P323 The use of High-Resolution Seismics in tunnel construction projects in the Spanish Massif

ROBERTO FRANCESE *, JACQUES CENTONZE *, FRANCISCO MERCHAN ALVAREZ **,
MARIANO HIGUERAS GIL**, JOSE' ANTONIO ABEGER MONTEAGUDO ** AND NIGEL WARDELL *

** Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS*
Borgo Grotta Gigante 42/c, 34010 Sgonico, Trieste, Italy

*** Orellana Consultores S.A.*
C/ Ginzo de Limia 9, bajo 2, 28029 Madrid, Spain

Summary

A high-resolution seismic reflection survey was recently carried out in the area of the Umbria valley located north of the city of Madrid in Spain. The aim of the survey was to outline the structural framework of the near surface deposits to support a railway tunnel construction project. The field records exhibit poor reflectivity and a meticulous processing was required to achieve an adequate stack of the primary signal. Geological information from a series of nearby vertical and inclined boreholes was utilized to aid and refine the initial seismic interpretation.

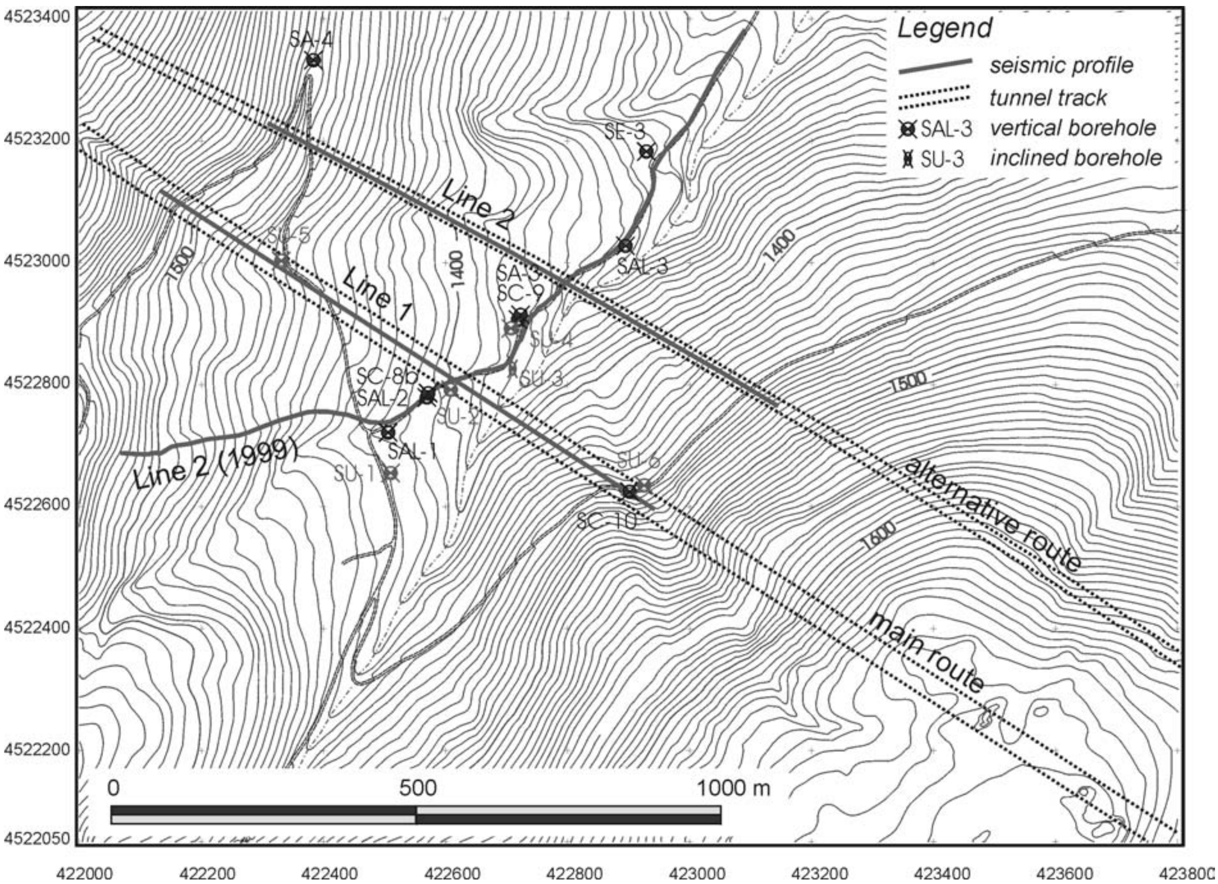

Fig.1 Sketch map showing the location of the seismic profiles with respect to the projected railway tunnel.

A number of well defined horizons generated detectable signal within the target depth of exploration. The stacked sections indicates that this geophysical technique could be implemented and generate useful results to characterize the metamorphic rocks of the spanish massif.

General settings

Near surface geology in this segment of the Umbria Valley is mainly comprised of an ensemble of metamorphic rocks laying on a pre-cretaceous bedrock. The ensemble is further divided into an upper gneiss unit and a lower cretaceous rock unit. The tectonic structure is quite complicated with a diversity of high-angle fractures and faults and low-angle thrusts. The fault gauges exhibit thicknesses of many meters and they are frequently altered in sands and clays. These mechanically weak zones represent a potential safety hazard when drilled while excavating the tunnel. The projected plan of excavation, beneath the seismic profiles, is located at a depth ranging from 200 to 300 m.

Data acquisition and processing

Two 1-km seismic profiles were collected in the study area. A third profile, collected in 1999, was reprocessed for the purposes of the current investigation (Fig.1). The recording geometry was a 24-channel end-on array, with 5 m station spacing, resulting in a maximum of a 24-fold dataset.

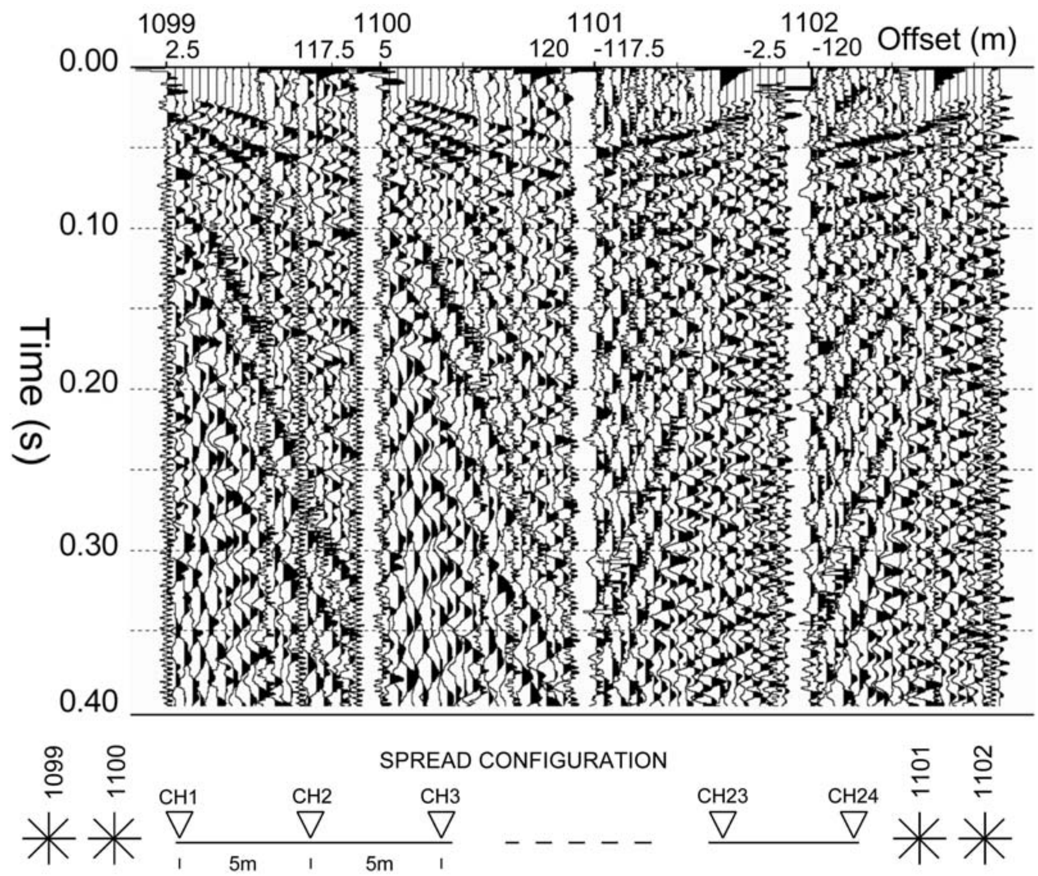

Fig.2 A typical gather of four raw records from the study area. A 0.1 s AGC was applied for display purposes.

Two shots were generated at each end of the spread before moving the entire spread one station forward. A single 40 Hz geophone at each station location detected the incoming signal. Recording parameters included a sample rate of 0.125 ms. Elastic energy was generated by stacking 5-6 records of a 8-kg hammer at each shot point.

The major effort in data processing was devoted to the calculation of refraction and datum statics and to the definition of the best choice parameters for spectral equalization. Velocity analysis was also conducted very carefully in order to properly stack the primary signal. An additional effort was devoted to migrate the final section and increase the spatial resolution of the seismic image.

Results and discussion

The migrated sections (Fig.3) exhibit a general low-medium degree of reflectivity and this is due to the local geology mainly comprised of metamorphic rocks with similar acoustic impedance. Acoustic property variations could be expected in cases when a sudden change in the upper gneiss facies occurs.

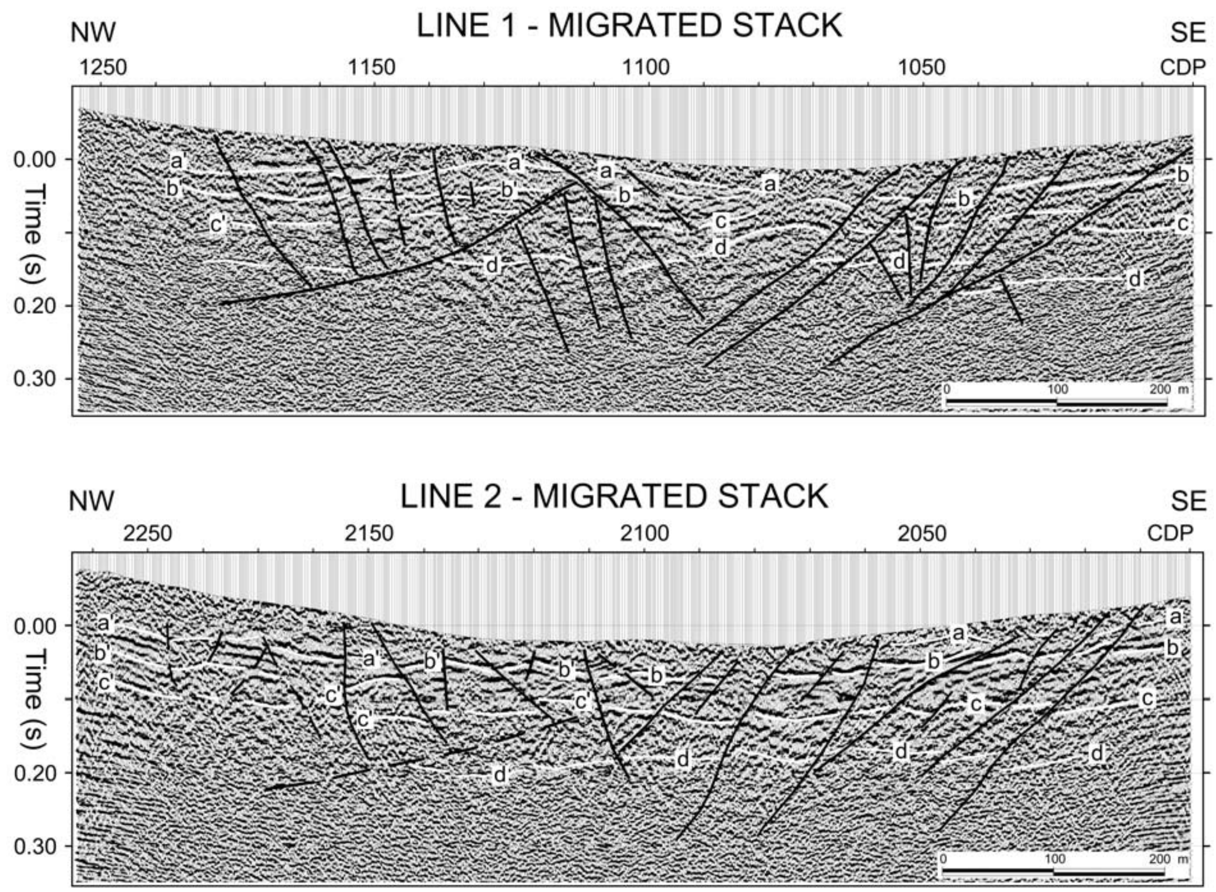

Fig.3. Migrated and interpreted stacks of line 1 and line 2.

Geological information from borehole stratigraphy, associated with the seismic image, suggested the existence of two distinct domains separated by a major thrust structure. Lithology in the north-western side of the profiles is mainly comprised of granular gneiss while in the south-eastern side lithology is comprised of blasto-mylonitic gneiss. The tectonic structure, separating the two geologic domains, seems to be clearly outlined by the seismic image and it's located in the CDP interval 1210-1130 and 2190-2120 respectively in Line1 and Line2. The structure has a good correlation across the two profiles and is truncated by a sub-vertical fault.

The seismic signature of the different domains is similar and it is not possible to predict the lithology based only on the seismic data. A variety of well-defined reflecting horizons are visible in each domain. Event marked with letters a', b' and c' (blasto-mylonitic gneiss domain) and a, b and c (granular gneiss domain) were interpreted as internal reflectors.

Although these events do not represent the signature of a geologic boundary the internal reflectors were utilized as direct markers of vertical displacements in the rock massif. The majority of the sub-vertical fractures and faults visible in the seismic interpretation were recognized through this process. Borehole stratigraphy confirmed the initial interpretation and suggested further analysis of specific events. The major structures intersect the surface at CDP 1050 and 1020 (Line 1) and CDP 2010 and 2070 (Line 2).

One of the most important event of the section is the horizon marked with letter "d". Direct evidence of the geological contact was found at borehole SU-2. This event was interpreted as the top of the cretaceous unit. The reflector was then correlated throughout the seismic section (Line 1). The correlation across the two profiles was achieved projecting horizontally from Line 1 to Line 2. Mapping of this unit, because of the poor mechanical properties, was within the objectives of the seismic survey.

Conclusions

The seismic survey integrated by borehole information defined the structural framework of the study area in the Umbria Valley. The reflectivity was generally poor, due to minimal changes in the acoustic properties in the formations with similar lithology. The top of the deep cretaceous unit, one of the targets of the survey, was recognized by correlating reflecting horizons with borehole stratigraphy. Some reflecting boundaries occurring within the upper gneiss unit were utilized to recognize sub-vertical displacements and to map fractures and faults along the seismic profiles.

High-resolution reflection seismics have proved to be an effective and reliable imaging technique to support tunnel construction projects in the metamorphic formations of the Spanish Massif.

The use of High-Resolution Seismics in tunnel construction projects in the Spanish Massif

R. FRANCESE *, J. CENTONZE *, F. MERCHAN ALVAREZ **, M. HIGUERAS GIL**, J. A. ABEGER MONTEAGUDO **, N. WARDELL *

* *Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)* - Borgo Grotta Gigante 42/c, 34010 Sgonico, Trieste, Italy
** *Orellana Consultores S.A.* - C/ Ginzo de Limia 9, bajo 2, 28029 Madrid, Spain

Summary

Two case histories from a series of high-resolution seismic reflection surveys, recently carried out in central and eastern Spain, are presented and discussed. The aim of the surveys was to outline the structural framework of the near surface deposits to support tunnel construction projects. The field records exhibited poor reflectivity and a meticulous processing sequence was required to achieve an adequate stack of the primary signal. Geological information from a series of nearby vertical and inclined boreholes was utilised to aid and refine the initial seismic interpretation. The final sections indicate that this geophysical technique can be usefully employed to characterise the metamorphic rocks of the Spanish massif.

Case history I - High resolution seismic surveys in the Umbria Valley (Madrid)

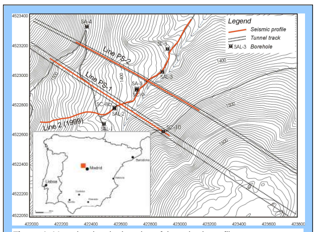

Figure 1: Map showing the location of the seismic profiles with respect to the projected railway tunnel.

General settings

Near surface geology in this part of the Umbria Valley is mainly comprised of an ensemble of metamorphic rocks laying on pre-Cretaceous bedrock. The ensemble is further divided into an upper gneiss unit and a lower cretaceous rock unit. The tectonic structure is quite complicated with a diversity of high-angle fractures and faults, and low-angle thrusts. The fault gauges exhibit thickness of many meters and they are frequently altered in sands and clays. These mechanically weak zones represent a potential safety hazard when drilled while excavating the tunnel. The projected plan of excavation, beneath the seismic profiles, is located at a depth ranging from 200 to 300 m.

Data acquisition and processing

Two 1-km seismic profiles were collected in the study area (Fig.1). A third profile, collected in 1999, was also reprocessed for the purposes of the current investigation. The recording geometry was a 24-channel off-end array, with 5 m station spacing, resulting in a maximum of a 24-fold dataset. Two shots were generated at each end of the spread before moving the entire spread one station forward (Fig.2).

ACQUISITION PARAMETERS	
Amplifier	EG&G 1225
A/D conversion	21 bit
N of live channels	24
Geometry	off-end
receiver array	Two 100-Hz geophones
receiver spacing	5.0 m
shot spacing	2.5 m
minimum offset	2.5 m
average CMP spacing	1.25
maximum fold	24
shot location	surface
shot type	hammer - 5 to 6 blows
Recording	
sampling rate	0.250 ms
low-cut filter	off

Table 1: Data acquisition parameters

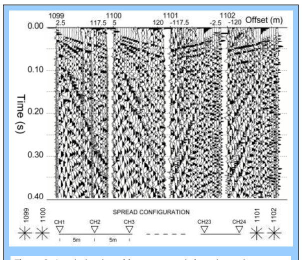

Figure 2: A typical gather of four raw records from the study area. A 100 ms AGC was applied for display purposes.

	DATA PROCESSING FLOW
-	data reformatting SEG-2 to FOCUS
-	trace editing
-	amplitude recovery
-	first break picking refraction and datum statics
-	band pass filtering (15/30 - 250/350 Hz)
-	band limited spectral whitening (50-500 Hz)
-	application of statics to floating datum
-	CMP sorting
-	CVS plus semblance velocity analysis
-	normal move out correction
-	front-end mute
-	CMP structure stack
-	application of datum statics
-	FX migration
-	post stack energy balancing

Table 2: Data processing sequence

Two 100 Hz geophones at each station detected the incoming signal. Recording parameters included a sample rate of 0.250 ms. Elastic energy was generated by stacking 5-6 records of a 8-kg hammer at each shot point. Data acquisition parameters are reported in Table 1. The major effort in data processing was devoted to the calculation of refraction and datum statics and to the definition of the best choice parameters for spectral equalisation. Velocity analysis was also conducted very carefully in order to properly stack the primary signal. Additional effort was devoted to the migration of the final section and to increase the spatial resolution of the seismic image. Data processing flow is shown in Table 2.

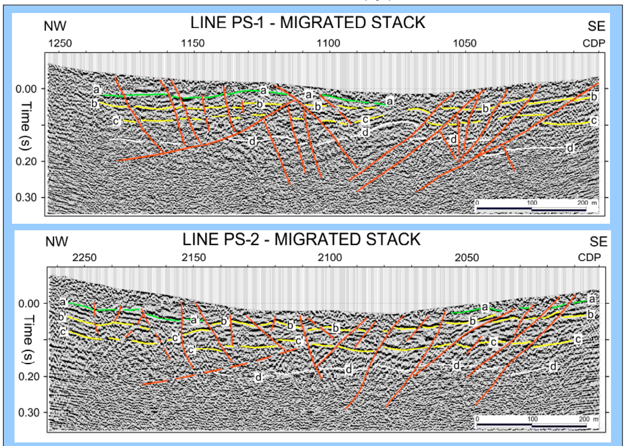

Figure 3: Migrated and interpreted stacks of line PS-1 and line PS-2.

Results and discussion

The migrated sections (Fig.3) exhibit a general low-medium degree of reflectivity and this is due to the local geology mainly comprising of metamorphic rocks with similar acoustic impedance. Acoustic property variations could be expected in cases when a sudden change in the upper gneiss facies occurs.

Geological information from borehole stratigraphy, associated with the seismic image, suggested the existence of two distinct domains separated by a major thrust structure. The lithology in the north-western side of the profiles is mainly comprised of granular gneiss whilst in the south-eastern side it is comprised of blasto-mylonitic gneiss. The tectonic structure, separating the two geologic domains, seems to be clearly outlined by the seismic image located between CDP 1210-1130 and 2190-2120 on Lines PS-1 and PS-2 respectively. The structure has a good correlation across the two profiles and is truncated by a sub-vertical fault. The seismic signature of the different domains is similar and it is not possible to predict the lithology based only on the seismic data. A variety of well-defined reflecting horizons are visible in each domain. Events marked with letters a', b' and c' (blasto-mylonitic gneiss domain) and a, b and c (granular gneiss domain) were interpreted as internal reflectors.

Although these events do not represent the signature of a geologic boundary the internal reflectors were utilised as direct markers of vertical displacements in the rock massif. The majority of the sub-vertical fractures and faults visible in the seismic interpretation were recognised through this process. Borehole stratigraphy confirmed the initial interpretation and suggested further analysis of specific events. The major structures intersect the surface between CDP 1050 and 1020 on Line PS-1 and between CDP 2010 and 2070 on Line PS-2.

One of the most important events of the section is the horizon marked with letter "d". This event was interpreted as the top of the Cretaceous unit and the reflector was correlated throughout the seismic sections. Direct evidence of the geological contact was found at borehole SU-2. The mapping of this unit was one of the main objectives of the seismic survey.

Case history II - High resolution seismic surveys in Enguera (Valencia)

General settings

Near surface geology in the Enguera region is comprised of an ensemble of Cretaceous and Tertiary formations. The tectonic structure is complicated with various folds, faults and thrusts. The seismic profile is located over an important anticlinal structure where the Cretaceous units locally overthrust the Tertiary formations. Cretaceous units are mainly comprised of massif limestones and dolomites while the Tertiary formations are comprised of marls and sandstones. The projected plan of excavation, beneath the seismic profile, is located at a depth ranging from 100 to 280 m.

Data acquisition and processing

A 3.5-km seismic profile was collected in the study area (Fig.4). Acquisition geometry and parameters were very similar to the ones of the Umbria Valley survey. Elastic energy was generated by stacking several blows of a 8-kg hammer at each shot point. In this case also reflectivity was poor and a careful processing sequence was required to constructively stack the primary signal.

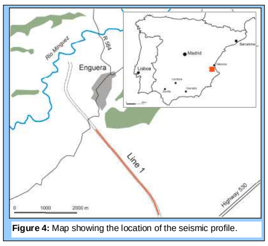

Figure 4: Map showing the location of the seismic profile.

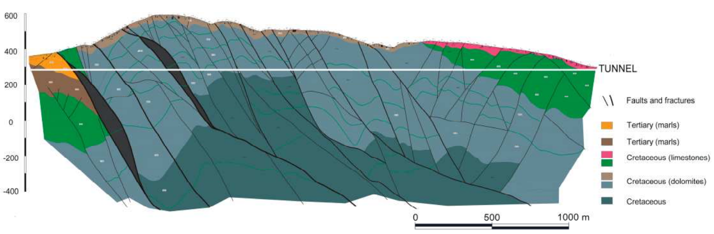

Figure 5: Geological profile along the projected tunnel

Results and discussion

The migrated section (Fig.6) exhibits a general low-medium degree of reflectivity. Some major reflectors are visible along the profile and these horizons were recognised by tying the seismic data to the borehole stratigraphy (a total of five boreholes have been drilled along the seismic profile). The sub-vertical displacement of the reflecting horizons was used as an indicator of faults and thrusts. Two distinct geological domains are visible in the section. Between CDPs 1001-1630 the subsurface is comprised of limestones and dolomites of Cretaceous age verging on the two sides of an anticlinal structure with its axial plane approximately at CDP 1500. Between CDPs 1630-1680 the near surface is comprised of Tertiary marls and the statigraphic contact with the underlying Cretaceous strata is marked by the reflections occurring at about 150 ms. The two domains are separated by a high-angle inverse fault system with the south-eastern block overthrusting the north-western domain (Fig. 5).

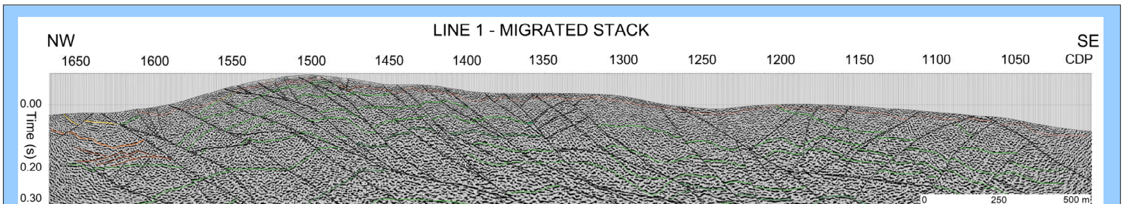

Figure 6: Migrated and interpreted stack of line 1.

Conclusions

The seismic surveys, integrated with borehole information, defined the structural framework of the study areas. The reflectivity was generally poor due to minimal changes in the acoustic properties in the formations with similar lithology. The top of the deeper Cretaceous unit, one of the targets of the surveys, was recognised by correlating the reflecting horizons with the borehole stratigraphy. Some reflecting boundaries occurring within the same formation were utilised to recognise sub-vertical displacements and to map fractures and faults along the seismic profiles. High-resolution reflection seismics have proved to be an effective and reliable imaging technique to support tunnel construction projects in the metamorphic formations of the Spanish Massif.