Unsupervised AI workflow to evaluate the transition of a 50-year giant gas field quickly and thoroughly to potential multiple CO2 storage and geothermal viable projects.

*Bernard p. Laugier * (Seisnetics) and Anthony Aming (Seisnetics)*

Summary

Seismic data remain a pillar of subsurface modeling and the understanding of the potential for transitioning from oil and gas production to applications such as CO2 storage and geothermal projects. However, interpretation is a biased and time-consuming process forcing geoscientists to spend more energy picking horizons and building models than interpreting the significance of the results and their implications for ultimate field development, CO2storage and geothermal project evaluation.
In this paper, we detail the use of a new unsupervised Artificial Intelligence based on genetic algorithm to automatically process the seismic data in an unbiased way and record time. We applied this approach to the Groningen project (Figure 1), using data available online from the multiple seismic campaigns.

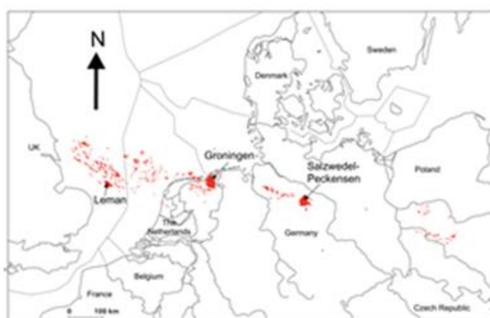


Fig. 1. Rotliegend gas fields in northwestern Europe.

After 12 minutes of processing by the artificial intelligence, we could display all horizons on the seismic and visualize attributes for all subsurface layers, only limited by the seismic signal penetration and build all necessary geological model to localize CO2 storage areas within the Zechstein salt and the Rotliegend reservoir and evaluate geothermal projects from multiple geothermal systems. The geothermal sources are in the same reservoirs/aquifers in which the oil and gas accumulations are hosted: Cenozoic, Upper Jurassic–Lower Cretaceous, Triassic and Rotliegend reservoirs. Additionally, the yet unproven hydrocarbon plays in the Lower Carboniferous (Dinantian) Limestones delivered geothermal heat in key geothermal systems.
We successfully demonstrate the use of such AI on the Groningen case and pave the way for geoscientists to focus their attention on visualizing and interpreting the significance of the results generated by this global, fully automatic, and unbiased approach for applications such as CO2 storage and geothermal projects.

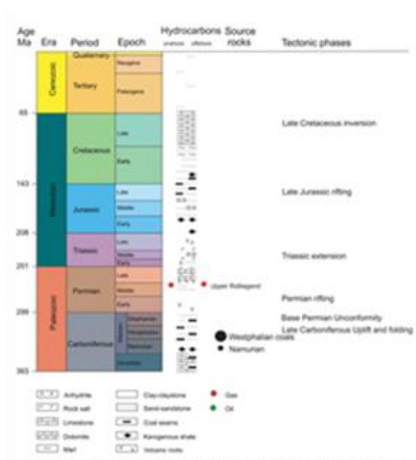
Introduction

Since the 1920’s, geoscientists have acquired several million square kilometers of 3D seismic data onshore and offshore looking for hydrocarbon or mineral deposits. The information extracted from the seismic data often constitutes the base of subsurface models which are used to make decisions for further exploration, appraisal, and development activities. A lot of progress has been made in acquisition, processing and interpretation which translates today into large libraries of high-quality data. The challenge? The time available for features extraction, analysis and interpretation remain limited, and very often the geoscientists spend more time picking horizons and building models than analyzing the significance of results. In this paper, we will describe a new approach using an Artificial Intelligence (AI) based on genetic algorithm (GA) to automatically extract information from the 3D seismic data in an unbiased manner and in record time. This new technique has been applied to the Groningen seismic dataset available online.

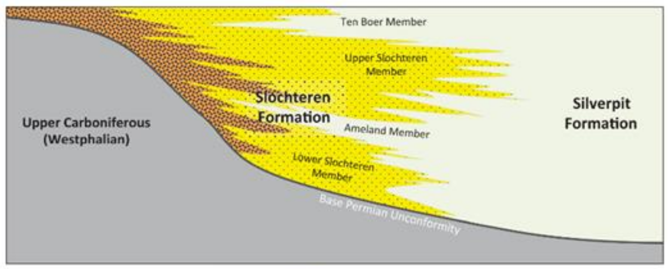
After more than half a century of production and with some 350 wells, the Groningen gas field must be one of the best-studied gas fields in the world. Initially, it was relatively simple and behaving like one big tank. Now that it is entering a phase of declining production it has become clear that many subtleties are not fully understood yet. Prediction and management of subsidence and induced earth tremors require a detailed understanding of the field geology. In addition, an optimum gas recovery is only possible if details of, for example, reservoir quality distribution and faulting, that did not appear relevant before, are well understood. The large Groningen field comprises a structurally high block during much of its history, probably already from Devonian times onwards. The desert sandstones of the Rotliegend reservoir exhibit a strong south-to-north proximal–distal relationship. Whilst diagenesis has in many fields led to deterioration of reservoir properties, this effect is small in the Groningen field. The field is dipping to the north and bounded by a series of normal faults in the west, south and east. Almost all faults are normal extensional faults, but locally inverse reactivation has led to small pop-up structures. Reactivation of older faults must have resulted in oblique movements along most faults. The challenges for future development of the Groningen field are immense. Managing the risks associated with recovery of the remaining gas, CO_2 storage areas and geothermal systems will continue to require an increasingly detailed knowledge and understanding of its geology.

The Groningen geology provide a unique opportunity to have a giant mature gas field that could transitioned to a CO_2 storage area within the Rotliegend sandstones reservoirs and Zechstein salt. Additionally, the structural history contributes to create an unusually high thermal maturity in the Carboniferous rocks directly below the Base Permian Unconformity (Dinantian) that could be exploited within geothermal projects.

The main reservoir is the Upper Permian Rotliegend sediments deposited in a very broad basin stretching from the UK in the west to Poland in the east (figure 2).

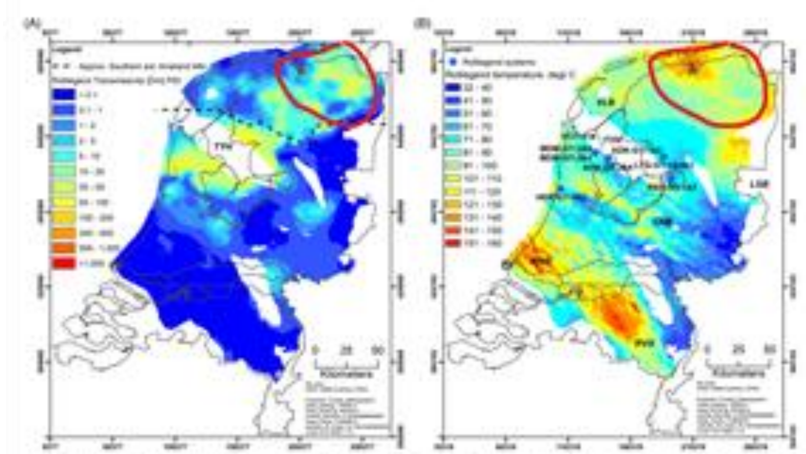


The entire sequence above the Base Permian Unconformity and below the overlying Zechstein is formally referred to as the Upper Rotliegend Group. This reservoir is sealed by the Zechstein salt. Both Rotliegend sandstones and Zechstein salt could be evaluated as CO2 storage containers.
At the end of the Carboniferous, a compressional event created broad anticlinal swells and regional uplift. Strong erosion of Carboniferous sediments occurred and locally up to several kilometers of sediments were removed by erosion (Figure 3).



Stratigraphy of the Rotliegend Group. After Van Ojik et al. (2012).

In some wells on the Groningen High unusually high thermal maturity is measured in the Carboniferous rocks directly below the Base Permian Unconformity (Kettel, 1983). These are tentatively attributed to local heat pulses from deep intrusive events associated with this latest Carboniferous to Early Permian phase of deformation (De Jager, 2007).
The coupling between the same reservoirs/aquifers in which the oil and gas accumulations are hosted: Cenozoic, Upper Jurassic – Lower Cretaceous, Triassic and Rotliegend reservoirs and the yet unproven hydrocarbon play in the Lower Carboniferous (Dinantian) Limestones delivered geothermal heat in several geothermal systems. (figure 4).



Rotliegend geothermal play maps. (A) The transmissivity of the Rotliegend Slochteren Sandstone reservoirs. (B) The average temperature of the combined Rotliegend Slochteren reservoirs. (Source: ThermoGIS v2.1, last accessed on 23 February 2021.)

Theory / Method

The key initial factor within those energy transition projects will be the understanding and integration of a huge amount of data available after so many years of Gas exploration and production and target a different focus workflow and reasoning with the objectives of CO2 storage and geothermal evaluation in mind. The traditional seismic data "interpretation" approach which basically refers to human intervention to pick horizons or analyze the seismic images obtained

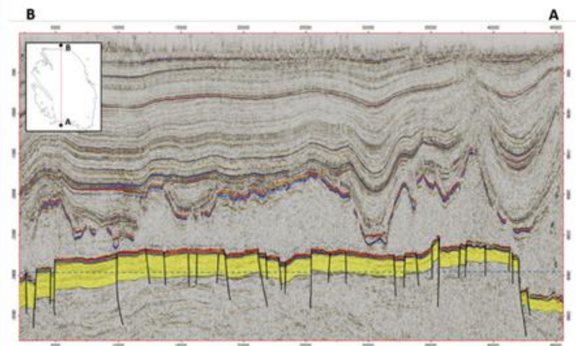
over the years could be an issue with the introduction of bias, the time required to process and analyze the data and finally the lack of accuracy.
On the contrary, the AI system described below, is global, fully automatic, and unbiased. The extraction of geological features (e.g., horizons) from seismic data can be seen as a data segmentation problem where the objective is to split the whole into the most coherent parts. Among the many AI algorithms, the genetic algorithm proved to be robust and very well adapted to the seismic data analysis (see Dirstein & Fallon in 2011 for a more detailed description). The application of the GA for the seismic data segmentation can be described as follows:
• An individual is a location in the volume characterized by the neighboring seismic waveform (the chromosome). Each waveform is characterized by its own unique suite of attributes (i.e., location, amplitude value, neighbor trace shape, etc.),
• The population is the set all the individuals as all the locations in the entire seismic volume,
• A sub-population is a group of individuals (a seismic horizon) that have the maximal genetic similarity (maximal waveform similarity).
The purpose of the GA is to mimic the genetic process of biological evolution based on the "survival of the fittest" principle applied to the seismic samples to produce the optimal "sub-populations" i.e., the horizons. The seismic volume is represented as a population of individuals that must be grouped into horizons throughout the process of the biological evolution. Therefore, at every generation:
The selection - only the fittest: individuals and sub-populations that have the highest fitness (seismic similarity) are allowed to evolve. The selection is in favor of cohesion: it tends to bring together those seismic waveforms that constitute the most "balanced" horizons,
The crossover: the selected individuals and sub-populations combine their genetic information to build a new generation. The combination tends to straighten the contribution of some seismic character and therefore to maximize the intra-sub-population similarity and maximize inter- sub-population dissimilarity.
The evolution continues throughout the entire volume until all the sub-populations have been identified, characterized, and categorized into a database of horizons ready for analysis and interpretation.

Workflow and Results

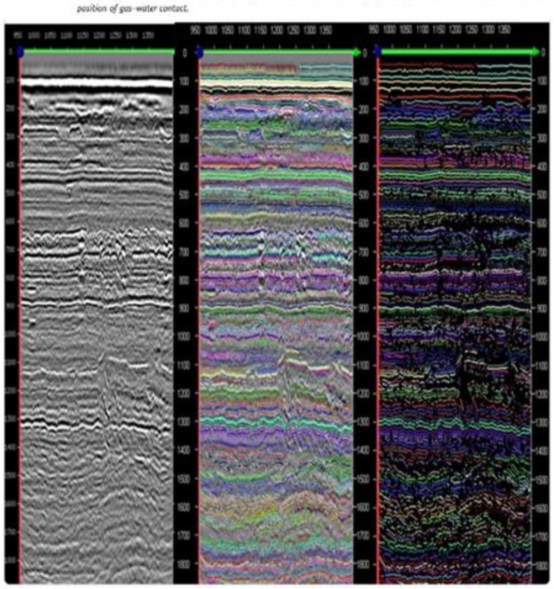
We developed a 7 steps workflow to go through the input database to the technical and economical project viability analysis.
The utilization of the AI approach in the front end reduces the time spent clicking and manually interpreting during the first 2 steps, allowing us to have more time focusing on understanding the results and the key geological elements of both specific plays (CO2 storage and geothermal).

Step 1.
Seismic volumes were downloaded in SEGY format from the online Groningen library and were directly processed without any additional treatment, by the GA in less than 12 minutes for each dataset .

Seis-H pr-interpretation analysis is fully automated and is applied consistently through the all-seismic datasets, thus producing a database of unbiased and high-quality attributes Seis-H extracts almost every peak and trough surfaces allowing 100% of the seismic data to be examined, meaning previously underexplored and potentially missed features can be analyzed. A total of 774 horizons have been automatically computed by the AI with different continuities over the seismic volumes. The surfaces, their specific waveform and their associated attribute maps are integrated into an easily accessible visual database through an interactive visualization software. (Figure 5a & 5b)



North–south seismic line through the Groningen field. Most faults at the level of the Rotliegend (indicated in yellow) are extensional. The overlying Zechstein salt acts as a detachment level, and supra-salt structuration is notably different from sub-salt structuration. Blue dashed line indicates approximate position of gas–water contact.



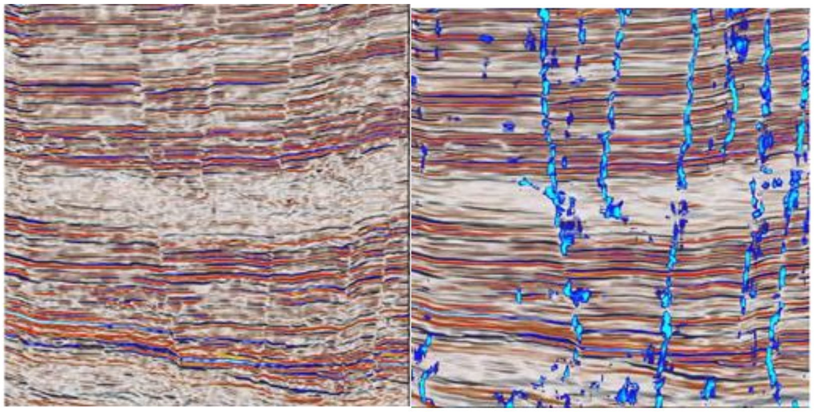
Step 2.

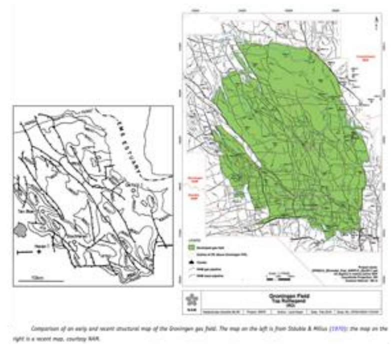
Seis-F the fault extraction application is completely unsupervised and only data driven based on the seismic data and the surface database from Seis-H.

Seis-H does not require any questionable learning or the step backwards manual labelling. It extracts almost every fault plane objects from the seismic volume by going beyond detection of simple discontinuities on the seismic image and searching for planar breaks in the geological layers database built with Seis-H.

Seis-F extracts first all fault polygons which are defined by its geometry and a throw map. Secondly Seis-F group them into fault planes considering the fault polygons properties, geometries, throw maps and the underlying seismic data.

(Figure 7a ,7b and 8)





Step 3.
The interactive and query able database of surfaces and faults with their own suite of attributes allows for the rapid screening of the data and bring to light any viable and prospective areas.
Each surface is characterized by their waveform genomes, and we can build seismic facies maps through sub-waveform analysis and identify stratigraphic domain within all datasets including unconformities, stratigraphic trap, seal, and reservoir units.
In addition, the fault polygons properties are used to identify structural domain within the datasets.
Subtle features both stratigraphic and structural are automatically identify and characterized within the resulting database.
Step 4.
After more than half a century of production and with some 350 wells, the Groningen gas field must be one of the best-studied gas fields in the world.
We built this unbiased database of surfaces, fault planes, seismic facies, and stratigraphic/structural domains in less than one day for the complete seismic volumes (Surface to about 12000m).
This database allows us to spend our time analyzing the data and integrating the geologic data base including 350 wells, outcrops, production history and previous studies.
The well ties and rock physics model help us to link waveform and attributes for all key surface/faults to essential geological properties and quickly establish their spatial distributions.
Step 5.
The interpretation and integration of all geological / geophysical data provide us the tools to build an extensive portfolio of opportunities with relative ranking based on potential values and uncertainties.
After technical and economical screening of this portfolio, we can identify a large variety of viable prospective area for both CO2 storage and geothermal projects.
Step 6.
For each identified potential areas, we can quickly build the geological model necessary for full evaluation.
The key zones surfaces and main faults that will influence the flow are easily selected from our database, cleaned, and integrated in a tight framework.
The model is then populated with any sub-zones layers and subtle structural features pertinent to our projects, quickly picked from the Seis-H and Seis-F databases.

Lastly, we add the corresponding properties extracted from our extensive attributes database calibrated to wells and outcrops.
This all process is done in less than a day as each element were built by our AI approach into a query able database for the entire data volumes.
Step 7.
In this final step we proceed the full technical, reservoir engineering, drilling and economical project and portfolio analysis based on the developed geological and reservoir models.
With a fast turnaround to build and eventually recycle those models, we have more time to integrate, interact with the larger team of experts and perform a sounds economical evaluation.

Conclusions

An artificial Intelligence based on genetic algorithm (GA) has been used successfully to automatically compute an extensive horizons/faults/attributes database

After a processing step which lasted less than 12 minutes for each seismic volume, maps with various attributes were displayed for all the layers computed by the AI including amplitude for instance.
Main faults planes and subtle features were also extracted and integrated into a database with their own properties and fault throw maps.
The genetic algorithm automatically generated a suites of e waveform, attributes and other characterization of surfaces and faults that help build stratigraphic /structural domain and seismic facies maps within the entire Groningen area top to bottom in less than a day.
Such an automatic, extremely fast, and unbiased approach can help the geoscientists directly focus their time and attention visualizing and interpreting the significance of the results delivered by the artificial intelligence for various applications, as base for the entire Groningen area undergoing evaluation for CO_2 storage and geothermal projects.

Acknowledgements

The authors would like to thank Groningen official organization for allowing online access to the Groningen seismic and well data.

References

Jan de Jager & Clemens Visser, 2017, Geology of the Groningen field – an overview: Netherlands Journal of Geosciences — Geologie en Mijnbouw |96 – 5 | s3–s15 | 2017

Harmen F. Mijnlieff, 2020, Introduction to the geothermal play and reservoir geology of the Netherlands: Netherlands Journal of Geosciences, Volume 99, e2. https://doi.org/ 10.1017/njg.2020.2

Dirstein J.K., Fallon G.N., 2011. Automated interpretation of 3D seismic data using genetic algorithms. Preview, 2011:151, 30-37. doi: 10.1071/PVv2011n151p30