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Seismicity in France / *Sismicité en France*

Special issue *Comptes-Rendus Geosciences* for the 100 years of the BCSF "Seismicity in France"

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The BCSF (Bureau Central Sismologique Français —https://www.franceseisme.fr) celebrates its 100 years in 2021. The BCSF has been in charge of centralizing all the information on French seismicity for a century. To celebrate this anniversary, and in partnership with the Action Transverse Sismicité Résif (https://www.resif.fr/actions/action-transverse-sismicite/), we wanted to produce a special issue of Comptes Rendus Géosciences on French seismicity.

The issue of French seismicity has come back to the forefront in recent years. The deadly earthquakes in Italy (2009, Mw 6.1 L'Aquila; 2016 Mw 6.0 Amatrice and Mw 6.5 Norcia) and the recent seismicity crises in Mayotte, Le Teil and Strasbourg have reminded us that seismicity is a non-negligible natural hazard for our country. Moreover, new technical and theoretical advances have recently challenged the classical understanding of the link between seismicity and crustal deformation in France [Masson et al., 2019, Henrion et al., 2020] and elsewhere [Craig and Calais, 2014]. The question of the origin of this seismicity is the subject of various hypotheses and models widely discussed by the scientific community [Calais et al., 2016, Leclère and Calais, 2019, Mazzotti et al., 2020]. This questioning is based on new measurements made possible by the large-scale equipment launched by Résif in the last ten years. All these elements justify a review of our knowledge of French seismicity, as well as the way this knowledge has been built.

In order to understand the origin of the French seismicity, a strong knowledge of its spatial and temporal characteristics is fundamental. This is classically provided by instrumental seismicity catalogs, which have been significantly strengthened in the last decade owing to the Résif seismological networks (the Permanent Accelerometric Network, RAP, and the Permanent Broadband Network, RLBP). However, this dataset is far from sufficient, because it only covers at best the last 50 years, whereas the instrumental coverage was weak during the early 20th century and non-existent before the 20th century, precluding a detailed image of the seismicity. Thus, knowledge of past seismicity strongly relies on historical, archaeological, paleoseismological, and seismotectonic studies.

The special issue that we propose is composed of four parts that form a complete panorama of what is

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known today about French seismicity, covering both the spatial diversity of metropolitan and overseas France and the different time scales.

As an introduction, Roger [2021] presents the major role of E. and J.-P. Rothé in the rise of the BCSF from 1921 to the 1960s, followed by the more difficult period of the 1970s and 1980s when its hegemony was challenged. As a complement, Sira et al. [2021] show the evolution of macroseismic observation methods since 1921. These two articles form a rich and contrasted panorama of a century of BCSF history; history that fortunately continues today.

In a second part, a series of regional syntheses are presented that review the seismicity and its original seismotectonic context in France. Metropolitan France has been divided into four quadrants. The Southeast [Larroque et al., 2021] covers the Jura, the Bresse, the Rhone valley, the Southeast Basin, the Alps, the Ligurian Sea, and Corsica. The Southwest [Sylvander et al., 2021] covers the Pyrenees and a very large southwestern part of the Massif Central. The Aquitaine Basin has almost no seismicity. The Northwest [Beucler et al., 2021] covers all the territories north of the Aquitaine Basin to the English Channel, including the seismicity zones of the Atlantic coast from Oléron to Brittany and the northwest of the Massif Central. Finally, the Northeast [Doubre et al., 2021] covers eastern France (Rhine Graben, Vosges), as well as the Ardennes and Hainaut, up to the North Sea. These four articles, written by experts of these regions, compile all the available information on seismicity, on a large time scale, by placing it in its tectonic context. They are major synthesis works that will serve as reference for students and researchers working in the future on these regions. Generally speaking, they show that these regions, and thus metropolitan France, present a diversity of seismic behaviors that can be explained by the complexity of the different geological domains, with variable rheological characteristics and structural heritage at the scale of the crust, as well as by the joint action of different deformation mechanisms. In addition to these four syntheses, three articles are proposed on the Antilles [Massin et al., 2021], Reunion [Duputel et al., 2021], and Mayotte [Bertil et al., 2021]. Massin et al. [2021] propose a new catalog of 46703 earthquakes that synthesizes all existing catalogs by objectively selecting the preferred location. Their work shows the difficulty of proposing a catalog of seismicity usable for characterizing the seismic hazard in the Antilles and the attention that must be paid in the analysis of the data. Duputel et al. [2021] present the diversity of seismicity in Reunion (tectonic events, volcano-tectonic earthquakes, volcanic tremors, long-period and very-long-period earthquakes) and the link with volcanic systems. Finally, Bertil et al. [2021] review the recent seismic crisis in Mayotte and its implication for the understanding of the seismotectonics of the Comoros archipelago.

The third part of the special issue presents methodological articles: How are data acquired, processed, and interpreted on different time scales? Jomard et al. [2021] present the SIFRANCE historical seismicity database, which contains exhaustive information and analyses on historical seismicity in metropolitan France. The article explains how these data are acquired, what is archived, what are the potential levers to enrich the database. It describes how this database can be used, and as or maybe more importantly, all the limitations that must be respected in the use of these data in order to avoid over-interpretation. This article can be associated with that of Stocchi et al. [2021], who, using the example of the Tour du Pin earthquake of 1889, present how data obtained by a combination of in situ observations and fragility characteristics of historical buildings can be used to improve the magnitude estimation for historical earthquakes. Poursoulis et al. [2021] explain what archeoseismicity is, a discipline that is finally quite recent, and how the back and forth between archeoseismologists and engineers permits, on the one hand, to characterize past earthquakes experienced by buildings and, on the other hand, to consider the preservation of these buildings in case of new earthquakes. Longer time scales are the domain of paleoseismology. Bellier et al. [2021] detail the work done on active French faults over the last 30 years. In addition to these four articles, we propose in this section three other articles, also on methodological topics. The first one by Ritz et al. [2021] discusses how potentially active faults must be studied today in order to address the complex questions of its past—and potentially future—earthquake activity, in light of the modern tools that can be used, from laboratory imaging to preliminary field measurements before potentially trenching. The second

is a synthesis by Beauval and Bard [2021] on how seismic hazard assessment studies have been carried out in France. The goal of this paper is to provide readers with an overview of the successive seismic zoning in mainland France together with the associated background, as well as an overview of the probabilistic seismic hazard studies performed in the last 30 years. The third by Rivera et al. [2021] presents the collection of historical seismograms of the University of Strasbourg, historically associated with the seismological station installed by the Germans at the end of the 19th century in the gardens of the university. The collection covers the period 1903–1981.

In its fourth and final part, the special issue focuses on recent seismic events in metropolitan France. Three articles focus on the Le Teil earthquake. The first [Cornou et al., 2021] presents a synthesis of the first information obtained on this earthquake by the French scientific community, which was extremely mobilized, both by the deployment of instruments in the field and by numerous research works on the data. The second [Delouis et al., 2021] focuses on the characterization of the source of the earthquake through a multi-approach study. Finally, the last one [Schlupp et al., 2021] comes back in detail on the establishment of the macroseismic map of this event, the most important in terms of intensity (maximum intensity VIII) since Arette in 1967 for metropolitan France. For comparison, such intensities had been reached in Guadeloupe during the earthquake of Saintes in 2004 [BCSF, 2005]. The following two articles are interested in notable seismic swarms. Guéguen et al. [2021] present the seismic swarm triggered in 2017–2019 in the Maurienne Valley (French Alps), with more than 5000 events detected by the regional SISmalp network. In addition, the article also presents how the public management of the crisis was conducted with the authorities. Baques et al. [2021] review in detail all the seismicity of the Ubaye region, which is marked by seismic swarms as well as by more notable earthquakes. In their article, great effort is made on the analysis of the historical seismicity in relation with present-day observations. Schmittbuhl et al. [2021] present the induced and triggered seismicity below the city of Strasbourg from November 2019 to January 2021, in connection with the presence of a deep geothermal site in Vendenheim. Finally, the last article reviews the historical seismicity of the Tricastin region in the Rhone valley [Bollinger et al., 2021], a seismicity for which the original mechanism is not yet clear.

This special issue, to which the best specialists in French seismicity in metropolitan and overseas France have contributed, aims to be a reference for the use of the entire geosciences community interested in French seismicity issues, and not only the seismology community! We hope that reading it will allow everyone to appreciate the importance of the work done in recent years on this subject, and to better understand the difficulty of proposing a simple image of seismicity, especially in mainland France. This collection of articles should convince that there is no single, simple cause of metropolitan seismicity, that its understanding is a difficult task, and that research on this subject needs to be widely supported.

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