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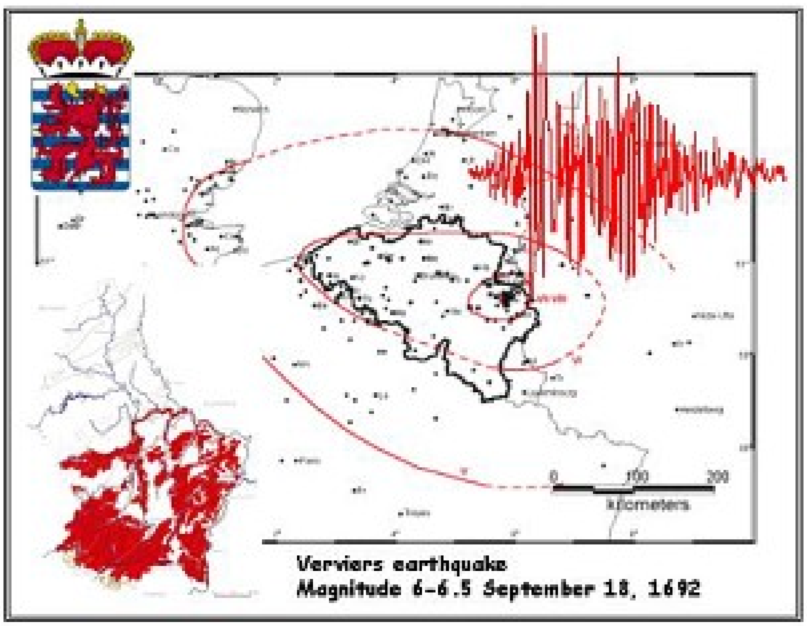
SITE EFFECT IN THE GRAND-DUCHE OF LUXEMBOURG PRELIMINARY STUDY
EFFET DE SITE AU GRAND-DUCHE DU LUXEMBOURG ETUDE PRELIMINAIRE



Verviers earthquake
Magnitude 6-6.5 September 18, 1692

Rapport / Report

Dr. Philippe Rosset

December 2005

INDEX

First page : Intensity map of the September 18, 1692 Verviers earthquakes (magnitude estimated up to 6). Red lines delimitate the zones with the same intensity. Intensity V represents the limit between strongly felt and slight damages. Few documents attest this level in Luxembourg (from Petermans et al., 2004).
(Right) Simulated accelerogram based on site amplification and reference earthquake scenario in Brussels.
(Left) Map indicated in red the zones that need further investigation to estimate potential site amplification due to local geology in Luxembourg.

NOTE : The background map used in this report is based on a PDF file from the Service Géologique of Luxembourg. The document untitled "Carte de risques géologiques du G.-D. du Luxembourg" (2003) is available at the address http://www.pch.public.lu/publications/cartes/. under "cartes géologiques "

LIST OF FIGURES AND TABLES

Introduction

The NW-Europe is a zone of moderate seismic activity where large earthquakes could occur in the future (Camelbeeck et al., 1999). The risk is presented as the convolution of the hazard and the vulnerability.

The seismic hazard is the earthquake and its probability of occurrence. It can be apprehended by the analysis of historical and recent earthquakes. By historical, we mean all earthquakes located by another sources than records from seismic stations. The strongest earthquake ever known in northwestern Europe occurred near Verviers in September 18, 1692. Its magnitude is estimated close to 6.5 and damages are known in the northern part of Luxembourg (Alexandre et al., 2002). The map of the Figure 1 shows the extension of the felt area for this event. Archives describing the effects of the ground motions in Vianden and Luxembourg were used to give an intensity V value in Luxembourg. It corresponds to ground motions strongly felt by the population and slight damages to houses and buildings. Several others damaging earthquakes of magnitude greater than 5.5 reported (Alexandre and Vogt, 1994) in Belgium were also, in the past, felt in Luxembourg.

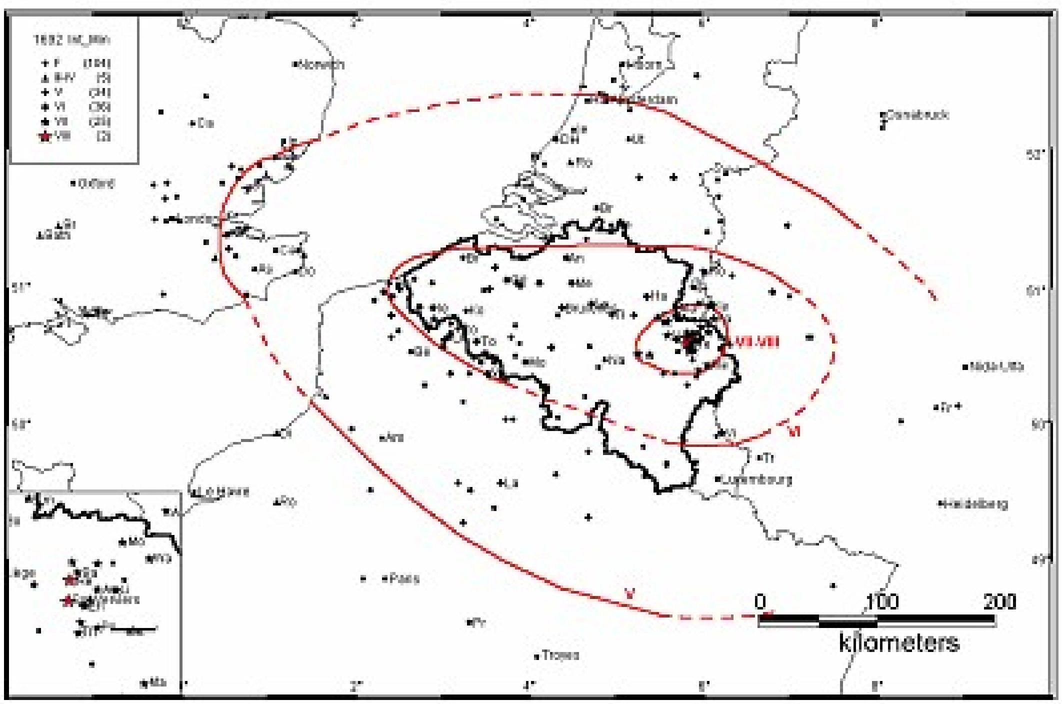


Figure 1 The September 18, 1692 Verviers earthquakes and its perception in the Northwest of Europe. Macroseismic intensity are indicated for documented cities. Red lines delimitate the zones with the same intensity. Intensity V represents the limit between strongly felt and slightly damaging (maps from Petermans et al., 2004).

Recent earthquakes are those which are recorded and located by seismic networks. Inhabitants of Luxembourg sometime reports felt ground motions during earthquakes although the seismic activity inside the country is almost null. It is often due to **what we called "site effects" or "site amplification"**. Numerous large earthquakes in the world indicated that unconsolidated sediments from ancient lakes, rivers and glacial episodes often amplify ground shaking conducting in important spatial variation of damages in urban areas as most of them are built on such a recent deposits. For this reason, **site**

amplification is the first cause of earthquake damage, more important than the size of the earthquake itself. A notable example of this has been the relatively modest (M=6.6) earthquake which stroke Central Mexico on September 19, 1985. It produced only light damage in the epicentral area, but caused the collapse of 400 buildings and the damage of many more in Mexico City, 240 km from the epicenter. The following investigations showed that Mexico City is built on a sedimentary basin with a proper resonance frequency f_0 of about 1 Hz, corresponding to the resonance frequency of 10 floors buildings, which were the ones most affected by the earthquake. One of the challenges for seismologists is to **estimate the resonance frequency f_0 of the unconsolidated deposits** to engage further analysis of vulnerability.

The vulnerability is defined as the capability of various systems as buildings, lifelines, etc. to resist to seismic ground motions. A recent study conducted in Belgium (Rosset et al., 2005a) indicate that the conjunction of ground shaking amplification due to unconsolidated sediments and deteriorated state of buildings could bring to heavy damages in cities in case of important regional earthquakes. The non-preparedness of population and stakeholders would then disrupt the economical systems for a long period and increase monetary losses. The preliminary study proposed here attends to **identify zones in Luxembourg where site amplification could occur** and then **envisage complementary analysis to reduce at an acceptable level the seismic risk** in the country.

Applied methodology

In order to identify zones where site amplification could occur in Luxembourg, a method, called H/V method, using ambient seismic noise records is chosen. Seismic noise exists everywhere on the Earth surface. It mainly consists in surface waves, which are the elastic waves produced by the constructive interference of the P and S waves in the layers near the surface. Ambient seismic noise are signals of low-amplitude motions of the ground generated by surface sources such as traffic and other human activities, but also come from oceanic waves and wind-structure interactions. Noise associated with wind and human activities is predominantly below 0.1s while noise generated by near-shore oceanic waves and currents is at higher periods.
The H/V method is a cheap and fast way to estimate site effects. Cheap, as it uses a single 3-components seismometer to record ambient vibrations (Figure 2). Fast, as the recording time is limited to10-20 mn per site in most of the cases. This method is especially well adapted in urban areas as it needs intrinsically anthropogenic and non-stationary signals.

Figure 2 Photo of the instrumentation used for ambient noise recordings.
The equipment is composed of a CityShark II acquisition system 24 bit from LEAS (black box) connected to a 3 components seismometer LE3D of 5s period from Lennartz (blue cylinder).

The horizontal (H) and vertical (V) components of ambient noises are simultaneously recorded at one single point. Spectral analysis are done on the ratio of H over V. The obtained spectral ratio generally exhibits a peak that corresponds more or less to the fundamental frequency f_0 of the site. The procedure to retrieve the f_0 is illustrated in Figure 3. This frequency is in relation firstly, with the predominant mode of oscillation of buildings. If the value f_0 is close to the resonance frequency of buildings near the investigated site, damages could be increased by constructive resonance phenomena. Secondly, the f_0 value depends on the thickness of soft soils beneath hard rock. A relationship between the thickness h and f_0 is given by f_0=Vs/4h. where Vs represents the mean shear waves velocity of the soft soil layer.

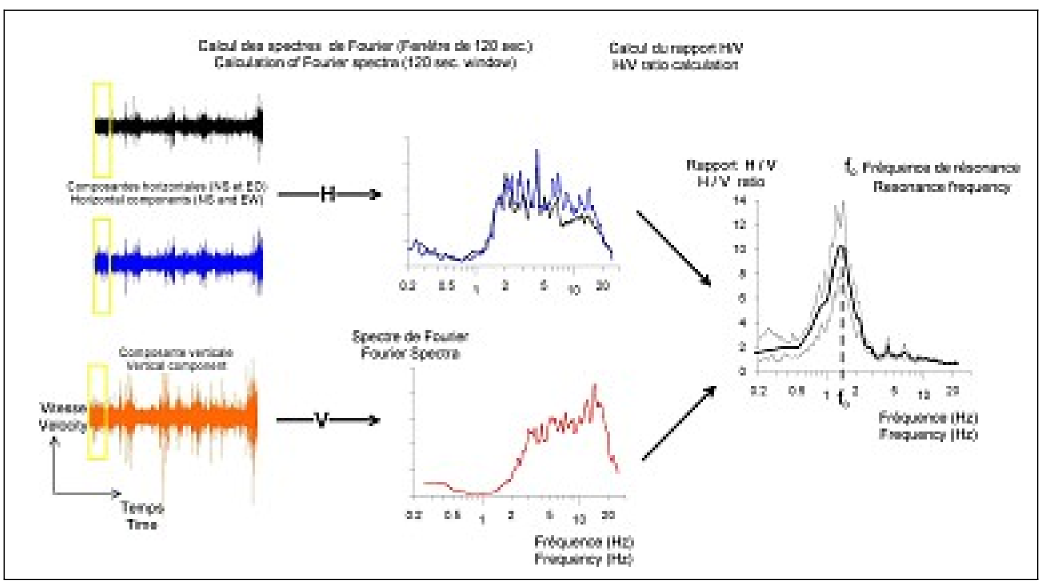


Figure 3 Illustration of the procedure used for ambient noise analysis.
The analysis of the recorded signal is done on a set of small time windows of 60s with an overlap of 30s. The sampling frequency is 100Hz with varying gain depending on the site.

Specific tools have been developed under Matlab © software to analyze a set of ambient noise records (Rosset, 2002, 2005). An screenshot of the tools is presented in Figure 4.

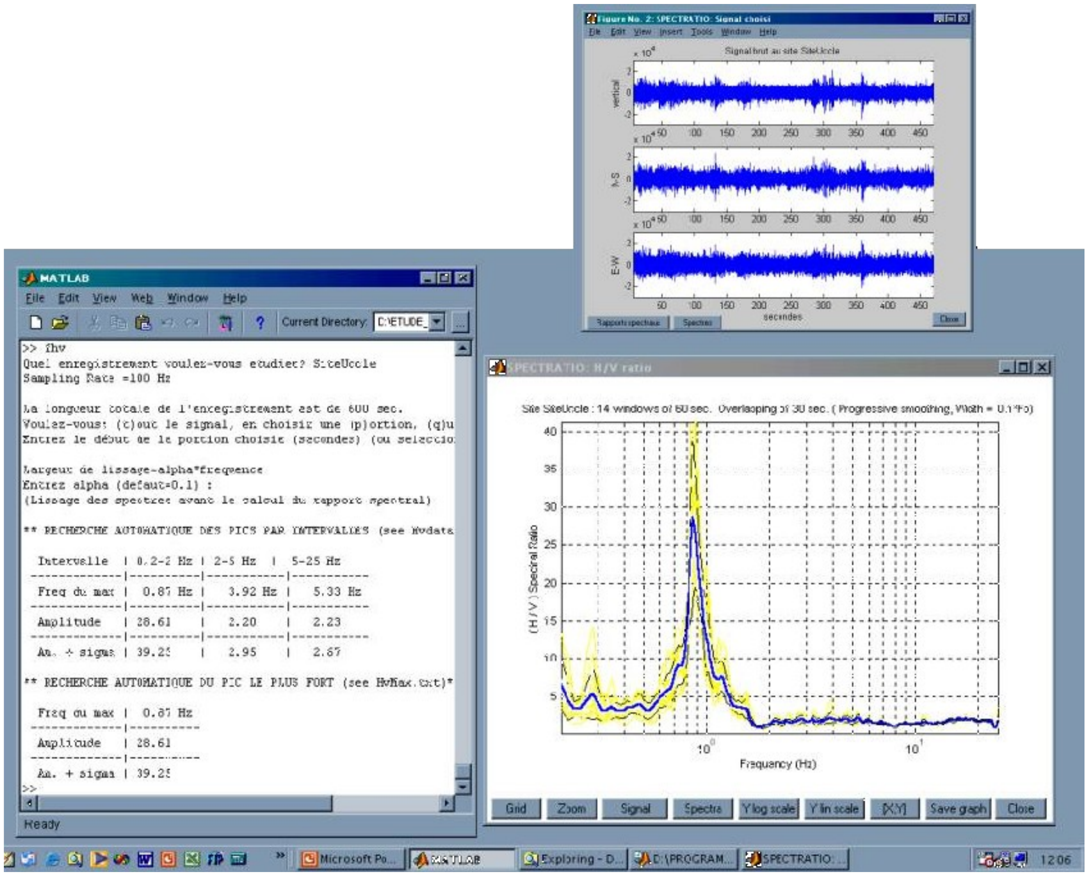


Figure 4 Ambient noise analysis software used in this study.
The screenshot shows the Matlab © window command (left) as well as the resulting H/V spectrum (right) and the portion of the recorded ambient noise used for the analysis (top-right). Several command buttons are available for detailed analysis. An automatic detection of the peaks is processed.

Investigated sites

The selection of the sites is based on the geological context of Luxembourg. A total of 35 sites are chosen. In a first stage, one or two sites on the main geological formations of the country are investigated. In the northern part, it concerns the schists and quartzites of the Eisleck and, in the southern part, the sandstones, dolomites, marls and limestones of the Gutland. Sites on recent alluvial deposits of the main rivers (Moselle, Alzette, Sûre and Wark) are also considered.
In a second part of the study, a detailed analysis is conducted within the Luxembourg city and the Alzette valley around Walferdange. 7 sites on a transversal profile of the Alzette river are selected to identify the influence of sandstones, marl and alluvial layers on the seismic response. 8 sites are selected in the historical center, the railways and European center of Luxembourg city.
Coordinates of the sites are indicated in Table 1. A map from the geological survey identifying the landslides and rock falls (Service Géologique, 2003) is used as background to localize the selected sites in Figure 5.

SiteID	X	Y	City	Map ID	SiteID	X	Y	City	Map ID
A01	72189	108306	BOURSHEID	8	A19	68335	69759	RECKANGE-SUR-MESS	25
A02	62859	114874	WILTZ	4	A20	79617	81189	WALFERDANGE	22
A03	70026	124583	CLERVAUX	3	A21	78784	80772	WALFERDANGE	22
A04	82813	111157	VIANDEN	9	A22	77344	80386	WALFERDANGE	22
A05	79272	103445	DIEKIRCH	9	A23	77193	80500	WALFERDANGE	22
A06	64506	99438	GROSBOUS	11	A24	76937	80077	BERELDANGE	22
A07	59658	92763	REDANGE	15	A25	76632	79391	BERELDANGE	22
A08	75173	91059	MERSH	16	A26	74973	79116	BRIDEL	22
A09	91853	94061	CONSDORF	13	A27	76697	75535	LUXEMBOURG	22
A10	98523	97684	ECHTERNACHT	13	A28	77173	75426	LUXEMBOURG	22
A11	86510	96515	FRECKEISEN	12	A29	77560	75353	LUXEMBOURG	22
A12	86092	86551	JUNGLINSTER	17	A30	78187	75586	LUXEMBOURG	22
A13	99310	87462	LEILIG	18	A31	77863	75051	LUXEMBOURG	22
A14	98256	77007	AHN	23	A32	77392	74917	LUXEMBOURG	22
A15	94669	67825	REMICH	27	A33	76718	74917	LUXEMBOURG	22
A16	82998	68366	HASSEL	26	A34	77332	74444	LUXEMBOURG	22
A17	74078	60647	DUDELANGE	28	A35	78564	76465	LUXEMBOURG	22
A18	66368	62732	ESCH-SUR-ALZETTE	28					

Table 1 Geographical localization of the investigated sites with H/V method.
The East and North coordinates are given in the Gauss-Luxembourg projection in m. The closest city is indicated as well as the corresponding number of the 1/20000 topographic map (Map ID).

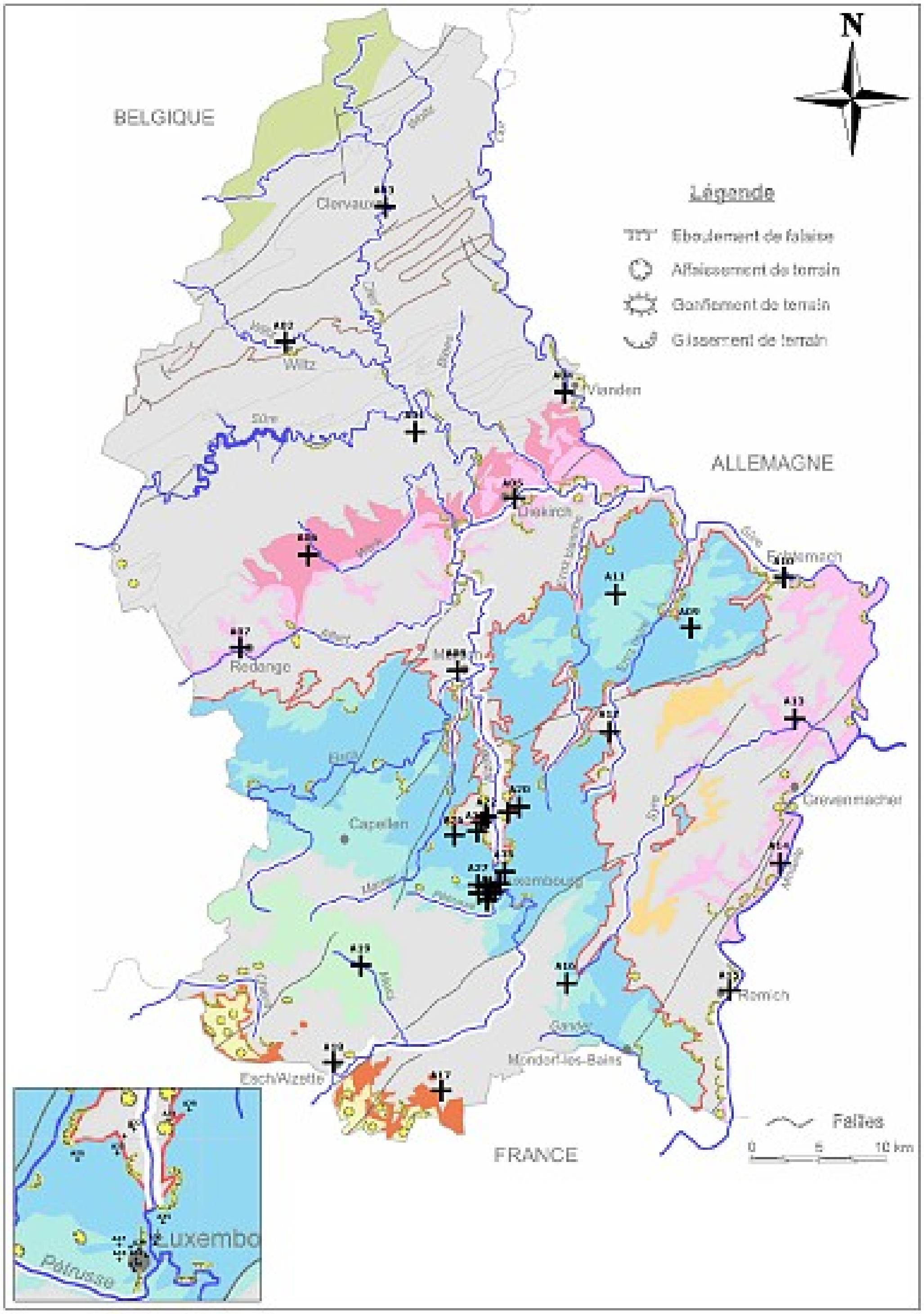


Figure 5 Localisation of the investigated sites with H/V method.
Colours of the maps are related to different geological formations (see Risques géologiques, Ministère des Travaux Publics, Service Géologique, 2003)

Results

The 35 sites investigated are interpreted. The quality of the calculated H/V spectra is ranked from 1 (good) to 4 (bad). It depends firstly, on the capability of the site to generate homogeneous surface waves field (i.e. without particular and oriented noise sources) and secondly, on the capability of the soft soils beneath the site to propagate surface waves. It means that better is the velocity contrast between rock and soft soil layers, more visible is the peak of amplitude. 6 sites over the 35 present a H/V spectra without any clear peak (quality rank 3 and 4), 12 sites have several peaks that need more investigations to be well-interpreted (quality rank 2) and the others presents a clear peak explained by a site response (quality rank 1). Figures 6 and 7 show the H/V spectra calculated for each site investigated. The Table 2 sums up the interpreted values indicated in the map of the Figure 8 in terms of predominant frequency of resonance.

SiteID	X	Y	F_HV	Q rank	Geology
A01	72189	108306	**22.7**	1	Schiste
A02	62859	114874	**9.2**	2	Schiste
A03	70026	124583	**1.7**	4	Schiste
A04	82813	111157	**22.7**	2	Schiste
A05	79272	103445	**5.9**	2	Alluvial
A06	64506	99438	**3.2**	2	Sandstone
A07	59658	92763	**2.6**	3	Sandstone
A08	75173	91059	**5.9**	1	Alluvial
A09	91853	94061	**2.1**	1	Sandstone
A10	98523	97684	**4.9**	2	Marl
A11	86510	96515	**3.5**	2	Marl
A12	86092	86551	**2.5**	1	Marl
A13	99310	87462	**14.7**	1	Dolomite
A14	98256	77007	**7.5**	1	Marl
A15	94669	67825	**7.1**	1	Marl
A16	82998	68366	**3.1**	1	Sandstone
A17	74078	60647	**3.4**	1	Marl
A18	66368	62732	**5.0**	1	Marl
A19	68335	69759	**3.3**	1	Sandstone
A20	79617	81189	**3.3**	1	Sandstone
A21	78784	80772	**8.0**	1	Marl
A22	77344	80386	**4.7**	1	Alluvial
A23	77193	80500	**5.7**	3	Alluvial
A24	76937	80077	**3.5**	2	Alluvial
A25	76632	79391	**2.9**	1	Marl
A26	74973	79116	**2.1**	2	Sandstone
A27	76697	75535	**13.5**	2	Sandstone
A28	77173	75426	**1.1**	2	Sandstone
A29	77560	75353	**8.0**	2	Sandstone
A30	78187	75586	**4.3**	3	Sandstone
A31	77863	75051	**6.6**	3	Sandstone
A32	77392	74917	**20.5**	2	Sandstone
A33	76718	74917	**1.3**	2	Sandstone
A34	77332	74444	**1.3**	1	Sandstone
A35	78564	76465	**19.0**	1	Sandstone

Table 2 Interpretation of the investigated sites with H/V method.
The East and North coordinates are given in the Gauss-Luxembourg projection in m. The predominant frequency F_HV interpreted on the HV spectra is given. The outcropping geological formation of the site is indicated. The quality rank Qrank expresses the reliability of the given value of F_H from 1 (good) to 4 (bad).

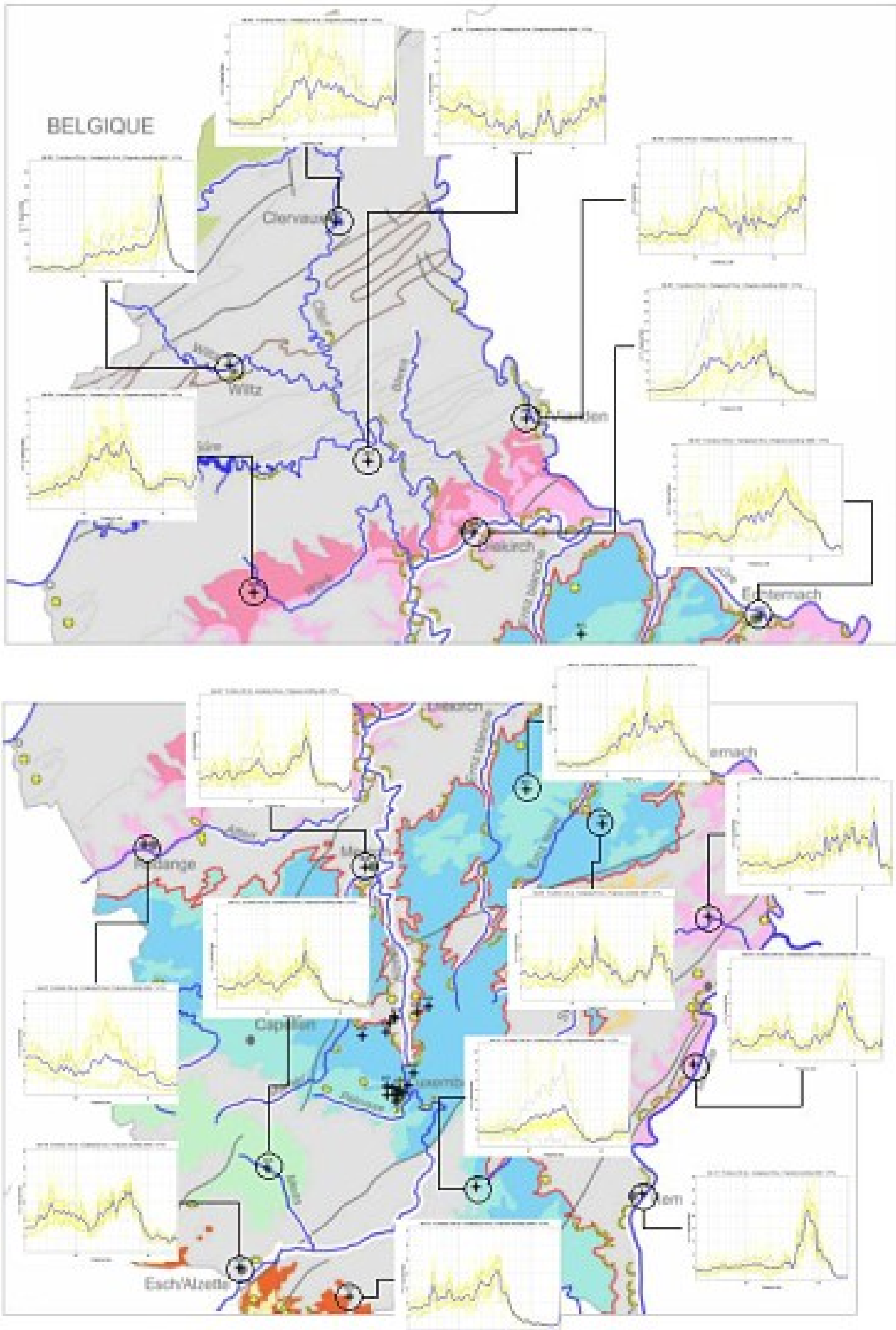


Figure 6 Site response to seismic ambient noise.
The H/V spectra for sites chosen within the country are shown.
(Background : Risques géologiques, Ministère des Travaux Publics, Service Géologique)

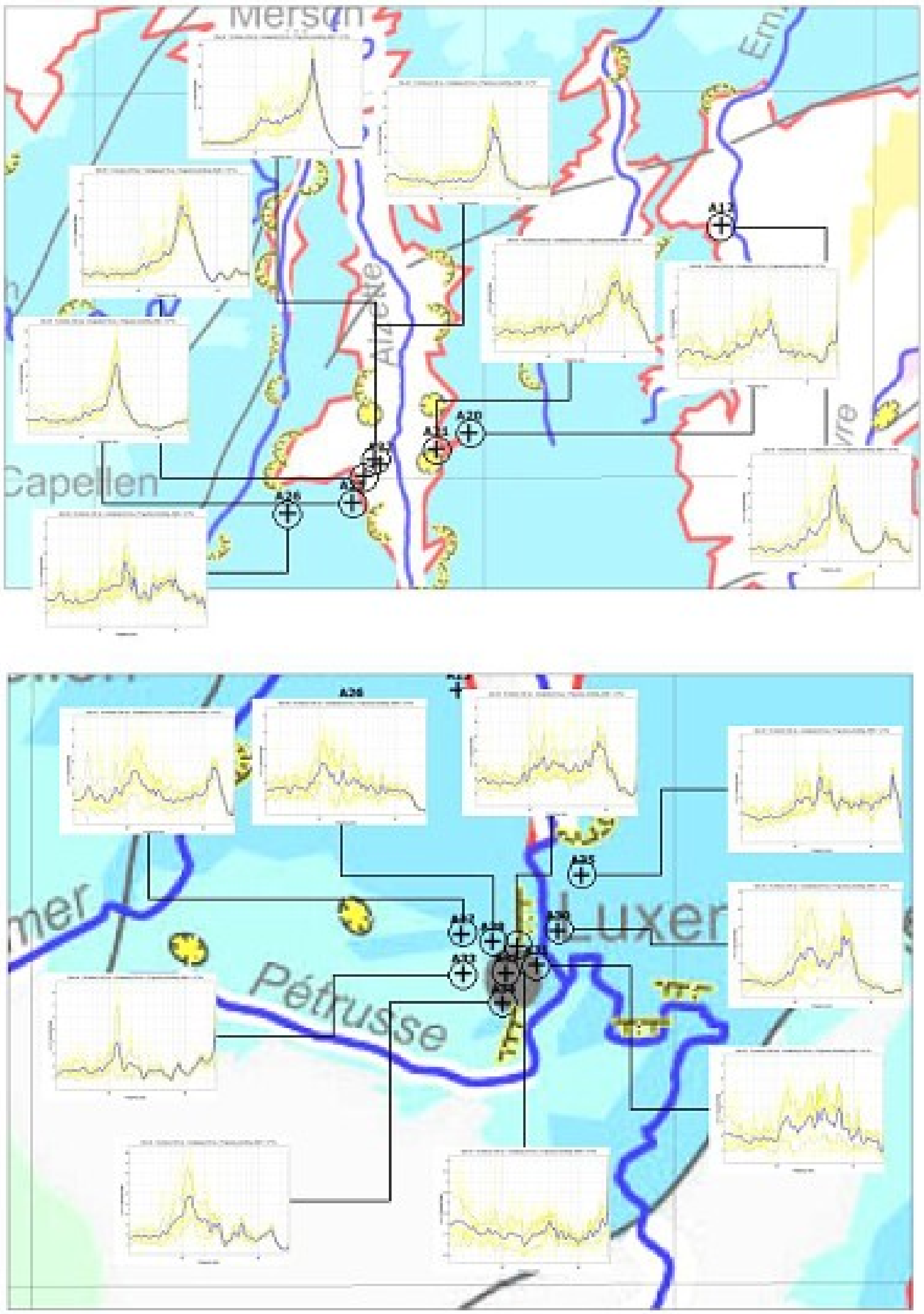


Figure 7 Site response to seismic ambient noise (suite).
The H/V spectra for sites chosen in Luxemboug city and in the Alzette valley are shown.
(Background : Risques géologiques, Ministère des Travaux Publics, Service Géologique)

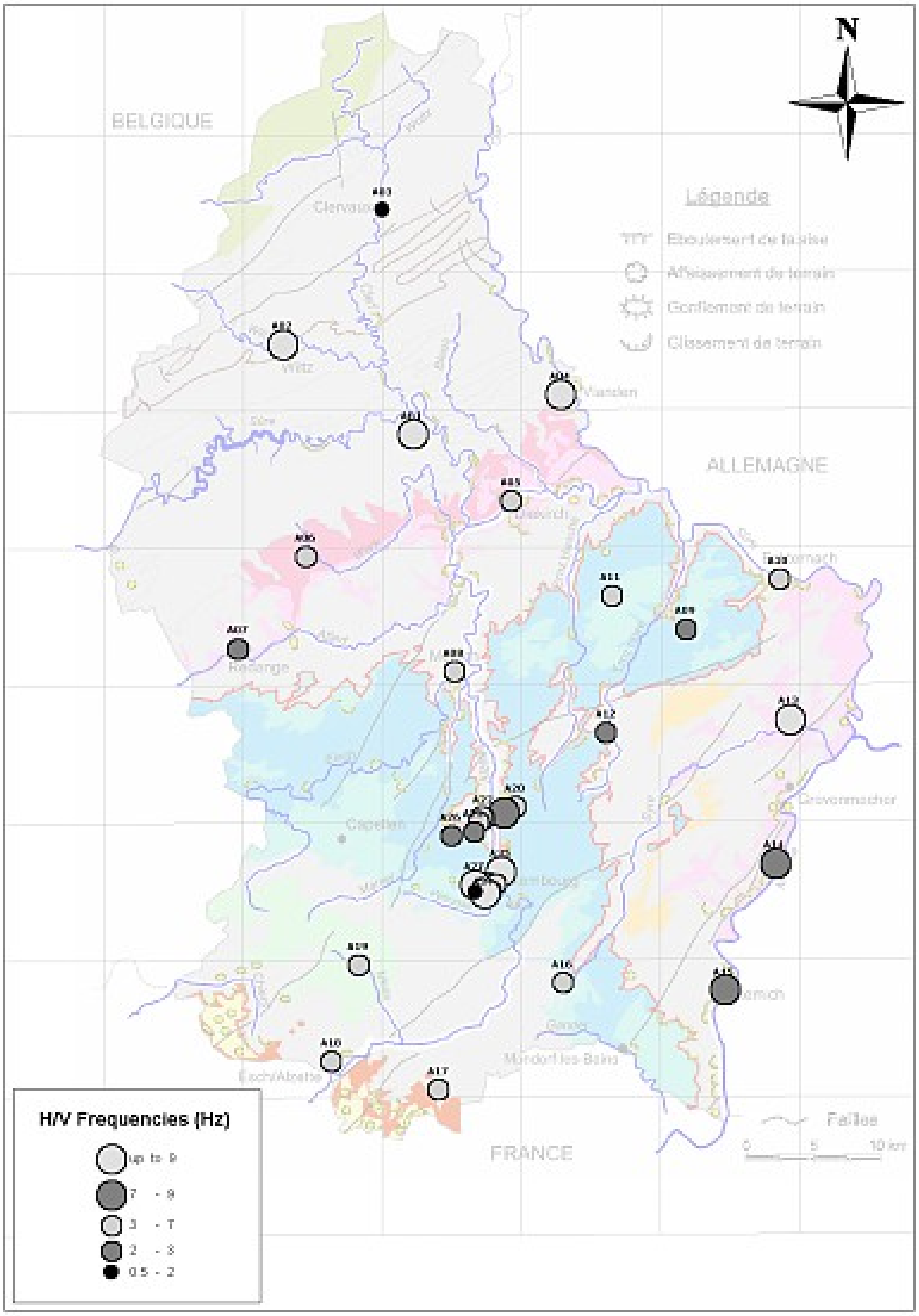


Figure 8 Resonance frequencies obtained by seismic noise analysis in Luxembourg.
Values of frequencies calculated by the H/V method are ranked and plotted on the map.
(Background : Risques géologiques, Ministère des Travaux Publics, Service Géologique)

Preliminary conclusions

Based on the results of the H/V spectral ratio analysis, four types of sites are distinguished :

1. Sites located in schists, quartzites and sandstones that not exhibit clear peak amplitude or have almost flat response (e.g. A1, A3, A4, A31, A32). Those sites will not be affected by local seismic effects in case of important earthquake.

2. Sites located in sandstones and dolomites exhibit a unclear peak at high frequency up to 7 Hz (e.g. A30, A35, A29). Those sites will not be affected by local seismic effects in case of important earthquake.

3. Sites located in marls and clay formations (mainly Lias and Dogger ages) have a peak at medium frequencies from 3 to 7 Hz (e.g. A17, A18, A11, A08). The seismic response of those sites should be further analyzed as they could generate amplification at frequencies corresponding to high building or infrastructures.

4. Sites located in recent alluvial deposits show a very clear peak at various frequencies depending on the thickness layer (e.g. A22, A23, A15, A10). The seismic response of those sites should be further investigated as they could be the place of amplification for a range of frequencies affecting all types of buildings and infrastructures.

The map of the Figure 9 delimitates the different zones (red color) in Luxembourg where further investigations should be planned to estimate potential seismic amplification due to local geology. In this zones, the performed analysis should be complement with in depth geological investigation coupled with numerical analysis in order to define the expected level of amplification at determined frequencies. Scenarios could be then produce by formulating adequate seismic ground motions related to the European regulation Eurocode8. Similar analysis are already performed in cities of Mons and Brussels in Belgium (Rosset et al., 2005a, 2005b).

It has been noticed that larger damages occur for buildings with resonance frequency close to the resonance frequency of the soil beneath. The presented results are a first attempt to identify the resonance frequency of the soil and could be conjugate with effort to define structure resonance for buildings that are vital for crisis management and other important ones. First analysis for building in the center of Mons, in Belgium, have shown that seismic ambient noise records could be use to derive the resonance frequency of buildings (Rosset and Camelbeeck, 2005). Graphs of the Figure 10 show an example of such an analysis for a typical building in the historical center of Mons. It indicates that the ground noise excite the building at the resonance frequencies of 4.1 Hz and make it clearly visible on the noise spectrum. An explorative study should be also engaged in this way in Luxembourg to define the more vulnerable buildings when resonance of the soil and the buildings are at the same frequency.

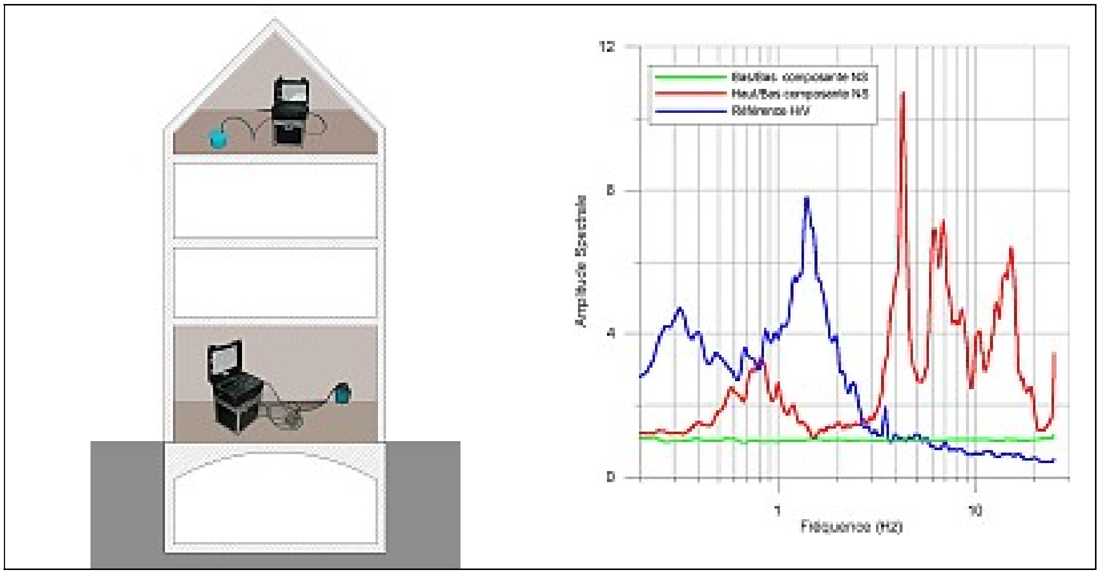


Figure 10 Analysis of resonance frequency of building using two seismic stations; example in the historical center of Mons, Belgium.

Ambient seismic noise are recorded simultaneously at the ground and the top floors of the building to estimate its resonance frequency by spectral analysis of one components of both records.

Spectrum indicate clearly the resonance frequency of the soil around 1.2 Hz (in blue), and the resonance frequency of the building at 4.1 Hz (in red). The flat spectra represents the analysis performed when the two stations are located on the ground floor (from Rosset and Camelbeeck, 2005).

Finally, in the zones where the landslide and rock fall are present, the hazard analysis for both phenomena should envisage additional horizontal acceleration due to earthquake.

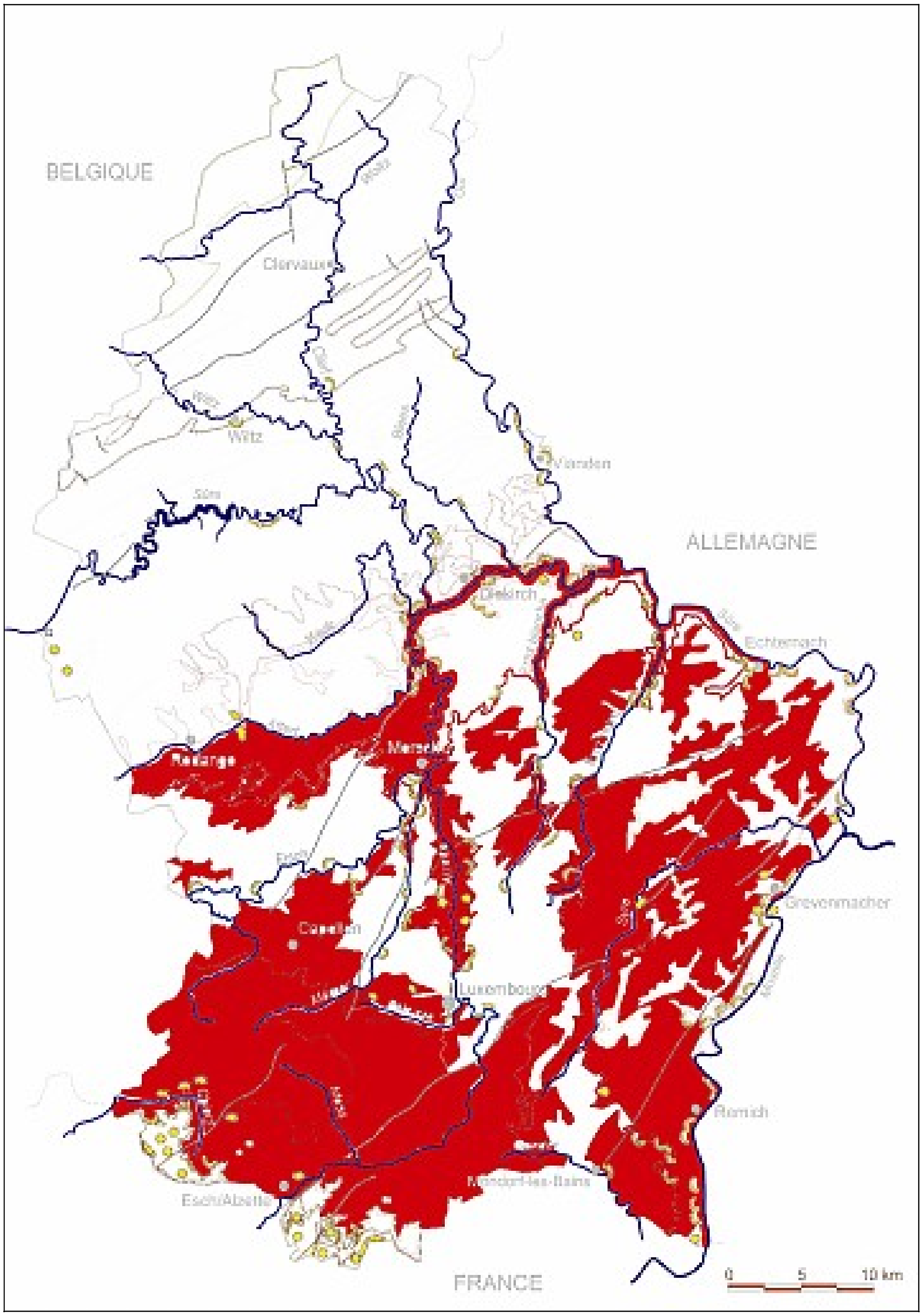


Figure 9 Identification of the zones prone to site amplification.
The preliminary analysis of site response with H/V method using seismic ambient noise records helps to define zones suspected to amplify seismic waves in case of important regional earthquakes. **Outcropping geological formations of the zones in red** should be further investigated to quantify amplification and estimate related vulnerability for important buildings and lifelines. The ultimate objective should be the reduction of the seismic risk in Luxembourg.
(Background : Risques géologiques, Ministère des Travaux Publics, Service Géologique)

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