

Seismic imaging without a source

In their search for hydrocarbons, oil companies employ the seismic reflection method to image the Earth's subsurface and delineate hydrocarbon reservoirs. To this end, they send seismic waves into the subsurface. For this they use either dynamite sources or heavy seismic-vibrator trucks when the acquisition takes place on land (Fig. 1), or seismic vessels with energetic airguns when the acquisition is done at sea. The waves are reflected by the different geological layers in the subsurface and are subsequently recorded at the surface by geophones (on land) or by hydrophones (at sea). Geophysicists feed the terabytes of recorded waves to a supercomputer and form three-dimensional images of the subsurface, from which geologists and petroleum engineers derive the location, size and content of hydrocarbon reservoirs.

In populated and/or environmentally sensitive areas, it is often not possible to employ highly energetic seismic sources. Geophysicists at the Department of Geotechnology at Delft University of Technology, the Netherlands, are developing a seismic imaging method that employs ambient seismic noise that comes from microseismicity or cultural activity. This method, which is called 'seismic interferometry' (SI), circumvents the use of manmade seismic sources. SI is not going to replace the traditional seismic method, but it will form an attractive addition to it. Apart from the mentioned advantage for hydrocarbon exploration in sensitive areas, SI can also be applied to monitor processes in the subsurface, such as CO₂ sequestration, over a longer period of time. Moreover, because SI can be applied at different scales, it is of interest to image the larger structures in the Earth's interior.



Fig. 1: Traditional seismic acquisition on land is done with dynamite or seismic vibrators

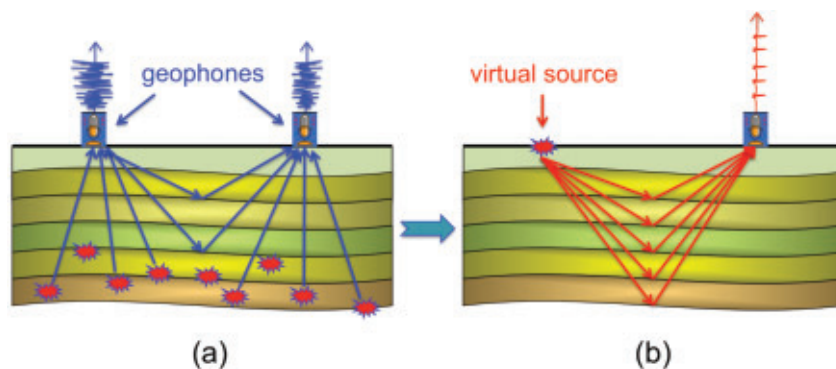


Fig. 2: Seismic interferometry: retrieving the seismic reflection response to a virtual source (b) from ambient noise recorded by geophones at the surface (a)

Changing the mindset about noise

The fact that one can use ambient noise for seismic imaging is not at all obvious. Traditionally, noise is considered as a nuisance that masks relevant signal. Compare it with listening to an old vinyl record, where the main challenge is to hear the music behind the noise. Similarly, in the traditional view, seismic signal needs to be recovered from behind the noise before one can obtain a clear image of the subsurface.

In SI, noise is not separated from signal, but noise itself is turned into useful signal. This is almost like listening to a vinyl record with noise only, and hearing a symphony of Beethoven. Imagine a distribution of uncorrelated noise sources in the subsurface, for example, associated to microseismicity (Fig. 2). One might think that the wave-field recorded at

Circumventing the use of manmade seismic sources...

the surface is completely diffuse, but it is not.

‘...oil companies employ the seismic reflection method to image the Earth's subsurface and delineate hydrocarbon reservoirs.’

While propagating from the sources to the receivers, the noise field obtains an imprint of the subsurface geology. Noise responses recorded at neighbouring receivers have been imprinted by the same geology and are therefore not uncorrelated. A simple operation applied to noise recorded at two receivers can create the situation as if there were a seismic source (eg. dynamite or a vibrator) at the position of one of the receivers, whereas the other receiver measured the reflection

response to this virtual source. Once this has been achieved for many source and receiver positions, the last step in the imaging process can be carried out with traditional seismic imaging methods.

Seismic exploration with ambient noise

The group at Delft have applied SI to ambient seismic noise, recorded by Shell in the northeast part of the Sirte Basin, east of Ajdabeya, Libya. The acquisition configuration consisted of eight parallel geophone lines of 20km with a separation distance of 500m. Each receiver recorded a total of 11 hours of noise. Much of the processing was dedicated to suppressing surface waves caused by nearby road traffic. Using SI, 3,200 virtual sources were retrieved from the noise. The seismic reflection responses to these virtual sources were used to image the subsurface. Cross sections of the resulting 3D image are shown in Fig. 3. The horizontal stripes indicate discontinuities in the Earth's subsurface associated with the juxtaposition of different rock types. Such images help geologists and petroleum engineers understand the geologic structure of the subsurface and are a major tool in the exploration and production of oil and gas.

Continuous monitoring of processes in the Earth

Because geophones are small and relatively cheap instruments, they can easily be installed at permanent

positions and record ambient noise for a longer period of time. For this reason, SI is very well suited to monitor processes in the subsurface, like CO₂ sequestration, oil-water replacement during production, subsidence due to gas extraction or salt production, tectonic processes, etc.

The Department of Geotechnology takes part in the Netherlands Research Centre for Integrated Solid Earth Science (ISES), in which it cooperates with Earth science faculties of Utrecht University and VU University Amsterdam. Due to the efforts of ISES, the understanding of the tectonic processes in the Netherlands has been improved significantly. An important conclusion is that all faults in the tectonic system have the potential to be reactivated. This has implications for the assessment of the natural hazard and long-term subsidence and uplift of the Netherlands, as well as for the production of hydrocarbons, salt and geothermal heat, and storage of CO₂. The risk of hazards is evidenced by the tremors induced by the gas extraction in the northeast of the Netherlands.

To monitor such processes with SI, use will be made of an infrastructure, initiated by the Dutch astronomical community, called LOFAR. LOFAR is a digital telescope of some 70km in diameter in the Netherlands, a unique development in the world. It consists of a multipurpose, wide-area sensor network with an ultra-fast link to a central node. Geophysicists at the

Department of Geotechnology, the Dutch research institute TNO and the Royal Netherlands Meteorological Institute (KNMI) have coupled geophones to this network and are now ready to use this network to continuously monitoring the subsurface of the Netherlands.

‘The group at Delft have applied SI to ambient seismic noise, recorded by Shell in the northeast part of the Sirte Basin, east of Ajdabeya, Libya.’

Finally

Ambient-noise imaging is not restricted to seismic noise. Ongoing developments concern the use of natural electromagnetic noise (solar and cosmic noise) to obtain virtual ground penetrating radar data for shallow subsurface investigations, for example, to monitor subsurface fluid dynamics.

Seismic and electromagnetic interferometry provide a way to image and monitor the Earth's interior without manmade sources. This is an interesting addition to the traditional geophysical method, with much potential for exploration in environmentally sensitive areas, and for the monitoring of processes in the subsurface.

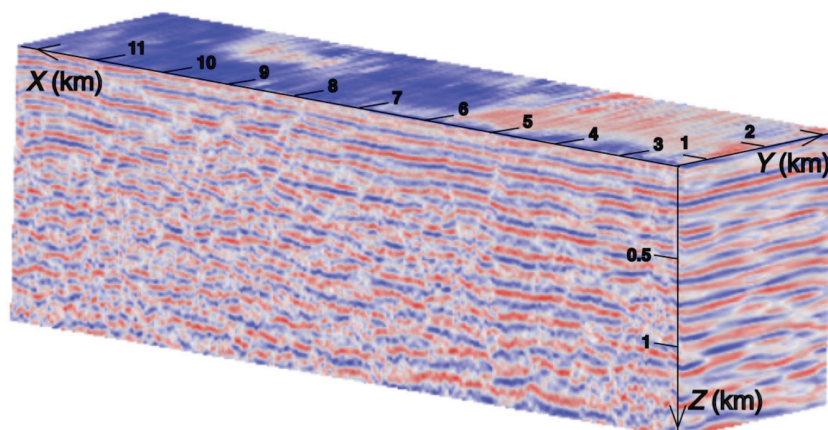


Fig. 3: 3D image of the subsurface obtained from ambient noise



Kees Wapenaar
Deyan Draganov
Guy Drijkoningen
Evert Slob

Department of Geotechnology
Delft University of Technology
Stevinweg 1
2628 CN Delft
The Netherlands

Tel: +31 15 2782848

c.p.a.wapenaar@tudelft.nl
www.gt.citg.tudelft.nl