Let us speak about Earthquakes and induced seismicity

Origin and classification of earthquakes

Earthquakes are caused by the sudden slippage of large, deep faults (several dozen or sometimes several hundred kilometers deep) that instantly release huge quantities of energy. Their distribution across the globe is not random, but rather follows narrow fault lines along tectonic plate margins[1] (**Figure 1**).

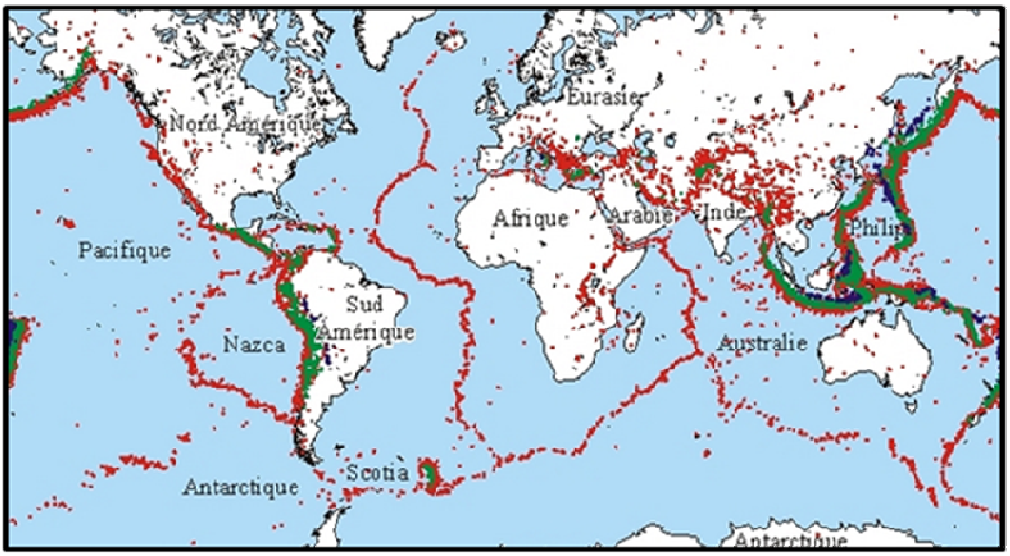
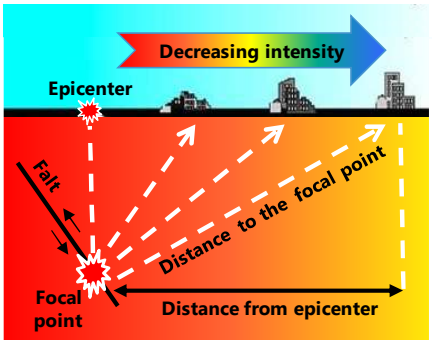


Figure 1 – Global seismic activity begins at a depth of 70-350 km on the tectonic plate margins, akin to lines of stitching between portions of the earth's crust. The map represents earthquakes of an intensity higher than 5 on the Richter scale.
(Source: Institut de Physique du Globe, Paris)

The intensity of an earthquake is graduated on the Richter scale which is logarithmic (**Figure 2**). In other words, when the unit is increased by one, the intensity of the earthquake is multiplied by ten. The Richter scale also links the intensity of an earthquake to the consequences of such an event. Below 3, earthquakes cannot be felt and only high-precision instruments can record them.



10	Extremely rare	Total destruction
9	Exceptionnal	
8	Major	Only few intact structures
7	High	Displaced buidings, large cracks in the earth
6	Severe	Severe damage to light buildings
5	Intermediate	Fissured walls, furniture displaced
4	Moderate	A few windows broken
3	Minor	Vibration of a truck
2	Low	Only detectable by intruments
1	Insignifiant	

Figure 2 – Earthquakes are caused by the slippage of major faults. Logarithmic Richter scale

[1] http://www.ensLyon.fr/RELIE/Centre_de_la_Terre/v2001/fichiers%20a%20utiliser/tous%20les%20PDF/sismo_pdf.pdf

Seismic events higher than three 3 can be felt by humans (this is the intensity of an earthquake induced by a train running on the Paris subway) but no damage is observed unless the intensity is greater than or equal to 4. Over a million earthquakes are recorded worldwide (especially at sea) each year, about 2,000 of which have an intensity greater than 5 and the number of such earthquakes appears to have been increasing over the last decade[2] (1,500 in 2000, 2,000 in 2010). The largest earthquake ever recorded hit 9.5 on the Richter scale in Chile on May 22, 1960. Those in Sumatra in 2004 and Japan in 2011 (Fukushima disaster) were offshore earthquakes that registered 9 on the Richter scale and induced gigantic tsunamis. It is this kind of event and not earthquakes themselves that claim so many victims.

Induced seismicity

Although most earthquakes have natural causes, certain human activities such as mining excavation or the variations in water levels in a hydraulic fill dam can cause micro-slippage in the encasing rock, equivalent to very small seismic events. They are mostly lower than 3 on the Richter scale and the phenomenon is referred to as "induced seismicity". Extracting or injecting fluid into the ground can also induce seismic events. For example, injecting water[3] into hot dry rocks to produce geothermal energy caused moderate seismic events in Soultz[4] (eastern France, 2.9 Rs) and near Basel[5] (Switzerland, 3.4). Exceptional values exceeding 4 on the Richter scale were recorded in Australia and in California during the same type of operations.

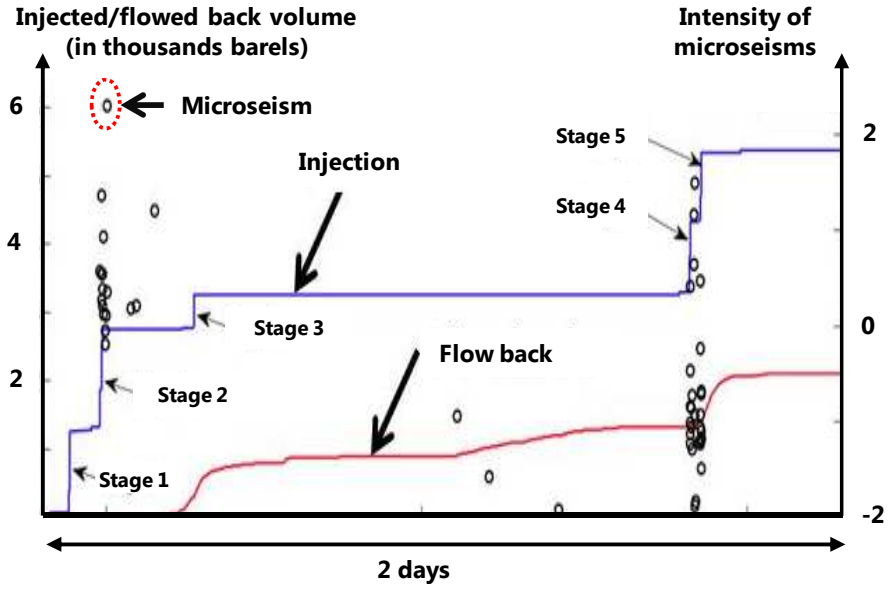


Figure 3 - Bowland Shale Seismicity Hydraulic fracturing causes small seismic events reaching up to 2.3 on the Richter scale by relieving stresses on existing natural faults
(Source: de Pate & Baisch)

Oil and gas activities are no exception and production or injection induce very minor seismic events. In particular, the seismic surveys associated with the extraction of hydrocarbons from the Lacq[6,7] field in southwest France have been the subject of extensive studies, and events of an intensity of 3 on the

[2] http://www.wikistrike.com/article-le-nombre-de-seismes-en-augmentation-83624291.html
[3] Mark D. Zoback (2012) Managing the Seismic Risk Posed by Waste water Disposal - www.earthmagazine.org
[4] http://www.brgm.fr/brgm/geothermie/fichiers/num6.pdf
[5] http://www.liberation.fr/terre/010191741-la-geothermie-fait-frissonner-la-suisse
[6] Bardainne, N. Dubos-Sall´ee, G. S´en´echal, P. Gaillot4 and H. Perroud (2008) "*Analysis of the induced seismicity of the Lacq gas field (Southwestern France) and model of deformation*" *Geophys. J. Int.*
[7] JR Grasso "*Effet des injections sur la sismicite du champ de Lacq*" (1975 - 1995)

Richter scale have been recorded there. The same applies to hydraulic fracturing[8] which causes small seismic events during the injection phase and in the well flowback phase. However, as the Bowland recording made in Great Britain shows (**Figure 3**), the intensity of such events remains low and in fact **it is essentially the reinjection of production water[9] and not hydraulic fracturing which was the cause of a certain number of seismic events higher than 2.5 Rs in the United States particularly in Oklahoma**[10]. Those recorded in Blackpool[11] in England which "shook the town" according to the press, in fact were of intensities between 1.5 and 2.3 on the Richter scale, an energy level 5 to 30 times lower than that released by the vibrations of…a train running on the Paris subway.

How is induced seismicity measured?

When a micro-seismic event occurs, the energy released emits noise which travels through the surrounding rock as sound waves, called "seismic waves". Measuring such weak vibrations requires the installation of very sensitive detectors called geophones, either at the surface or in an observation well (**Figure 4**). This method also helps locate microseisms in space and therefore map the fractured area around the well.

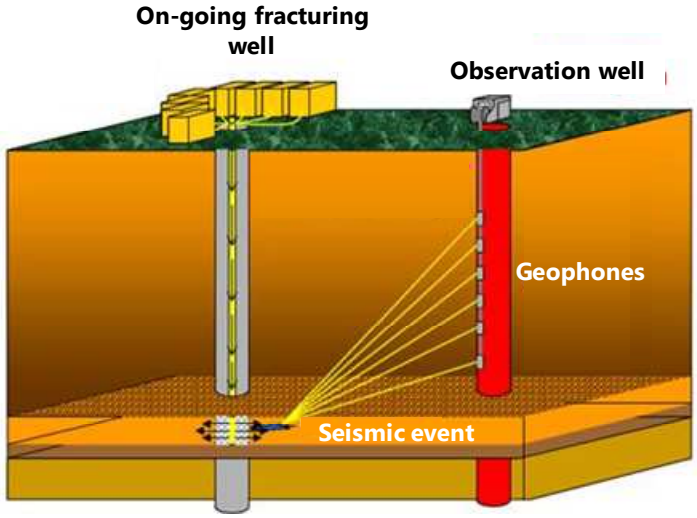


Figure 4 – Diagram of microseismic recording[12] using geophones located in an observation well[13]

Contrary to popular belief however, it is not the opening of the major fractures[14] but the slippage associated with the secondary fissures that generate most of the seismic activity during a hydraulic fracturing operation. Micro-seismic detection associated with hydraulic fracturing, is also an opportunity to measure, and therefore to control, the propagation of the fractured area.

Two examples of microseismic surveys are presented in **Figure 5.** In the case of the Barnett shales, the well has nine fracturing stages (each color represents a different stage). The results of the microseismic recording show the development of a complex Stimulated Rock Volume with very distinct fracturing stages (plan view) that are perfectly contained (vertical view) in the reservoir. In the second case however, the microseismic data suggest the development of a system of planar, transverse fractures not very conducive to a good production rate.

---

[8] http://gallery.mailchimp.com/27ed33877e4cbef4f0b684b7b/files/FracQuake_Backgrounder_Ao_t_2012_4_.pdf
[9] http://www.actualites-news-environnement.com/27717-fracturation-hydraulique-seismes.html
[10] http://wat.corp.local/sites/s1/Documents/a_012_14032016_ef5328c8-0041-453c-947c-8d580caa7592.pdf
[11] http://schiste.owni.fr/2011/06/01/seism-a-cause-de-la-fracturation-hydraulique-en-angleterre-gaz-de-schiste/
[12] http://www.geospacetech.com/pdf/Microseismic-Hydraulic-Fracture-Monitoring-032004.pdf
[13] http://www.harbourdom.de/frac_monitoring.htm
[14] Opening mode 1 does not generate sound, it is "aseismic"

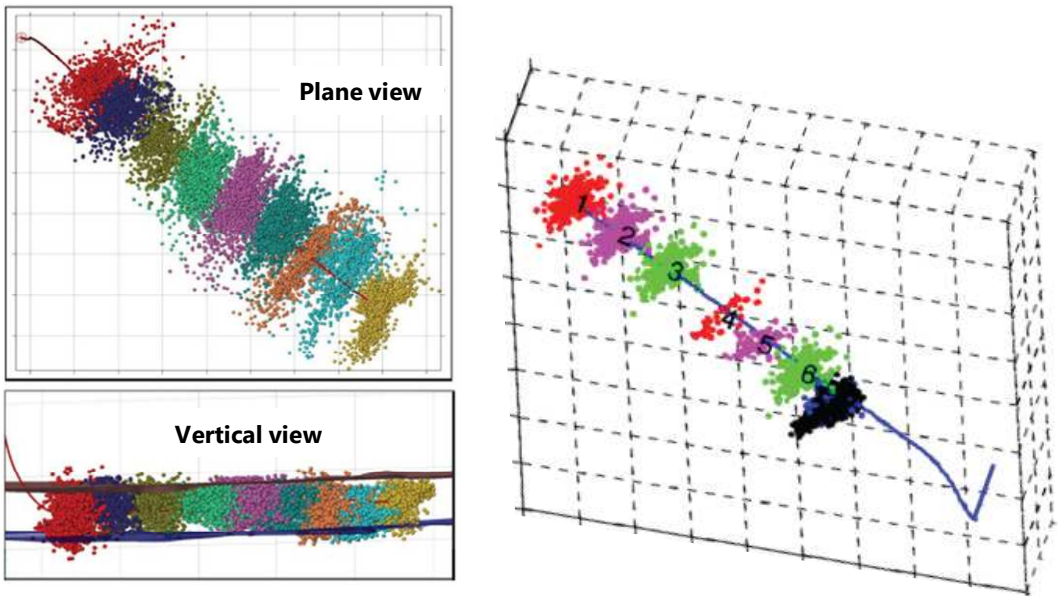


Figure 5 – Two examples of microseismic scatter graphs, each color represents a different fracturing stage. In the Barnett shales (left) the scattering shows a complex fractured volume with very distinct, well-contained fracturing stages. In Montney (right) the fractures are planar.

Seismicity as an integral part of the environmental baseline study

Unless a field is developed in a highly active tectonic region, the seismic risks related to hydraulic fracturing are extremely low. Nonetheless for stakeholders, they represent an ontological threat that must be given serious consideration.

Any shale oil and gas development project must include a natural seismicity baseline study for the zone concerned. It must include the history, frequency and intensity of natural and induced seismicity. Next, an impact study should be carried out, including numerical simulations to estimate whether or not the seismic activity generated by the project could be higher than existing levels and likely to interfere with human, social and economic activities.

In order to monitor seismic activity continuously, the project zone will be covered by a monitoring network to detect seismic events of an intensity less than 1 on the Richter scale.