REPORT: PILOT PROJECT

Deployment of RAP Method for shallow study in support of geotechnical investigation

LOCATION

Khalifa City, Abu Dhabi, U.A.E.

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1 INTRODUCTION

In most of civil engineering works, it is critically important to characterize the mechanical behavior of geotechnical materials under various types of loading. This characterization has normally been expressed in terms of elastic moduli, of which shear modulus is most important because it is directly related to the stiffness of the subsurface material. In general, there are two methods to characterize mechanical behavior of geotechnical sites under various types of loading. One is the deflection-response method that measures stress-strain behavior of the sites caused by static or dynamic load. In this report, the subsurface conditions under the proposed site have been evaluated based on a second method, direct measurements, of acoustic profiling: RAP Method. The survey has been used to record the stable acoustic waves along five (5) parallel profiles across the project site.

1.1 Objectives of the Report

The objectives of the geophysical program are summarized as follows:

1- Locating and defining the subsurface geologic anomalies as potential hazards.

2- Understanding the mechanical structure of the subsurface.

1.2 Service Details

The details of the geophysical investigation and data acquired for this site are summarized in Table (1) below:

Table 1. Details of Geophysical Survey

General Information	
Project Name	Proposed Construction of Residential building
Location	Khalifa City, Abu Dhabi, United Arab Emirates
Reference Datum	Abu Dhabi Coordinate system
Site Coordinates	Per MASW report
Site Condition	The site is thinly covered sand over fill materials.
Geophysical Data Acquisition	
Geophysical Contractor	GeoTechnologis FZCO for Geophysical and Geological Surveys and Studies
Type of the Survey	Resonance Acoustic Profiling (RAP) for both 2-D and 3-D

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Aim of the Survey	To assess and advise on likely subsurface geologic hazards such as shallow or deep cavities, unconsolidated weak zones under the proposed construction site.
Total interval acquired / Area study	Approximately 200 linear meters, with approximate minimum lengths of 40 m (repeating 5 MASW profiles @ 39 meters length)
Data acquisition System	RAP Resonance Acoustic Profiling system
Data Processing Software	RAP: Surfer and Voxler from Golden Software (Colorado, U.S.A)
Depth of investigation Required	≥30 m below EGL
Final Data acquired	2-D & 3-for D acoustic profiles
Geophysical Contractor	**M/S: GeoTechnologies FZCO**
	Tel **+971 50 336 1075**

1.3 Site Description

1.3.1 Project Boundary

The proposed project is located in Khalifa City, Abu Dhabi, UAE. Plan calls for construction of a Residential building, as shown in Fig. 1 below:

Figure 1. Site Layout – General location map of the site (Not to Scale)

Site plan of the **RAP** profiles, based on the previous **MASW** profiles, coordinates of start and end points for each geophysical line are presented in **Appendix-A**. RAP lines were repeated in the same sequence as the MASW lines, in this case.

1.3.2 Position of the Surveyed RAP Profiles

Fig. 2 below is a sattelite image beside geophysical survey lines conducted over the proposed construction site area.

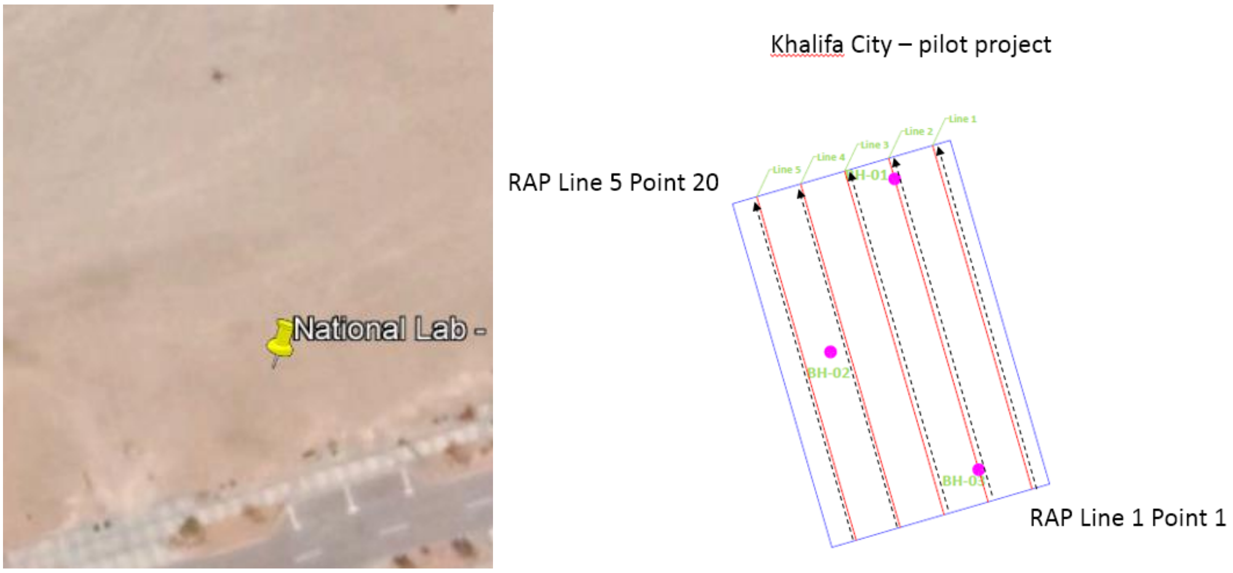

Figure 2. Satellite Image and surveyed geophysical lines for both MASW and RAP lines

1.4 Methodology

A direct investigation utilizing geophysical Resonance Acoustic Profiling (RAP) has been used to demonstrate the effectiveness of this technology for geotechnical investigation. RAP not only detects cavities but, just as important, reveals weak zone anomalies that become preferential pathways for groundwater and seawater seepages.

1.4.1 Data acquisition

RAP was proposed to provide an alternative method to support the requirements of this project (Table 3).

Table 2. Adopted Geophysical Acquisition Methods

Site Name	Acquisition Interval	MASW	ERT	GPR	Gravimetric	Magnetic	Others
Geophysical Investigation at Proposed Construction of Commercial building	RAP (2m)	-	-	-	-	-	RAP

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1.4.2 Fieldwork Parameters and Setup

The field parameters and equipment settings for the RAP are presented in Tables 4 and 5, respectively.

Table 3. Fieldwork Parameters (RAP)

Parameter	Setting
Survey Type	RAP (with trigger)
Survey Purposes	2-D and 3-D vertical profiling
Acquisition System	RAP (USB-2) working from Panasonic Toughbook
Source	Passive Seismic; rubber mallet (16 oz) used as trigger
Receiver (Geophones)	Piezoelectric sensor
Number of Receivers (N)	1
Receiver Array	Points: Linear (@ 2 meter spacing being points)
Receiver Spacing (dx)	1 repeated every 2 meters
Minimum depth of investigation (Z max)	≥50m
Profiles Spacing	5m between lines

Table 4. Equipment Settings (RAP)

Parameter	Setting
Sample interval (dt)	0.07 milliseconds (ms)
Record length (L)	2 seconds, approx.
Number of record files / Station	One
File type to save	RAP to TXT

The RAP diagram is presented in Fig. 3, below:

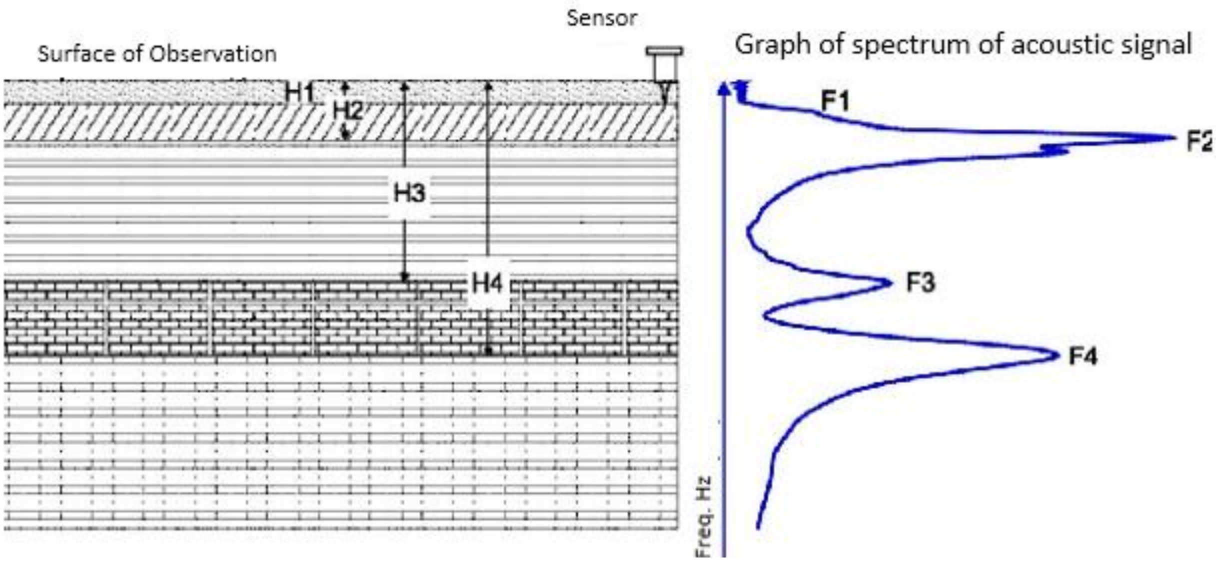


Figure 3. Geophysical RAP Method diagram

In conclusion, RAP is a methodology developed and deployed—in a wide range of applications in the mining, oil and gas, groundwater and geotechnical fields—for over 25 years using technology that is now in its fourth generation. Resonance acoustic profiling is, in effect, a combination of passive (deep) and active (shallow) seismology. The parameters are not those of the MASW or other traditional active seismic geophysical systems. It is not the objective of this document to provide a full course on RAP but rather to introduce the RAP Method and demonstrate its application to the geotechnical engineering and soil laboratories in the United Arab Emirates and GCC.

2 GEOPHYSICAL DATA PROCESSING

The procedure for RAP data processing usually consists of the following steps:

1. Acquiring individual point recordings at each point on the line
2. Downloading point recordings and processing into rapid 2-D onsite for quality control
3. Converting from RAP to TXT files for 2-D and 3-D profiles in commercial software

2.1 RAP Data Quality Control

The RAP method uses the same physical principles as some well-known geophysical methods used to solve the problems of seismology. The method of spectral ratios of horizontal and vertical components of the acoustic wave field (HVSRM method Y. Nakamura, 1989) proposes the use of natural acoustic oscillations to determine the thickness of unconsolidated sediments above the crystalline basement rocks using the amplitude ratio of horizontal and vertical components of the acoustic wave field; as well as the microseismic method (Okada H., 2003) and others. The difference between these methods and RAP is that, rather than only performing in the low frequency of natural acoustic noise measurements, RAP performs in the full range of frequencies. However, it should be noted that RAP functions in the vertical component only and therefor is able to collect both shallow and deep measurements (0 – 2000 meters depth).

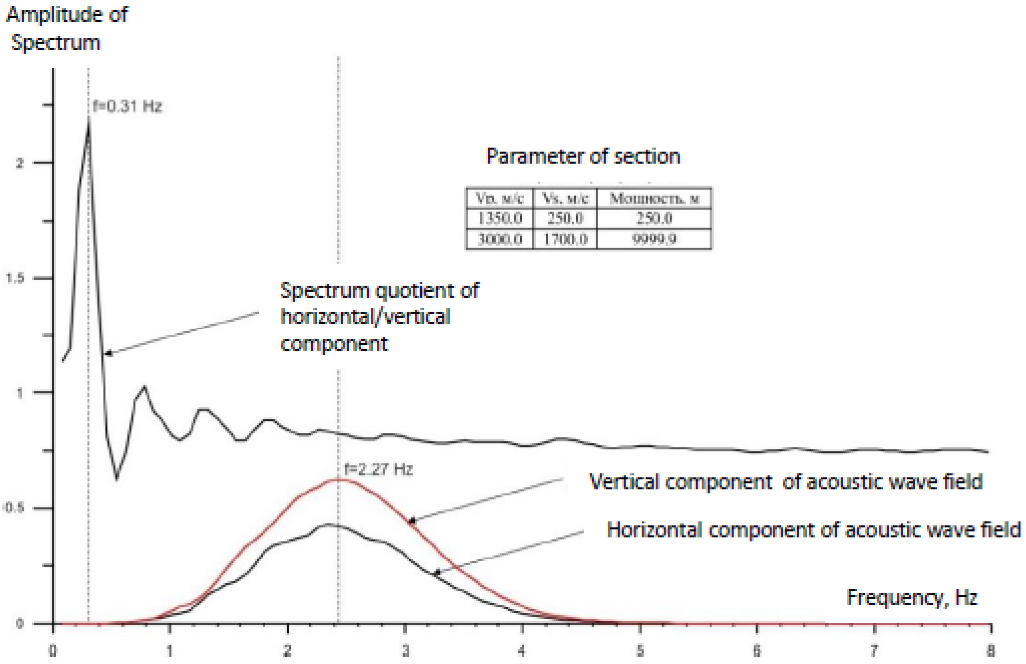
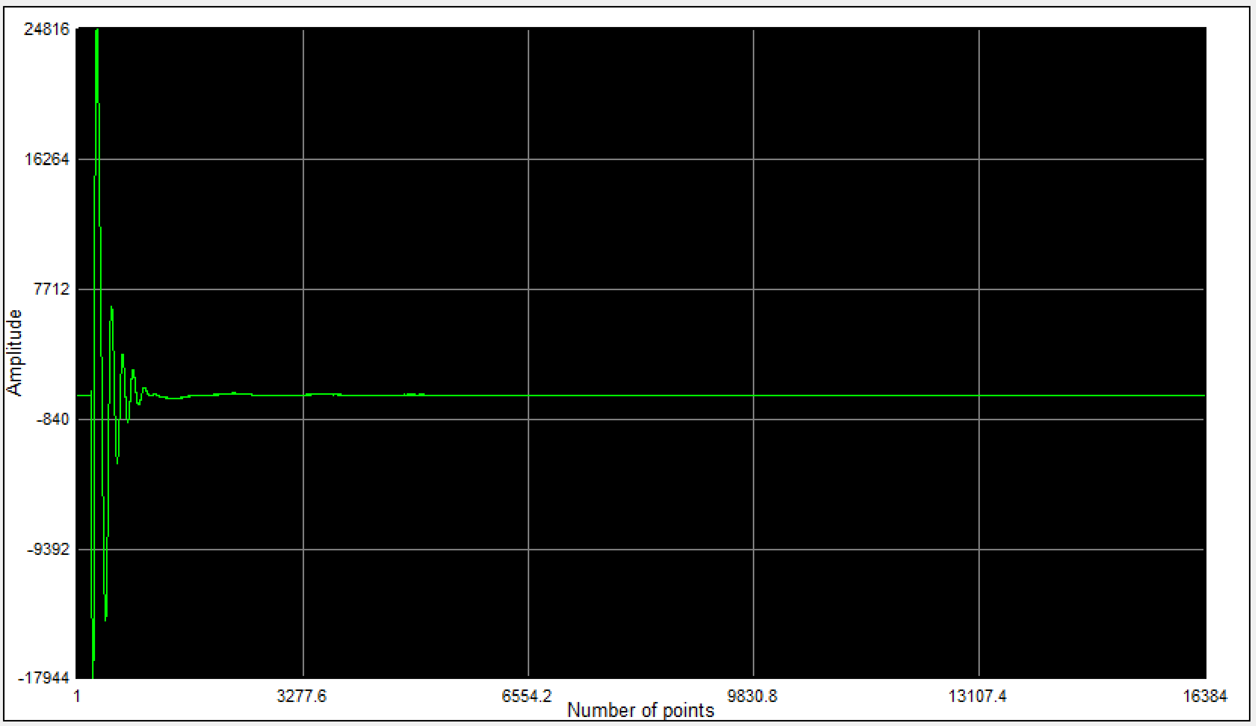
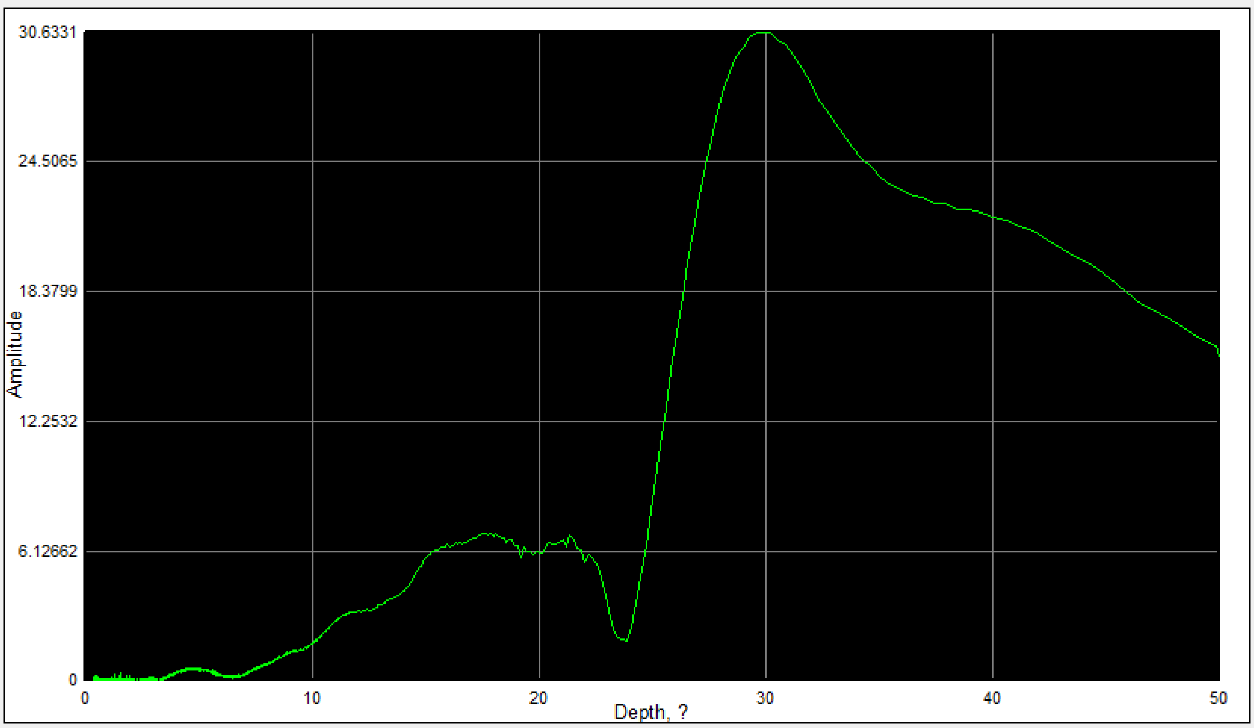


Figure 3. Example of RAP versus HVSRM (Nakamura)

Observed signal for Line 1 Point 10 of Khalifa City – Pilot Project:



The spectrum of the signal for Line 1 Point 10 of Khalifa City – Pilot Project:



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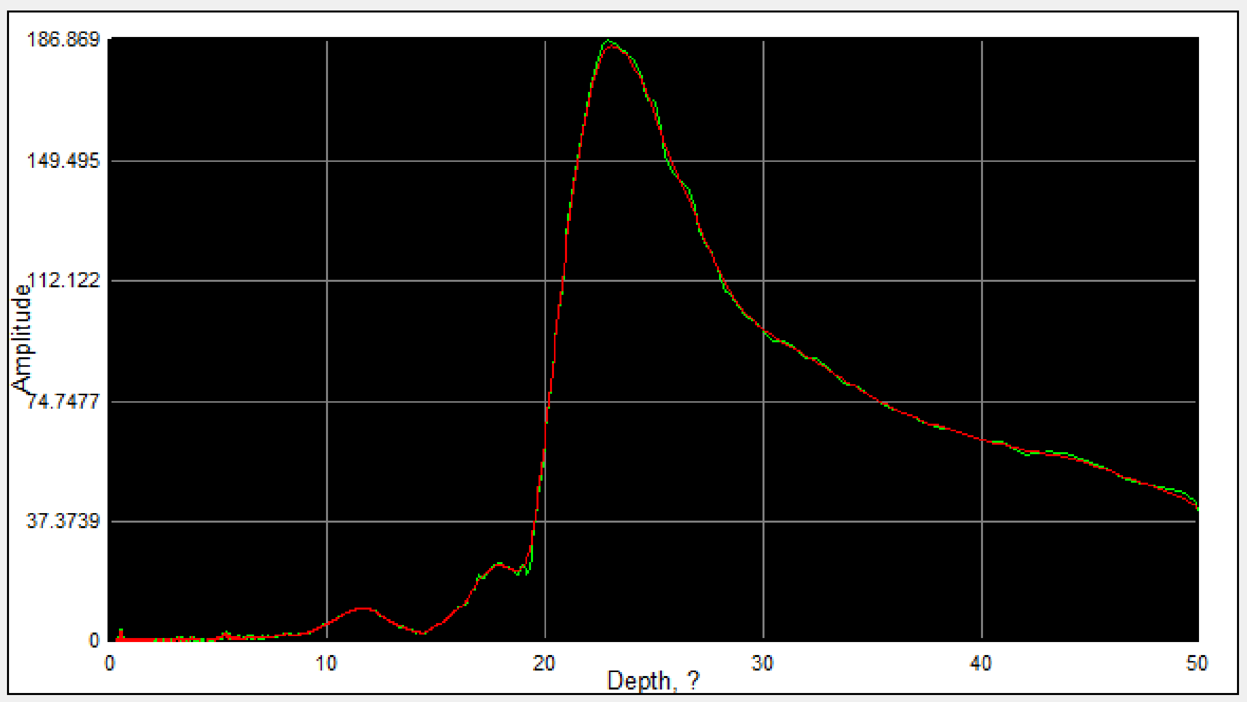
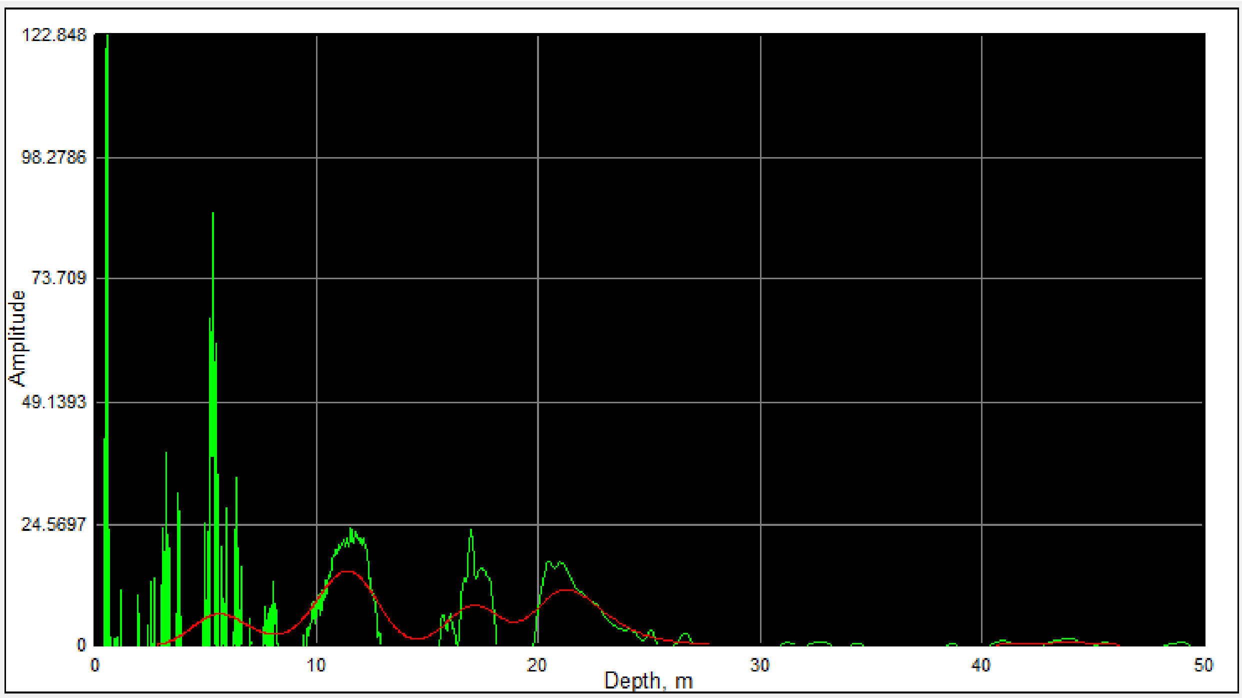
Amplitude of the spectrum for Line 1 of Khalifa City – Pilot Project:



Local component of the spectrum for Line 1 of Khalifa City – Pilot Project:



2.2 Processing Parameters

The Resonance Acoustic Profiling (RAP) 2-D and 3-D data obtained were processed using RAP software and then Surfer (2-D) and Voxler (3-D) from Golden Software (Colorado, U.S.A). A summary of data processing steps using RAP software are presented as follows:

Processing of RAP data

Step.1: Formatting

RAP software produces passive seismic data in a .rap file that is converted to .txt file for use in standard commercial software.

Step.2: Field Setup

Data is collected at each point as required by the survey. In the case of MASW this is 2-meter spacing at 5-meter interval between lines. Khalifa city required 5 lines of 38 meters for a total of 100 RAP points.

Step.3: Setting of frequency

14400 was used for 50-meter depth prospection.

Step.4: Processing to 2-D profiles (at least 3 or more points)

Data is processed in the field into TXT files for rapid analysis of data collection quality control using 2-meter spacing for data interpolation.

Step.5: Processing to 2-D and 3-D profiles in the office

Data is processed to both full spectrum (filtered) and calculation of the logarithm of the spectrum (smoothed) for analysis of stratigraphy and anomalies.

The results of Resonance Acoustic Profiling (2-D profile in contour and/or relief maps) are shown in Appendix–B attached to this report. They present 2-D sections for amplitude versus depth (m).

The X- axis represents the depth in meters and the Y–axis represents the amplitude of the spectrum. The images use a color scale, with white/yellow showing areas of low spectral amplitude (higher relative mechanical strength) and red/purple areas of high spectral amplitude (lower relative mechanical strength).

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3 RESULTS OF THE GEOPHYSICAL RAPID ACOUSTIC PROFILING SURVEY

One of the main purposes of the geophysical passive seismic Resonance Acoustic Profiling (RAP) survey is to evaluate the subsurface conditions and identify geologic anomalies for interpretation (if any) at the site, to assist in planning and development of the project. The amplitude of the spectrum varies between rock layers and within layers where anomalies exist. Is the anomaly a cavity or water or a mineral body (e.g., gypsum pocket)—this must be determined through interpretation and of course additional geophysical methods depending on the client's objective. In the case of RAP it should be used in advance of geotechnical investigation to recommend bore hole locations over potential hazards.

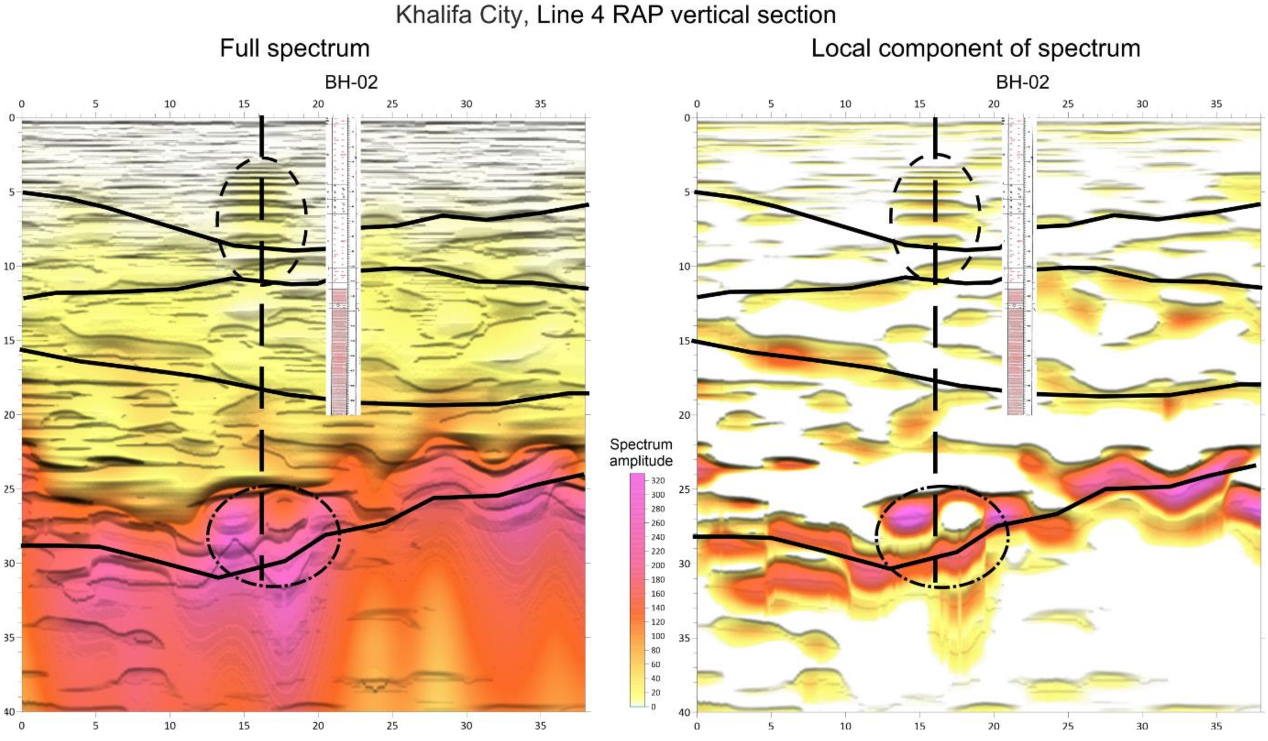

Figure 5. 2-D RAP profile obtained from survey Line 4; full spectrum at left and local component at right

The above profile of Line 4 reveals a distinct change in stratigraphy at 16-meter mark (RAP Point 9) with a prominent anomaly both near surface and extending to below 30 meters. The uneven stratigraphy as drawn on the profiles lines up with the borelog from the 24-meter mark.

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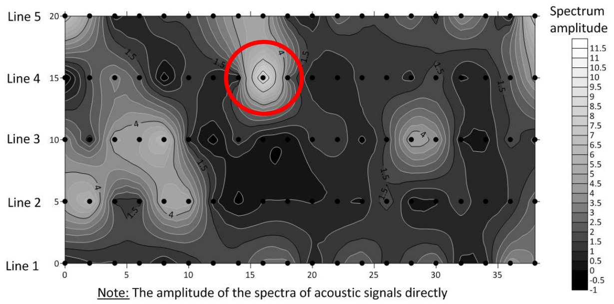
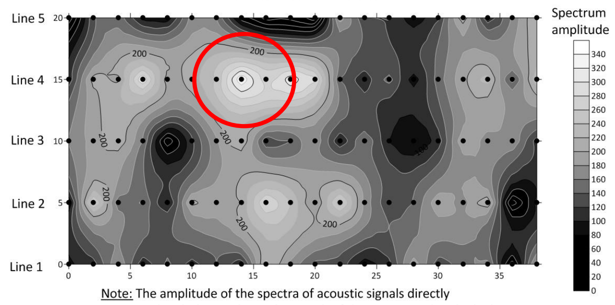
This is also revealed in the horizontal cross-section at both 5-meter and 30-meter depths:

Horizontal section of the relative mechanical strength of rocks along the Khalifa City area.
Depth of section - 5 m



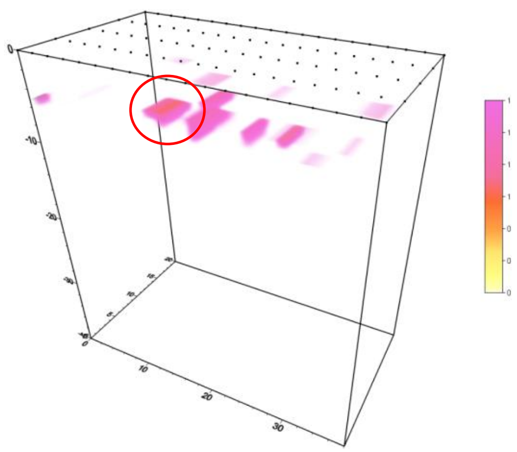
Note: The amplitude of the spectra of acoustic signals directly associated with the mechanical strength of the section rocks. The higher amplitude of the spectrum - the less mechanical strength of rocks (higher degree of fracturing, watering, etc.)

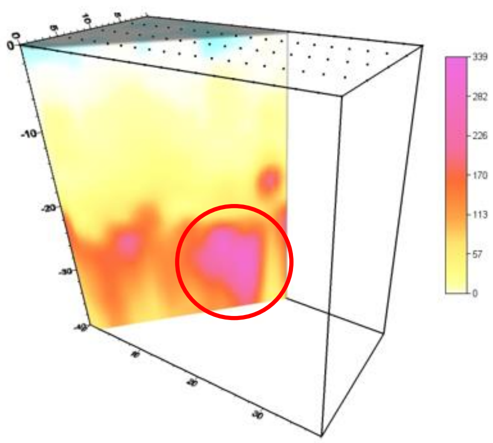
Horizontal section of the relative mechanical strength of rocks along the Khalifa City area.
Depth of section - 30 m



Note: The amplitude of the spectra of acoustic signals directly associated with the mechanical strength of the section rocks. The higher amplitude of the spectrum - the less mechanical strength of rocks (higher degree of fracturing, watering, etc.)

The size and deeper connectivity of this zone of comparative mechanical weakness is clearly visible in the vertical 3-D cross-sections below:





3.1 Summary of Suspected Anomalies

RAP Method maps a much more detailed sub-surface profile of the stratigraphy and reveals potential geological hazards as well as the much deeper source of potential preferential pathways for water seepage. The greatest hazard is evident at the 16-meter mark of Line 4 both at a shallow 5-meter depth (3-D rendering on the left) and from 25+ meters depth (3-D rendering on the right).

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3.2 Limitations of the RAP Surveys

The general limitations of the geophysical RAP method are as follows:

Resonance acoustic profiles are best collected with minimal surface noise. The Khalifa site offered almost ideal conditions to use the flat sensor directly on the surface rather than the integrated sensor with spike (see photos below). Topographical variation does not matter for RAP including, for example, bedrock or extrusive volcanics at the surface. However, care must be taken to select the correct sensor before starting data collection to avoid switching sensors and combining disparate data sets. This is not unique to piezoelectric sensors. No ground obstructions or structures existed and none of the above limitations were encountered at this site.

Figure 6. Two types of piezoelectric sensors available for use with RAP: flat sensor on the left and sensor with spike on the right. Flat sensor can also be placed on top of a steel spike in certain conditions.

It must also be understood that RAP Method—at this time—does not provide the same parameters as MASW or other active seismic methods to characterize stratigraphic layers. RAP simply provides a comparative scale of mechanical strength to weakness of the underlying lithology. This data can be compared to bore logs taken at or near the site for interpretation as presented in the next Section.

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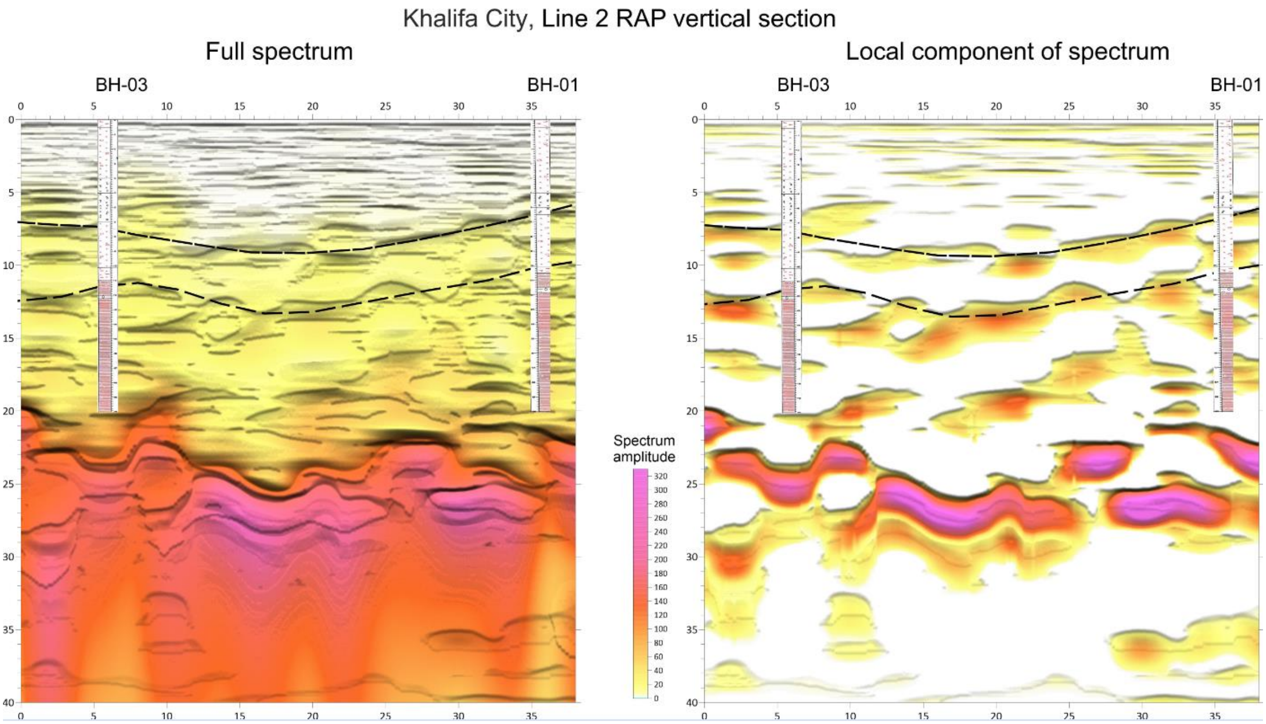
4 DISCUSSION

4.1 Discussion and Interpretation

The geophysical survey was completed within the investigated site on February 7, 2021. The survey utilized the Resonance Acoustic Profile (RAP) technique. The main objective of the geophysical survey is to identify possible subsurface hazard that may contribute to more complete knowledge of the subsurface conditions to a minimum depth of 30m beneath the proposed construction site.

The RAP profiles have provided subsurface information that would ultimately be used to determine subsurface conditions beneath the site area. High amplitude of the spectrum is an indication of low mechanical properties of the strata. The minimum depth covered by the RAP survey is 50m. However, the core drilling was only conducted to 20-meter depth. As can be seen below from the profile of Line 2 compared against the borelogs, it would be recommended at this site to drill to 25-meter depth to better calculate depth to deeper formation and determine its composition.



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Based on our review of the RAP Method results, the following analysis is made from the present survey:

1. The amplitude of the spectra of acoustic signals is directly associated with the mechanical strength of the subsurface strata. A higher amplitude of the spectrum implies a relatively lower strength of the revealed strata.
2. High amplitude of spectrum encountered at both 5m and 30m depth is considered as a potential geologic hazard at the location of line No.4 at a distance of 16m from the beginning of the line equal to RAP - Point 9 on this line. Rather than core drilling at the 22-meter mark of Line 4 we would have move it to the 16-meter mark to confirm the anomaly and its potential as a hazard to be considered by engineering and construction.
3. The RAP sections and geotechnical results provide a higher resolution of the subsurface to support more detailed engineering foundation design of the proposed construction.
4. Core drilling should be conducted to a minimum depth of 25 meters at this site.
5. Calibration / Verification borehole to a depth of 35 meters is recommended to be drilled at the location of the suspected anomaly on Line 4 at the 16-meter mark (rather than 20 meters at the 22-meter mark as was already completed).

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APPENDIX A

Map of Site Showing

Orientation of Geophysical Lines

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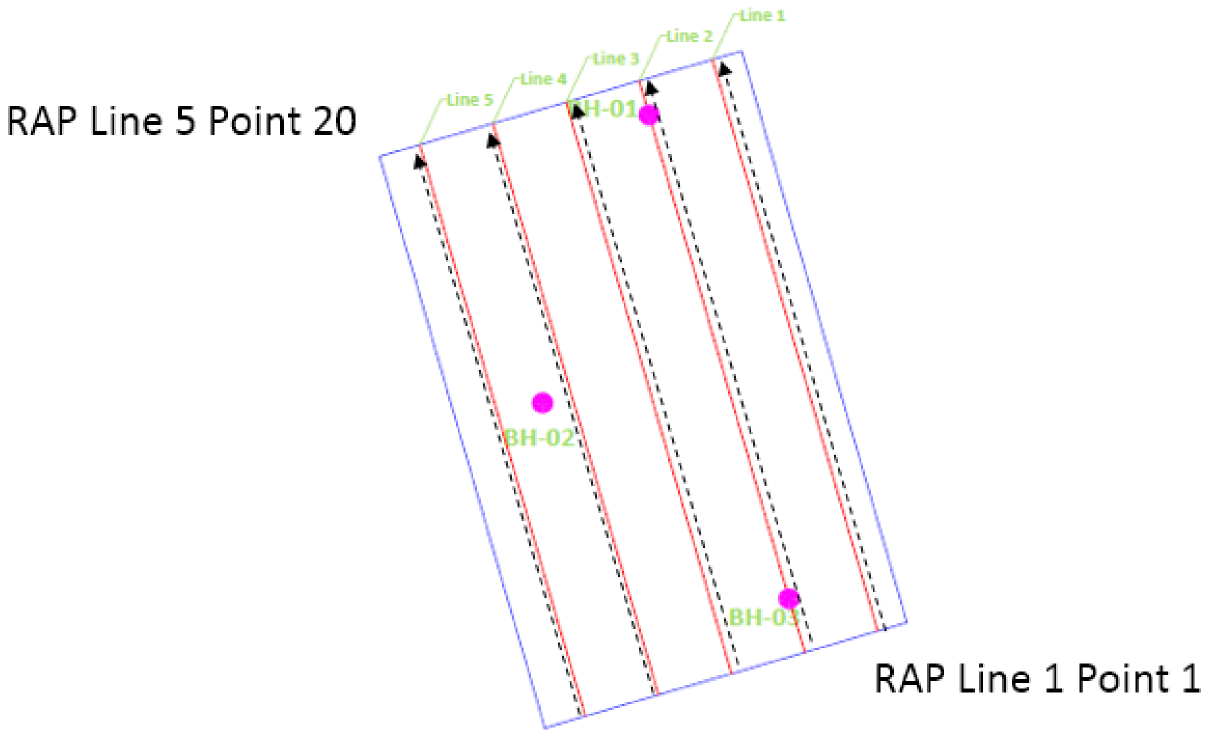
Coordinates of Start and End Points of RAP Profiles

Line No	Start		Level	End		Level	Length (m)
	Easting	Northing		Easting	Northing		
RAP Lines							
L1	Per MASW	Per MASW		Per MASW	Per MASW		39
L2	"	"		"	"		39
L3	"	"		"	"		39
L4	"	"		"	"		39
L5	"	"		"	"		39

SITE PLAN WITH MASW and RAP LINES

Khalifa City – pilot project



APPENDIX B
RAP PROFILES
2-D AND 3-D Slices

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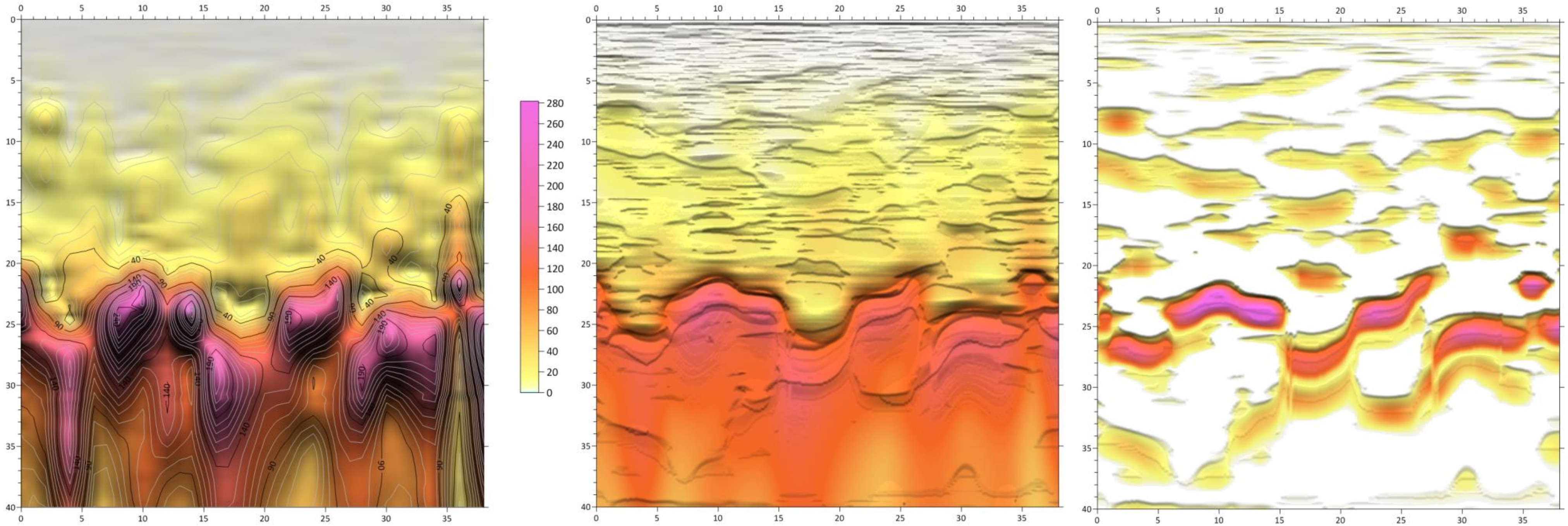
VERTICAL PROFILE – LINE 1

Khalifa City, Abu Dhabi

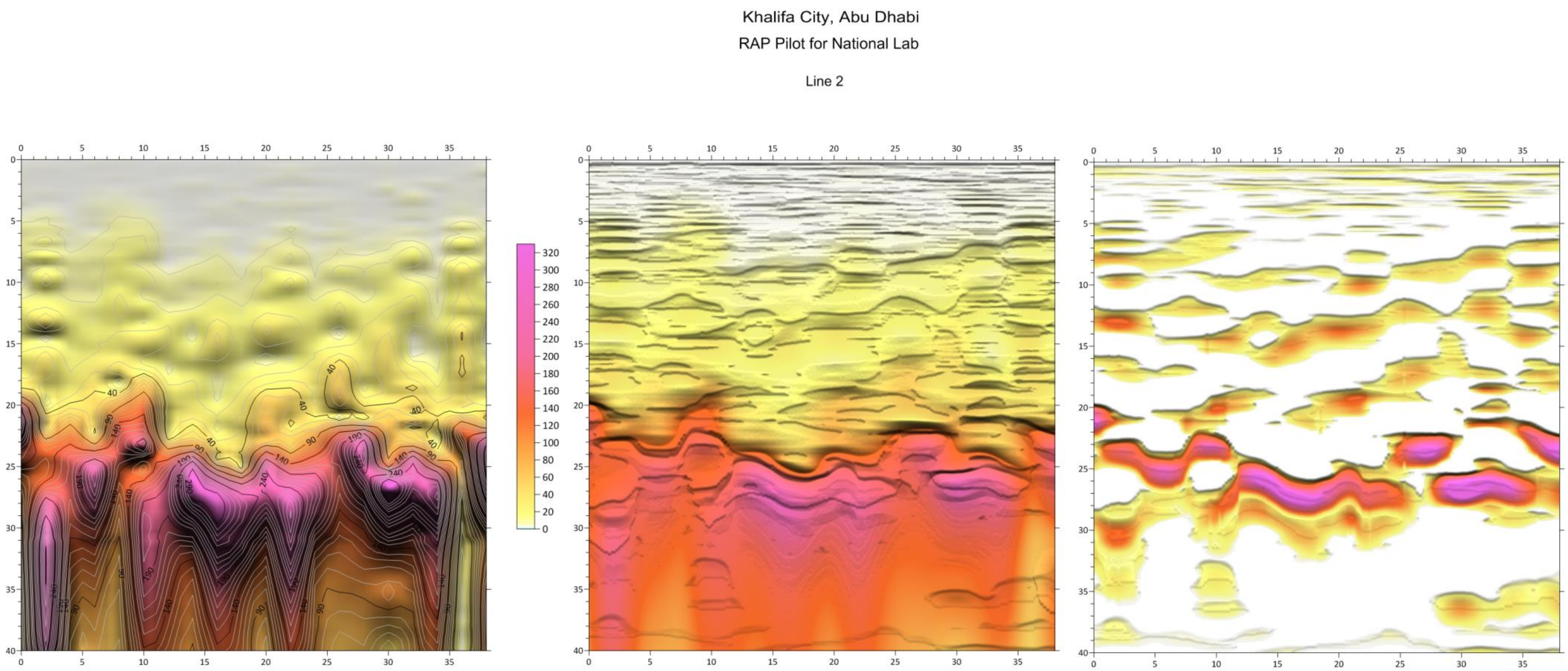
RAP Pilot for National Lab

Line 1



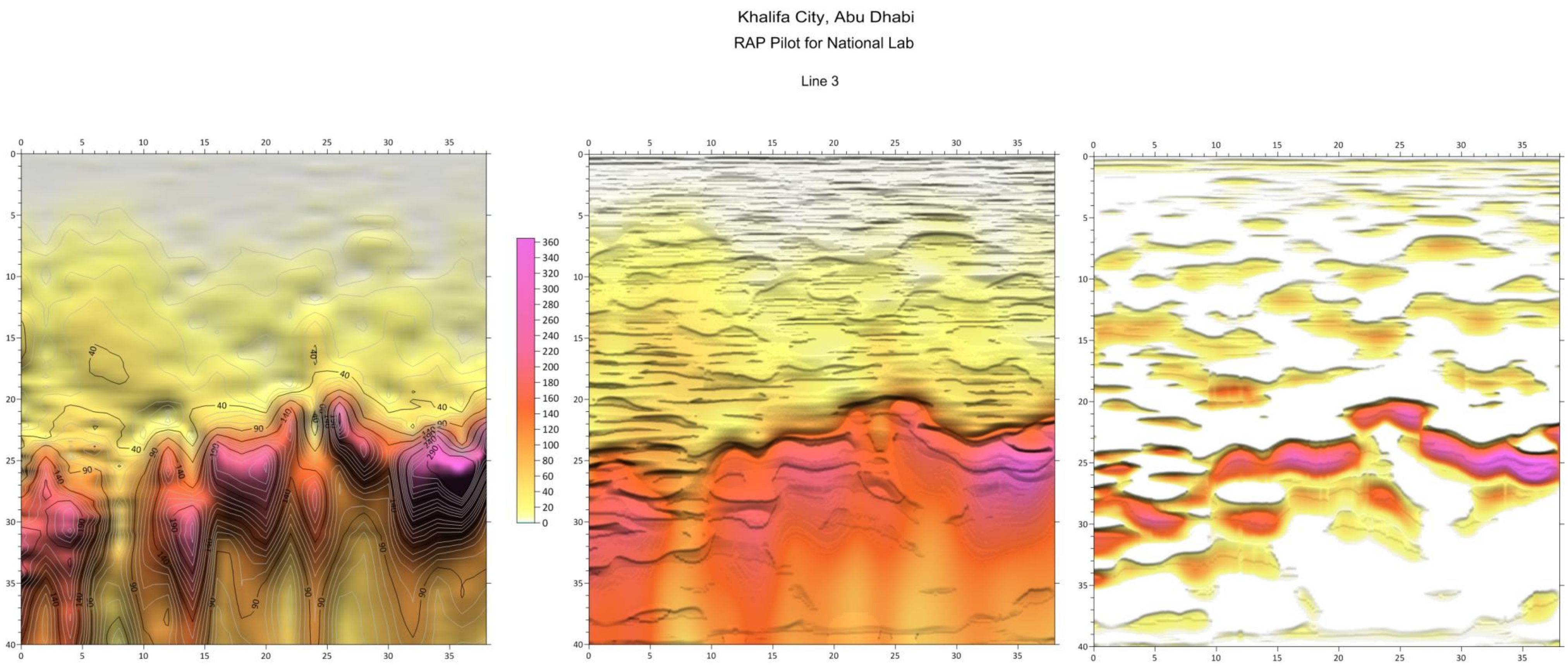
The profile on the left presents the Full Spectrum as visualized in Surfer with relief map overlaying contour map. The second profile is Full Spectrum processed and visualized in Centre program. The third profile is a presentation of the Local Component of the Spectrum, also processed and visualized in Centre program.

VERTICAL PROFILE – LINE 2



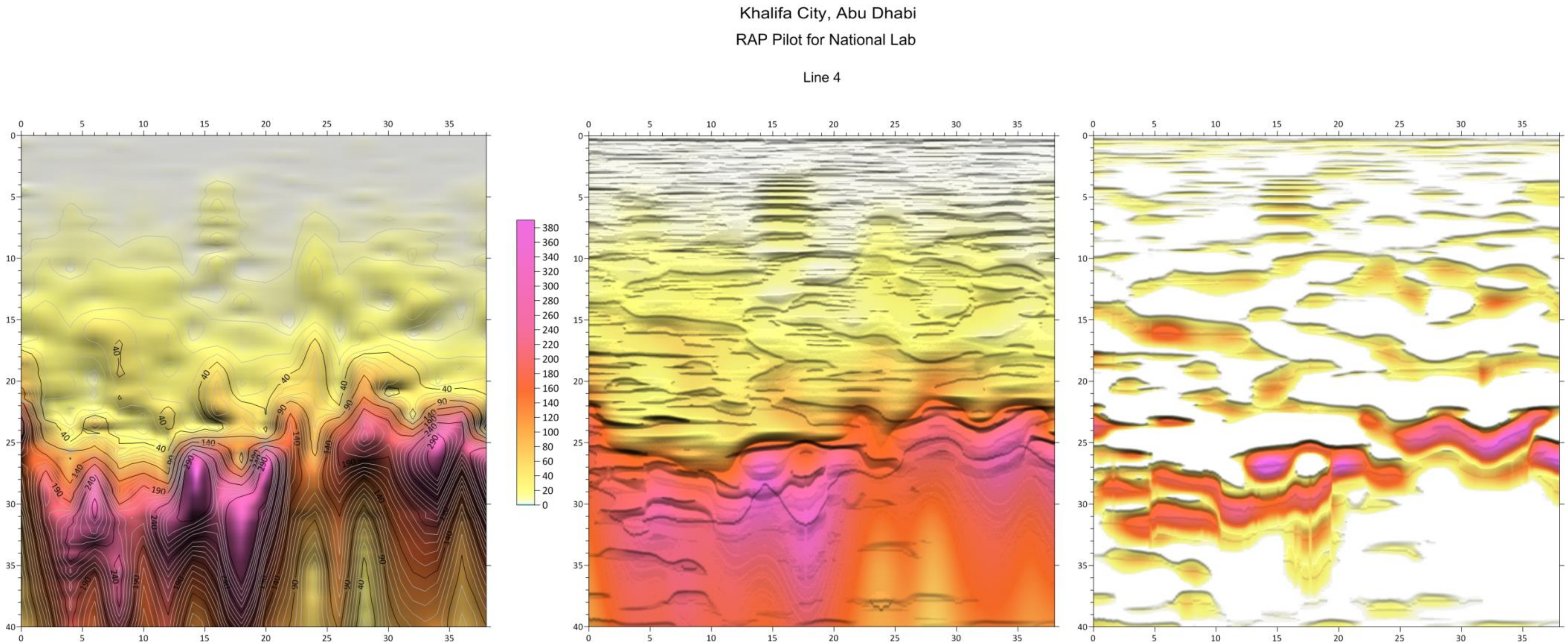
The profile on the left presents the Full Spectrum as visualized in Surfer with relief map overlaying contour map. The second profile is Full Spectrum processed and visualized in Centre program. The third profile is a presentation of the Local Component of the Spectrum, also processed and visualized in Centre program.

VERTICAL PROFILE – LINE 3



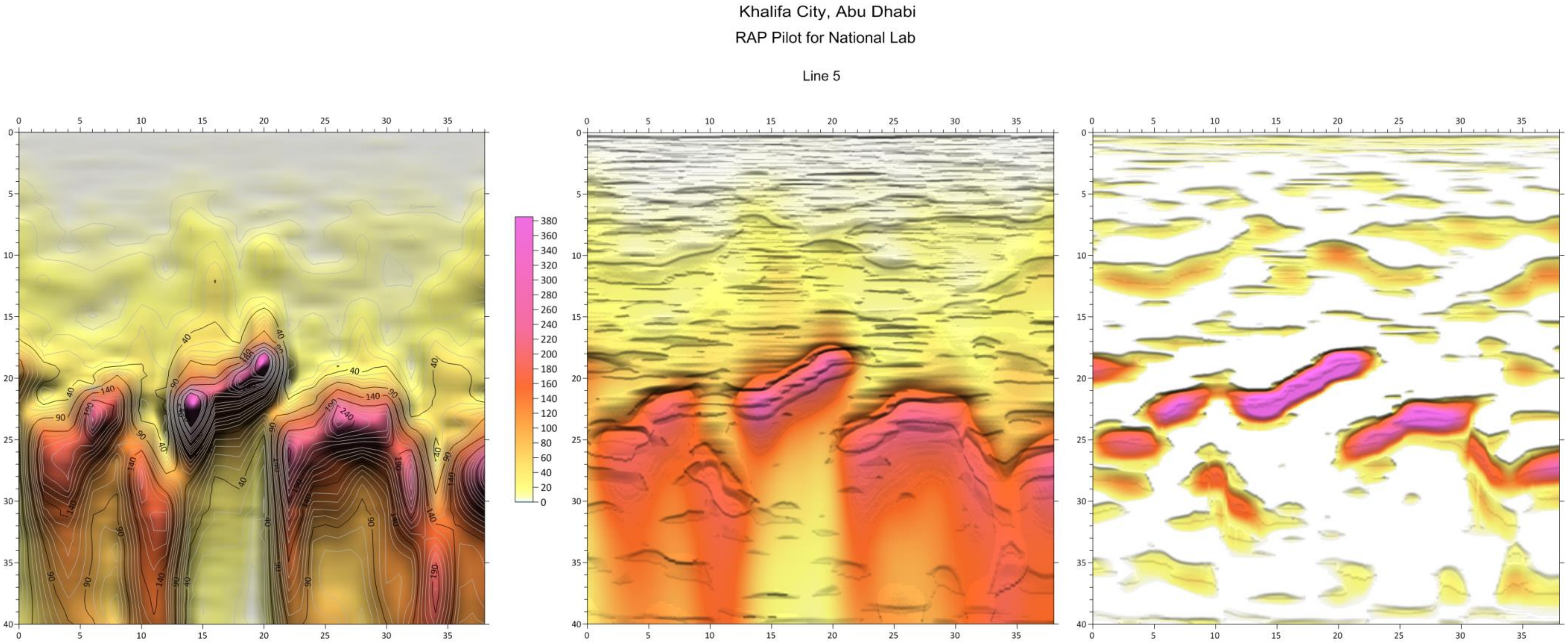
The profile on the left presents the Full Spectrum as visualized in Surfer with relief map overlaying contour map. The second profile is Full Spectrum processed and visualized in Centre program. The third profile is a presentation of the Local Component of the Spectrum, also processed and visualized in Centre program.

VERTICAL PROFILE – LINE 4



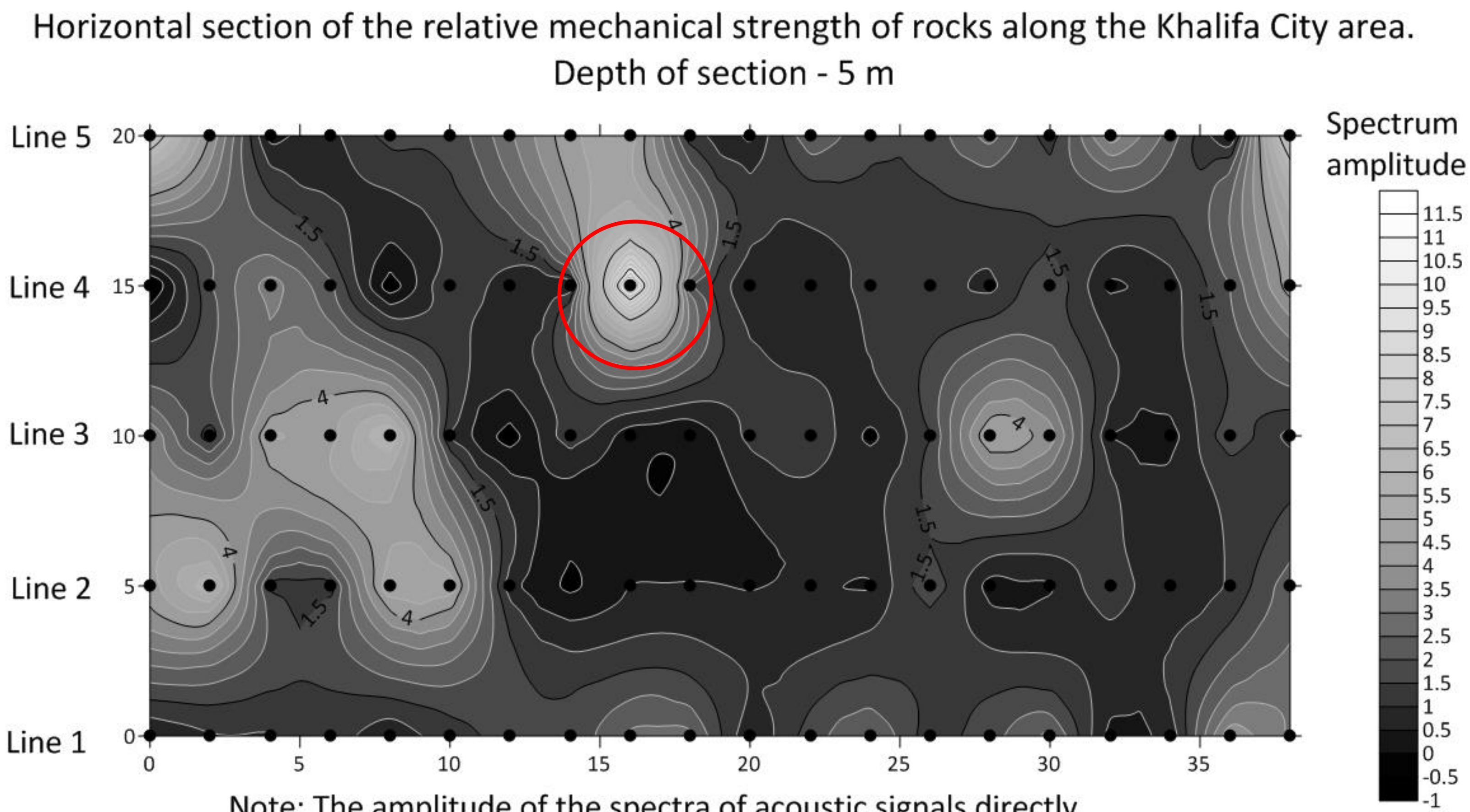
The profile on the left presents the Full Spectrum as visualized in Surfer with relief map overlaying contour map. The second profile is Full Spectrum processed and visualized in Centre program. The third profile is a presentation of the Local Component of the Spectrum, also processed and visualized in Centre program.

VERTICAL PROFILE – LINE 5



The profile on the left presents the Full Spectrum as visualized in Surfer with relief map overlaying contour map. The second profile is Full Spectrum processed and visualized in Centre program. The third profile is a presentation of the Local Component of the Spectrum, also processed and visualized in Centre program.

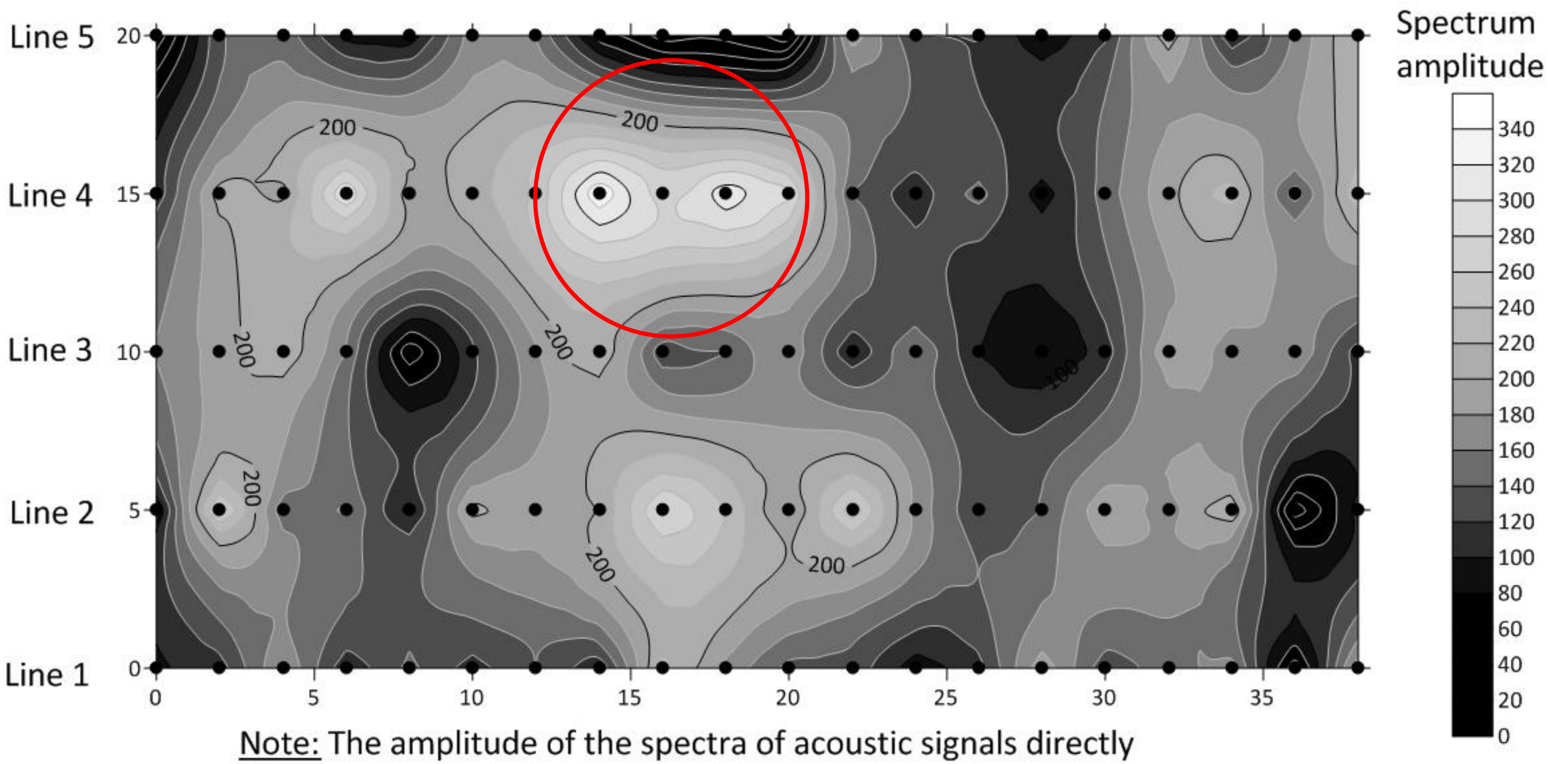
HORIZONTAL PROFILE – 5 METERS



Note: The amplitude of the spectra of acoustic signals directly associated with the mechanical strength of the section rocks. The higher amplitude of the spectrum - the less mechanical strength of rocks (higher degree of fracturing, watering, etc.)

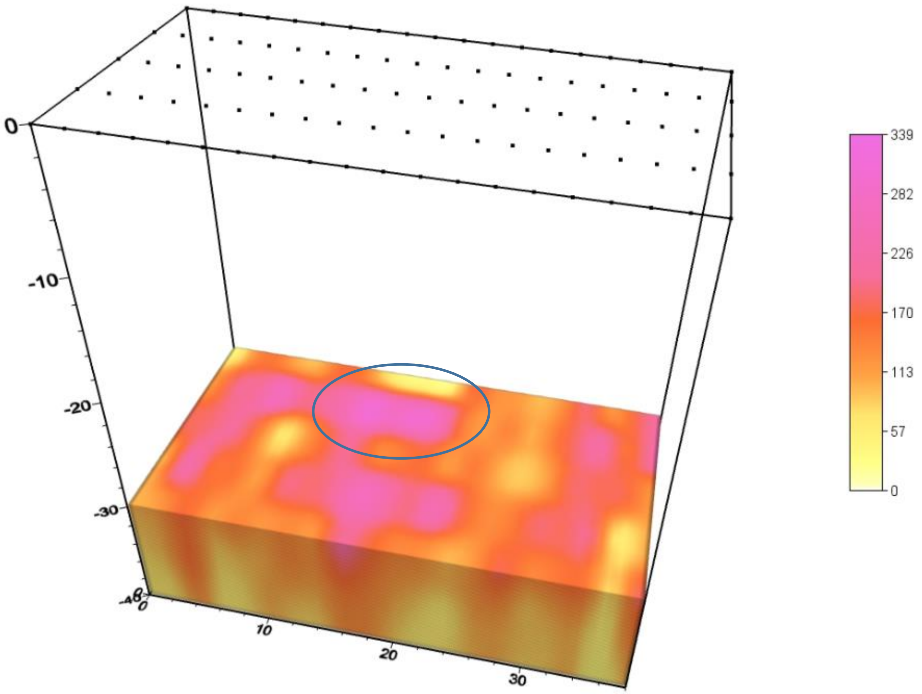
HORIZONTAL PROFILE – 30 METERS

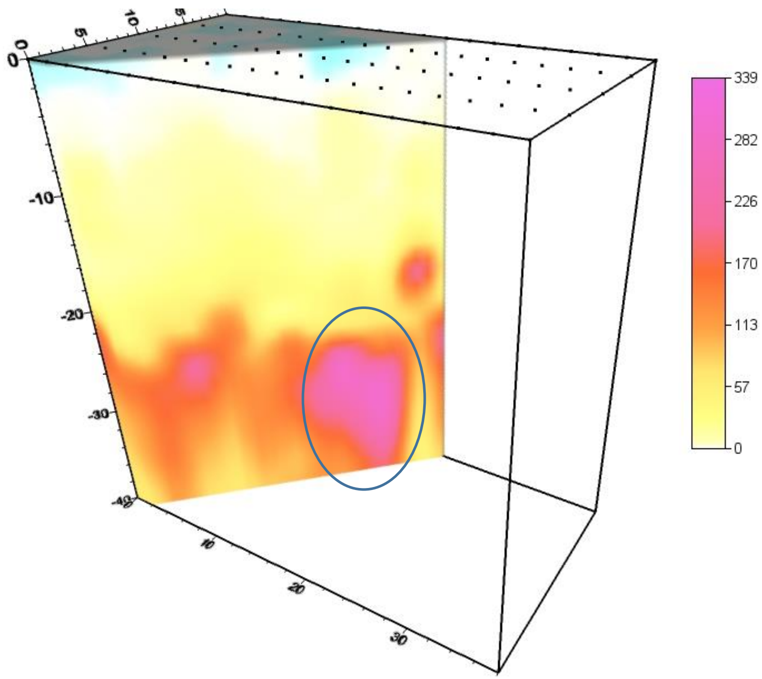
Horizontal section of the relative mechanical strength of rocks along the Khalifa City area.
Depth of section - 30 m



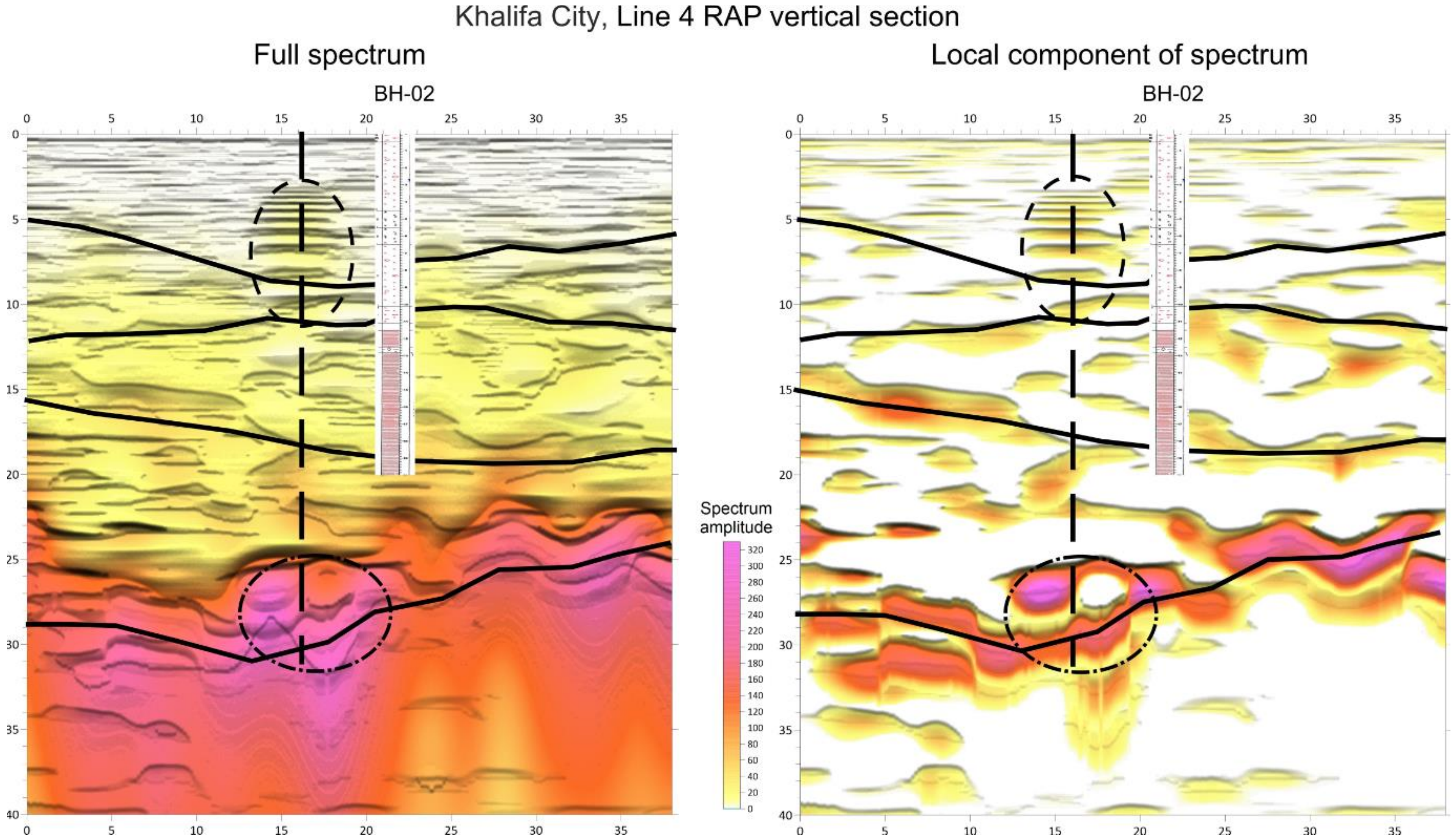
Note: The amplitude of the spectra of acoustic signals directly associated with the mechanical strength of the section rocks. The higher amplitude of the spectrum - the less mechanical strength of rocks (higher degree of fracturing, watering, etc.)

3-RENDERINGS

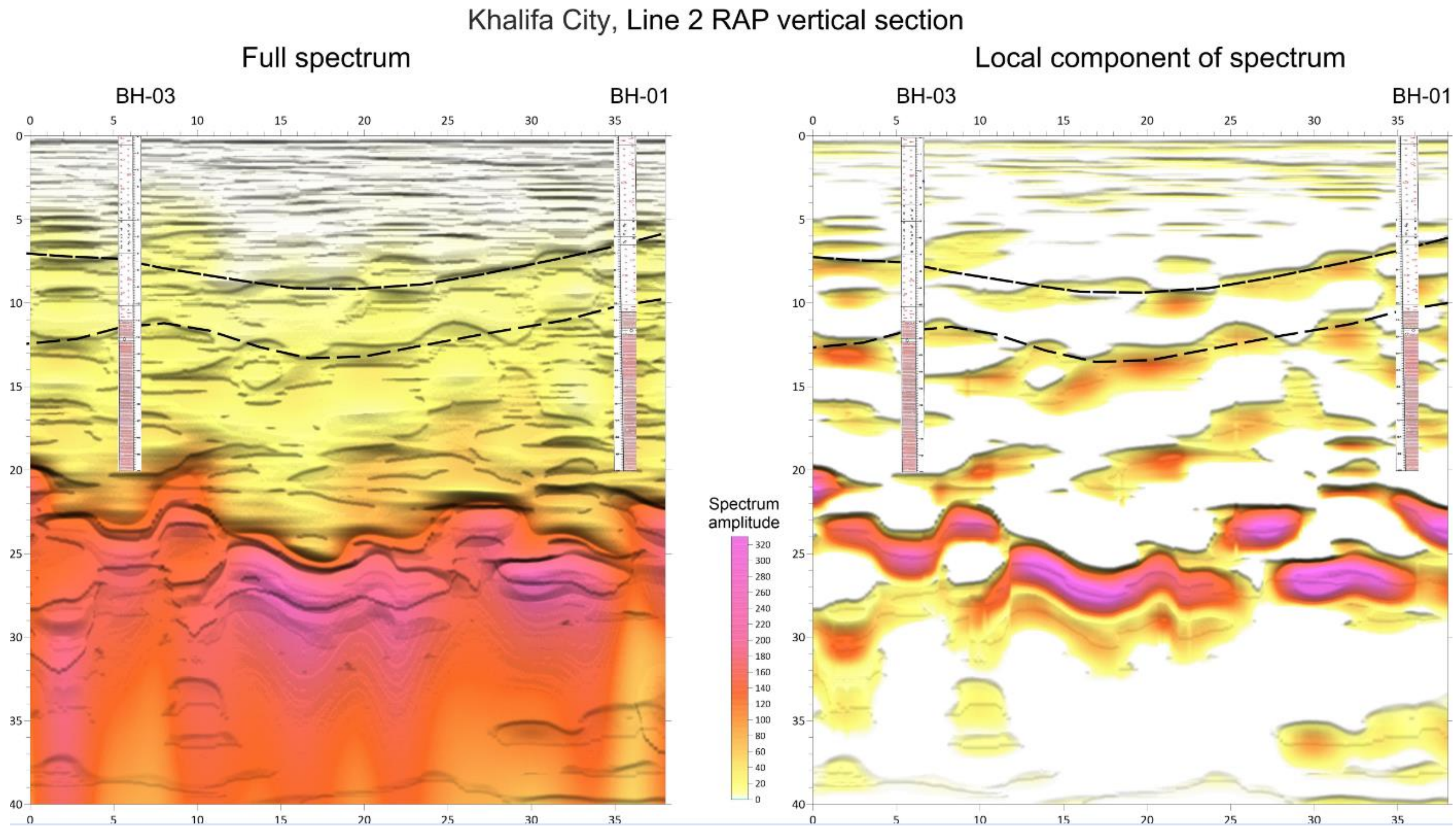




Significant anomaly appears as very weak zone at 30+ meters depth at the 16-meter mark (Point 9) of Line 4


Khalifa City, Line 4 RAP vertical section
Full spectrum
Local component of spectrum
BH-02
BH-02
Spectrum amplitude
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320

2-D PROFILES WITH BORELOGS



APPENDIX C
SITE PICTURES COLLECTED DURING THE SURVEY

JOB SITE PHOTOS