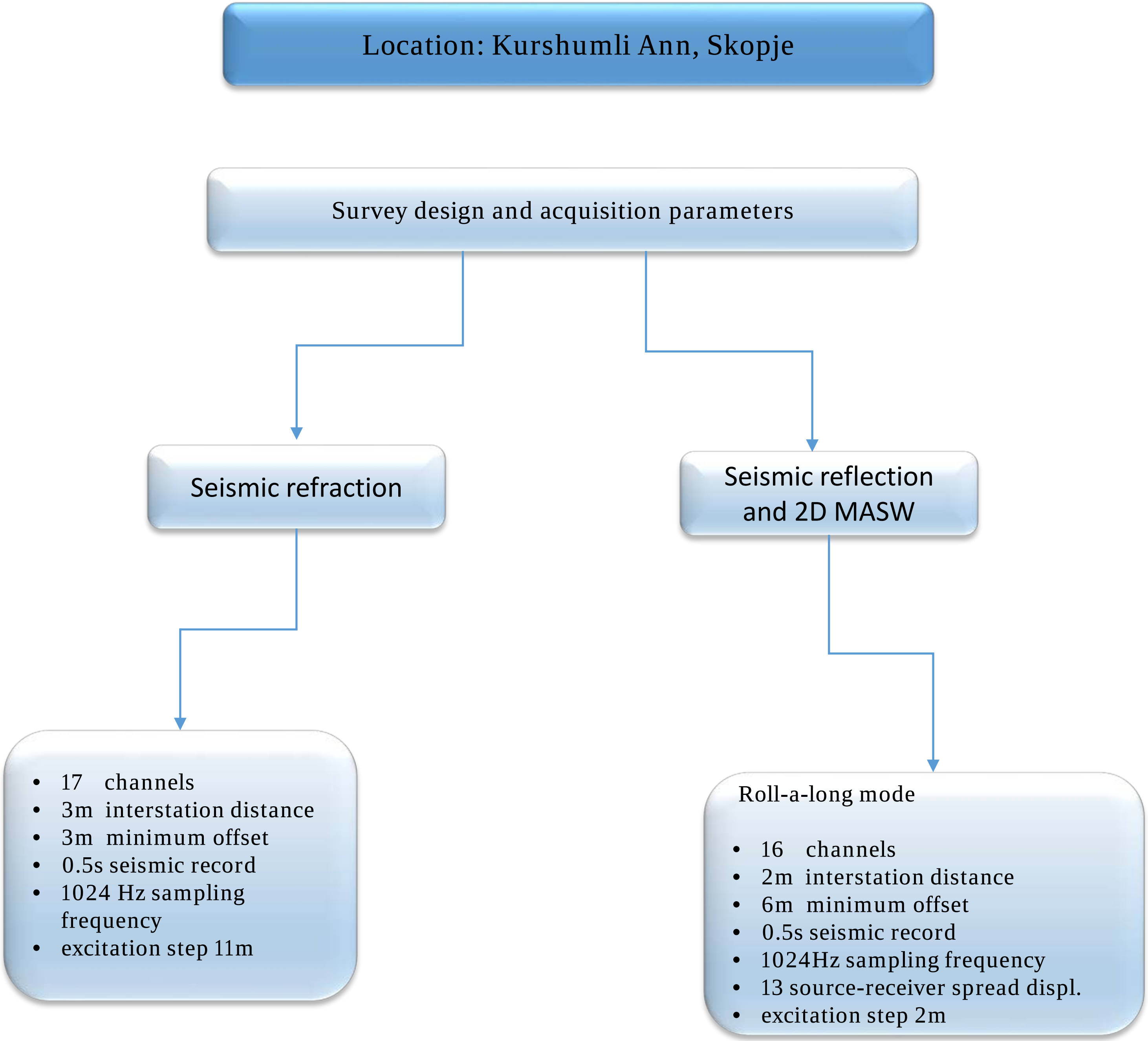
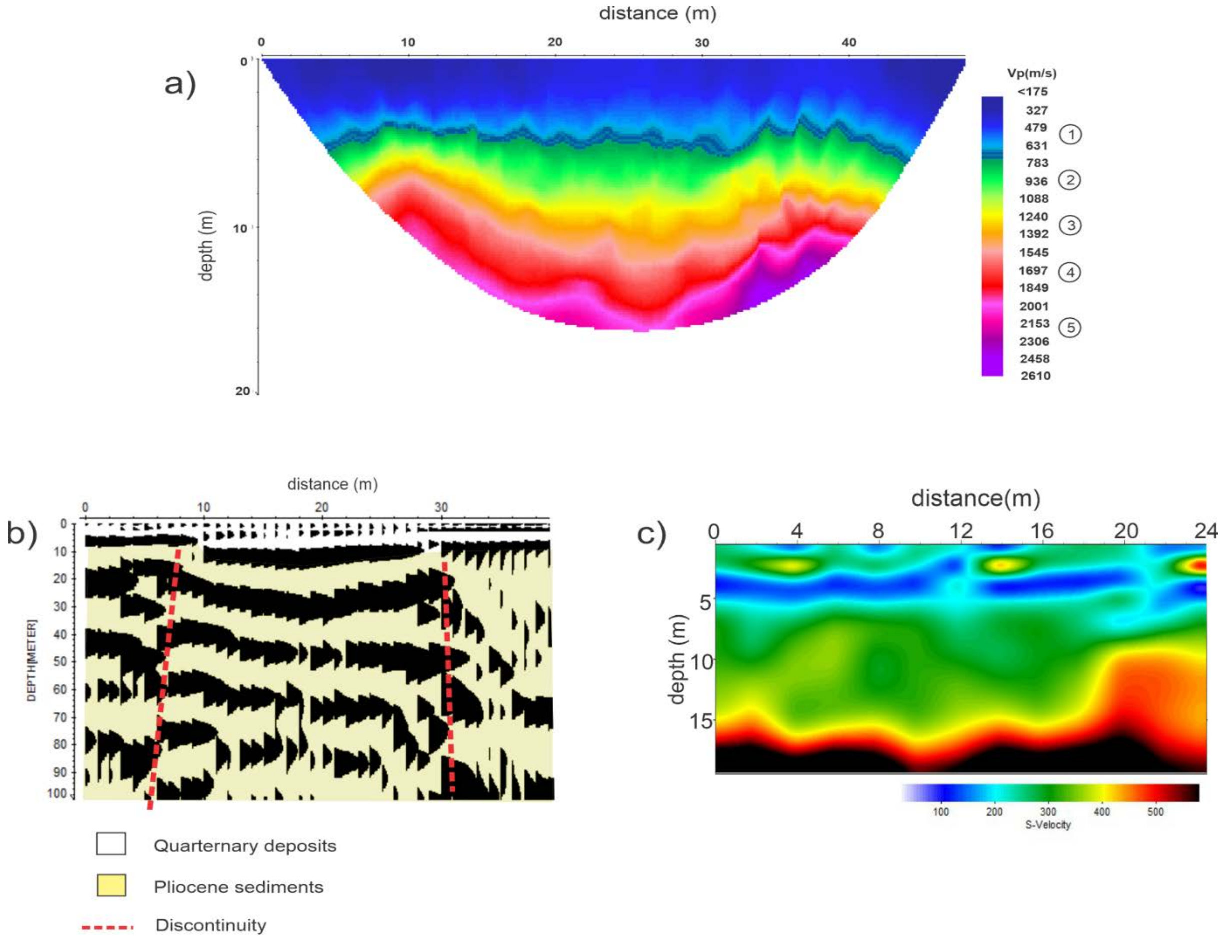
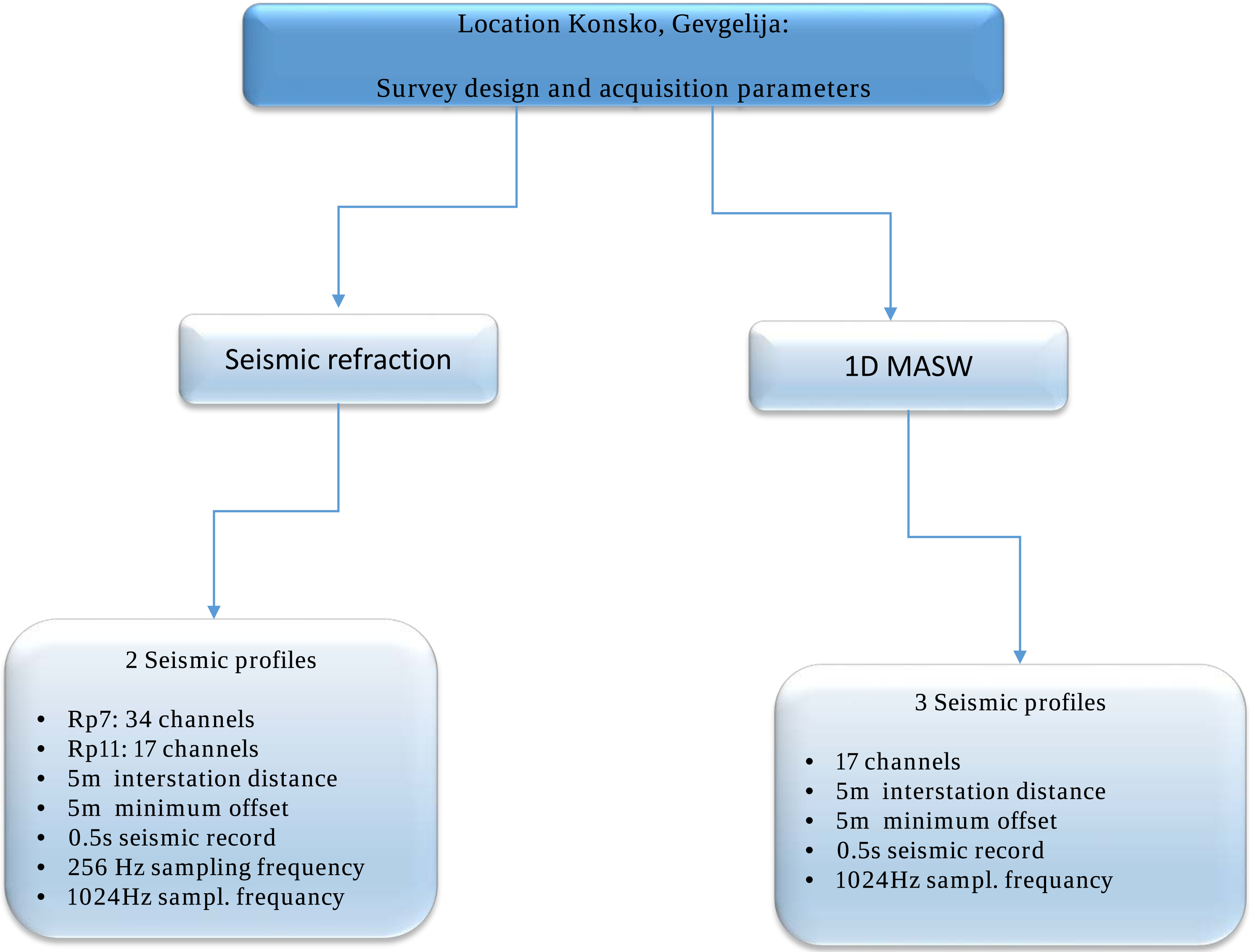

Location: Kurshumli Ann, Skopje
Survey design and acquisition parameters
Seismic refraction
Seismic reflection and 2D MASW
17 channels
3m interstation distance
3m minimum offset
0.5s seismic record
1024 Hz sampling frequency
excitation step 11m
Roll-a-long mode
16 channels
2m interstation distance
6m minimum offset
0.5s seismic record
1024Hz sampling frequency
13 source-receiver spread displ.
excitation step 2m

Fig.6. 2D model as a result of the survey performed in Skopje, Kurshumli Ann a) Vp seismic refraction tomography model b) 2D Seismic reflection section. c) 2D Vs model as a result of the MASW survey



- The surface layers of the terrain are composed of quaternary, alluvial-proluvial deposits, characterized by seismic velocities in the range of Vp=170-1750 m/s, and Vs=100-630m/s.
- They overlying Pliocene sediments which are mainly composed of gravel, sand, sandstones etc., characterized by Vp>1800m/s, Vs>680m/s
- The thickness of the quaternary deposits varies in the range of 8m to 15m. The anomaly is clearly mapped on the seismic refraction model (along a distance of 10-38m) and the MASW model.
- The same variation of the seismic bedrock topography is interpreted at the seismic reflection 2D model. The reflection model indicates deformations in the deeper layers, as well.
- The velocity inversion mapped at 4-5m in the 2D Vs MASW model indicates a groundwater level.


Location Konsko, Gevgelija:
Survey design and acquisition parameters
Seismic refraction
1D MASW
2 Seismic profiles
Rp7: 34 channels
Rp11: 17 channels
5m interstation distance
5m minimum offset
0.5s seismic record
256 Hz sampling frequency
1024Hz sampl. frequancy
3 Seismic profiles
17 channels
5m interstation distance
5m minimum offset
0.5s seismic record
1024Hz sampl. frequancy

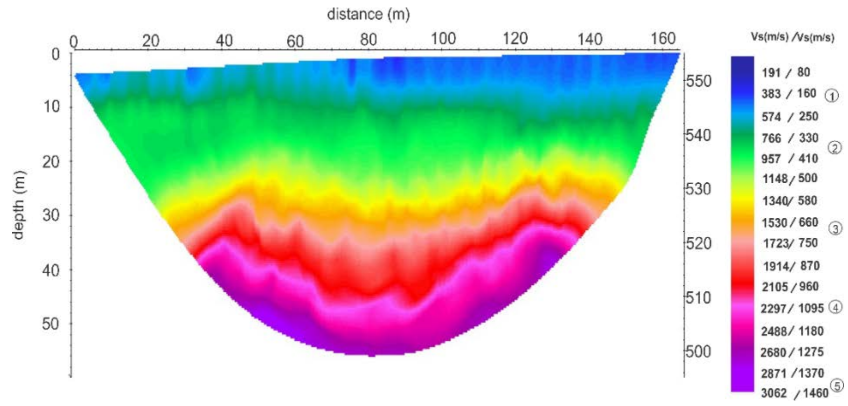


Fig.7. 2D Vp seismic refraction model Rp7 (Fig1)
as a result of the survey performed in Konsko

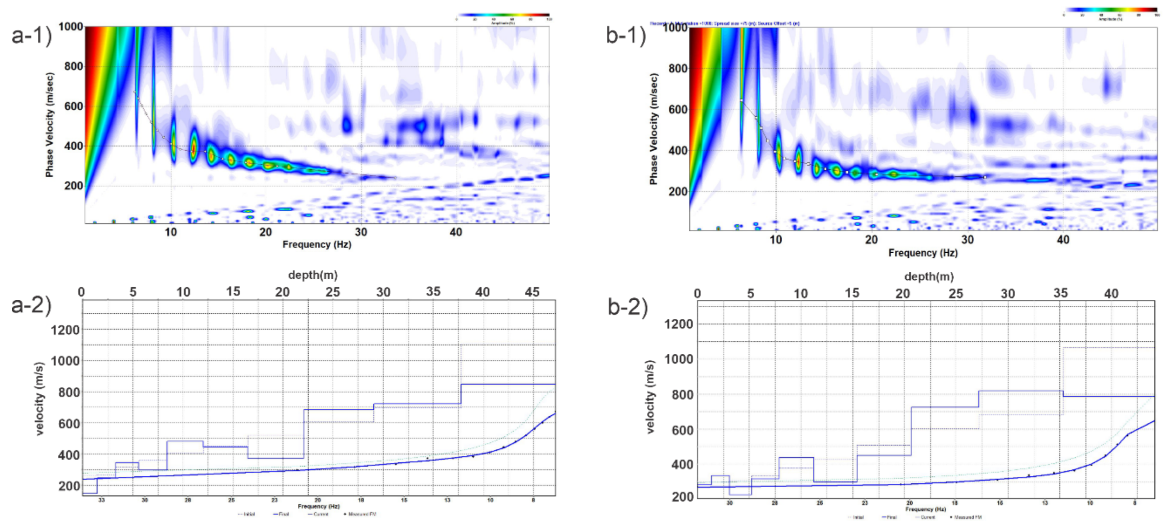


Fig.8. a-1) Dispersion image D1 with extracted dispersion curve (white dots). 1D MASW survey along first half of Rp7 seismic profile. a-2) 1D Vs model as a result of D1 dispersion curve inversion (refers to 40m position of the Rp7 profile). b-1) Dispersion image D2 with extracted dispersion curve (white dots). 1D MASW survey along second half of Rp7 seismic profile. b-2) 1D Vs model as a result of D2 dispersion curve inversion (refers to 120m position of the Rp7 profile)

- The terrain of the location is composed of gabro covered with diluvial material.
- The main objective of the survey was definition of the depth of the surface critical zone: diluvial material with clay infill and layer of intensively cracked, degraded rocks (Vs=100-480m/s)

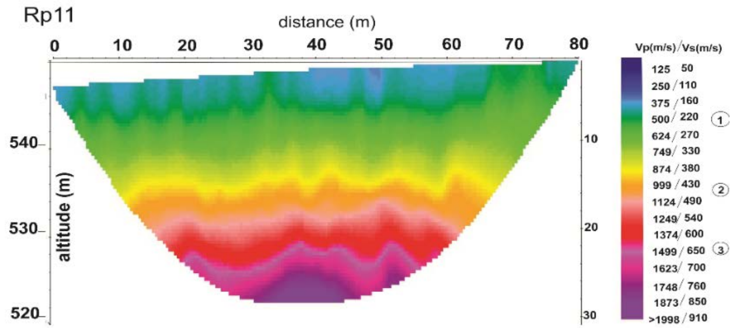


Fig.8. 2D Vp seismic refraction model Rp11 (Fig1)
as a result of the survey performed in Konsko

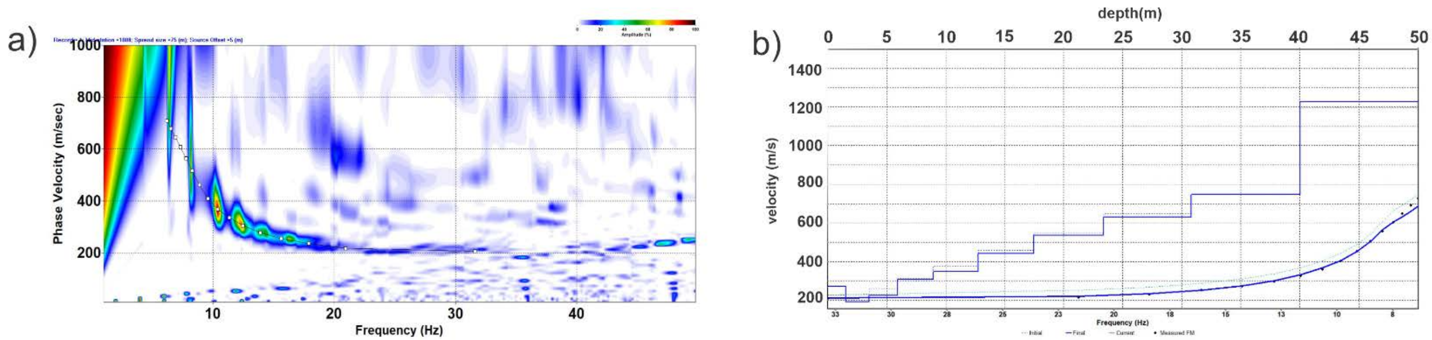


Fig.9. a) Dispersion image D3 with extracted dispersion curve (white dots). 1D MASW surveys along Rp11 seismic profile. b) 1D Vs model as a result of D3 dispersion curve inversion (refers to 40m position of the Rp11 profile)

- The high impedance contrast between the surface degraded layers and more compact rock layers in their base contributed to extraction of good quality dispersion curves.
- According to the seismic refraction models, the max.thickness in this part of the location is approximately 20-22m
- The reliability of the results is confirmed by the 1D Vs MASW models

Conclusions

- ✓ From the above presented can be concluded that using an integrated geophysical approach is very significant for a high quality, accurate and reliable subsurface modeling

- ✓ The in-situ measurements and data processing were conducted in the most practical, cost and time-effective way, with the same equipment, and in some cases the same acquisition parameters.

- ✓ The seismic refraction tomographic approach enabled modeling of the subsurface with both lateral and vertical velocity gradients, which provided high resolution imaging of the subsurface structure and proved to be great tool for subsurface characterization and detecting potential anomalies.

- ✓ 2D MASW survey complemented and improved the subsurface modeling of the investigated location mapping the velocity inversion i.e. trapped low velocity layer. The roll-a-long technique enabled the data to be used for seismic reflection processing. Using the CMP method for reflection processing resulted in very accurate, high resolution modeling of the subsurface up to the depth of 100m.

- ✓ The seismic refraction and 1D MASW survey at the Konsko location, performed along the same profile lines using the same acquisition parameters, proved to be an excellent combination for fast and accurate subsurface modeling especially in hard terrain conditions.

- ✓ Each of the techniques showed some limitations and disadvantages, but their application in an integrated approach enabled the results to be compared and to complement each other, which reduced the error likelihood in interpretation.