Is the future of seismic passive?

Ernst D. (Paul) Rode[1], Hatem Nasr[1] and Monzer Makhous[1] introduce their work on the possibilities of passive seismic, particularly infrasonic passive differential spectroscopy, as a supporting technology for reflection seismic and other methods. A separate article follows with a case study of the techniques used in India.

We must start by asking what we mean by passive seismic. First of all no signal travels passively – where there is a signal there is a source. It is well understood that passive recording means not using a technically controlled source. But still there is a source and it is very important to understand the source signal and the behaviour and the properties of this source signal.

Under passive seismic, the geosciences community today understands in general three different categories:

- Passive spectroscopy of the seismic background
- Passive reflection seismic
- Passive recording of micro seismic events

Passive spectroscopy will be discussed later and it is the most challenging of the passive methods. Passive reflection seismic is very well proven and it delivers very precise results and will probably play an important role in structural analysis. Passive recording of micro events is nearly a standard technology.

However more important than these categories is the understanding that the philosophy of 'passive' monitoring technologies differs substantially from 'active' technologies like vibrator driven reflection seismic. Passive monitoring is a change from active to passive or from a controlled monochromatic signal to a random spread spectrum noise as the source signal or better, 'the information driver'.

Going from active to passive means going from monochromatic light to polychromatic light, or going from one dimensional information to multidimensional (broadband) information space. It requires a totally different sensor environment and a totally different understanding of information tools.

There was nothing which was especially designed for the oil industry but passive seismic has been adapted to the needs of the industry. However, it is unlikely that the traditional proven and sophisticated existing technologies like 3D reflection seismic will be replaced by any of these 'passive' tools. But it may be that the application of active tools will be more efficient in conjunction with passive tools, or the combination of both, will lead to new solutions.

The bottom line is that for a new technology to become established, there must be a reason for it. In the case of passive monitoring technologies, there are plenty of reasons why it is relevant to the oil industry:

- We need more oil, and so we are looking for new technologies which give us more information and can lead us to new discoveries or to more oil in production.
- All the 'easy' discoveries have been made, so for exploration we need new tools which can unveil more complicated and non-structural traps
- Very large basins remain unexplored and we need to explore them in a more economic way, more rapidly – with lower risk.
- We have to increase the recovery factor and the yield of exploitation. This is a non-structural problem which cannot be resolved with traditional methods alone!

Why passive systems and why now? The answer is simple. Passive monitoring systems are broadband information systems which carry much more information than an active one-dimensional system. They are also much simpler to understand, but much more complicated to apply. Passive monitoring systems need more technical intelligence, more computing power, more sensitive receivers, more data, and a change in thinking.

'Pattern recognition' and 'genetic code recognition' are two ways to think about how passive monitoring has begun to evolve. To get to grips with the technology we did not have the necessary instruments and software for passive monitoring technologies until we had powerful data processing tools and gigabyte memories. We were used to explosives, hammers (vibrators), and travel time. Nobody could imagine that anything else would be needed – and the pressure to look for technical and economical alternatives had not reached today's boiling point.

There is another good reason for passive monitoring systems or passive seismic systems specifically in the oil industry. They can be applied in a non-invasive mode and there is an endless powerful generator which delivers a wonderful broadband signal permanently for free, e.g., seismic background noise with a random spread spectrum

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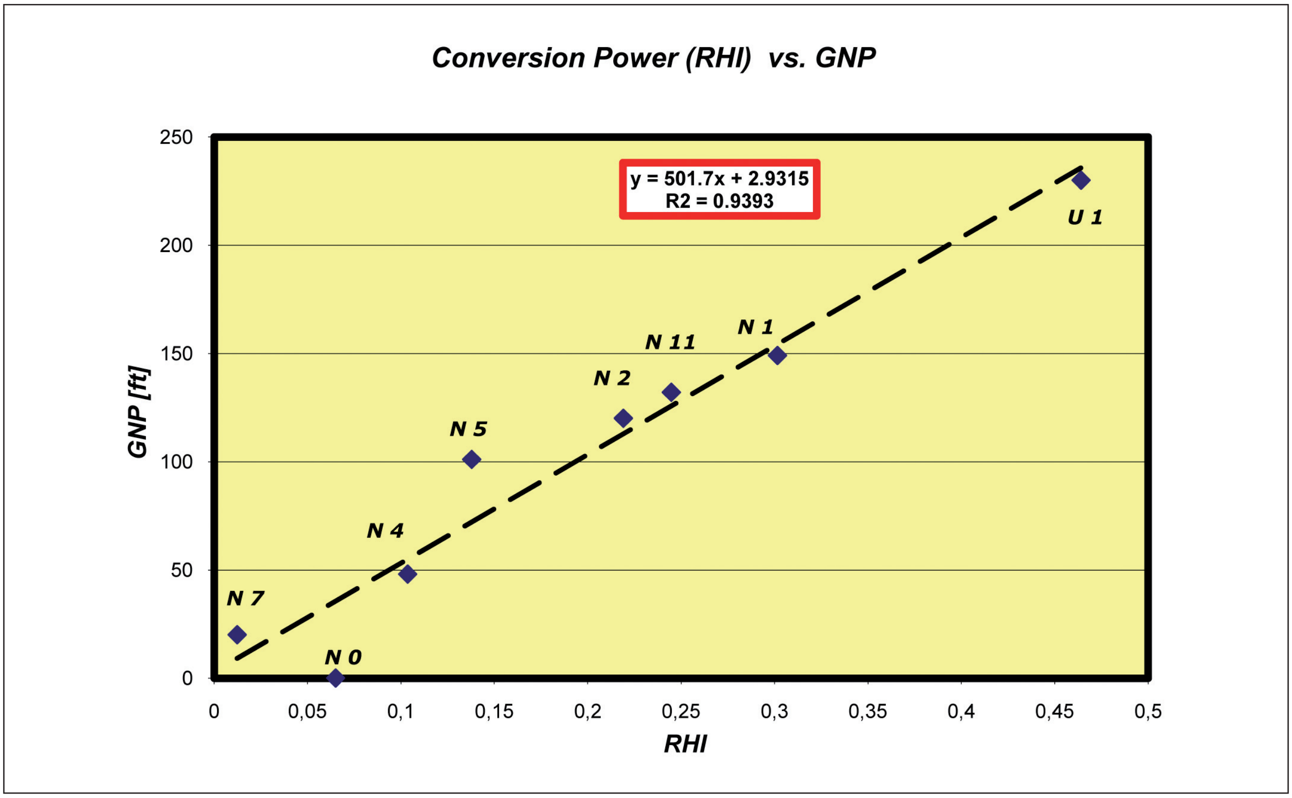

Figure 1 *Conversion power (RHI) vs. GNP (Gross Net Pay).*

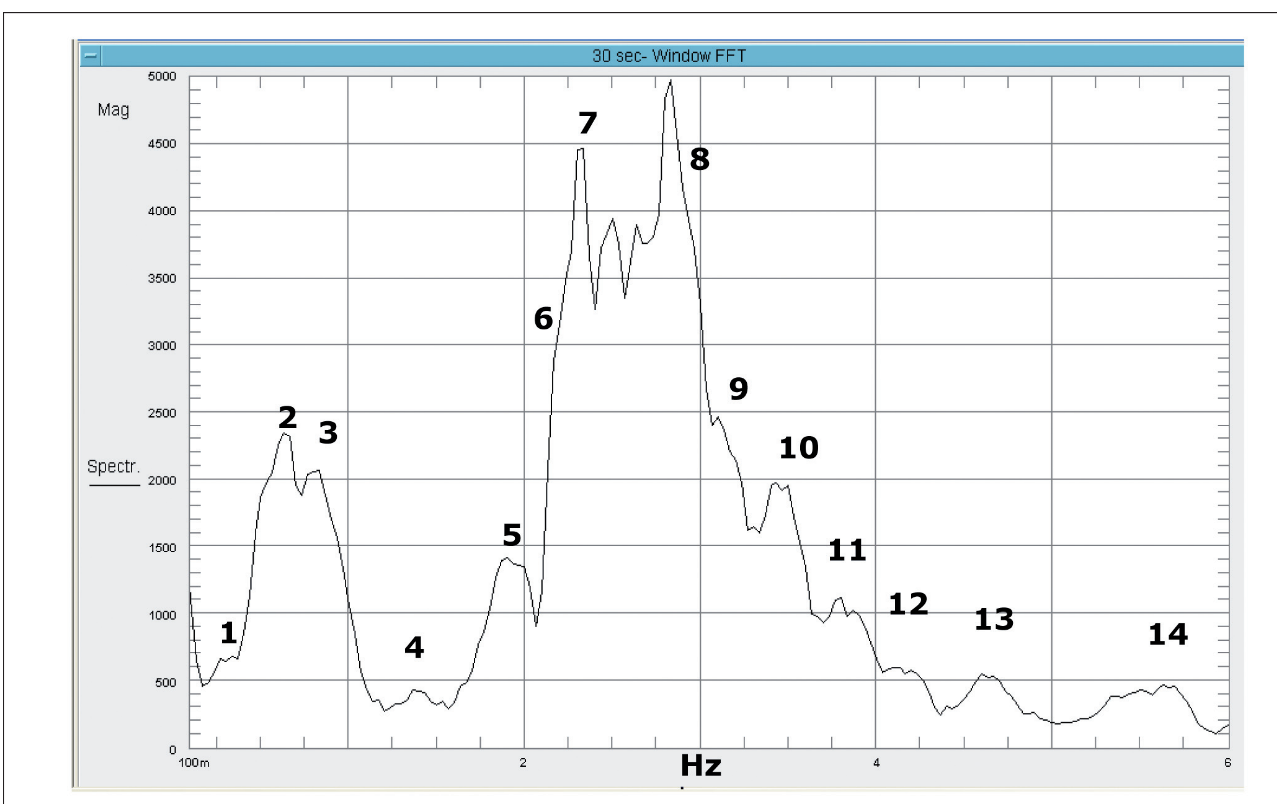

Figure 2 *Regular spectral lines.*

of a chaotic nature which delivers us any kind of test pulse which we need – in other words, a very useful source for the analysis of the transfer properties of an object called 'reservoir'.

Infrasonic passive differential spectroscopy

When we started to think about a method to detect a reservoir and its properties in 1995 we did not come from the oil industry – we came from the detection industry. Detection means in this case 'to locate an object and to identify its nature'. We were not triggered to find oil but we were keen to solve a detection problem. i.e., detect a reservoir and increase the information content about its properties. A reservoir was for us defined as 'a porous and permeable sphere with a finite spatial distribution filled with a multi-fluid system' – no multi-fluid system, no reservoir.

The simplest way to detect something is to try to communicate with the 'client' and for such communication there are two possibilities: electromagnetics or acoustics (mechanics) and we decided at first to go the acoustic way. Two conclusions came automatically:

- Because of the absorption problem of weak signals we could only use the very low frequency (VLF) or 'infrasonic' part of the spectra (the interval of interest is 0.1 < 10 Hz)
- For technical and energetic reason we could not use a technically active controlled source and so consequently we decided to use the omnipresent and omnidirectional seismic background as the primary signal source.

At the beginning of the development – and still today – we were observing phenomena where in many cases we needed a lot of data and experiments before we could explain them because the problem in this development is not in processing chaotic data: the problem is to get hold of reliable reference or correlation data from reservoir properties!

Three of these phenomena derived from static spectra imaging observed on top of a hydrocarbon reservoir are dominant:

- 'Downward conversion' in the spectral signal composition caused by non-linear transfer elements and expressing a transfer of energy from higher parts of the spectra to lower parts: increase of low frequency energy (Lesurf, 2006).
- 'Stochastic resonances' where the fluid column in a macro fracture acts as a $\lambda/4$ resonator – secondary permeability (Golushubin, 2002, Golushubin, patent).
- 'Spectral anomalies' caused by complex faulting systems and the transformation of acoustic energy into chemical energy (Makhous et al., 2009).

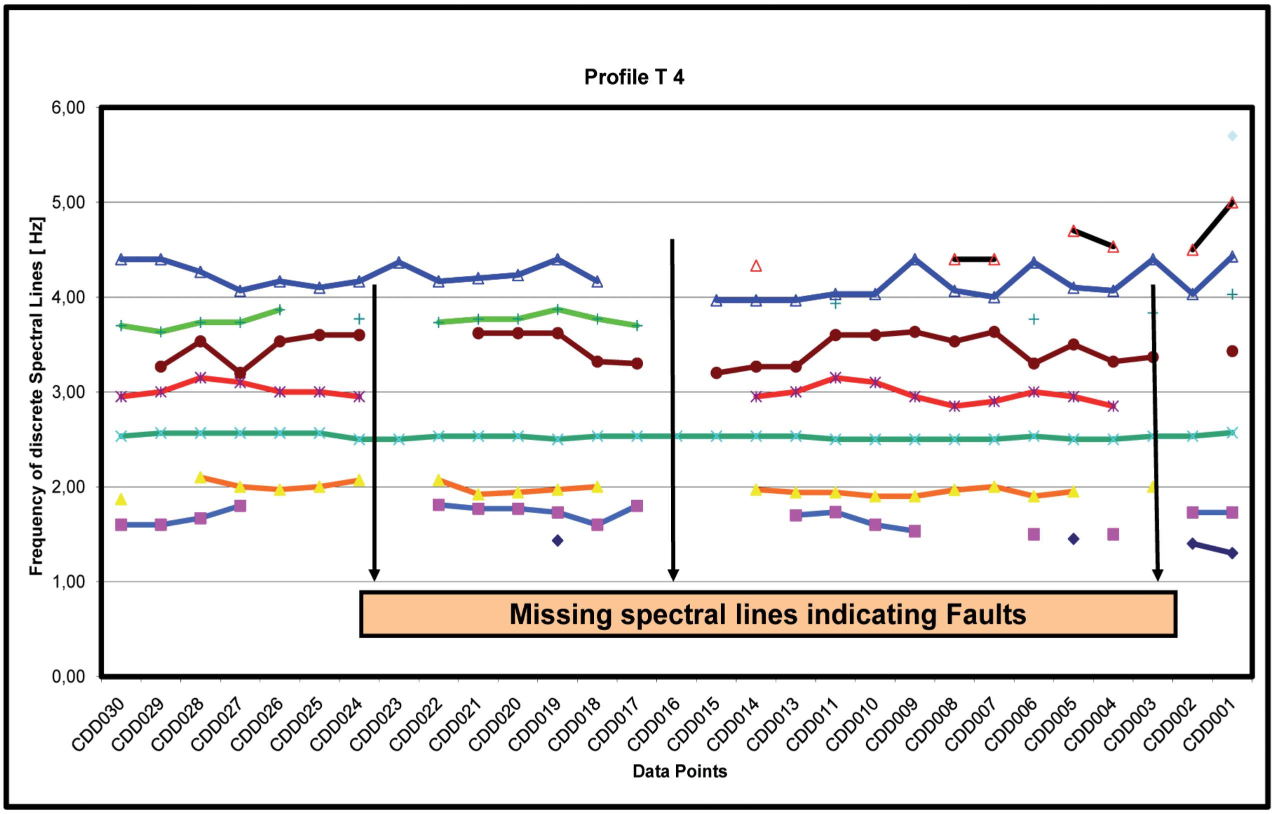

***Figure 3** Missing spectral lines.*

The first phenomenon delivers precise information about fluid saturation because the conversion power is a function of fluid volume in a porous system (see Figure 1 correlation of eight different wells in a similar environment).

The second phenomenon delivers information about structural conditions of the rock matrix of the reservoir. Any rock structure filled with fluid has a characteristic spectral pattern with discrete spectral lines, see Figure 2.

The third phenomenon delivers information about complex faulting systems and its boundary conditions observed as 'holes' in the spectra similar to absorption spectra. An example of this phenomenon is shown in Figure 3. This is a plot of all spectral lines recorded from data points along a profile T4. In three sections the absence of a number of spectral lines indicates the presence of a strong faulting system.

In Figure 4 the positions of the faults indicated by the missing spectral lines are plotted on the iso energy map – following the general trend of the fault direction. This example shows a very good correlation between the simple phenomenon of spectral anomalies and the presence of barriers. However, it gives an idea how useful passive seismic could be as a precursor in combination with reflection seismic, i.e., pinpointing the targets and coming to a conclusion about hydrocarbon content before entering into a higher resolution structural analysis. The latter is much more costly and less efficient if it is applied as the principal technology by itself.

There seem to be a lot more information about the reservoir contained in the dynamic behaviour of the infrasonic spectra – but this is a subject for further research in progress (Rode et al., patent). The information can be derived from low frequency analysis of the seismic background but to a certain extent could probably also be derived from the content of traditional reflection seismic signals. Nobody has looked at these spectra because the informative part was considered as 'noise', a negative regarded as something which has to be removed.

And so we come to the fundamental difference between active and passive:

- Active methods are based on a clear signal to noise ratio because 'noise is bad'.
- Passive methods are in fact BNI (beyond noise infometry) where 'noise is good', because it is the information carrier and the driving force.

It is essential to understand that in case of the reservoir response, the secondary signal is created inside the reservoir as a conversion product which did not exist before. This is the substantial difference compared to reflection seismic where the 'reflected' signal is the original source signal, otherwise it would not be 'reflected'.

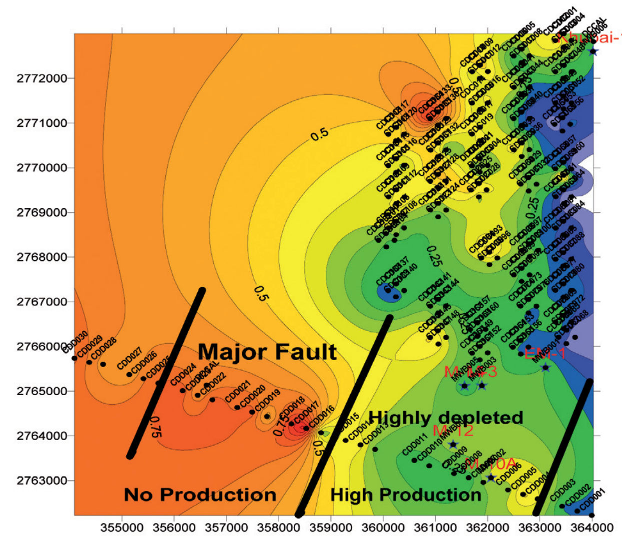

Figure 4 *Iso energy map plot.*

The application of passive seismic methods will for sure be a challenge in future, but they potentially offer a wide range of new possibilities and supply another kind of information. Of course, they will be complementary and not replace any other existing and proven technology. The key point is that there can be the availability of a random spread spectrum generator in support which delivers continuous energy and information, and this offers the possibility for continuous visualization of the fluid behaviour in a reservoir.

In a real sense passive seismic methods will be the 5D monitoring of the future.

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