SEISMOTECTONIC AND GEODYNAMIC SYNTHESIS OF SE FRANCE

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DISSEMINATION: *Authors; Steering Committee; Work Package leaders, Scientific Committee, Archiving.*

Executive Summary

Accurate knowledge of faults seismotectonic characteristics constitutes an important upstream contribution for both deterministic and probabilistic seismic hazard analysis, as it plays a role when building seismotectonic zonation and/or performing fault model approach in SHA. Two main objectives are associated with this study that deals with a seismotectonic synthesis of Southeast ¼ France (in the sense of bibliographic synthesis of seismotectonic parameters for faults): i) to propose a database structure of potential active faults; ii) to perform an updated compilation of published data about seismicity and tectonics of the main faults located in the study area.

Two kinds of results are expected from the actions carried out in the frame of the SIGMA project: operational results (guidelines, recommendations, etc.) and scientific results (improve the scientific knowledge). This work is part of the WP1 "Faults and seismic sources" and deals with the scientific objective of improving/updating the knowledge of faulting in the Southeast ¼ France. Additional ongoing works are performed on this topic in the WP1: "Geomorphological and tectonics study of the Belledone fault system" (PhD) and "Geomorphological and topographical markers analysis in the lower Rhône Valley and Provence" (Postdoc).

The aim of such a seismotectonic synthesis effort is to provide to SHA operators relevant informations when dealing with faults characteristics and their uncertainties. The work is based on the compilation and synthesis of published material; the interpretation is thus reduced to its minimum. This approach allows reporting on uncertainties of seismotectonic parameters estimates and, therefore, the range of values for parameters can be taken into account. The main difficulty is to leave out irrelevant and/or biased estimates. We propose, based on our feedback and on the analysis of already existing databases, a reflexion about what could be the structure of a "Potentially Active Faults Database". Due to the limited time of the study (1 year; the study started in November 2013), the database was not implemented and we focus on the seismotectonic synthesis.

The synthesis is performed fault by fault, as the data presented in the literature generally refer to individual faults. Input data and information we have used in this study are presented and described hereafter:

1) National and international seismotectonic synthesis/databases serve as reference works to elaborate the seismotectonic synthesis: the BRGM seismotectonic synthesis of Provence, Alps and Côte d'Azur (2006) is a key document as it is focused on a large part of our study area; the DISS database for Italy produced by INGV has been formalized in detail and provides a very clear protocol for building such a database; QFaults database from USGS is an example of interactive data displaying and effective integration of active tectonic data nationwide. We also pay attention to other databases: Japan and New Zealand.

2) Available scientific publications dealing with all aspects of potentially active geological structures are of primary importance. Both old key publications and recent ones, that deals with latest advances in tectonic and seismic potential, are consulted and used.

3) Geological maps at different scales, all provided by the BRGM (Bureau de Recherche Géologique et Minière), are carefully analysed so that the scale has an impact on the faults traces.

4) Different seismicity catalogues are considered:
   - The SiHex (www.franceseismes.fr) and CEA-LDG (www.dase.cea.fr) catalogues cover the instrumental period, between 1962 and 2009 for the first one and since 1962 until today for the second.
   - SisFrance database of macroseismicity (www.sisfrance.net), founded by EDF, IRSN and BRGM, extends the seismic record to the historical time-scale. The use of macroseismic information is of primary interest when dealing with seismic hazard in regions, such as metropolitan France, that undergo low deformation rates and consequently low to moderate seismic activity.

5) To extend the observation window as afar as recent deformations and paleoearthquakes, we use the NEOPAL database of neotectonic indexes (www.neopal.net). In this database that overlays the Quaternary period, neotectonic indexes published in the literature have been reviewed by a group of experts coming from BRGM, CEREGE, CEA, EDF, EOST, IRSN and UPMC.

Results are presented in different formats (see below for detailed description): an ArcGIS workspace that allows to geographically represent various data related to the structures; an individual synthetic worksheet document that summarises key informations about considered faults seismotectonic behaviour; an individual synthetic table sheet that gathered all seismological and tectonics data extracted from published material. This table could be easily used as an input to a "Potential active faults database". Work organisation and interactions between the different products are presented in Figure 1.

First of all, the *ArcGIS work package*, in mpk format, is the common numerical support displaying the data of all the faults and segments carried out in the synthesis, as well as shared data coming from various dedicated servers. This workspace provides the different fault traces already proposed either by previous synthesis or by individual reference papers (the studies that only focus on a minor part of the faults are not displayed here but rather mentioned in the synthetic worksheet and table sheet). In addition, the seismicity catalogues and neotectonic database are included, together with toponimic elements and various base maps.

Secondly, the *synthetic table sheet*, delivered in xlsx format, consists in a table that gives a panoramic overview of seismotectonic data collected for each bibliographic source related to an individual fault. It allows to directly and clearly examine the range of values proposed in the literature for each seismotectonic parameter. Uncertainties (when available in the published documents) and comments (generally brief description of how a value has been determined by the authors of the publication) are also indicated. The consideration of uncertainties (when available in the documents) on each parameter is made through an horizontal reading of the table. The lower and upper bounds of each parameter collected in the literature are identified and stored in assigned lines. Columns correspond to references. Methodologies used to acquire the data, clarifications of data correspondence with other parameters or explanations of additional details to support the data are given in the "comments" column.

Finally, the *synthetic worksheet*, provided in docx and pdf formats, is a synthetic document that gathered table sheet informations into thematic sections, in order to facilitate the reading and understanding of data. Five sections are identified:

- Fault identification and cartography
- Fault geometry
- Tectonic characteristics
- Seismicity
- Figures and comments

Within these five sections, all parameters are organized into specific tables showing the data with associated references. In order to provide a complete view of the data, together with additional information from the comments, key figures or attribute tables and metadata, the *ArcGIS workspace* and the *synthetic table sheet,* can be consulted simultaneously with this document.

The *database structure* has been developed in parallel to the synthetic table sheet in order to respect the same architecture. This database consists in tables with attributes and primary keys, linked together by simple or multiple relations. The elementary object of the database is the value, which is related for each entry to three other tables: the fault or segment, the seismotectonic parameter and the scientific publication. As further development of this database and once the data implemented, catalogues might also be integrated and all vector data such as fault lines and geolocalized point values are intended to be linked to a PostGIS geodatabase.

Faults that are treated in this study are: the Trevaresse Fault, Middle Durance Fault, Vuache Fault, Cevennes Fault, Ligure Thrust, Digne Thrust Front, Serenne Fault, Ubaye Fault, Nîmes Fault, Salon-Cavaillon Fault, Nice Arc and Belledone Border Fault. At that time, the seismotectonic synthesis has been performed for the Cevennes Fault, Trevaresse Fault, Middle Durance Fault and Vuache Fault. For each of these faults, we present in this deliverable the table sheets and the worksheet documents that include pictures coming from the ArcGIS workspace.

The present report is delivered in a folder that also contains the independent documents of the synthetized faults in the different formats (Excel data tables, Word and PDF versions of the synthetic worksheet) and the GIS work package that can be run with ArcGIS.

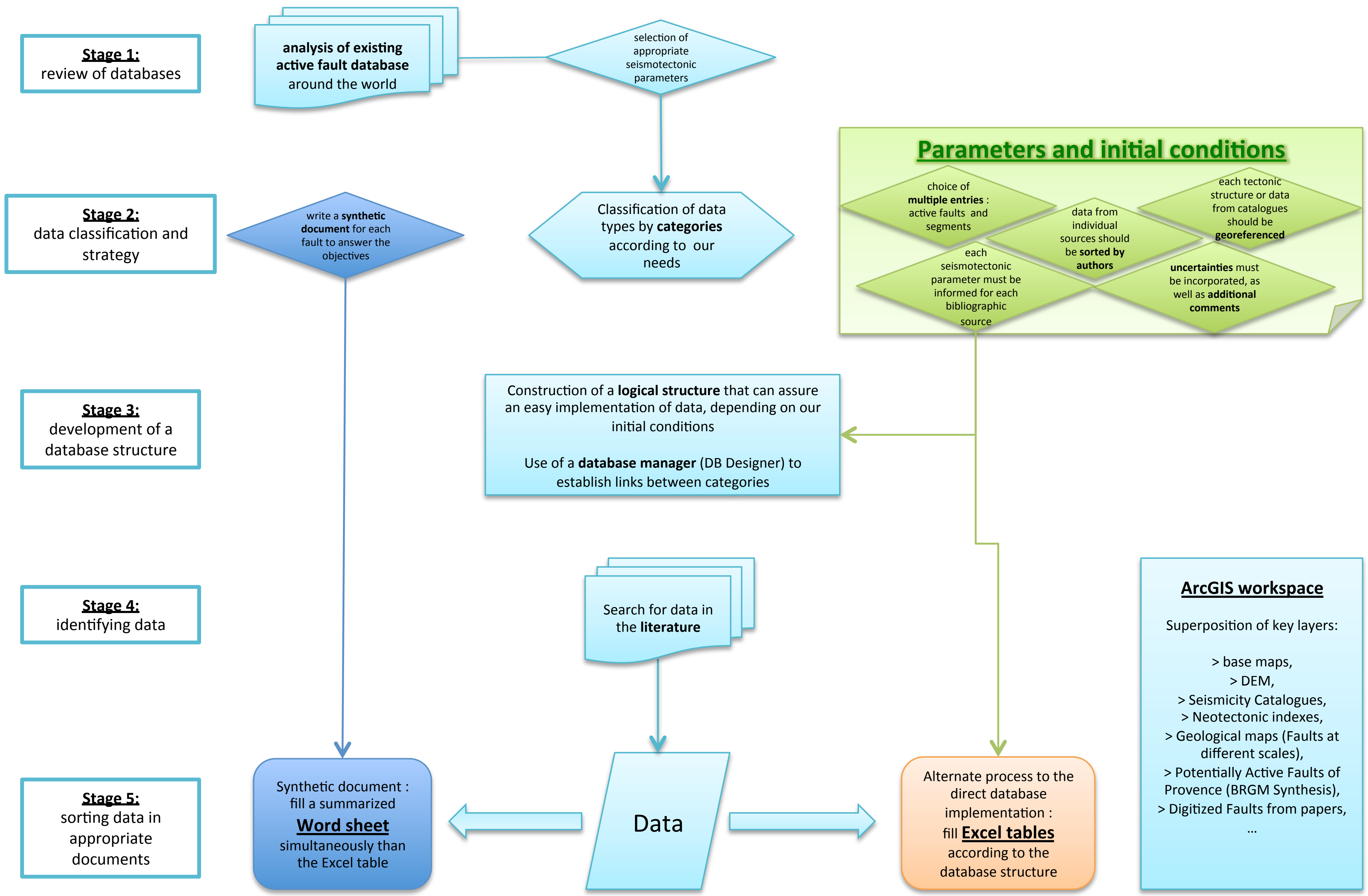

Figure 1: General flowchart of the study, summarizing all the stages that led to the final version of the seismotectonic synthesis of Southeast France

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Introduction

The purpose of this report is to present the work carried out in the frame of the WP1 of the SIGMA project concerning a seismotectonic synthesis of Southeastern France. The first part consists in a review of the current state of the art in the field of active fault database around the world. Eventually, we propose a new database design for the test area of Southeast France. The second goal of this work is to perform a synthesis of the available tectonic and seismological informations related to individual and supposedly active faults.

This study intends to compile different kind of data, observations and time scales together with a complete list of faulting and seismic parameters at a given place. We constructed the architecture of the database and the format of the synthesis simultaneously in order to provide a coherent frame that allows transposing the data from the synthetic tables toward the future database. In a later stage, we filled the descriptive records through individual tables and sheets, so that each fault covered by the synthesis can be consulted through a set of documents, and over an ArcGIS platform that displays the faults and additional mapping content.

The present report is delivered in a folder that also contains the independent documents of the synthetized faults in the different formats (Excel data tables, Word and PDF versions of the synthetic worksheet) and the GIS work package that can be run with ArcGIS.

1. Review of available worldwide active faults database with a focus on data structure and seismotectonic approach.

1.1. Compilation provided by French institutions

1.1.1. <u>BRGM (Identification and classification of active faults of the Provence-Alpes-Côte d'Azur – PACA region, 2006)</u>

A compilation of existing seismotectonic data in PACA region was performed by the BRGM between 2002 and 2006 and aimed to identify and rank the structures that have a potential seismic activity. They first collected/selected raw data and gathered them as detailed descriptive record for each fault. Faults analyzed in this study are presented in Table 1 and Figure 2. The next step was to bring data face to face through seismotectonic maps and then to identify and characterize the potentially active structures. The criteria taken into account were mostly the geometry (extension and fault trace reliability), the neotectonic activity (age of the last tectonic offset, morphological expression, morpho-tectonic features) and the seismicity at different time scales. Given this criteria and an arbitrary system of weighting data, each fault was associated with a relative value as a function of its presumed level of activity (summing all factors related to potential activity). Six temporary level of activity were thus defined as well as an appreciation of a level of knowledge. It eventually resulted in the proposition of classification rules considering the level of seismic activity versus level of knowledge. The structures are presented on a map with several ranges of colour and thickness depending on their level of activity and knowledge, respectively (Figure 3). However, we identified five structures that were not classified whereas they could have been gathered in the null category; the reason of this choice is unclear to us.

Note that the time frame considered as relevant for characterizing the neotectonic structures in this synthesis is the base of the Pliocene, but the Miocene and pre-Miocene indices of activity are also listed.

Table 1: List of the faults analyzed in the frame of the BRGM compilation of the PACA region.

N°	Name	N°	Name
1	Hungary lineament	36	Vinon-sur-Verdon fault
2	Veynes bundle	37	Gréoux-les-Bains thrust
3	Poil-Creisset bundle	38	Montmeyan fault
4	Moustiers – Saint Jurs – la Maline fault network	39	Aups thrust
5	Ceüse thrust (Digne Arc – North lobe)	40	Vérignon - Bauduen thrust
6	Frontal thrust of the central lobe (Digne Arc)	41	Canjuers fault
7	Thrust of the Robine lobe (Digne Arc)	42	Nîmes fault system
8	Thrust of the Cousson lobe (Digne Arc)	43	Arlesian fault
9	Thrust of the China unit	44	Guillaume - Daluis – Castellane fault system (or Rouaine bundle)
10	Valavoire thrust	45	NS fault set of Barcelonnette
11	Frayssinie fault network	46	High Durance fault system
12	Grand Vallon fault system	47	Serenne fault system
13	Monges fault system	48	Argentera NW-SE faults
14	Vermeilh fault system	49	Briançonnais thrust front
15	Bès fault	50	NE-SW fault sets of Briançonnais-Ubaye
16	Thrust at the front of the Barcillonnette slice	51	Pont-du-Fossé - Eychauda fault
17	Selles slice	52	Saorge - Taggia fault
18	La Fare - Coudoux fault	53	Breil-Sospel-Monaco fault system
19	Costes thrust	54	Peille–Laghet and de Blausasc faults
20	Alpilles thrust	55	Saint Blaise - Aspremont fault
21	Lubéron thrust	56	La Vésubie - Mont Férion fault
22	Trévaresse fault	57	Var fault
23	Salon-Cavaillon fault system	58	Mont Vial thrust
24	Ventoux thrust	59	Huesti thrust
25	Lure thrust	60	Baous thrust (or Vence thrust)
26	Middle Durance fault	61	Audibergue – Séranon thrust
27	Compressive relay of Beaumont-de-Pertuis	62	Castellane - Lachens faults bundle
28	Aix fault	63	Chasteuil-Taloire thrust
29	Sainte-Victoire fault	64	La Palud-sur-Verdon thrust
30	Concors thrust	65	La Blache thrust
31	Etoile thrust	66	Lauppe thrust
32	Nerthe fault system	67	Crémon thrust
33	Olympe-Aurélien faults	68	Touyet – Castelanne fault (or Tambalonne fault)
34	Allauch fault	69	Hidden crustal thrust of the Argentera
35	Vautubières thrust	70	Hidden crustal thrust of the North Ligurian margin

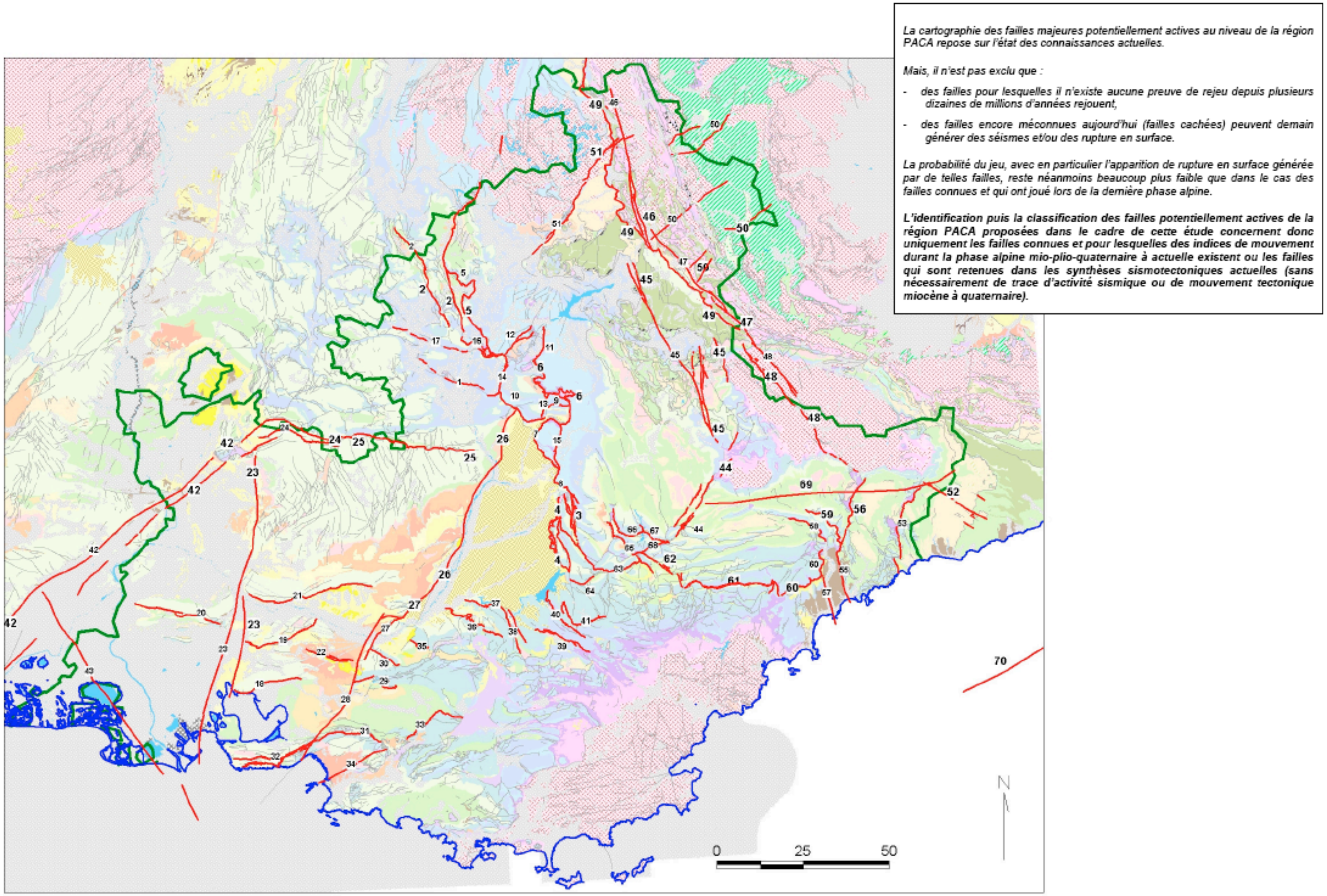

Figure 2: Potentially active faults retained for the BRGM study (Terrier, 2002)

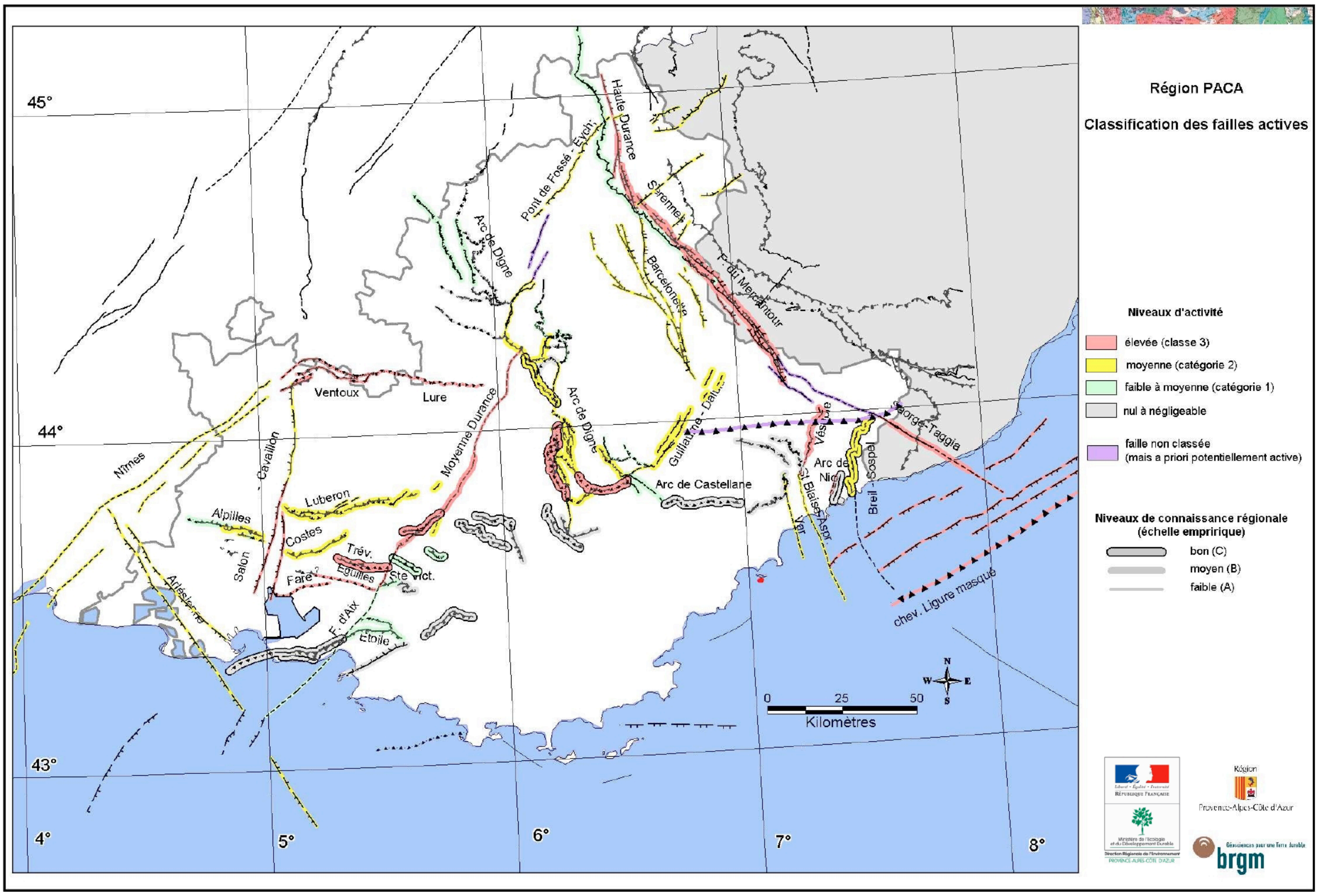

Figure 3: Classification of potentially active faults of Provence (Terrier, 2006)

1.1.2. IRSN (Potentail active faults database, 2012)

The BERSSIN institute (Bureau d'évaluation des risqué sismiques pour la sûreté des installations nucléaires), in charge at IRSN (Institut de Radioprotection et de Sureté Nucléaire) of the Seismic Hazard Assesment elaborates a potential active fault database covering the metropolitan France, with a focus on faults within 50 km from the nuclear facilities. The period of fault activity considered within that database is 5 Ma, and follows the safety standards of IAEA-SSG9.

Their database contains a SIG platform giving access to fault segments representation, a precise description of seismotectonic parameters (geological information from literature as well as geological and topographic maps, covering recent and on-going tectonics) and a descriptive synthesis of each fault with additional arguments and references than those already available in the seismotectonic tables of the database.

The IRSN developped the database structure to several test regions, among which the PACA and Rhône-Alpes regions are directly linked to our study area (Figure 4). From this

work, operational procedure is suggested in order to fasten the process of object and data selection:
1. Establish a list of faults that have to be considered
2. Group together the available bibliography for each fault
3. Define the cartographic trace of the fault and its segmentation, as well as a respective identifier, according to geological maps and bibliographic material. Each fault trace has to be justified in the descriptive synthesis.
4. Fill the database attributes after a bibliographic synthesis and documents analysis and record the:

- Morphological indices associated with the fault
- Fault geometry (in agreement with the more relevant cross-section)
- Age of the last tectonic offset with justification
- Convincing and existing neotectonic arguments
- Fault kinematics and known stress field in the surroundings (regional scale)
- Fault slip rate (deduced from the offset of dated markers)

The database and descriptive records must be considered at the same time to ensure the coherence of information. The descriptive synthesis is only created for potentially active faults whereas small faults are only mapped and entered in the database.
5. Index the fault and identify related NEOPAL neotectonic indices, associated historical earthquakes from SisFrance and compile bibliographic sources.
6. Conclude with an appreciation of the recent activity of the fault from the reported results.
7. Validate the synthetic record systematically for each fault.

The faults covered by this database for the Southeast France are the following:

- Cévennes Fault
- Nîmes Fault
- Roquemaure Fault
- Pujaut Fault
- Alpilles Thrust
- Ventoux-Lure Thrust
- Lubéron Thrust
- Costes Thrust
- Trévaresse Fault
- Fare-Coudoux Fault
- Middle Durance Fault
- Costières Anticline
- Vauvert Fault

In order to pursue the compilation of active faults over the metropolitan territory, the BERSSIN proposes to implement the database following a priority order:

1. The largest active or supposed active accidents and closest to the power plants, with a last known movement estimated from the Plio-Quaternary (minimum length of 10km and within 50km around nuclear power plants)
2. Faults located farther than 50km from the nuclear power plants, with a length superior to 10km, and with a recent activity age are already reported on the seismotectonic map of France (Grellet et al. 1993)
3. Faults with the same characteristics than points 1 and 2, with a recent activity age and that appear undetermined on the seismotectonic map of France (Grellet et al. 1993). It usually corresponds to old structural features.
4. Small-length faults with an undetermined activity age.

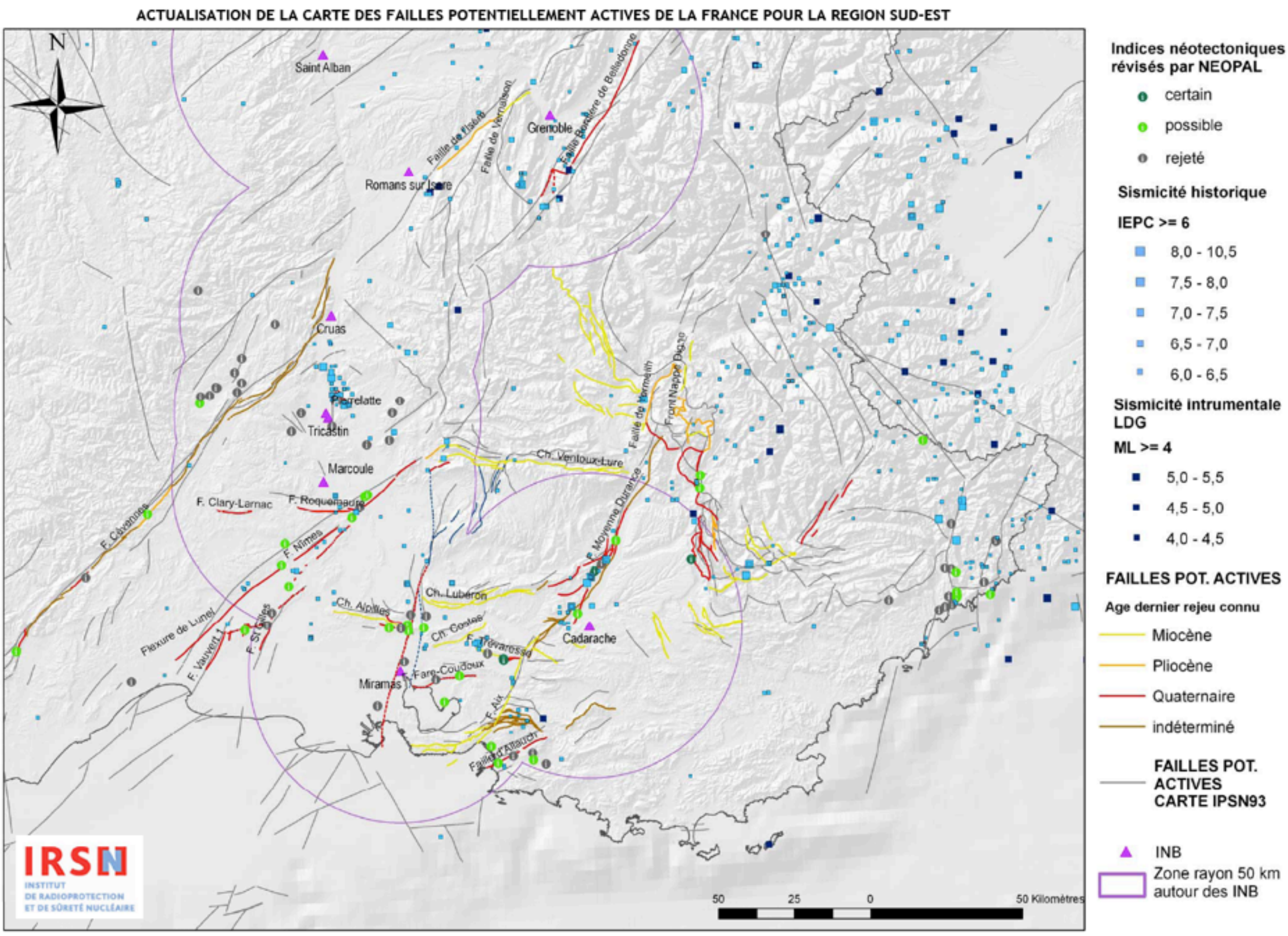

Figure 4: Updated map of the potentially active faults in Southeast France (David et al., 2011).

1.2. Active faults databases of high to moderate seismic activity in foreign countries

The compilation of these active fault database is based on the synthesis of IRSN (David et al. 2011) and take stock of what has been done so far in active countries. It has been updated with additional informations found in the dedicated supports. The critical study of the parameters found in each database has been made in the frame of the working group in order to guide our choice of parameters; Thus, the following sections do not reflect the analysis of how were chosen or used the seismotectonic parameters in the different databases, but rather consists in a global overview.

1.2.1. Japan, AFRC-AIST (Active Fault Database of Japan, 2012)

A database is maintained by the Active Fault Research Center (AFRC) and is accessible on the following website: http://riodb02.ibase.aist.go.jp/activefault/index_e.html (Figure 5 - Awata and Yoshioka, 2003). It describes characteristics of 161 faults segments (localization, strike, dip, length, speed and age of the last movement, return period, rupture probability…). This database can be requested through a dedicated interface. Cartographic elements and tables can be downloaded in the Google Earth or ArcGIS formats. The timeframe considered in this database is not specified but one can suspect that it is very likely in the Holocene window since very active subduction zones surround Japan.

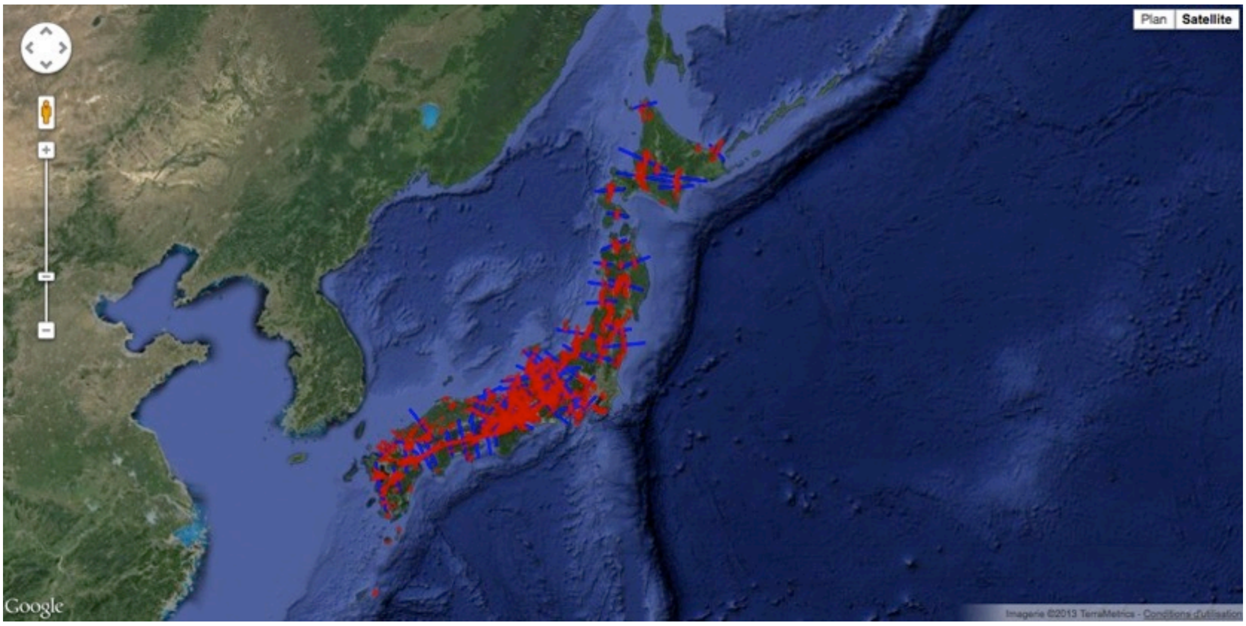

Figure 5: Faults location of the AFRC database.

1.2.2. New Zealand – GNS (New Zealand Active Faults Database, 2011)

A web database has been created by the GNS Science of New Zealand and displays the main active faults (http://data.gns.cri.nz/af/index.jsp - Figure 6). This interactive portal proposes information such as kinematics, recurrence, main bibliographic references and pictures associated with each of the available fault segments. It is thus possible to display faults by sense of movement, recurrence interval, slip rate, or fault rupture. Two query modes are available: either by fault names, or by seismic and kinematic parameters: data ranges categorize the recurrence intervals, slip rates and single event displacements, which facilitates the query.

The fault activity in the geological context of New Zealand is confirmed if known evidence for rupture in the past 120,000 years is attested. So, the Holocene-Late Quaternary is their time frame.

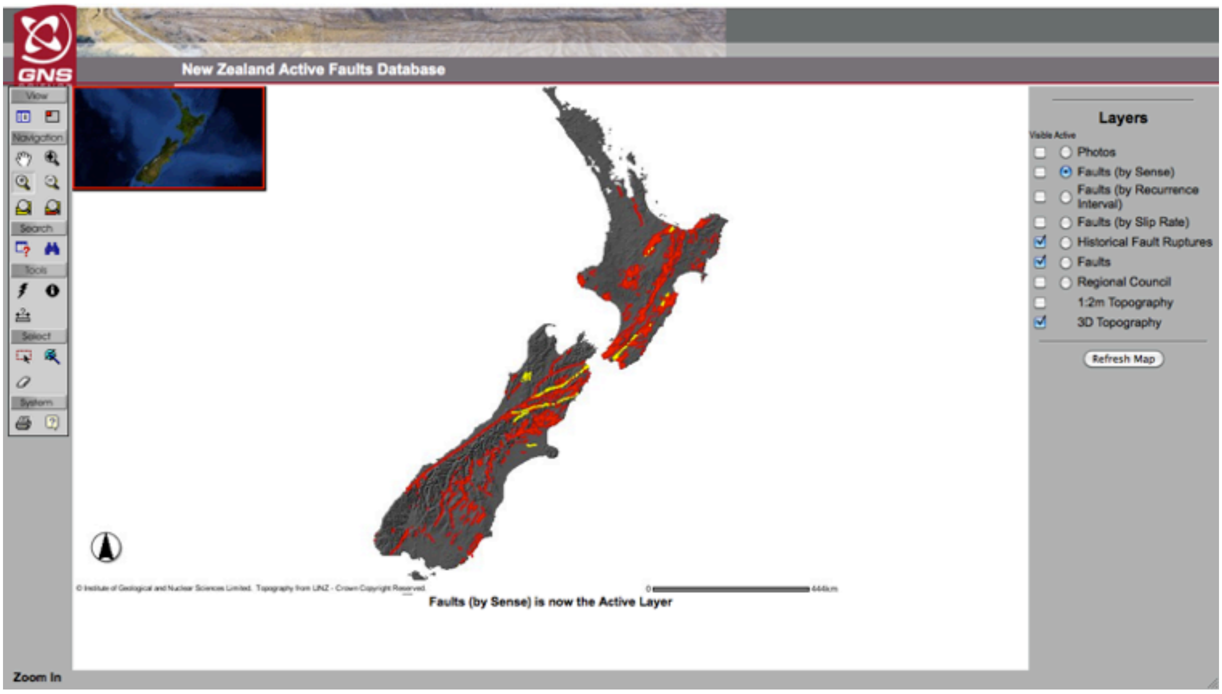

Figure 6: GNS Active Fault web database.

1.2.3. United States – USGS (Qfaults, 2008 – last updated in 2010)

USGS provides a Quaternary fault and fold database that is also accessible on Internet (Haller et al., 2004 - http://earthquake.usgs.gov/hazards/qfaults - Figure 7). The main features are faults and associated folds that could potentially generate earthquakes with magnitudes greater than 6.0 and affecting terrains of quaternary age (younger than 1.6 Ma). This database covers a very large area (mostly California but also the surrounding states) and groups together more than 10000 pages of information about 2000 faults and folds. The cartographic base can be interactively requested in order to extract ArcGIS or Google Earth files. The faults characteristics are accessible through web tables where each field can be displayed as the length, the mean strike, the fault kinematic, the paleoseismicity studies, the geomorphological expression, the ages of affected formations, the historical seismicity, the prehistoric deformation, the return period and the relevant bibliographic references.

A parallel work has been performed by the USGS during the last couple of years in the field of seismic-hazard assessment since they released a set of PSHA maps showing the peak horizontal acceleration and horizontal spectral response acceleration for 0.2 and 1.0- second periods with probabilities of exceedance of 10 and 2 percent in 50 years. The open-file contents are available online and give access to the integral production of maps and shapefiles (Petersen et al., 2011 - http://pubs.usgs.gov/sim/3195/).

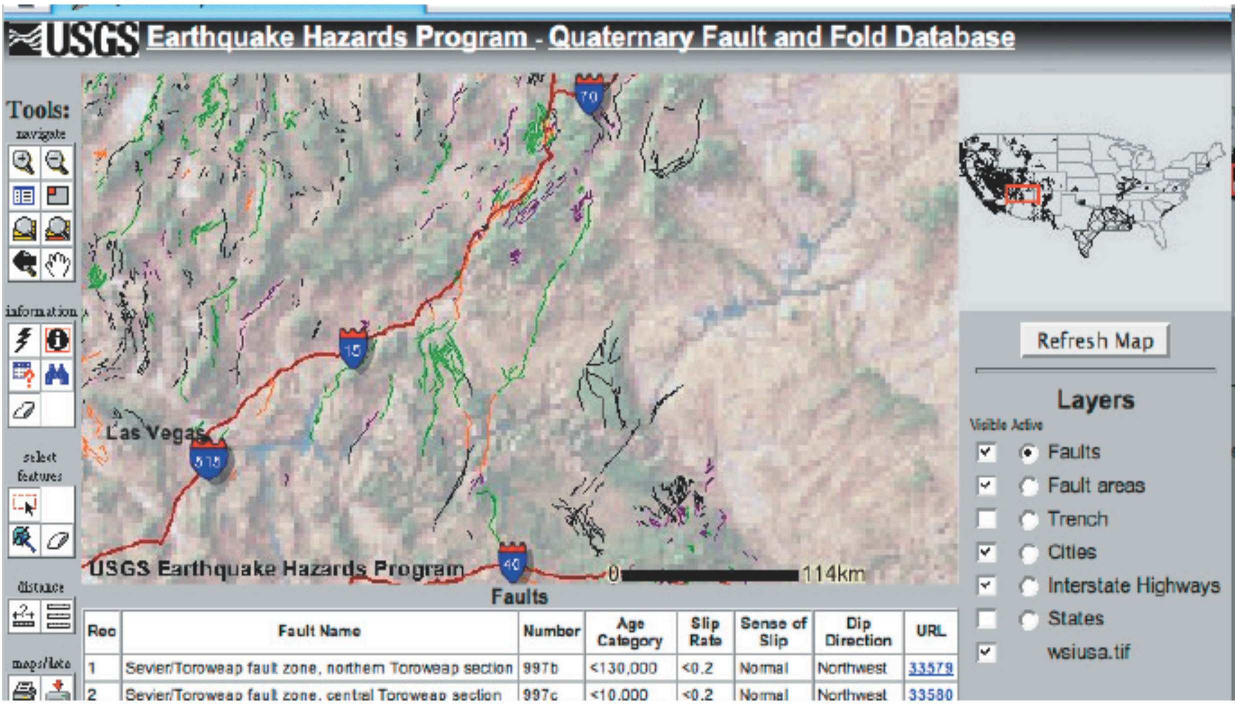

Figure 7: QFaults active faults database of western United States.

1.2.4. Italy – INGV (DISS, 2008)

In Italy, two databases are available:

- The DISS database (Figure 8) released by the Instituto Nazionale di Geofisica e Vulcanologia (INGV - http://diss.rm.ingv.it/diss/index.html) describes individual, composite or debated seismic sources with a high amount of information: geometry, fault velocities, paleo-earthquakes… An active fault and fold category can also be described independently. For each integrated data, the bibliographic source, the compiler and additional relevant documents are provided. The DISS team published their achievements (Basili et al. 2008) as well as an explanatory guideline for the use of the database (Basili

2009). The former provides further details concerning the database structure and the way sources have been differentiated according to their level of knowledge and activity.

Seismogenic sources identified in the DISS for the Po Plain (Italian target area of the SIGMA project) have been presented in the SIGMA deliverable D1-27. In a second time, sigma deliverable D1-67 aimed at presenting the analysis of subsurface data, in addition to DISS information, for the Po Plain which allow to constrain geometry and slip rates of presumed active faults. These two deliverables dealt with the elaboration of regional earthquakes source models for the three Italian SIGMA sites: Tortona, Novellara and Casaglia.

No time frame is openly defined in the DISS-related papers; the seismogenic sources are thought as having cumulated some displacement in the recent past so that we can speculate it is very likely that the fault will be offset again in the near future.

- The ITHACA catalog of capable faults published by the ISPRA Ambiante (http://193.206.192.227/wms_dir/Catalogo_delle_Faglie_Capaci_ITHACA.html)

A comparison between two of the most accomplished databases of USGS and INGV (QFault and DISS, respectively) has recently been published by the two researchers in charge of these databases. It aims to confront the main similarities and differences in the contents of these two seismogenic source models (Haller and Basili 2011).

Figure 8: DISS Seismic Source Database of Italy.

1.2.5. <u>Spain – IGME (QAFI, 2012)</u>

The QAFI (which stands for "Quaternary Active Faults of Iberia" – see on Figure 9) incorporates 262 active faults, directly accessible on a web interface (http://info.igme.es/qafi/). The structure of the database, detailed in García-Mayordomo (2012), includes data types divided into seven categories: Identification and compilation, geometry and kinematics, quaternary activity, seismic parameters, associated seismicity, extended data and references, uncertainties (this last category is associated to a table in the database and is linked with all other tables).

The scientific conception of QAFI database was made according to existing ones of national and continental scope. It is in accordance with the DISS database, which is the basis for the European project SHARE (www.share-eu.org, cf. section 1.2.8.1), as the purpose of QAFI is eventually to be implemented in a European active faults database.

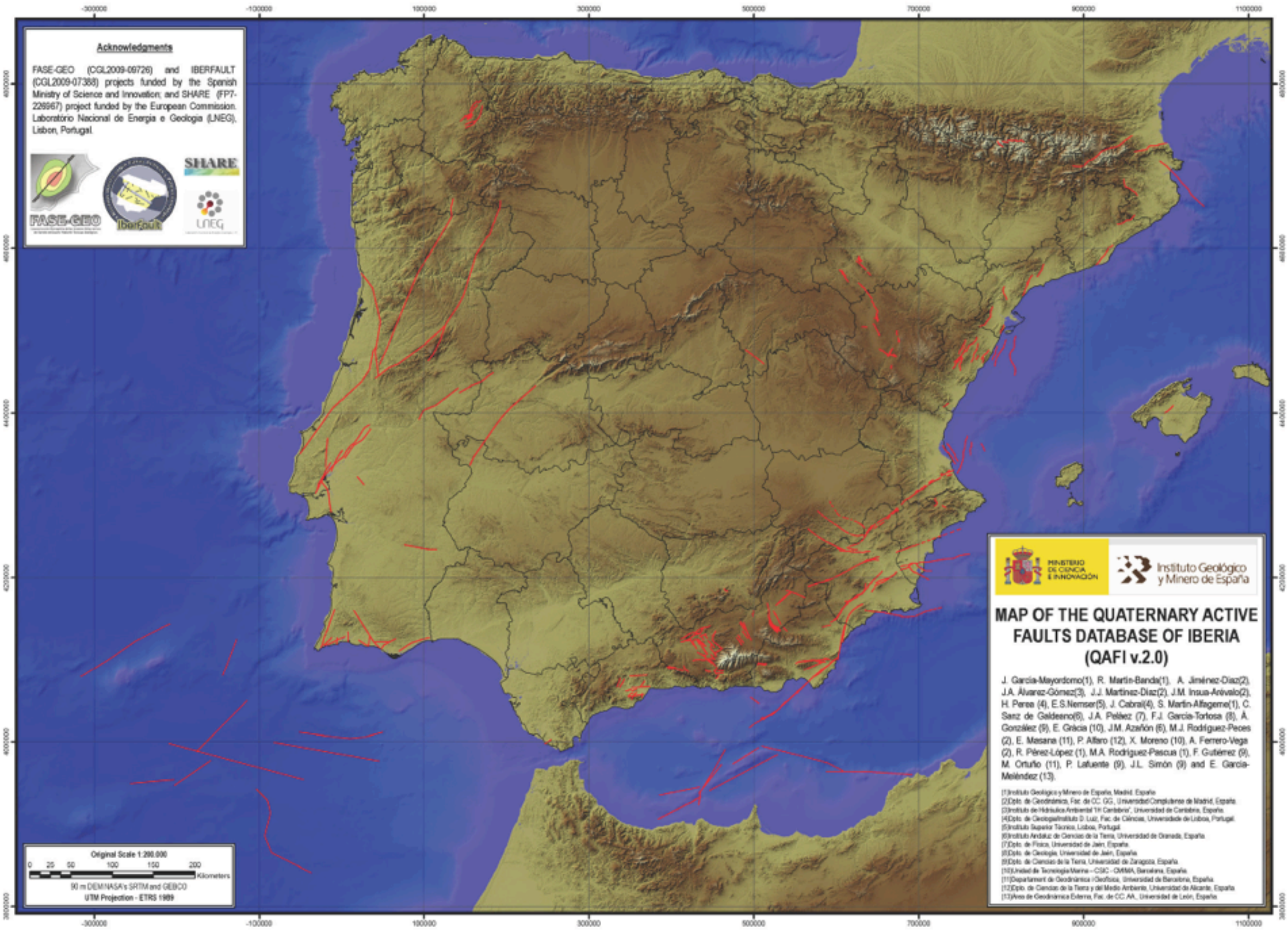

Figure 9: Map of the Quaternary Active Faults Database of Iberia (QAFI v2.0).

1.2.6. Germany – Aachen University (PalSeiDB, under development)

The Aachen University is currently developing a paleoseismic database -PalSeiDB- (Hürtgen and Reicherter 2013), which will integrate paleoseismic studies with trenching sites that can provide evidence for paleoearthquakes in Central Europe. It is based on the DISS database structure, and adds information on loose sediment deformation and mass movements. This database could bring an overview of the state of paleoseismic research in that area.

1.2.7. Europe (Database of Potential Sources for Earthquakes larger than M 5.5 in Europe, 2001)

The Database of Potential Sources for Earthquakes Larger than M 5.5 in Europe (http://legacy.ingv.it/roma/banche/catalogo_europeo/index.html) is the main outcome of FAUST (Faults as a Seismologists' Tool), a project funded by the Environment and Climate Programme of the European Union (1994-1998). The main target of the project was to

"*...Collect all the available information about individual seismogenic faults in Europe and implement a data-base on an public-accessible website.... The consultation of this site will be guided according to the usefulness of the data to various interest groups (geologists, seismologists, engineers, civil defence officers)...*". Although the FAUST site has been fully operational for about one year, the *Database* was at risk of becoming obsolete since no follow-up or periodical update had been envisioned at the end of the project.

1.2.8. Collaborative projects on seismic hazard

1.2.8.1. SHARE (Seismic Hazard Harmonization in Europe)

SHARE (http://www.share-eu.org/) is a Collaborative Project in the Cooperation programme of the Seventh Framework Program of the European Commission. SHARE's main objective is to provide a community-based seismic hazard model for the Euro-Mediterranean region with update mechanisms. The project aims to establish new standards in Probabilistic Seismic Hazard Assessment (PSHA) practice by a close cooperation of leading European geologists, seismologists and engineers, in particular DISS and QAFI members. The DISS v.3 has been selected as a template for the European database of active faults and seismogenic sources within the SHARE project (Vanneste et al. 2013), whereas QAFI database was partially funded by SHARE. In turn, the SHARE project participates in a recent initiative for a Global Active Fault and Seismic Zone Database as part of the Global Earthquake Model (see below).

A model of composite seismic sources has been presented in (Vanneste et al. 2013) with a first attempt to develop a parameterized fault-based source model for the Lower Rhine Graben (LRG). It is part of a European-wide effort (within the SHARE project) to construct a database of fault sources that can be used as input to seismic hazard computations.

1.2.8.2. GEM (Global Earthquake Model)

The Global Earthquake Model (GEM - http://www.globalquakemodel.org/) is a public-private partnership initiated in 2006 by the Global Science Forum of the OECD to develop global, open-source risk assessment software and tools. With committed backing from academia, governments and industry, GEM contributes to achieving profound, lasting reductions in earthquake risk worldwide by following the priorities of the Hyogo Framework for Action. From 2009 to 2013 GEM is constructing its first working global earthquake model and will provide an authoritative standard for calculating and communicating earthquake risk worldwide. The model is supposed to be released in the near future.

1.3. Conclusions

Among the various types of active fault databases that are available around the world, it seems clear that these databases present several common features.

Concerning their context and objectives:

- The main goal is to provide key information for seismic hazard assessment at national and local levels;
- They are developed by national scientific institutions
- They deal with seismotectonic characteristics of faults along the entire territory of a given country/region;
- They are maintained and supported by governmental institutions;
- They tend or aspire to completeness inside the area they cover;
- They developed a scientific strategy to classify and harmonize data through a clear database structure that can be used in a GIS platform;
- Most of the database are accessible on a web-based interface and give access to seismotectonic criterion such as: length, average strike, kinematics, fault speed, paleoseismicity studies, geomorphological expression, age of affected terrains, historical seismicity, prehistoric deformation, recurrence time, references…
- They are based on the available scientific literature (either raw or interpreted data).

Despite the efforts that have been deployed, every attempt to build an active fault database follows its own scientific progression/strategy and these databases thus present some differences:

- They have a look at different maximum ages for fault activity (if any), due to different geological/seismological/geodynamical settings;
- They do not attribute the same importance in reconstructing the history of movement on identified faults;
- They attach different importance to the ability of the fault in rupturing at the surface;
- Different classification systems are developed to qualify the bibliographic sources, to attribute a level of confidence to the data or to estimate the level of knowledge;
- Some of the databases relie on the compiler interpretations or calculations and might be partially biased or non-exhaustive;
- They use different strategies to map, represent, and characterize faults.

The analysis and attention paid to these seismotectonic databases available around the world constituted the starting point of our reflexion. It allowed us to set up selection criteria for available/published information on seismotectonic parameters for potentially active faults in Southeast France. Our strategy was also led by our objective of building a synthesis in a format that would easily be implemented in a seismotectonic database in the future. The retained seismotectonic parameters for our seismotectonic synthesis are presented in section 3.1.

2. Catalogues/Database of neotectonic, historical and instrumental seismicity in France

After reviewing the most accomplished databases around the world, we present here the French catalogues and databases that inventory the instrumental seismicity, macroseismicity and neotectonic indexes of recent deformations. Practically, these mediums enable us to extend the range of observation as far as possible in the past so that we can better assess the seismic hazard. When represented on thematic maps, the catalogues/databases enrich the seismotectonic analysis that can be performed with fault parameters extracted from the literature. In the following sections, the types of data that are considered in the catalogues/databases are explained in detail.

2.1. NEOPAL

NEOPAL (www.neopal.net) is a database compiling the geological arguments of recent deformation that occurred during the last 2 Ma (neotectonic indexes) in France, published in the scientific literature and evaluated by an expert committee (Figure 10).

The NEOPAL expert committee work and the associated database started in 2001. The expert group activity stopped in 2009 but the database is now available through the web page. This database is not exhaustive about recent tectonic activity as it reflects the state of knowledge. The NEOPAL data are presented as reports describing and evaluating the indexes and faults. The access to these reports is made possible through geographic or fault name requests. The indexes are represented by different symbols depending on the evaluation of the expert committee.

It is possible to display an abstract of the descriptive report of the selected fault or index on the website. The complete report is available as an Adobe PDF file.

NEOPAL contains 229 indexes, and the expert committee has reviewed 153 of them. 57 of the 153 indexes are declared “possible” (53 indexes, 35% of total) or “certain” (4 indexes, 3% of total). 66 indexes have not been examined by the expert committee. Several new indexes have been published since 2009 (Bollinger 2012).

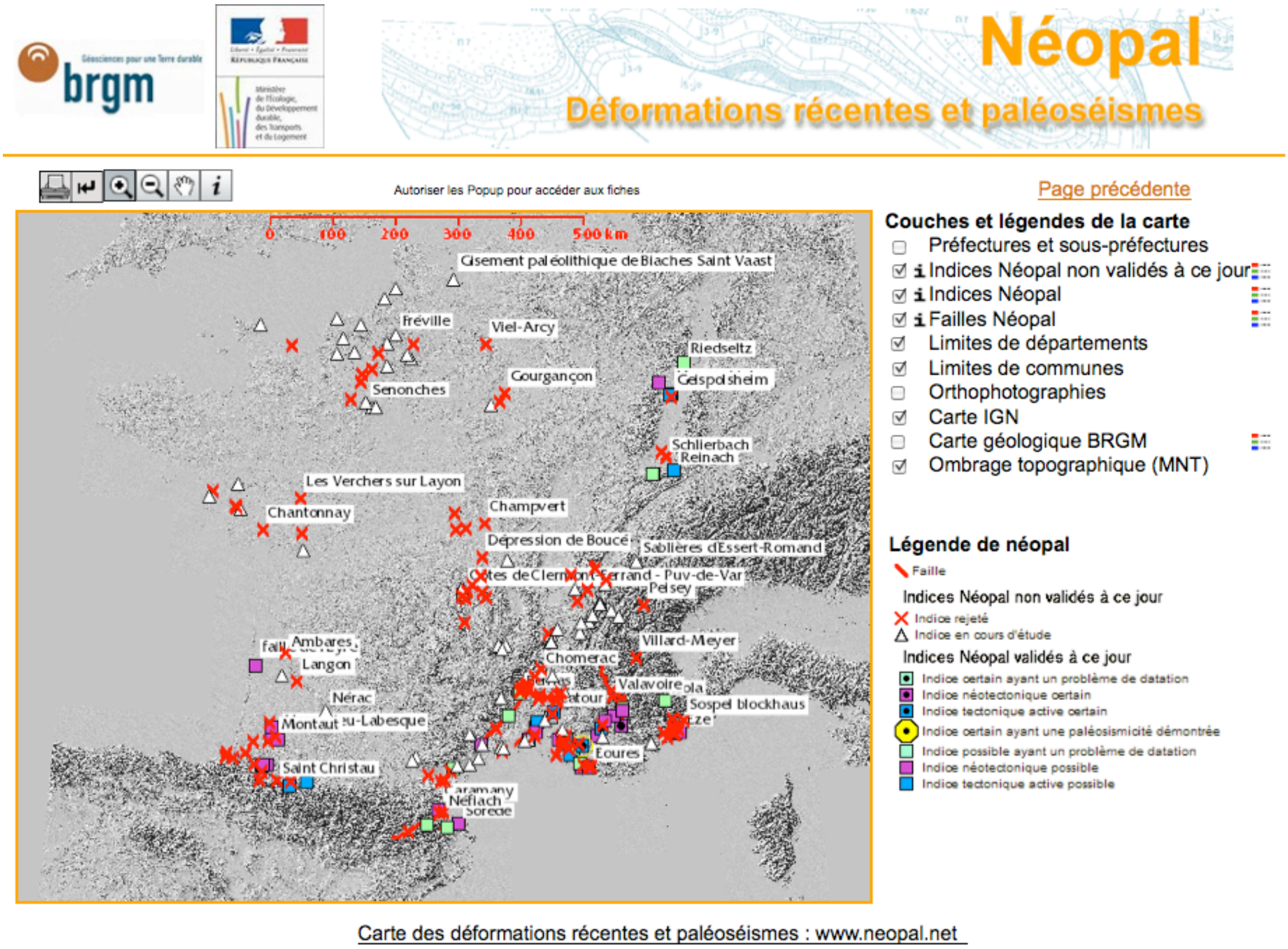

Figure 10: Map of neotectonic indexes referenced in NEOPAL.

2.2. SisFrance

In order to improve the knowledge of past earthquakes that have occurred within the French metropolitan territory, EDF (Eléctricité de France), IRSN (Institut de Radioprotection et Sureté Nucléaire) and BRGM (Bureau de Recherche Géologique et Minière) collaborate, since 1975, in implementing and maintaining the SisFrance macroseismic database (www.sisfrance.net).

More than 106 000 macroseismic observations are gathered in the SisFrance database. These observations are associated to more than 6000 earthquakes that occurred between 217 BC and 2007 (Figure 11). Macroseismic data come from historical archives studies (before 1920) and/or analysis of people feedbacks collected through questionnaires sent by the BCSF (Bureau Central Sismologique Français) to the city councils located in an earthquake area. Among these 6000 earthquakes, half of them have sufficient and reliable information to allow the estimate of their epicentral intensity (Iepc) and location. The epicenter location provided by SisFrance is obtained through manual drawing of isoseimals. Epicentral (I_{epc}) and Observed (I_{obs}) intensities in SisFrance are expressed in the MSK scale (Medvedev et al. 1964). A quality index is associated to these parameters.

The SisFrance Internet portal provides temporal, geographic, and spatial request menus, thematic maps, as well as numerical archives with some of the documents that were interpreted in order to estimate macroseismic intensities of past events.

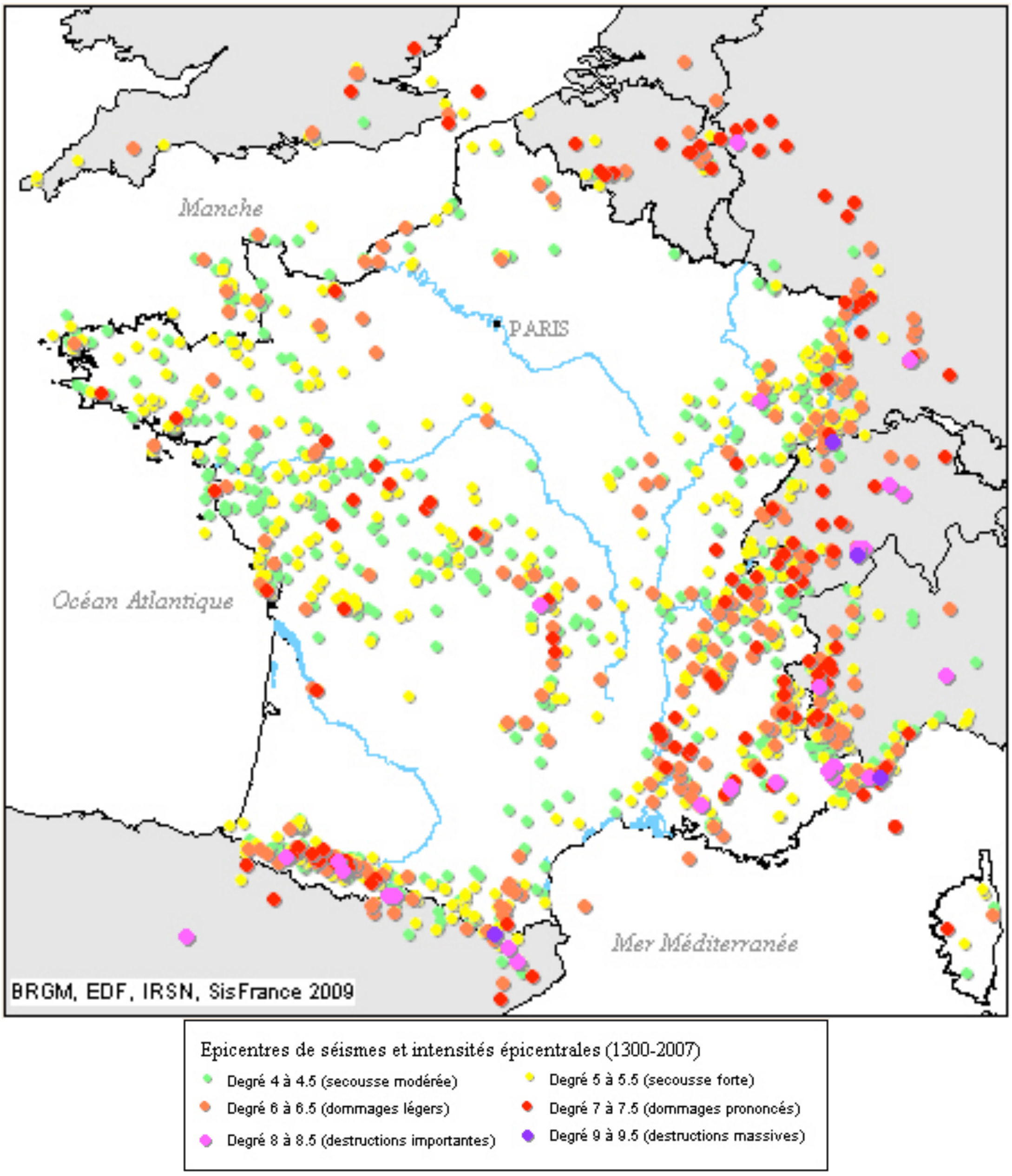

Figure 11: Historical seismicity of France between 1300 and 2007, provided by SisFrance.

2.3. CEA-LDG

The “Département Analyse, Surveillance, Environnement” (DASE), of the French Atomic Energy Commission (CEA), established and operates a national seismological network. It provides a seismic alert to authorities. Its “Laboratoire de Détection et de Géophysique” (LDG) is responsible for the analysis of the seismicity and generates seismic bulletins since the early 60s. These bulletins are compiled in a national earthquakes catalogue covering 1962 to present (Figure 12 - www.dase.cea.fr). This catalogue is rather homogeneous in time and space on that period and at the scale of the metropolitan territory because of continued maintenance and operation of the stations.

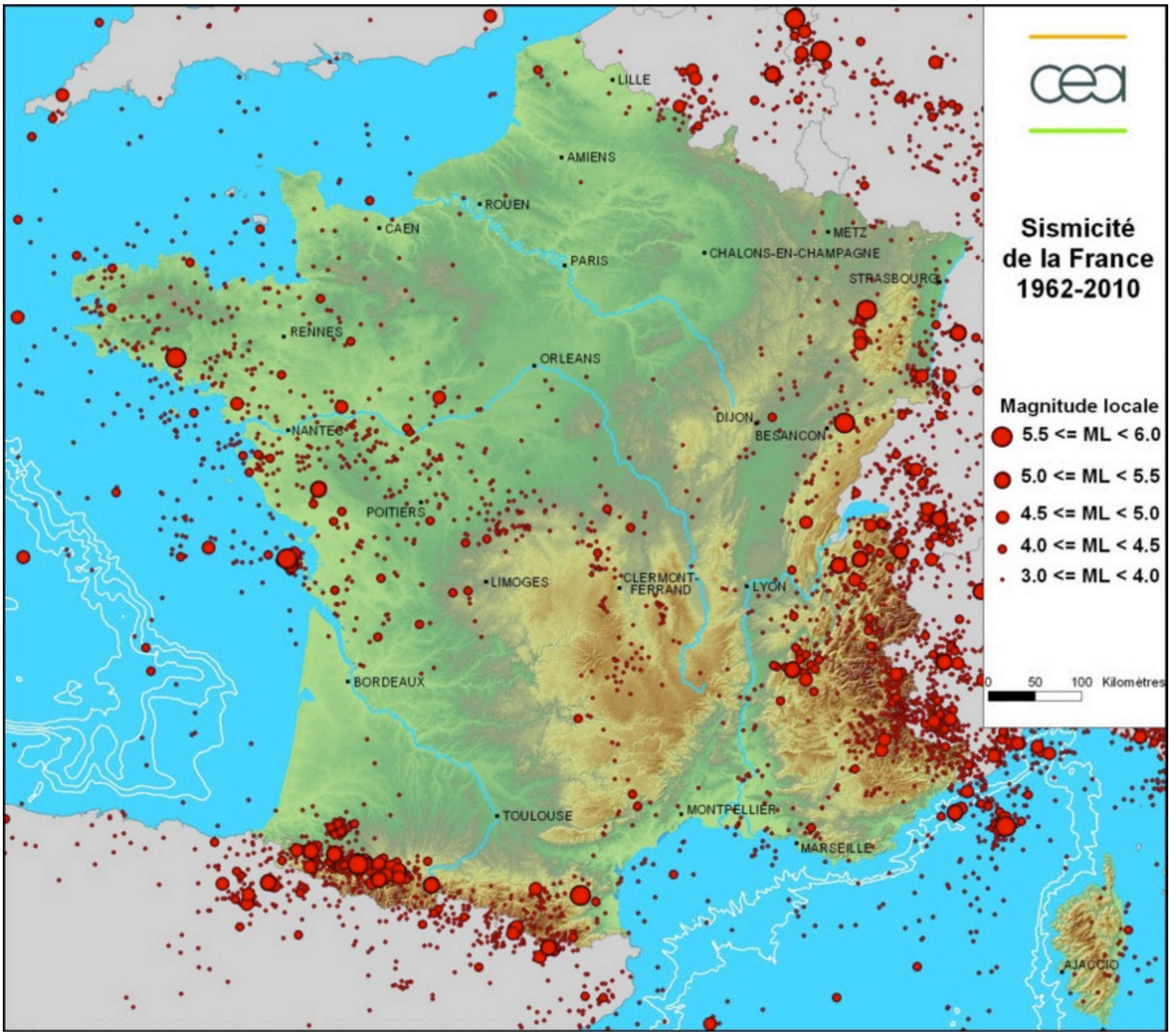

Figure 12: Natural seismicity of France and surrounding countries between 1962 and 2010, expressed with ML (CEA-LDG catalogue)

2.4. SI-Hex

The SI-Hex catalogue ("Sismicité Instrumentale de l'Hexagone, Catalogue BCSF-LDG, 2014" - Figure 13) is the result of a collaborative project conducted between 2009 and 2013 by the BCSF and takes into account the instrumental data of seven french observatories of Universe Science (OSU CNRS/INSU – Universities) plus CEA-LDG. Implicated OSU are EOST (Strasbourg), IUEM (Brest), OCA (Nice-Sophia Antipolis), OMP (Toulouse), OPGC (Clermont-Ferrand), OSUG (Grenoble) and OSUNA (Nantes). SiHex catalogue is available since March 2014 (www.franceseisme.fr). SIGMA WP1 worked in collaboration with the SiHex project, through a PhD funded by SIGMA about magnitude M_w Coda estimation, which has been applied to estimate magnitudes for SiHex catalogue larger events ($M_{L(LDG)}$>3.4).

The SiHex catalogue covers the French metropolitan territory and the exclusive economic zone, plus 20km outside the borders that corresponds to the typical uncertainties on the epicentre location.

Hypocentral locations and magnitude estimates in the SiHex catalogue come from a re-processing of available instrumental data. Locations have been performed by using regional velocity models for Pyrenean, Inner Alpine, Ligurian and Armorican regions. Along the rest of the territory a unique 1D velocity model has been applied. Three different methodologies were used to compute M_w magnitudes, according to different magnitude ranges. Induced anthropic events (quarry blasts, explosions, events of mining origin) have been identified and deleted from the catalog.

The SI-Hex catalogue can now be considered as the reference instrumental seismicity catalogue, as it benefits from a common effort between the main seismological observatories in France and from the use of uniform and identified procedures.

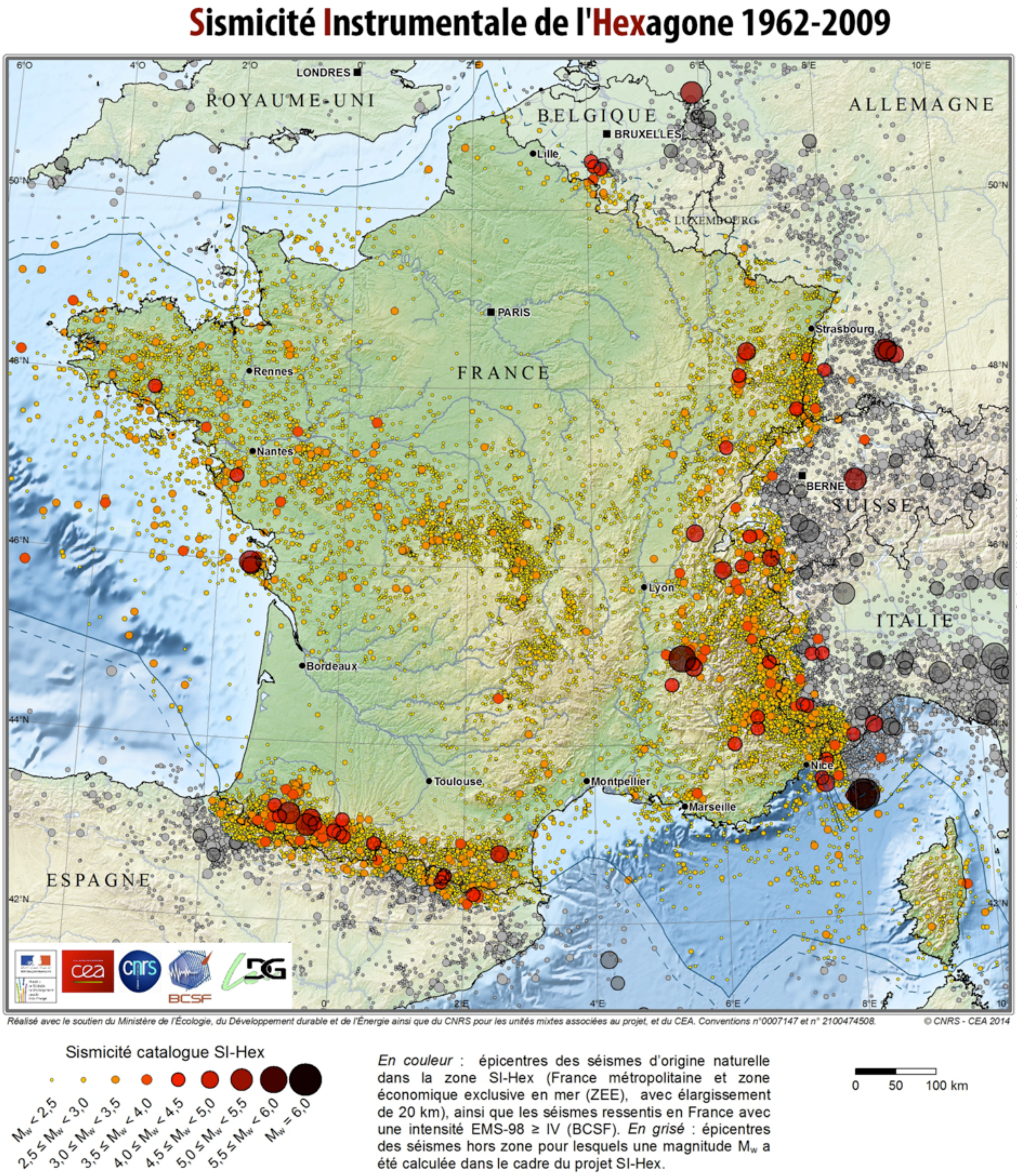

Figure 13: Instrumental Seismicity of the Hexagone between 1962 and 2009 (Catalogue BCSF-LDG, 2014)

3. Development of a database structure for the seismotectonic parameters of potentially active faults of Southeast France

One of the aspects of the SIGMA project is to improve the knowledge of seismic sources that play a role in seismic hazard analysis. For that purpose, it is essential to compile and summarize geological, tectonic and seismological characteristics presented in the literature and associated to faults. It is also important, for seismic hazard assessment, to classify these parameters in a logical way, so that they can be stored, consulted, interrogated and rendered efficiently. This approach would allow providing to seismic hazard operators a synthesis of available information concerning seismotectonic characteristics of potential active structures.

3.1. General approach

The approach that has been followed consists in several successive steps:

- A reflexion on a database structure for potential active faults in context of low deformation and low to moderate seismic activity
- To determine which geological structures would be studied as potential seismic sources according to their location and dimensions/length, as they are supposed to represent the major structures of Southeast France;
- To regroup the available relevant bibliography for each structure;
- To compile the information in clear and functional tables and data sheets that would be used to implement the database structure (see section 3.2 for database structure presentation and section 4 for a description of tables);
- To build a GIS platform displaying different geolocalized fault traces according to various authors and geological maps, and a set of thematic seismotectonic maps that incorporate part of the synthetized information (such as the most recent tectonic offset, if available);
- The next step would be set up a junction between the database and the GIS in order to make data accessible and requestable through the GIS interface. This was not planned in the time of the study and has consequently not been performed.

This process has guided our study and defined the stages of our work. It should be accompanied by further development on the reasons why we chose certain faults and based on which parameters. In the next paragraphs, these elements are detailed with solid arguments in order to support our choices.

The length has been chosen as the **primary criterion for fault selection**. Major structures are favoured because they delimit structural domains or have demonstrated a tectonic inheritance with polyphased kinematics. The length criterion is a key parameter for seismic hazard assessment as there is a trade off between structure length and earthquakes magnitudes. Satellite faults, which are supposed to follow a similar behaviour than the major fault, are included in the analysis.

Some additional criteria have been taken into account in the fault selection:

- Various kinematic and tectonics context had to be considered;
- The area of investigation needed to spread out of the Alps and Provence, in order to sample faults in regions with different degrees of activity. The Rhône Valley and the Jura Mountains were thus selected to extend the observations to the West and to the North, respectively.
- Finally, we decided to summarize the available seismotectonic information for poorly known structures as well as for well-known structures, in an equal proportion. This implicated to not only concentrate our synthesis approach on faults with large amount of available data but also to supposed active structures that benefit from less published material and long enough to satisfy our first selection level.

The final list of selected faults to be reviewed in the synthesis is presented in Table 2.

Table 2: List of active faults that will be study in the seismotectonic synthesis of Southeast France. Fault written in bold are those currently finished whereas the other ones are supposed to be delivered by the end of the work.

Priority	Selected Faults	Approximate lengths
Test / High	**Trevaresse Fault**	**15 km**
High	**Middle Durance Fault**	**70 km**
High	**Vuache Fault**	**45 km**
High	**Cevennes Fault**	**180 km**
High	Ligure Thrust	100 km
High	Digne Thrust Front	100 km
High	Serenne Fault	95 km
High	Ubaye Fault	100 km
High	Nîmes Fault	120 km
High	Salon-Cavaillon Fault	90 km
Middle	Nice Arc	60 km
Middle	Belledonne Border Fault	70 km

Geographic extension of the studied area, according to selected fault traces, is presented in Figure 14. It appears quite clearly that the chosen faults are scattered over the whole Southeast ¼ France.

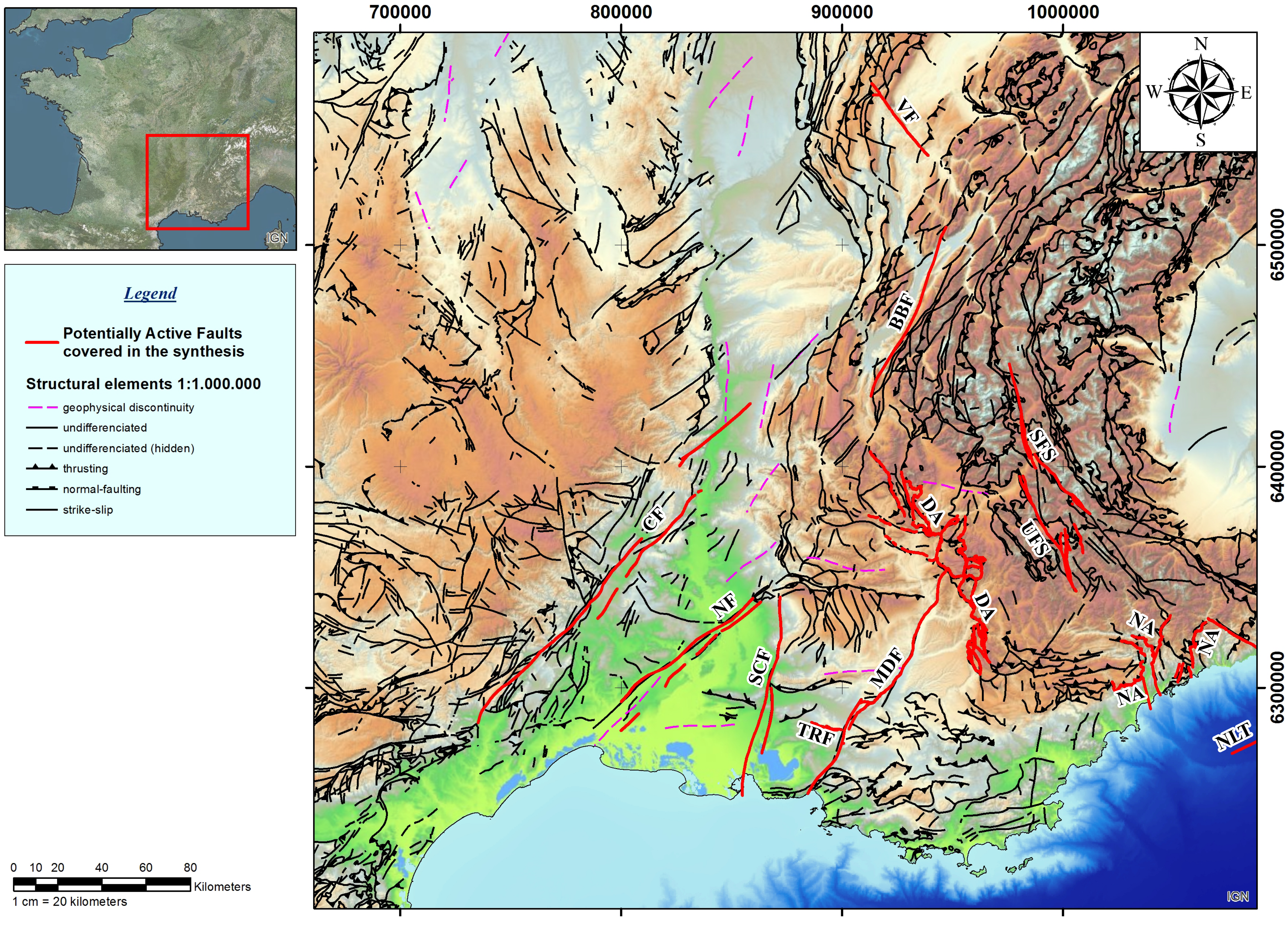

Figure 14: Representation of the potentially active faults of Southeast France covered by this synthesis. CF: Cevennes Fault, NF: Nimes Fault, SCF: Salon-Cavaillon Fault, TRF: Trevaresse Fault, MDF: Middle Durance Fault, DA: Digne Arc, NA: Nice Arc, NLT: North Ligurian Thrust, UFS: Ubaye Fault System, SFS: Serenne Fault System, BBF: Belledonne Border Fault, VF: Vuache Fault.

As seen in Table 2, The Trevaresse Fault has been chosen as a **testing geological structure** for the selection of attribute fields that are used in the synthesis (synthetic tables especially) and database structure (cf. section 3.2). The reason for this choice lies on the fact that it has one of the most complete set of available seismotectonic data for Southeast France (neotectonics, paleoseismic, instrumental and macroseismic data) (e.g. Lacassin et al. 2001; Baroux et al. 2003; Chardon and Bellier 2003; Chardon et al. 2005). Through this example we have addressed and achieved important points of the study which were i) the identification of the key parameters to be compiled in our synthesis and ii) the classification of these parameters in groups of data fields. Main fields are expressed hereafter.

⇨ Fault trace

A crucial part of this study is to define and represent the **fault traces**, because it could have been drawn differently depending on the scientific teams or purposes, and one can easily be confused between several options.

Therefore, all fault trace options proposed in the literature are taken into account and presented. The ultimate GIS workspace would then be coherent with these considerations and would represent each fault trace with its related bibliographic source, so that the database user would have an overview of the different possible traces.

It appears that the 1:50.000 scale allows a good recognition of faults and segments, and most of them have been mapped by the BRGM at that scale. So, without a more precise cartographic scale available, it will be taken as the **reference scale** for representing faults traces in the GIS workspace. On the contrary, if several studies and geological maps do confirm the presence of a fault, even though the fault traces are inconsistent between each other, all of them are integrated in the GIS. If the 1:50.000 scale or other more detailed works are not available or do not provide a good surface trace from our point of view, the 1:250.000 scale would then be chosen, and perhaps the 1:1.000.000 ones if the later is not satisfying/available.

For a given fault, proposed segmentations are reported in the Word sheet document and drawn in the GIS maps. In the table sheet we retain a preferred solution for the segmentation, based on type and completeness of data used by the authors to define their segmentation, together with the publication date. Every single segment is a database entry, unless there are not enough supporting arguments in the literature to characterize a segment (at least geographically) and to differentiate it from the other segments.

⇨ Age au fault activity

The **maximum age of fault activity** is fixed to the beginning of the Burdigalian (20 Ma) because it is well accepted that extensional regime that occurred during the Oligocene still lasts several million years during the early Miocene, and more specifically during the Aquitanian (Terrier 1991). The compressional state starting around 20 Ma is much more representative of nowadays tectonics although slight changes occurred in the orientation of the stress axis (e.g. Combes 1984; Baroux 2000; Shabanian and Bellier 2012). Thus, we define this time range as typical of long-term neotectonics in Southeast France.

However, one must have in mind that other contributions to the seismotectonic analysis of Southeast France have considered different time range for neotectonic activity (e.g. Champion et al. 2002; Terrier 2006; David et al. 2012)

The SSG-9 report of IAEA suggests: "for studies to assess fault capability, the tectonic information […] through the Pliocene-Quaternary (i.e. the present) may be adequate for intraplate regions."

To extend the reasoning, it is well accepted that in "low active regions located hundreds of kilometres from the nearest plate boundary, seismic cycles are generally thousands to tens of thousands of years long", which is one scale magnitude higher than for very active regions that are closer to plate boundary (Haller et al. 2011). Therefore, the appropriate time frame that should be adopted for our case must necessarily be higher than those of very active regions, which usually consider the Holocene-Late Quaternary. So, the choice of the Burdigalian (20 Ma) for the maximum age of fault activity is in accordance with the very long seismic cycles that are predicted for the Southeast of France.

⇨ Fault labels

The **fault labels** are standardized in order to keep an homogeneous system. The BRGM nomenclature (at 1:1.000.000 scale) is used. For faults that have not been named so far in BRGM maps, a new Fault ID is attributed following this rule: SIGMA_####, with # being an incremented number in the order of the treated faults.

⇨ Bibliographic sources

It is of great necessity to group together all the **bibliographic sources** that are directly or indirectly related to the seismic sources of Southeast France. Indeed, over 380 references have been shared and gathered; they all deal with at least one of the selected seismotectonic parameters for at least one of the potential active faults this study deals with. These references have been classified according to the main research subject they focus on. We cannot guarantee that this compilation of published scientific material is exhaustive. One can assume that despite our efforts to gather all relevant seismotectonic informations on selected faults we might have missed some publications/informations. See **Appendix 1** (p. 44) for the list of bibliographic sources used in this study.

⇨ Fault characterization

Once the identification of active faults is done and the literature collected, the tasks consist in extracting and collecting the data from the articles, thesis or reports and to fill the data fields of the main groups defined in the database structure (cf. section 3.2). The step of **fault characterization** is further developed in a dedicated section (cf. section 4) and is divided into two main tasks:

- The infill of an Excel table for each fault that details specific fields of each group that has been defined according to the analysis of available worldwide active faults databases;
- The infill of an individual synthetic and written sheet with a reduced amount of categories for more clarity.

These two tasks must be performed simultaneously in order to not go for- and backward several times and to attenuate the number of possible mistakes inherent in such a compilation work.

3.2. Database structure

The first part of the study consists in the constitution of a database structure in order to organize, classify the data and to prepare the migration of data, arranged in Excel tables and synthetic sheets, to a geodatabase. To achieve this project, we needed to design a logical data structure that corresponds to the type of information we want to synthetize. This was performed using the DBDesigner® software and the result is a database map presented in Figure 15. In this sketch, the data tables are partitioned into several major units, decribed hereafter.

The upper left-handed five data tables refer to the basic objects and related informations:

- The faults and segments identification,
- The different properties that allow to characterize an active structure,
- The available bibliographic sources where the parameters are exctracted from,
- The value, uncertainties and comments fields that consist in quantitative, textual or geographical attributes,
- A reviewing table that is intended to validate the creation of a new entry and the infill of information.

The blue, pink, green and yellow boxes represent respectively the focal mechanisms, the GPS catalogue (these two tables were not specifically considered in this synthesis project but have been represented in case of one want to compile such data in the future), the instrumental and historical seismicity catalogues, and the neotectonic and paleoseismology catalogues. They are linked to a table that lists all of them, in order to attribute them a catalogue ID, which may be associated to a specific bibliographic source (bridging link between the bibliographic source and the list of catalogues).

The left-handed purple box represents the geodatabase that should contain all the geographical information of the objects and catalogues. So far, the link between the geodatabase and the catalogues is rather straightforward and appears on this database structure. On the contrary, the geological objects, their seismotectonic properties and related sources are of different types (numerical values, textual fields, or geographical coordinates) and only part of the data can be directed to the geodatabase. The way the geographical information can be extracted from the overall value fields is thus a part of the task that remains to be achieved. That is the reason why the links are not represented yet on this database map.

Eventually, the geometrical parameters and geographical features that aimed at being represented on the GIS could constitute independent tables that would be automatically integrated into the geodatabase. The links between catalogues and geodatabase, as well as those between geographical fault properties and geodatabase would then become unnecessary. However, this task is still under development. As a suggestion for the future implementation of the database, it might be interesting to test the database structure by generating the real tables in the database manager, filling several examples with data already classified in the Excel tables and synthetic sheet. It could be created on the PostGRES Database Management System, which has the advantage to be open-source and to link data with their geographical features that are managed by the PostGIS extension. Then, some improvements could be done to the current database structure in response to these tests.

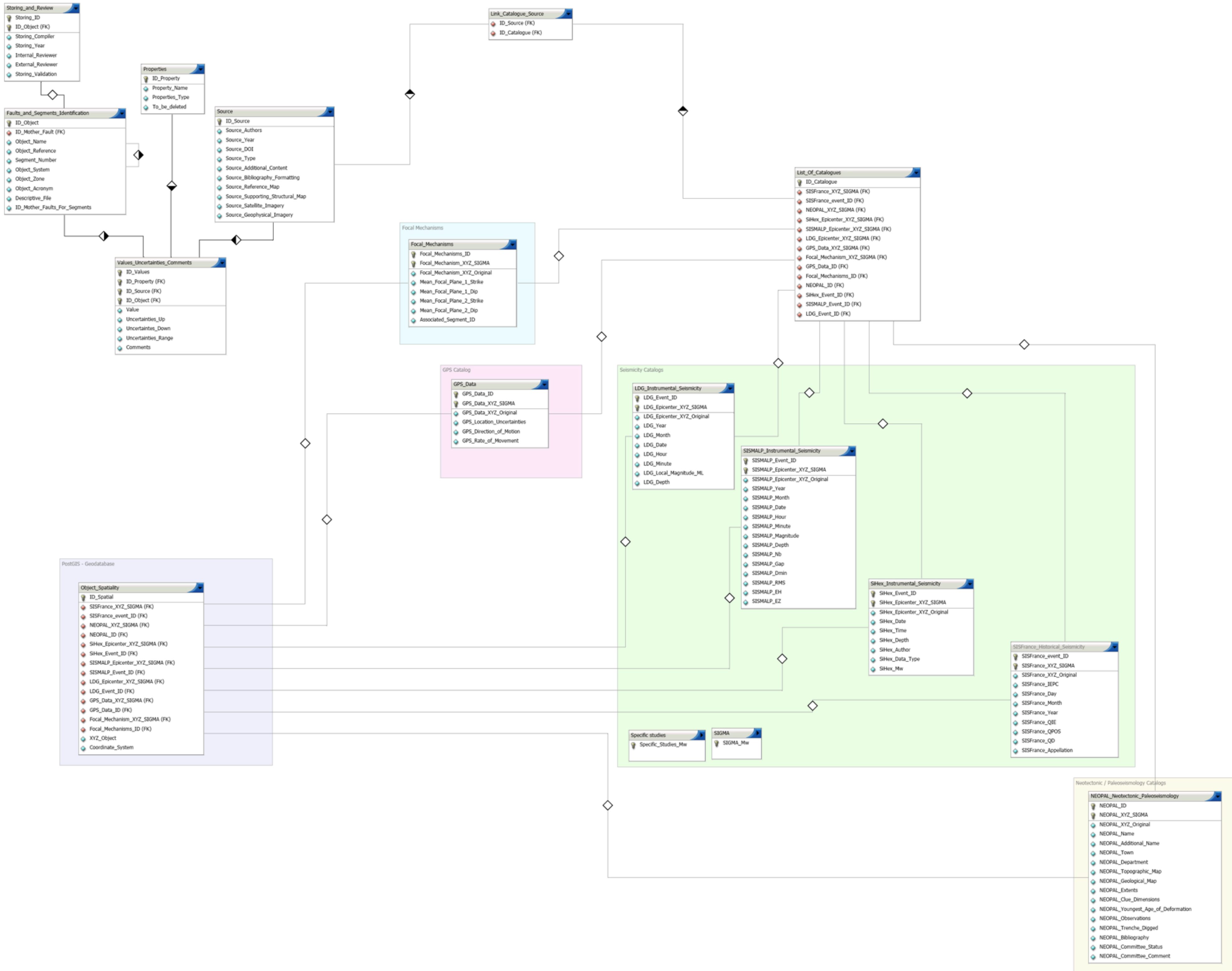

Figure 15: SIGMA Database structure representing the main categories of data. The general database architecture comprises clockwisely an object field associated with its properties, sources, values and reviewing fields, a list of catalogues of different timescales, and a geodatabase.

4. Descriptive synthesis of individual faults

4.1. The synthetic Excel table

The Excel table presents an organised compilation of published information on seismoetctonic parameters for selected faults in Southeast France Interpretation is reduced to the minimum (segmentation, preferred representation scale, reference publications). In this perspective, a clear panoramic view of the overall dataset is crucial for a good inter-comparison between each bibliographic source. Consequently, it has been chosen to use an Excel table for every active structure, so that all the data are easily available for consultation and the compilation is facilitated.

The synthetic Excel table is organized as following (see the joint faults synthesis):

- Thumb indexes are used for describing/presenting/describing a fault or a fault segment;
- In each of these thumb indexes, the structure is exactly the same and consists in data groups, specific data fields, individualized values for each bibliographic reference, uncertainties (upper/lower limit), type of source and comments;
- The groups are partitioned into the fault or segment characteristics, the additional information (references) and the compilation (compiler information and reviewing);
- The data fields are: the fault or segment identification, the fault or segment geometry, the kinematics, the degree of activity (which means neotectonic, active tectonics or Holocene activity), the seismic hazard parameters, the reference information, and the storing and reviewing information;
- The values are organized by authors, so every parameter can be filled with a textual, numerical, alphanumeric or geographic value, depending on the bibliographic source in which it has been found.
- The uncertainties columns are filled in case there are several values proposed in the literature. It stands for lower and upper limits of these data. The dedicated columns are rather designed for a combination of uncertainties associated with a unique field.
- The comment column tends to explain the way the data have been acquired, the reasoning that led the authors to propose a particular value, the calculation method, the type of uncertainties and what it exactly considers, and all other information judged important by the working group.

The "compilation" part of the table must retain the attention, in the lower part of the Excel table. Indeed, this sub-table stores the informations related to the people in charge of the compilation and review, as well as of the approval of the data table for the migration into the future database. In our approach, the synthetic Excel table is reviewed by internal reviewers (working group = co-authors of the deliverable). Then external reviewer should review the compilation and synthesis. Once this last step is completed, the implementation of gathered seismotectonic parameters in the database is authorized.

This table will then constitute a basic element for implementing a seismotectonic database. In the optimal case, the data would be migrated from the Excel table to the database, following the same column organization.

For more details, a general table with the explanations of expected data is presented below (Table 3):

Table 3: Explanations of the expected information that must be filled for an active fault and its segments in the Excel table.

Data groups	Data tables	Fields and units (Fields in bold are keys to link different tables)	Fields explanations
Fault/Segments Characteristics	**Fault/Segment Identification**	**Fault_ID**	Numerical ID with respect to BRGM 1:1.000.000 one if possible, or with a new ID following the SIGMA naming system, if not referenced yet. (Alphanumerical field: SIGMA_####)
		Fault_Name	Fault name used in the literature. (Textual field)
		Fault_Acronyme	Acronyms found in the literature. (Textual field: XXX)
		Fault_System	Fault system that includes the fault, if several. (Textual field)
		Fault_Zone	Fault zone involved in the fault system, when it exists. (Textual field)
		Segment_ID	Numerical ID, following the SIGMA naming system. (Alphanumeric field: XXX_###)
		Segment_Number	If a fault is composed of several segments, each of them is given a number, following a three digit convention. (Numerical field: ###)
		Segment_Acronyme	Acronyms found in the literature. (Textual field: XXX)
		Segment_Name	Full segment names found in the literature. Without such, another name is attributed corresponding to a close locality. (Textual field)
	Fault/Segment Geometry	Cartography	Information about the fault mapping at the surface, if it is certain or hypothetic. (Textual field)
		Average_Strike (°)	Average strike of a segment or fault, as mentioned in the literature. When it varies too much, the large-scale strike will be privileged. The convention follows "Aki & Richards, 1980". (Alphanumerical field: N###°)
		Dip (°)	Mean representative dip of the fault or segment. If there is not a single mentionned value in the bibliographic source, the average of all data will be taken. The convention follows "Aki & Richards, 1980". (Numerical field: ##°)
		Rake (°)	The chosen convention is the rake (-180° and 180° for right-lateral strike slip, 0° for left-lateral, -90° for normal slip, 90° for reverse slip). The pitch (0°-90°) will then be transformed to rake. The convention follows "Aki & Richards, 1980". (Numerical field: ###)
		Length (km)	The fault or segment length given by bibliographic sources only. (Numerical field: ###)
		Min_Depth (km)	Minimal depth of the active fault. If this data is not available in the literature, the field can be left blank. (Numerical field: ## or Textual field if the fault is crustal)
		Max_Depth (km)	In the case of a maximum depth given in the literature. The root of the fault can be considered the maximum depth. If only one value found for depth in the literature, inform this field and not the minimum depth. (Numerical field: ## or Textual field if the fault is crustal)
		Width (km)	The width is the distance along the dipslip fault plane and not the projected width of the fault at the surface. (Numerical field: ##)
		Area (km²)	The area field is filled only when it is given in the literature. In the other cases, it is left blank because it can be calculated from length and width parameters. (Numerical field: ####)
	Kinematics	Kinematic_Last_Age	Last tectonic regime. (Alphanumeric field: compression/extension/strike-slip)
		Orientation_Main_Stress_Axis	Azimuth of the last main horizontal stress axis, as well as type of tectonic regime. (Alphanumerical field: N###°)
		Sense_of_Movement	Last sense of movement on the fault or segment. (Textual field with one letter : R=reverse, N=normal, S=sinistral, D=dextral)
		Vertical_Component_Attested_Geology	Vertical component of the movement, when it has clearly been measured on the field or has been deduced from field arguments. (Textual field with a combination of R, N, S, D)
		Horizontal_Component_Attested_Geology	Horizontal component of the movement, when it has clearly been measured on the field or has been deduced from field arguments. (Textual field with a combination of R, N, S, D)
		Vertical_Component_Interpreted	Vertical component of the movement, when it has been interpreted from other kind of data, such as seismological inversions. (Textual field with a combination of R, N, S, D)
		Horizontal_Component_Interpreted	Horizontal component of the movement, when it has been interpreted from other kind of data, such as seismological inversions. (Textual field with a combination of R, N, S, D)
		Older_Kinematics_1	Older sense of movement with the associated geological period, if possible. (Textual field with a combination of R, N, S, D) - youngest
		Older_Kinematics_2	Older sense of movement with the associated geological period, if possible. (Textual field with a combination of R, N, S, D)
		Older_Kinematics_3	Older sense of movement with the associated geological period, if possible. (Textual field with a combination of R, N, S, D)
		Older_Kinematics_4	Older sense of movement with the associated geological period, if possible. (Textual field with a combination of R, N, S, D) - oldest
	Degree of activity - Neotectonic, Active Tectonics, Holocene Activity	Presence_Morphological_Expression (Y/N)	If a morphological expression has been mentionned in a bibliographic source. (Binary field: Y/N)
		Mophological_Expression	This field describes the morphological expression proposed in the literature. (Textual field)
		Shifted_Markers	Kind of markers that have been shifted by an active fault, it can be geological (layer) or geomorphic features (river network or scarps for example). (Textual field)
		Age_Youngest_Tectonic_Event (My)	Age of the last tectonic movement. (Textual field with)
		Age_Oldest_Non-Affected_Deposits (yr)	Age of the oldest non-affected deposits shifted by an active fault. (Textual field with)
		Age_Youngest_Affected_Deposits (yr)	Age of the youngest affected deposits shifted by an active fault. (Textual field with)
		Dating_Methods	Dating method employed for the determination of affected or non-affected deposits. (Textual field)
		Min_Offset (m)	Minimum offset that is mentionned in the literature. (Numerical field: #####)
		Max_Offset (m)	Maximum offset that is mentionned in the literature. (Numerical field: #####)
		Time_Offset (yr)	Equivalent time for the offset data. (Numerical field: #########.##)
		Cumulated_Offset_Late_Cretaceous (m)	Cumulated offset recorded since the late cretaceous, if any. (Numerical field: ####.##)
		Vertical_Slip_Rate (mm/yr)	Vertical component of the slip rate that have been measured or calculated, as long as it appears in publications or any other bibliographic source. (Numerical field: ##.##)
		Horizontal_Slip_Rate (mm/yr)	Horizontall component of the slip rate that have been measured or calculated, as long as it appears in publications or any other bibliographic source. (Numerical field: ##.##)
		True_Slip_Rate (mm/yr)	True or net slip rate that have been measured or calculated, as long as it appears in publications or any other bibliographic source. (Numerical field: ##.##)
		Age_Strati_Slip_Rates_Calculation (yr)	Age of shifted rocks that have been taken into account for slip rate calculations. (Numerical field: #######.##)
		Amount_Shortening (km)	Amount of shortening published in the literature. (Numerical field: ###.#)
		Time_Shortening (My)	Corresponding time for the amount of shortening. (Numerical field: ##.##)
		Shortening_Rates (km/My)	Shortening rates either found in the literature or calculated from the two previous fields if both are filled. (Numerical field: ##.##)
	s	M0_Seismic_Moment (N.m)	Seismic moment published in seismological references. (Alphanumeric field: #.#*10^#)
		Magnitude_Geology	Any kind of magnitude from papers that consider geological or dimensional arguments, such as coseismic offsets or fault length, later used in scaling relationship like Wells and Coppersmith (1994), for example, to calculate the magnitude. (Numerical field: #.#)
		Magnitude_Macroseismicity	Any kind of magnitude from papers that consider the macroseismic intensity field in a computation. (Numerical field: #.#)
		Magnitude_Instrumental_Seismicity	Any kind of magnitude from papers that clearly associate instrumental seismic events to the fault. (Numerical field: #.#)
		Magnitude_Max	Maximum magnitude at all time-scales for events clearly associated to the fault. (Numerical field: #.#)

4.2. The synthetic Word sheet

In addition to the data compilation under Excel, a Word sheet document is produced for each fault, synthetizing the compilation for a clearer overview of the data (see the joint faults synthesis). It is organized in thematic parts, in which the most important parameters are presented as individual tables. Each of these tables allows listing the data proposed by different authors or the major events that can be noticed in the vicinity of the active fault. This synthetic Word sheet has been developed on the basis of the Neopal index cards by faults.

Five categories have been identified to provide a complete document: fault identification and cartography, fault geometry, tectonic characteristics, seismicity, figures and comments.

The first topic (**fault identification and cartography**) presents the fault name and ID, the maps on which the fault trace can be found, the list of relevant references, the compiler and reviewers (as well as the date of validation), faults scales representations, and the proposed segmentations when available. In the second topic (**fault geometry**) are displayed the strike, dip, length, depth and width of the fault, as well as the minimum and maximum lengths of its segments, all supported by their references. The third topic (**tectonic characteristics**) groups all the structural, seismotectonic and neotectonic aspects of the fault, like the age of the structural set-up, the last tectonic regime (with the stress-axis orientation), the last fault kinematics, the age of the last movement, the recorded offset (geological or geomorphic), the age of faulted/deformed surficial deposits, the age of geomorphic markers, the dating methods, the recurrence interval, the displacement rates by time periods, and the NEOPAL indexes in the vicinity of the fault; all those data are also supported by references in order to track the data origin. The fourth topic (**seismicity**) put together the paleoseismology, historical and instrumental seismicity and gives the opportunity to inventory the noticeable events that occurred in the vicinity of the fault (from SisFrance, Si-Hex and LDG). The last topic (**figures and comments**) is dedicated to additional figures and reasoning, such as a set of seismotectonic map displaying all available catalogues, key cross-sections through the faults systems, key figures from the bibliography, explanations on the geomorphic expression and the geodynamic context.

5. Harmonization of GIS data

Data collection, synthesis and organisation is accompanied by a GIS with a full set of seismotectonic, geological and geographical data in order to provide a complete framework of Southeast France. The workspace is only available for ArcGIS 10.0 and later versions. The reference coordinate system adopted for the project is in agreement with the French national geomatic standard, that is Lambert 93 or RGF 93.

The faults processed in this SIGMA project are displayed on this georeferenced workspace and the existing fault characteristics synthesized or compiled by French institutions such as BRGM are already integrated, together with segmentation proposed in bibliographic sources for few well-studied structures. Indeed, some of the most accepted fault traces were digitized from papers in order to be available as layers of the GIS. In that way, it can be compared to the BRGM fault traces.

In addition, the different existing catalogues and databases for seismicity or neotectonic indexes in Southeast France, at different time-scales, are available. It is composed of the NEOPAL database, SisFrance macroseismicity catalogue, Si-Hex and LDG instrumental seismicity catalogues (cf. section 2).

One of the interesting features of this GIS workspace is the automatic link between visualisation of faults and catalogues on one hand, and the respective fault or event synthetic sheets provided by the institutions (that concerns especially the Identification of Active Faults in the PACA region –BRGM-, the NEOPAL and SisFrance catalogues). The hyperlinks that are stored in the tables of specific layers can be clicked with the button, which allow the user to be directly sent to the web page of a BRGM fault, a NEOPAL index or a SisFrance event.

In term of geological mapping, we present all the available cartographic scales provided by the BRGM (1:1.000.000, 1:250.000 and 1:50.000), either in vector or in raster formats, depending on the scales.

Several layers supplied in research access by the BRGM, IGN or ESRI platform are accessible through respective WMS server: geological maps at all scales, topographic raster at 1:25.000 scale, relief, orthophotos, etc. This gives the opportunity to consult cartographic elements without actually hosting it on the computer, with a fast data display.

Eventually, the ArcGIS workspace is provided as a package in .mpk format. Therefore, all the files used in the workspace are contained in the numerical folder "*SIGMA Seismotectonic and Geodynamic Synthesis of SE France – ArcGIS package*" and the user can access all the layers, with every thematic analysis performed on the datasets. The vector and raster data are displayed on the table of content and have been sorted according to a hierarchic tree. First are distinguished the vector layers, then the raster layers, and different WMS servers at the end. The raster files integrate the georeferenced figures, the 1:1.000.000 and 1:250.000 geological maps (the 1:50.000 are too numerous and heavy in size to be integrated), a topographic coverage of PACA and the different Digital Elevation Models used as base maps. Concerning the vector files, they are classified according to each fault (layer group with the name of the fault: _XXXXFault_) or just placed under the VECTORS layer group if it concerns the whole study area, as for example the seismicity catalogues. To sum up, the different layers that were grouped in this last category are listed hereafter:

- Coastline_SE_France
- NEOPAL Neotectonic database
- SisFrance
- Si-Hex (2013)
- CEA-LDG
- Cities (RGC_Communes)
- Potentially Active Fault – BRGM (Terrier, 2006)
- GEOL1M (1:1.000.000 geological map – BRGM)
- Hydrographic network_PACA
- EMMA_Focal_Mechanisms (not exhaustive, needed to be completed)

Conclusion

This final report presents the seismotectonic synthesis of Southeast France encompassed in the framework of the SIGMA WP1 Project. This seismotectonic synthesis deals with the compilation, analysis and organisation of published scientific material about seismotectonic parameters in Southeast France. The final goal of this work is to provide to SHA operators a global overview of available information about faults characteristics. The seismotectonic parameters are stored in Excel and Word tables. The first ones compile all the seismotectonic parameters extracted from the bibliography, according to the references, together with associated uncertainties and comments judged important by the synthesis working group. The second ones summarise identified key parameters to provide a clearer overview on the faults characteristics important for seismic hazard assessment. Finally a GIS workspace is created that allows combining geographically seismological, tectonics and geological information for each fault. Global approach and selection criteria for seismotectonic parameters have been guided by an analysis of already existing active faults databases around the world.

Building of data tables has been realized in the perspective of being easily integrated in a database. We propose here, in this deliverable, a structure of what could be, in our opinion, a database for potential active faults for region as metropolitan France that undergoes low deformation rates and consequently low to moderate seismicity.

Twelve faults have been selected, following mainly criteria of length, geographic location and amount of available published material. Among this selection, four faults analysis are already finished at the moment of the redaction of this report, and are presented (joint sheets by fault): the Cevennes Fault, the Vuache Fault, the Trevaresse Fault and the Moyenne Durance Fault.

This work will end at the end of November 2014. For the 8 remaining faults, the data are planned to be included into the standard documents from now until the end of the project, in November 2014. In the near future, a poster of this study will be presented at the RST meeting in October 2014, in Pau (France).

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