Seismic tools for deep aquifer exploration

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Summary

At present water supplies originate from underground resources, which are easily accessible as they are located at shallow depths in close proximity to consumer zones. This type of exploitation has reached its limitations over the last few years, in terms of quantity and quality, and has required the need for expensive wastewater treatment. In such circumstances, the utility companies are required to safeguard the resource currently being exploited or search for replacement aquifers.

Exploration is mainly conducted for three types of aquifers depending on the geology:

- Alluvial aquifers which are superimposed on other aquifers in the substratum;
- Sedimentary aquifers of which the productivity depends on the matricial porosity and the state of fracturing and/or karstification;
- Basement rock aquifers, which have by definition lost their matricial porosity and of which the productivity is chiefly linked to fracturing and weathering.

Chronologically the two main exploration phases are:

- Exploitation of existing data: geological maps, boreholes, seismic lines;
- Acquisition of complementary data: geophysical data and reconnaissance wells.

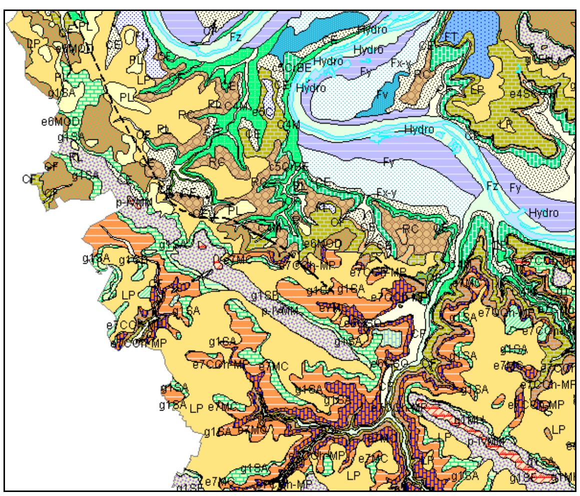

Figure 1 - Extract from the digital map of Mantes to the west of Paris.

1 - Exploitation of existing data

Surface data:

- Surveying, geological (Figure 1), and hydrogeological maps (Figure 2); examination of these maps can highlight aquifer types, outlets (sources) and the supply zones (outcropping).

Subsurface data:

- Wells providing information on the geology (logs, description) and the hydrogeology (water table level, flow, lowering of water level)
- Existing reflection seismic lines sometimes recorded in sedimentary basins for other targets (such as hydrocarbons). If the acquisition parameters are not optimum, this data can be re-exploited for hydrogeological purposes by reprocessing the data and giving priority to shallow events. The interpretation (Figure 3) of this data is used to determine the mapping of significant interfaces in terms of hydrogeology (continuous aquifer top, fault or flexure, etc.).

The analysis of existing data is a compulsory preliminary phase prior to any recording of new data, whether it is seismic or electric.

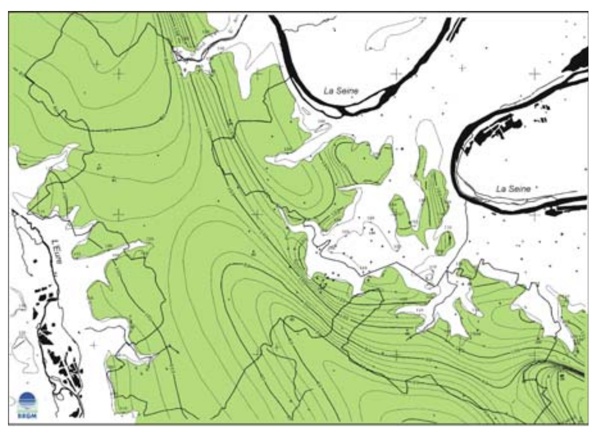

Figure 2 - Isohypses of the chalk top established from well and surface geological data (Mantes, west of Paris).

2 - Acquisition of new data

The decision to implement one or more geophysical methods is guided by the geological context and the lithological characteristics of the aquifers defined by the client.

High-resolution seismic applied to these new targets

For several years now seismic reflection has been deployed to characterize the geometry of aquifers. It is now possible to work on deep aquifers, using the same seismic processing tools as those developed for the petroleum industry, once the parameters have been adapted to the specificities of the aquifers in question.

These aquifers are classified into families of reservoirs. We shall examine two different types of aquifers in this paper.

Alluvial and continuous aquifers

A continuous aquifer is made up of sandstone or limestone formations with good porosity and permeability protected by overburden formations. This first type of aquifer is the more common. It can be selected by taking into account the depth of the formation. Investigation methods would be slightly different depending on whether the depth was under or over a hundred meters.

For continuous aquifers, reflection seismic methods could help to determine the geometry and interconnection of different formations, as well as the lateral or vertical facies variations and other elements required for good modeling. For targets up to 100 meters, refraction seismic and electrical methods could be applied.

As shallow levels have become polluted and shallow underground water resources exhausted, demand is ever increasing for the exploration of underground water up to 2000 m depths. For a good knowledge of these resources, high-resolution seismic is being increasingly used, either in 2D or 3D mode depending on the complexity and the accuracy required.

This technology originates from the oil industry. By adapting parameters, it is possible to obtain very useful information. This technology is being applied for the detection of mineral water resources, which delivers good added value over the cost of the resource.

An example of a continuous aquifer site is shown in Figure 4. This figure shows an aquifer supplied by a limestone formation localized outside the studied area. The water formation comprises mainly “molasses”. A mix with carbonic gas is done through a network of localized faults that allows communication between the different formations. The seismic section shows the extension of the molassic aquifer in depth and longitude, the fault positioning, the thickness of the overburden, and can be used as a guide for positioning the siting of exploration wells. A micro-structural study would help to define the preferential orientation of open fractures, and allow a correlation with fracturing obtained from dense 2D seismic data.

The seismic tools used to characterize oilfields are designed on the basis of seismic signal (attribute) and can be adapted without difficulty to water reservoirs.

An inversion of an impedance section is presented in Figure 5. The tie between seismic parameters and the petrophysical parameters of rocks is clearly shown.
This section was obtained from a combination of seismic and well data (sonic, density). A cross-correlation between wells and flow can be made with the seismic method.

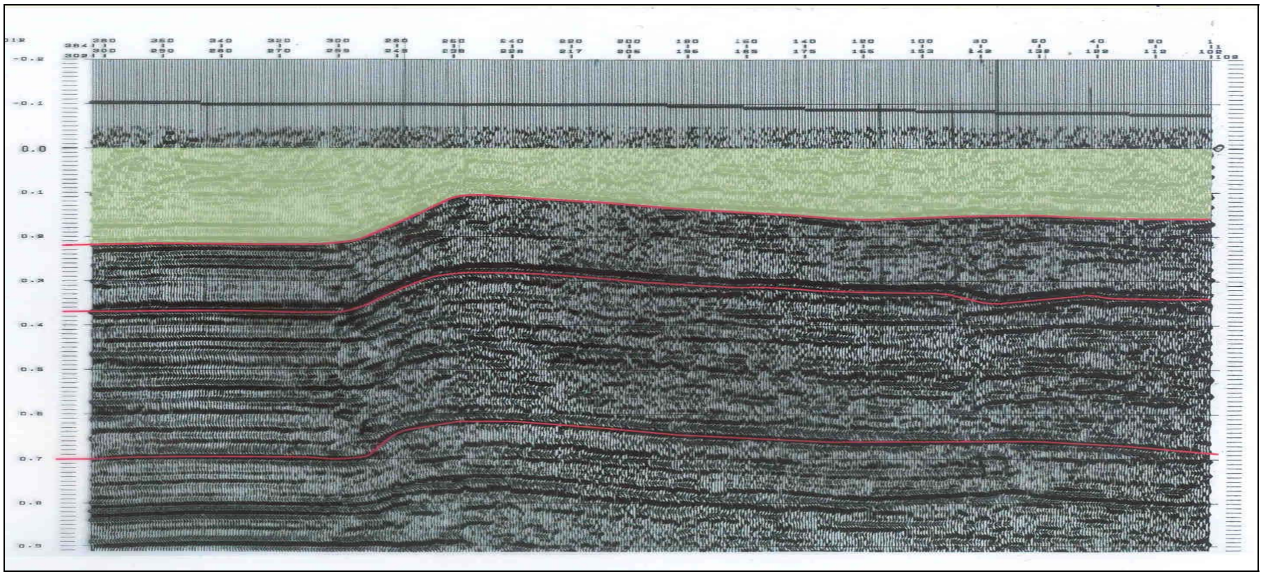

Figure 3 – Reprocessed and interpreted oil seismic line showing a flexure in the chalk.

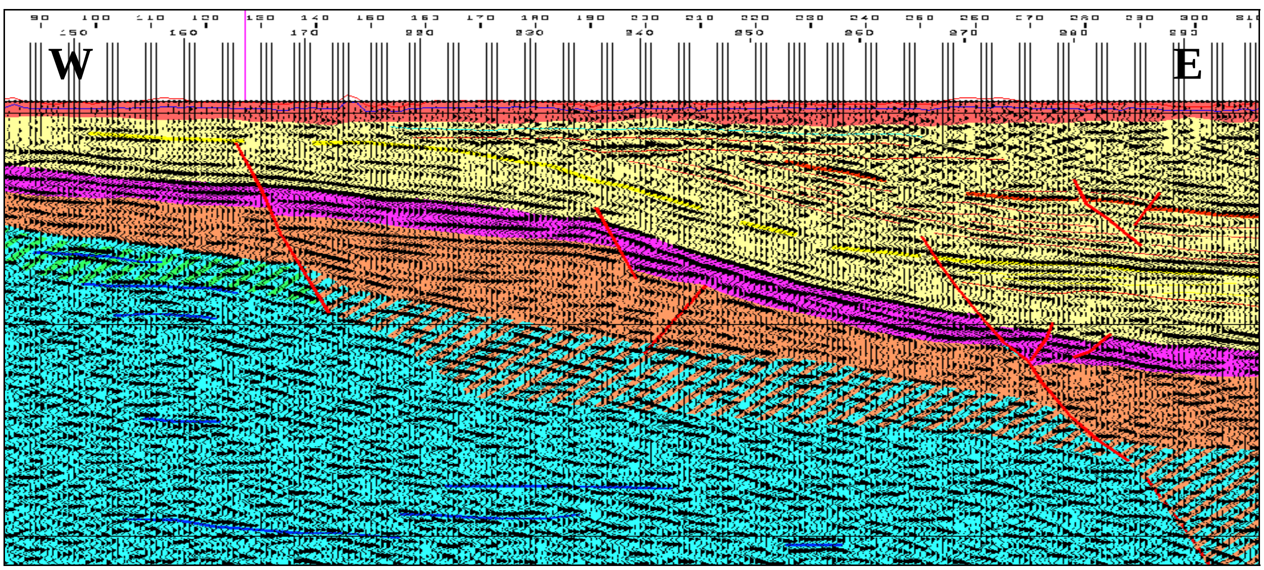

Figure 4 – Continuous aquifer (violet) under a clayey top (yellow). The water table is fed with water from the west and with gas by faults visible in the east.

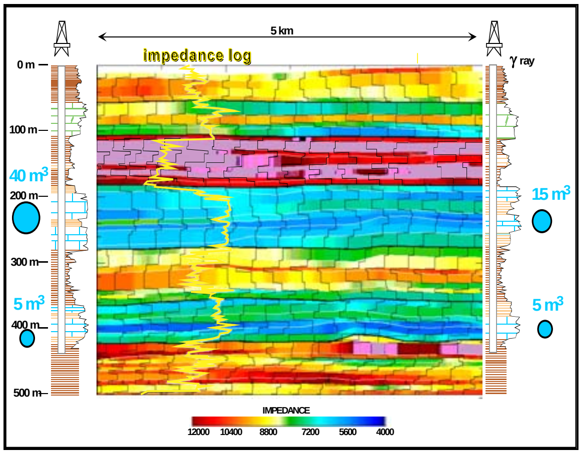

Figure 5 – Impedance section between wells.

Interpretation software such as Stratimagic is used to classify the seismic signal depending on its « shape ». A tie with the well and the correlation between a seismic attribute and the lithology or a physical parameter such as porosity or density can be used to obtain depth sections, which directly provide variations in the phenomenon in question. For 3D acquisition, isochron maps can also (Figure 6) offer information, particularly spatial.

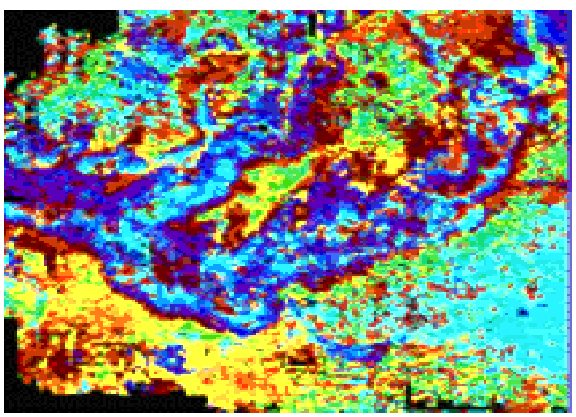

Figure 6 – Isochron map of a seismic attribute (Stratimagic). The meandering aquifer is clearly identifiable.

The paleo-valleys of the Rhone River and its affluents eroded during the Messinian regression have therefore been accurately mapped and enable the modeling of the corresponding aquifers (Figure 7). The envelope of the canyons mapped in 3D with information from 2D seismic will enable good analysis of the geological refilling in order to produce a hydrodynamic model.

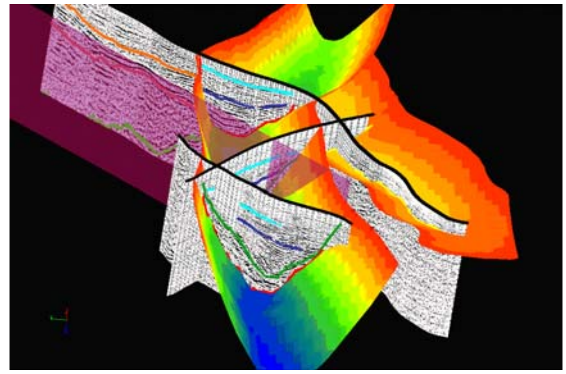

Figure 7 – Block diagram obtained from 2D seismic sections with the isochrons (red to blue colors) of the paleo-valleys of the Rhone during the Messinian phase.

Aquifers in faulted systems

This type of aquifer is found in rocks without intrinsic porosity but with interconnected crushed zones. It is of strong hydrological interest due to the flow rates generally observed. Karstic aquifers linked to this type of aquifer use the same geophysical exploration methods. High-resolution seismic reflection is used here for accurate positioning of surface faults and their extension in depth for well siting (Figure 8).

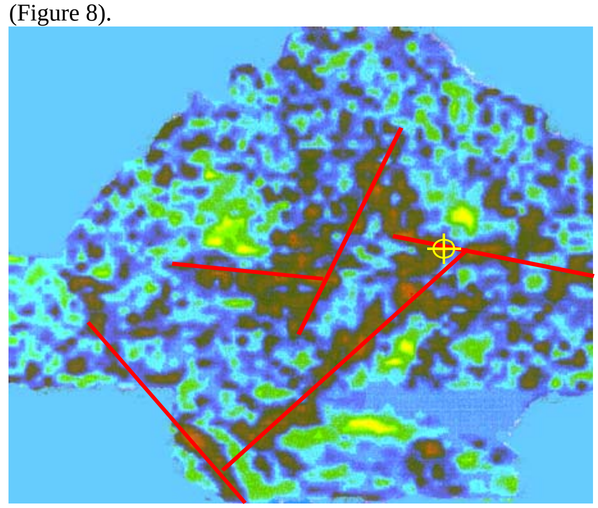

Figure 8 – 3D isochron map showing position of main faults.

3 – Conclusion

These technologies developed for the oil business can be successfully applied in numerous cases of water resources management and demonstrate the relevance of these cutting-edge seismic tools to help resolve water supplies.