Evaluation of the 3D Seismic High-resolution method at

argillaceous Tournemire IRSN site

J. Cabrera

IRSN/DPRE/SERGD

Abstract:

The 3D high-resolution experiment at argillaceous Tournemire IRSN site was carried out to evaluate the ability of this method to detect the secondary faults with small vertical displacement, mainly faults with strike-slip displacement. This fault type, already identified at Tournemire site, is not clearly detected by the classic 2D and 3D seismic methods.

The 3D seismic programme was conduced in several phases: a synthesis and state of the art of the existing 2D and 3D seismic methods, a previous numerical approach using known Tournemire data, the experimental design and fieldwork, processing and analyses of results and finally testing a new additional processing method. A new detailed an original 3D seismic high resolution experience was carried out: high geophone density array (5568 geophones) for a small surface area (0,5 square kilometres), additional geophones array in depth (6 geophones in the drifts of the underground experimental station), large frequency scale ranging from 14 to 140 Hz, investigated depth lesser than one kilometre.

The first processing and analysis of the results show fault detection mainly in the depth limestone layers. In the argillaceous medium, which is affected by the analysed Tournemire secondary faults, fault detection is not clearly shown. A new additional processing method is presently applied to the data and the final results will be available by december 2002.

1. Aim of the 3D seismic investigations

The safety assessment of deep radioactive waste disposal in geological formations concerns the evaluation of transfer possibilities and processes through these formations. The argillaceous medium is a potential geological barrier for deep radioactive waste disposal due to its very low permeability and the strong capacity for radionuclide retention. However, faults and fractures may affect this medium therefore it is necessary to analyse the transfer possibilities along these discontinuities. The first phase of this evaluation concerns the detection or survey of these discontinuities. The geophysical methods are favourable techniques to investigate, from the surface, the deep geological formations.

The natural discontinuities are of different scales ranging from the major regional faults of kilometric length to small microfractures of centimetric scale. The major faults are frequently detected from the surface cartography or by geophysical investigations. However, the secondary faults or fractured zones of hectometric length are not clearly detected from the surface, mainly the faults that show sub-horizontal displacements. Frequently, these faults are not detected by 2D or 3D seismic methods owing to their small vertical displacement.

The Tournemire experimental site, located in an old railway tunnel that crosses the well compacted argilites 250 meters below ground surface, shows these secondary faults which are associated with fractured zones. These discontinuities, with a known geometry in the western drift, allow us to evaluate the 3D seismic high-resolution performance for the detection of this type of faults. IRSN used 3D seismic method as a part of its research programmes for the expertise mission.

2. Geological and geophysical context

The argillaceous medium of the Tournemire experimental site was formed around 195-180 million years ago, in a Jurassic marine basin on the Southern border of the French Central Massif. It corresponds to a 250 m thick sub-horizontal layer, located between two limestones and dolomite layers (300-500 m thick), where two aquifers were developed (Fig. 1). This argillaceous medium consists of well-compacted (rock) claystones (argilites) and marls of Toarcian and Domerian formations (200 and 50 m thick respectively). Argillaceous matrix is characterized by very low water content (1 to 5% bww), small poral space (2.5 nm), very low permeability (10^{-12} and 10^{-15} m/s)

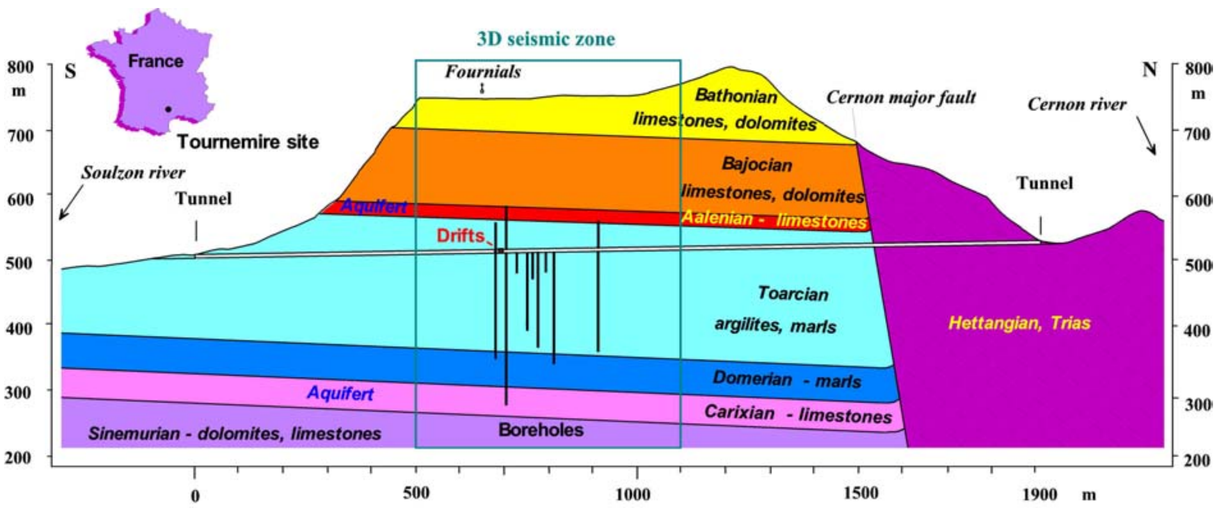

Fig. 1. Cross-geological section of the Tournemire site showing the 3D seismic zone

The Tournemire massif corresponds to a sub-horizontal monoclinal structure affected by an E-W striking regional fault in the northern border (Cernon fault, Fig. 1). The present water circulation is located along the lower and upper limestones aquifers and along this major regional Cernon fault. Secondary faults and fractured zones affect this massif and these discontinuities are related to different tectonic events (extensional and compressional tectonics). The Western Tournemire drift and the western borehole exploration show these secondary faults and associated fractured zones (Fig. 2). These faults are characterized essentially by a strike-slip displacement and consequently are difficult to detect by the classic geophysical methods (seismic reflection) from the surface. In depth, this discontinuities may be detected with seismic tomography between boreholes (decametric scale): at the Tournemire site, the P wave velocity changes from 3500 m/s in unfractured zones to 2500 m/s in fractured zones. On the other hand, and in a smaller scale, the artificial microfractures related to the drift excavation (EDZ) were investigated using geophysical methods. In this context, the 3D seismic evaluation corresponds to larger scale of geophysical methods tested in the Tournemire site and is part of a geophysical research programme of the Tournemire project.

3. 3D seismic programme

The 3D seismic Tournemire programme was carried out in several phases in a period of roughly two years (2001-2002). The first phase concerns syntheses work and the state of the art of 2D and 3D seismic methods. The second one corresponds to the previous numerical approach using the Tournemire data. After a validation of this precedent phase an experimental design was made taking into account the Tournemire secondary fault and fractured zones locations. The fieldwork, important 3D seismic phase, were conduced with a previous 2D seismic profile for to analyse the field seismic properties and consequently to adapt the more appropriated emission and reception devices. The last phase corresponds to processing and analysis of the field data that is carryed out in this present year. An additional new processing data, "semblance-seismic facies-azimuthal anisotropy approach", is conduced presently.

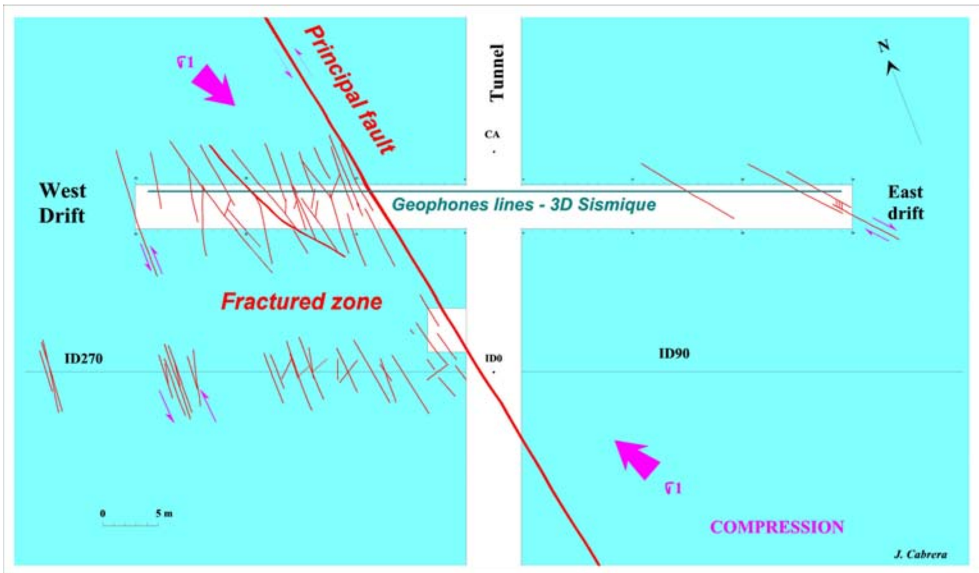

Fig. 2. Structural and tectonic sketch with the geophones lines location

The 3D seismic programme was carried out by the IRSN with participation of the Compagnie Générale de Géophysique CGG (previous modelling, design and fieldwork and processing of the data), the Bureau de Recherches Géologiques et Minières BRGM (technical participation) and the Ecole de Mines de Paris EMP (technical participation).

3.1. Syntheses and state of the art

The classic 2D and 3D seismic method is used particularly in the field of oil and gas exploration to investigate tri-dimensional characteristics of sedimentary rocks and structural heterogeneities in depths until several kilometres. On the other hand, the investigation of some tenths of meters below the surface is carryid out using seismic high resolution (geotechnical work, hydrogeology, mines). For intermediate depths, several hundred meters, this method is not used frequently. The 3D seismic method used in the petroleum domain may detect faults with vertical displacement over roughly 10 meters. In contrast faults that show mainly strike-slip displacements are difficult to detect. In this case, the 3D seismic method require a particularly devise and adapted acquisition parameters.

3.2. Previous numerical approach

A tri-dimensional velocity geological model was build from the Tournemire data: the main sedimentary layers from the surface to 800 m depth, the secondary western drift fault zone and a second virtual fault zone (Fig. 3).

Seismic velocity data were found from Tournemire previous geophysical research programmes or from the regional existing data. In unfractured medium these range between 5200 m/s in the massif limestone and 3000 m/s in the argillaceous medium (argilites). In fault zones they are 1000 m/s more smaller that in the unfractured zones.

Taking into account a well field theory coupling and response a virtual seismic simulation was carried out. The first results, cover-velocity-offset maps, suggest a probable detection of this fault zones.

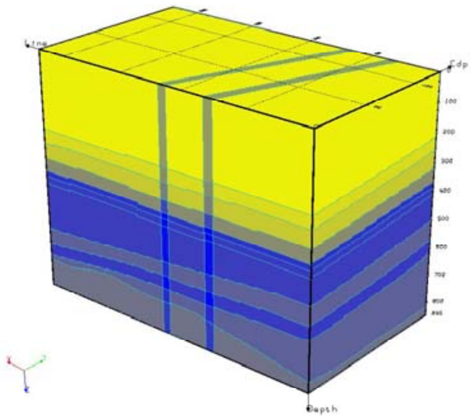

Fig. 3. Geological and property model with two vertical secondary fault zones used for the numerical approach (yellow – 5000-4000 m/s and bleu 3500-3000 m/s).

3.3. Experimental design and field work

The experimental design was defined after numerical approach, field survey and geological-geophysical analyses. The 3D survey area is focused around the drift locations (950 m x 650 m). The geophones lines are East-West trend and each line is composed by 95 traces, each trace by 6 geophones and a distance of 1,5 meters between each geophone. A total of 5568 geophones were appointed in a surface of roughly 0,5 square kilometres (Fig. 4). To this high density of surface grid of geophones were associated 6 geophones appointed in the two drifts, located 250 m below the surface (Fig. 2). A total of 14 lines traces were appointed with equidistance of 50 meters between each line (Fig. 4). The total seismic array was connected to a Sercel 408 – 1000 record laboratory. The seismic source lines are North-South strike with 10 meters equidistance between emission points. A total of 20 lines were used with equidistance of 50 meters between each line (Fig. 4). The M22 vibrator source was used with frequencies ranging from 14 to 140 Hz (Fig. 5). This frequency range was deduced from the previous 2D seismic test profile (Fig. 4), which gives maximum exploitable data until 140 Hz.

The fieldwork was developed in four phases during 3 weeks: detailed topographic appointment of emission and reception points, putting of geophones lines, the 2D seismic test and the acquisition 3D seismic data. This fieldwork was carried out with a particularly precaution not to damage the flora of the Causse du Larzac plateau national park.

3.4. Processing and analyses

The processing and analyses were carried out in the CGG Company with the IRSN, BRGM and EMP participation. The Geovector program was used for the seismic processing. The first phase concerns the formatting data, trace editions, different corrections (static), seismic velocity analyses, attenuation (linear noise), and other processes before the migration. The second one comprises the velocity model migration building, filtering and homogenisation.

A weak signal/noise relationship characterizes the 3D seismic Tournemire data. Organised noise exists between 1200 and 1700 m/s velocities. Processing concerns the high-resolution data and additional 3D FK filter was used. Results of this processing data show clearly the horizons mainly of the lower limestone layer with a break correlated to a fault zone (Fig. 6). The upper horizons of the limestone layer are not clearly defined in comparison to the lower ones. The argillaceous medium appears characterized by a relatively by homogeneous zone and the break shown in the lower layer is not clearly identified (Fig. 6). At this stage, the final migration maps, time constant, show this roughly N-S strike fault zone mainly in the lower limestone layer (Fig. 7).

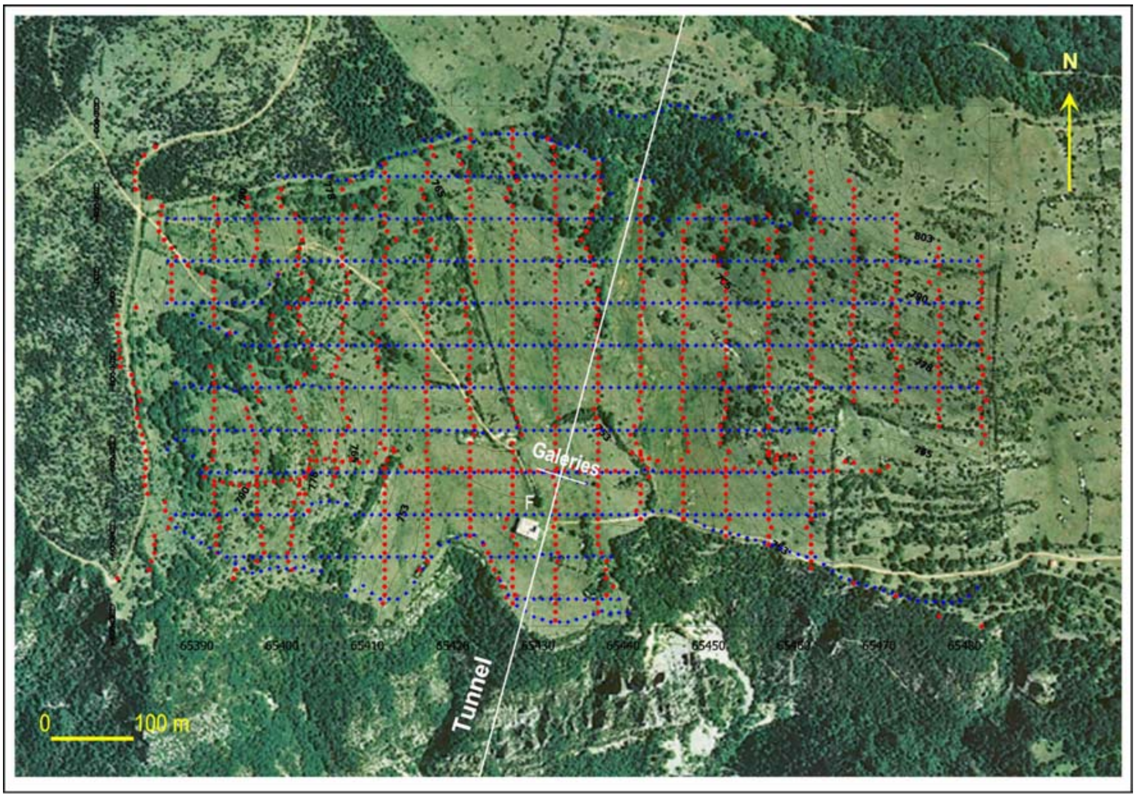

Fig. 4. 3D seismic field device on the Tournemire site with tunnel and drift locations (Bleu, geophones lines and red emissions lines).

The fault zone attributed from this 3D seismic data is correlated to the analysed faults in the drift Tournemire sector and consequently it is attributed to the same fault zone through the sedimentary series. Structural and tectonic analyses in the drifts and on the surface show that this principal strike-slip faults show a small vertical displacement that disappears towards the surface where is exhibits only a large fractured zones. If these characteristics are correlated to the recent 3D seismic data in depth, it may be in agreement with a general increasing vertical displacement component toward the surface for this type of secondary strike-slip faults. This is the first interpretation before the new additional data processing.

Fig. 5. Reception (geophones) and emission (M22 vibrator) device.

3.5. New additional processing method

In order to carry out more detailed analysis a new additional processing method is actually conduced. It concerns the semblance computing, seismic facies and azimuthal anisotropy analyses to characterise the fracturation. The final results will be available in the present year-end.

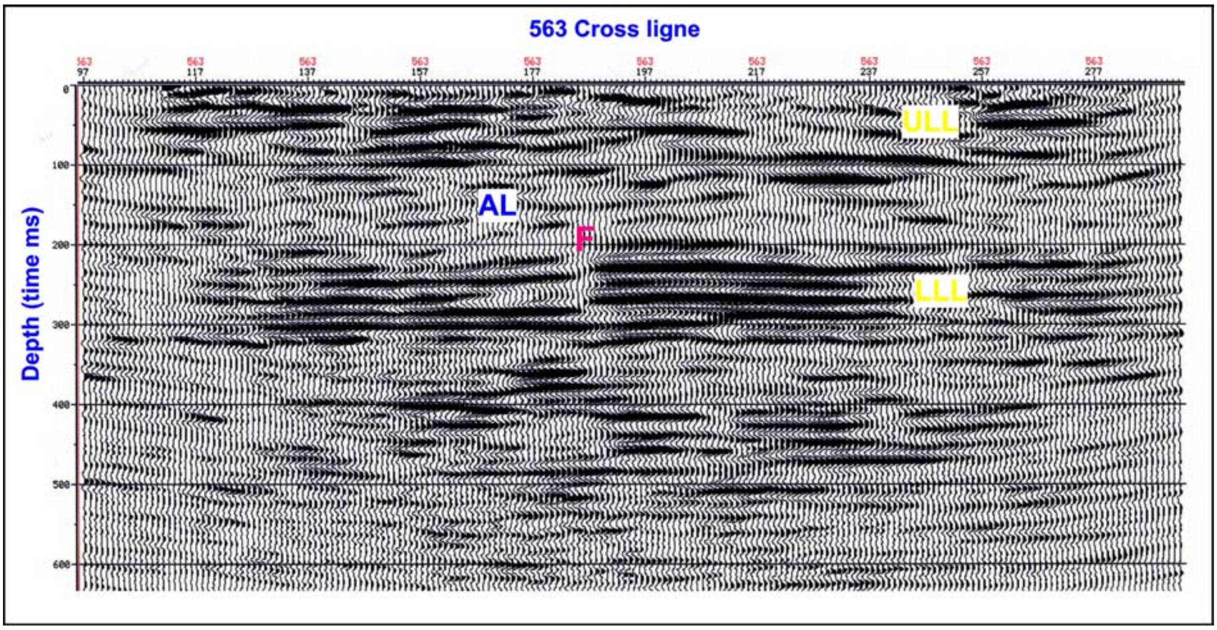

Fig. 6. 2D migrated section showing a break (fault) in lower limestone layer. ULL-Upper limestone layer, AL – Argillaceous layer, LLL – Lower limestone layer, F, Fault zone.

4. Conclusions

The 3D high-resolution seismic at the Tournemire site was carried out to evaluate the performance of this method to detect secondary faults with small vertical displacement, mainly faults with strike-slip displacement, which is the case for the Tournemire ones. The different phases carried out in this 3D seismic program show the importance to appoint the best appropriated experimental design and to adapt the processing methods in relation to the aim of the investigations. The previous numerical model simulation gave a favourable fault detection taking into account the best field conditions. However, the fieldwork has showed some limits in relation to the different field properties. For the high frequencies a maximum until 140 Hz was used to obtaine exploitable field data. A border effect, mainly near the cliffs, occurs and these noises had to be filtered. The high geophone density array (5568) for a small surface area (0,5 square kilometres), the additional geophones array in depth (drifts), and the large frequencies scales ranging from 14 to 140 Hz, characterise a new detailed original 3D seismic high-resolution experience.

The first processing and analysis of results show fault detection mainly in the limestone lower layer. However, in the argillaceous medium the faults in the drift sector are not clearly shown at this stage. The new additional processing method is presently applied to data and the results will be available by the present year-end.

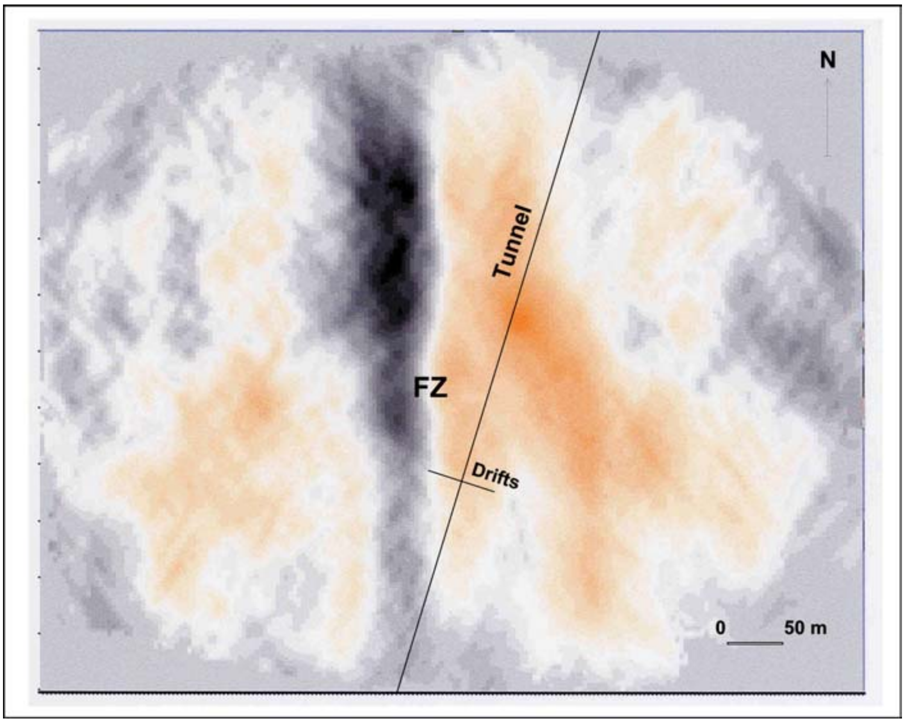

Fig. 7. Isochrone map in the limestone lower layer showing a roughly N-S trending fault zone (FZ).