SEISMICITY MAPS OF FRANCE

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ABSTRACT

Using a catalogue collecting numerous historical data, the oldest of which date back to the year 1021, a set of seismic maps has been drawn: a map of maximum felt intensity (1021-1964); an epicentre map (1861-1960); a map of probable maximum intensity; and a seismic zoning map. Districts are listed in which an official code and regulations for earthquake-resistant design and building construction should be enforced. A seismotectonic map shows the main seismic areas of France: North-Pyrenean Front; Briançon Seismic Arc, Pyreneo-Provençal Fold; and Rhine Graben.

Introduction

The collection of information about the seismicity of France is the responsibility of the Bureau Central Séismologique Français, which is attached to the Institute de Physique du Globe, Strasbourg. Since 1919, the study of earthquakes felt in France has been systematically carried out by means of questionnaires and instrumental recording(1),(2),(3). Before this, many notes appeared in the Comptes-Rendus of the Academy of Sciences and other scientific periodicals, and in catalogues kept at the Bureau.

From these archives, an index of shocks felt in French territory has been compiled under two headings: chronological, and geographical. This index provides the basis of the new French Anti-Seismic Protection Code (Regulations PS-64).

Epicentre Map (Figure 1)

A period of 100 years (1861-1960), for which sufficient data are available has been chosen, and a total of 1650 events has been used. If the final objective of seismotectonic interpretation was to be reached, the epicentres had to be known as accurately as possible, since the geological features to which they were to be related were often very small. The map therefore distinguishes between data (usually old) that do not allow a definite epicentre to be found, and those data that allow the epicentre to be located to within 1/10 degree of latitude and longitude. A suitable symbol shows the maximum intensity at the epicentre for

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each earthquake. Outside French territory, only those shocks which were felt in France have been shown.

Several regions of relatively high seismicity can be recognised in Fig. 1:

a - North Pyrenean Front. The foci are usually found in the immediate vicinity of the zone of contact between the primary axial zone of the Pyrenees and the secondary folded Jurassic and Cretaceous formations of the Pyrenean foreland, or a little to the north of it.

b - South-East France. The epicentres fall into two groups. One marks out the Briançon Arc, a zone of roots of the alpine folds; and the other involves the sub-alpine massifs that bound the course of the Rhône. Between these groups an aseismic region corresponding geologically with the Outer Crystalline Massifs and the Vocontian Trench can be clearly distinguished.

c - The Hercynian Basement (in Brittany, the Vendée, the Poitou Gap, the Massif Central, and in the South West Vosges) is the seat of fairly numerous shocks, probably related to the large fractures that divide it.

d - The Rift Valleys (Rhine graben, Limagne d'Allier and Limagne de Loire) show activity that cannot be neglected.

On the other hand, the activity of the great sedimentary basins is either very slight, like that of the Paris Basin, or negligible, like that of the Basin of Aquitaine.

It will be noted that the general character of French seismicity, as just defined by considering activity extending over a century, is reproduced more or less accurately in a much shorter period, for example, from 1940-1950 (2).

Map of Maximum Observed Intensities (Figure 2)

Fortunately, the seismicity of France is relatively low, and large earthquakes are infrequent. The period that has elapsed since instrumental recording began in 1919, and even the 100 year period used in drawing the epicentre map are much too short to show the earthquake danger in some parts of France accurately. We must turn to historical information going back in time as far as possible. The catalogue published by A. Perrey, Professor of Astronomy in the University of Dijon, in 1845 is very valuable for this purpose (4). By using his catalogue and the archives of the Bureau Central Séismologique Français, a map has been drawn that shows the maximum intensity observed in every part of France since 1021.

Really destructive earthquakes are rare, but their importance should not be minimised. The great earthquake of 1356, which destroyed Basle, caused damage in Haute-Alsace. In 1564 and in 1617, several villages in the valleys of the Tinée and Vésubie were destroyed, and hundreds of deaths were recorded. In 1682, many houses collapsed and casualties were reported. The large earthquake at Diano-Marina in 1887 rendered 115 houses at Menton and Nice inhabitable. In 1905 there was damage in the Chamonix valley. In 1909, several villages to the north of Aix-en-Provence

(Vernègues, Venelles, Saint-Cannat, Lambesc, Rognes) were partially or wholly destroyed, and about forty deaths were counted. Damage was reported in Normandy in 1775 and in the Vendée in 1799.

It would have been desirable to map the frequency of large shocks felt in France, and to use that map as the basis of another showing the seismic energy liberated in the different regions over some stated period.

Examination of the map of destructive earthquakes in France shows that the frequency of large shocks in any given region is in fact very low, except in the south-east (Normandy: only one shock; Vendée, two; Vosges (Remiremont), only one; and so on). On the other hand, South East France, and in particular Provence and the county of Nice had disastrous shocks in 1227, 1348, 1494, 1556, 1564, 1617, 1644, 1752, 1756, 1769, 1799, 1818, 1854, 1887, 1905, and 1909. Such a list implies that anti-seismic precautions should be taken in that region.

Repeated damaging earthquakes have occurred in several other districts:

a) North Pyrenean Front, between Lourdes and Bagnères (1660, 1750, 1850, 1854, 1904).

b) Tricastin (1773, 1873, 1934-36).

c) Chautagne (1882, 1841, 1958).

d) Briançon district and Queyras (1884, 1904, 1938, 1959).

e) Haute-Alsace (1021, 1346, 1356, 1531, 1610).

To complete the map in Fig. 2, the frequency of shocks has been shown by a figure giving the number of earthquakes of intensity 7 or more felt in each zone.

Map of Probable Maximum Intensity (Figure 3)

The engineer working on a construction project wants to know the probable maximum intensity in the region concerned. This information is provided for him in Fig. 3, which is an extrapolation from the previous maps, based on the main geological and structural data. In Fig. 3 the zones in which given maximum intensities (6, 7, 8 and above) are to be expected are shown, and suitable precautionary measures can therefore be incorporated in the structural design.

It is quite obvious that we must be very cautious when drawing maps of this kind. Surprises are still possible, and these surprises may prove tragic. Did not Montessus de Ballore, who catalogued more than 150,000 earthquakes and devoted his life to a study of world seismicity write in 1906 that Provence could be considered earthquake free? Three years later, this very region experienced the most disastrous earthquake ever known in France. On the other hand, no great destructive earthquake has been experienced in the Rhine graben since Basle was ravaged in 1356, an event which is commemorated by inscriptions in the churches. There is nothing to justify the assertion that there could not be another.

Particular attention should be drawn to the zone between Avignon and the Italian frontier, which is marked by the earthquakes of Avignon (1799), Carpentras (1738), Beaumont (1812), Lambesc (1227, 1909), Manosque (1708), Chasteuil (1855, 1951) and the numerous shocks of the Alpes Maritimes. On the other hand, Maures and Estérel, immediately to the south of this zone, must be considered aseismic.

Map of Cantons with Earthquake Regulations (Figure 4)

An anti-seismic building-code should be accompanied by a list of places in which its use is compulsory. At this point economic considerations come in. Anti-seismic construction methods are dearer than ordinary ones. We must therefore try to restrict the size of controlled areas as far as possible.

The commission which has had to discuss this question in France consists of engineers, architects, and seismologists, as well as representatives of the Ministries concerned.

Taking account of the frequency of shocks on the one hand, and of geological considerations on the other, we have asked the authorities to enforce anti-seismic regulations in certain cantons (the canton being a suitable administrative unit). These cantons are shown in Figure 4.

It will be seen that only a small part of France is subject to regulation. In the south east, the classification of the cantons into three categories (zero, weak, and moderate seismicity) is directly based upon the map of maximum probable intensity. There are other controlled cantons in the central Pyrenees, the Plombières-Remiremont district in the Vosges, and the Rhine graben. On the other hand, the old massifs (Brittany, Normandy, Vendée, Massif-Central) have been exempted from control, for large shocks are infrequent there, and the age of the principal orogenies is very great (Hercynian folding).

Seismotectonic Map

Since no detailed tectonic map of France is available, it is still difficult to draw a seismotectonic map. The map in Fig. 5 is an attempt to relate the major tectonic units to the seismicity, as defined in the maps above.**

A) Paleozoic Basement. (Armorican massif, Massif Central, Ardennes, Maures). This is broken by long fractures which have been active since the Hercynian epoch, and which became reactivated in the Tertiary, in the same direction. The most important of these fractures are shown on the map. They explain the not inappreciable seismicity of the Armorican massif and of part of the Massif Central.

** I wish to thank M. Jean Goguel for making available his unpublished work.

B) Where the Hercynian basement is buried under thin sediments, and many fractures still appear, the seismicity is appreciable. This is true of the Poitou Gap between the Armorican massif and the Massif Central, and of the Morvan-Vosges Gap between the Massif Central and the Vosges.

C) In the western Alps, the alpine chain has two active regions, the Briançon Seismic Arc and the Piedmont Seismic Arc, framing the Alpine Geosyncline. These two regions are those from which the great alpine nappes have sprung, nappes which are inclined to the west, in accordance with "gliding tectonics" (tectonique d'écoulement) (5).

D) Covering Folds. From the tectonic viewpoint, it is important to observe that the peculiarly deformable nature of this cover has made it quite independant of the basement, which in the Alps is represented by the outer crystalline massifs (appearing on the map in the outcrops of Aar (1), of Mont Blanc and the Aiguilles Rouge (2), Belledonne (3), Pelvoux (4) and Mercantour (5)). The cover has moved under gravity over a raised and inclined basement, and became folded against the outer crystalline massifs. The folds are often broken into faults along great tensional surfaces. This structure is typical of the northern sub-alpine massifs (Bauges, Chartreuse, Vercors).

E) South of Vercors the scale structure (structure en écailles) is replaced by a more flexible one that gives rise to the small basins and domes that are typical of Diois, Dévoluy, and Gapençais. In this whole region, the lower Cretaceous no longer belongs to the Urgonian calcareous facies, but to a facies of black marl, which is not brittle but flexible.

Although the whole of the sub-alpine massifs of the north are seismic, those in the southern area, the region of the Vocontian Trench are, on the contrary, completely without seismic foci.

Because of their weak seismic activity, they have been classed with the folds of the Jura.

F) The folds of the Pyrenees and of Provence form a sharply differentiated tectonic unit. The zone of seismic activity following the northern border of the Pyrenees probably continues into Provence, where important earthquake foci are known.

G) The molasse trough that fronts the Pyrenees is only weakly seismic, but those fronting the Alps, especially in Switzerland, are more active.

H) The Oligocene Grabens (Rhine Graben, Limagnes) are marked with numerous epicentres.

The map in Fig. 5 also shows the direction of the axis of the large positive magnetic anomaly in the Paris Basin, which is perhaps related to some epicentres, particularly in the Orleans and Rouen district. This anomaly is probably related to the line of drag ("schaarung") of the Hercynian folds beneath the Paris Basin.

In drawing a seismotectonic map, the final objective should be to establish the relationship between the seismic zones and the zones of

tectonic movement as precisely as possible. Research into "neotectonics" must naturally take first place. These investigations, unfortunately not far advanced, should depend upon a combination of the methods of geodesy (levelling and triangulation) and of morphology (study of river bends and stream captures, examination of Recent fault-traces, etc.). Two examples may be quoted. A French geographer, Mlle Alimen, has just shown that along the whole of the North Pyrenean Front, valley profiles, the position of terraces, and the location of breccias formed from the material of the blocks created by the tectonic disturbances show evidence of recent Quaternary movement (M.J. Gogmel, pers. comm.). A further example of the relationship that exists between tectonic accidents, fluvial morphology, and seismic activity appears in the Poitou Gap. The epicentres, and a related network of NE-SW striking faults, are indications of a continuing instability that is expressed in the drainage pattern, in particular by the tortuous course of the Charente (Fig. 6).

It would be desirable to have precise levelling profiles carried out in the major seismic regions of France, and repeated at regular intervals. The construction of a seismotectonic map is a long-term project, demanding the close cooperation of geophysicists, geologists and geographers.

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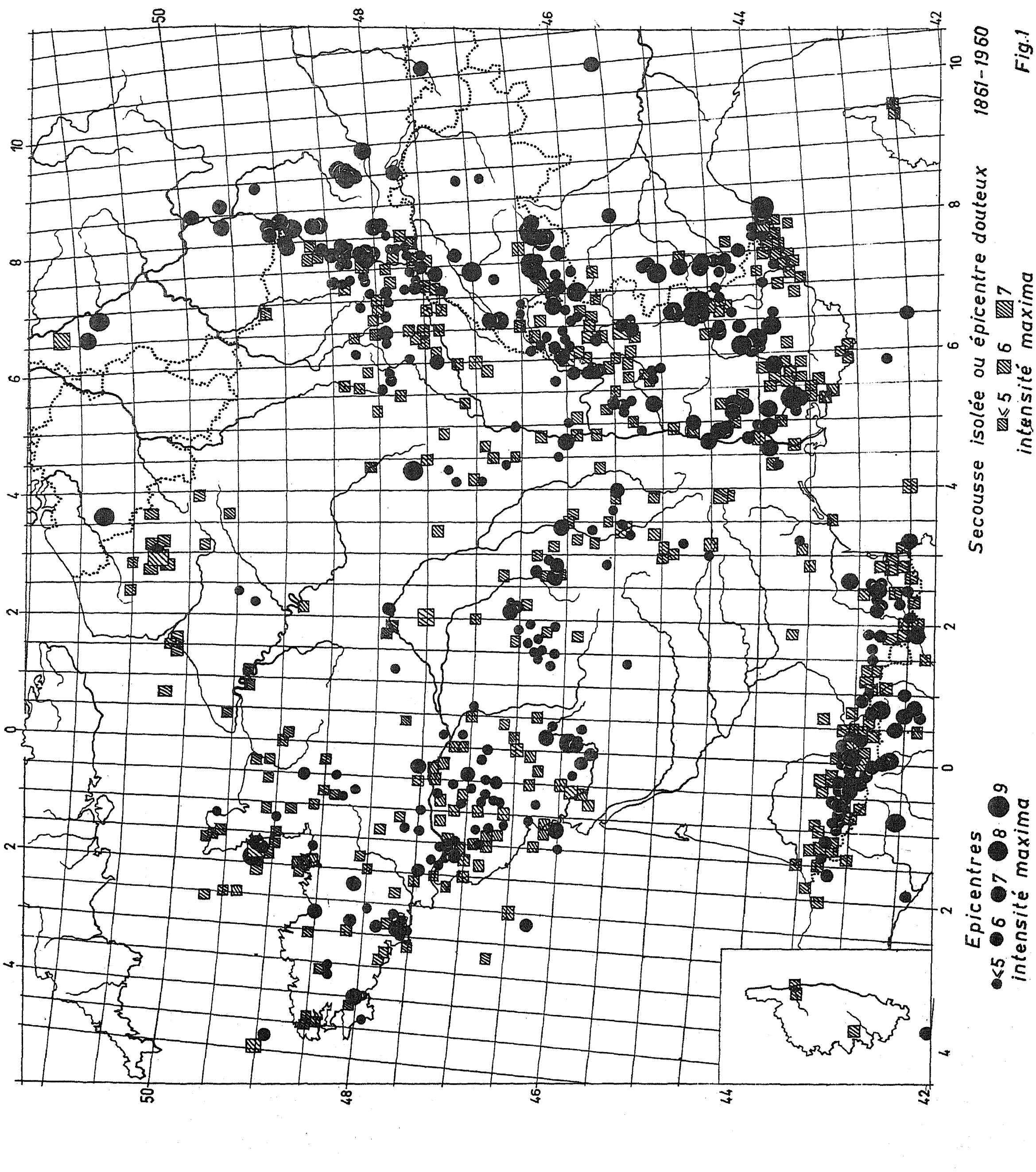
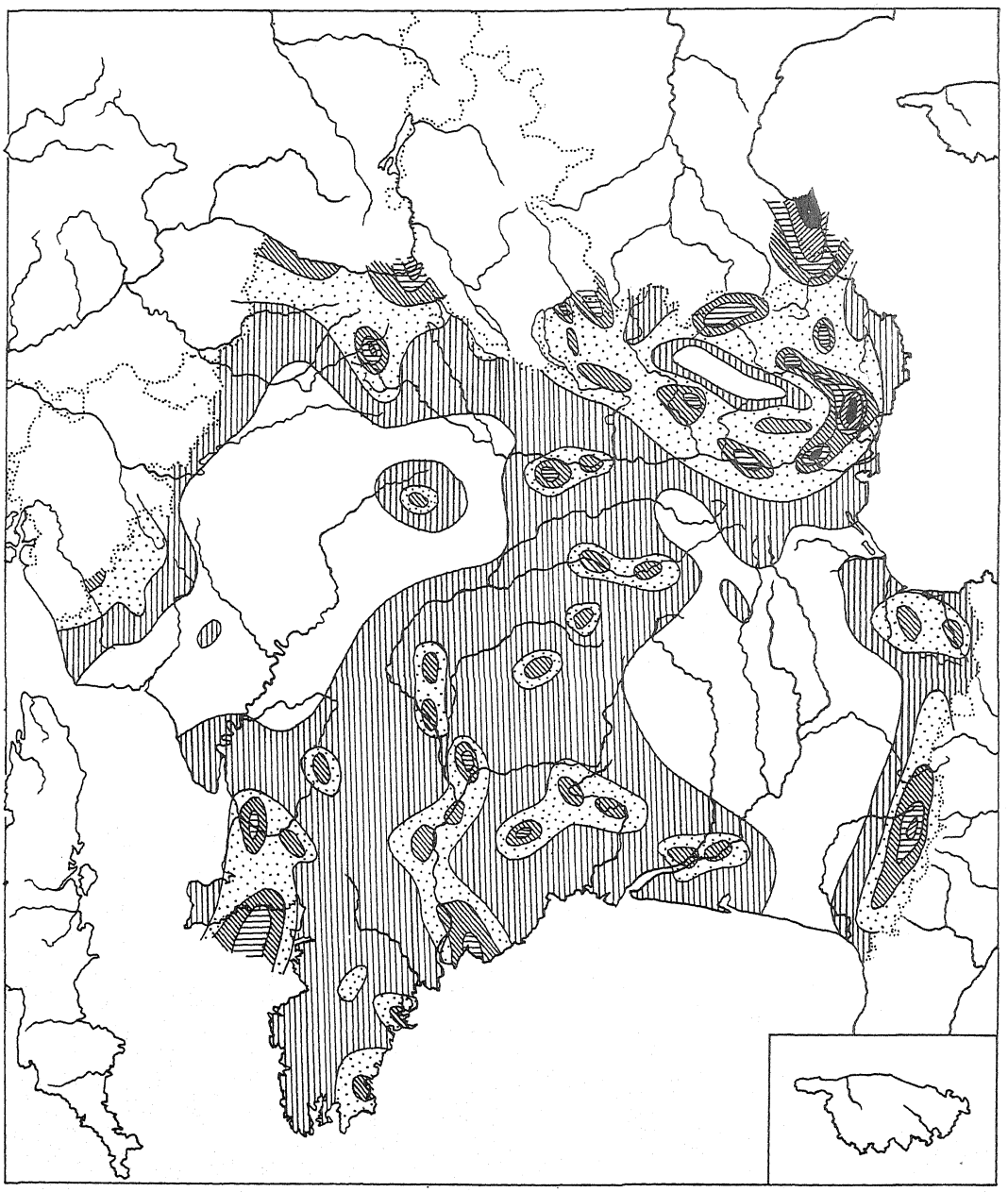

Secousse isolée ou épicentre douteux 1861-1960
≤5 6 7
intensité maxima
Epicentres
≤5 6 7 8 9
intensité maxima
Fig.1

INTENSITÉS MAXIMALES OBSERVÉES EN FRANCE (1021-1960)



Intensité maxima probable

Fig.3

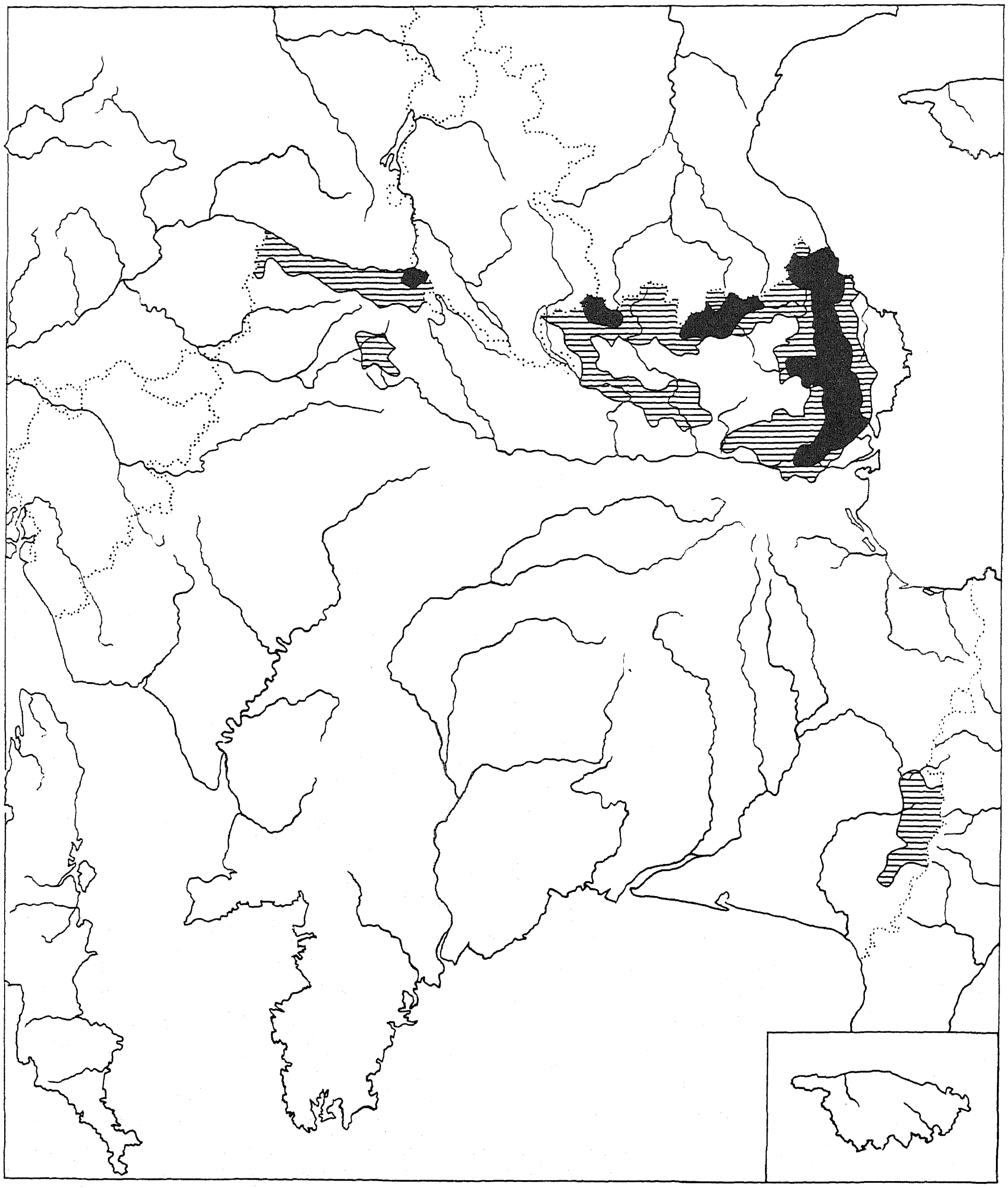


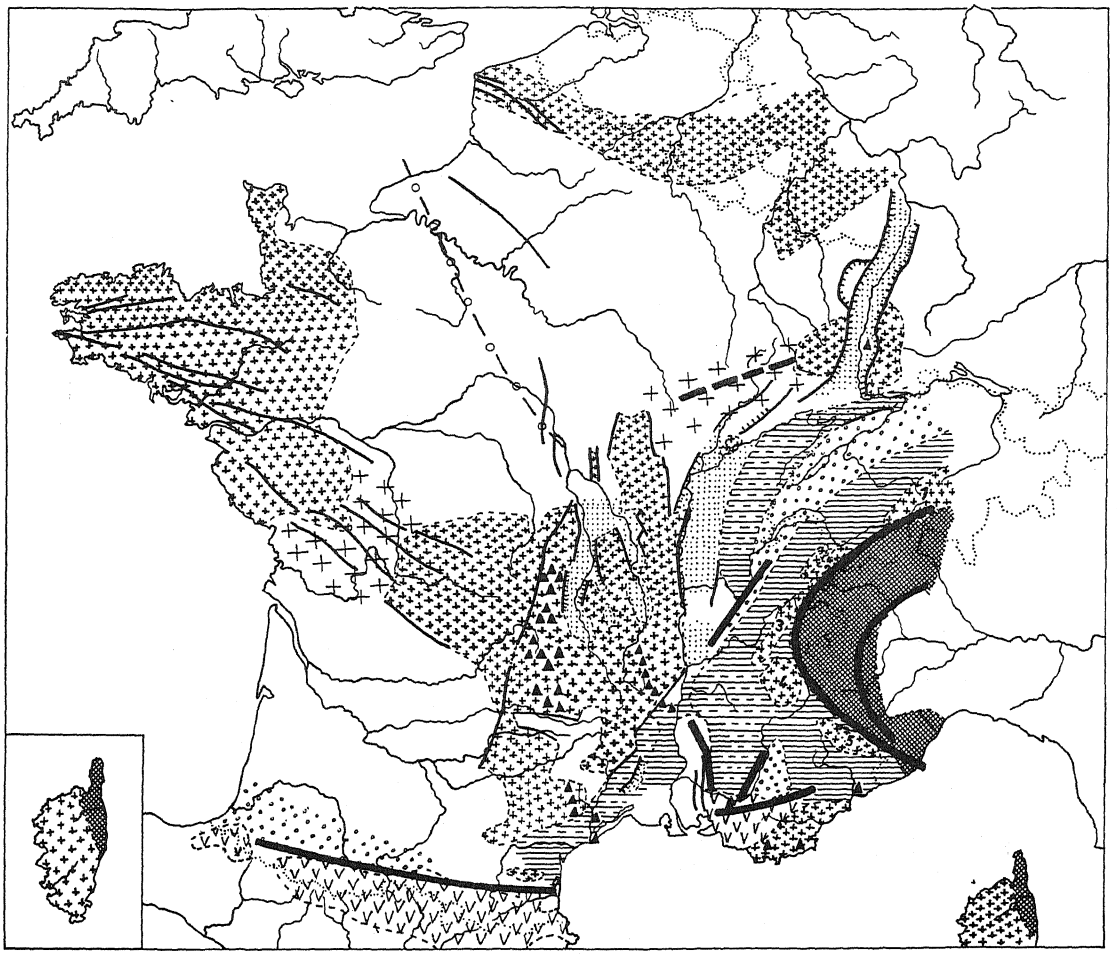
Fig. 4

Cantons réglementés

Séismicité moyenne zone 2

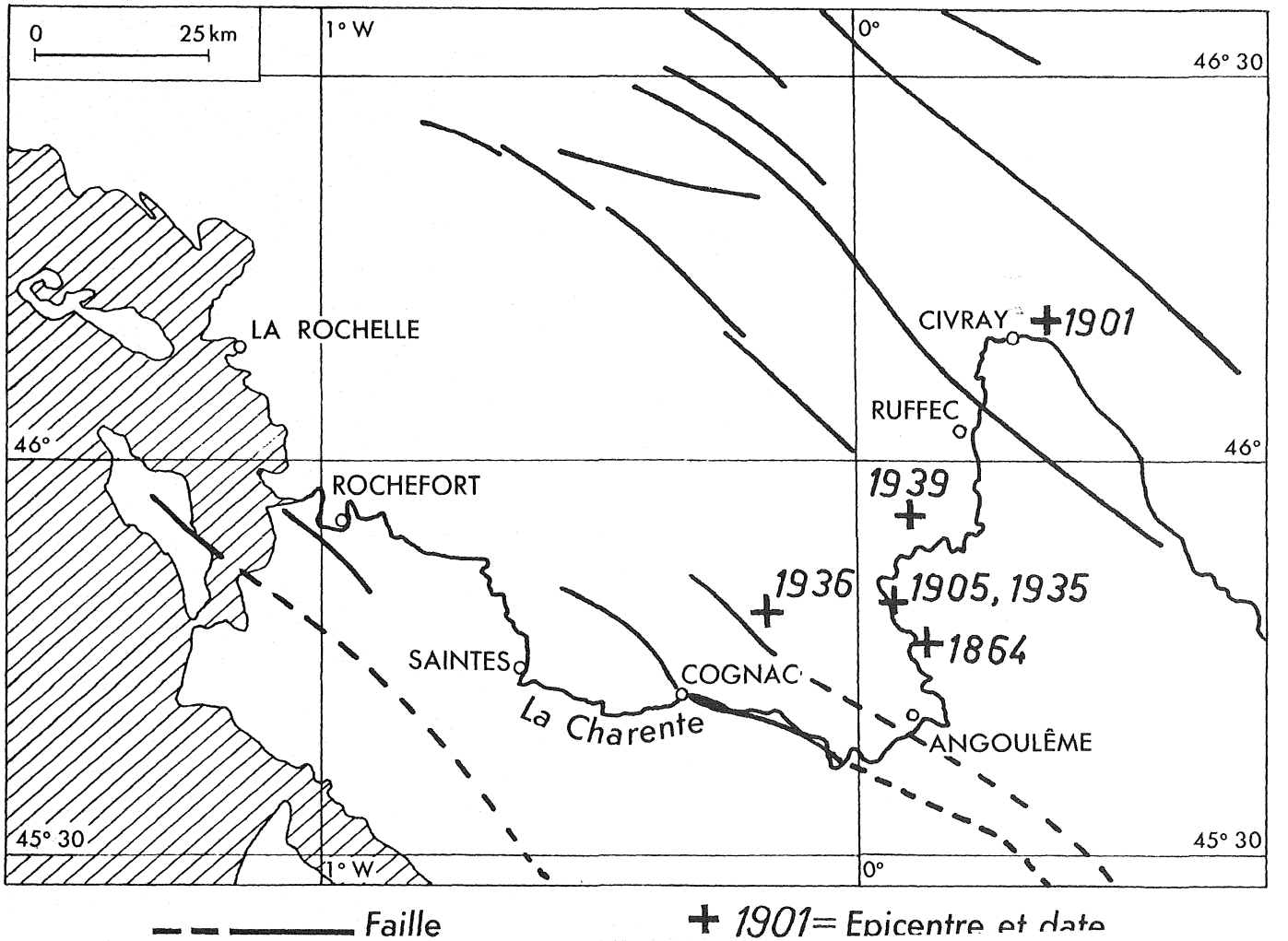
Séismicité faible zone 1

Fig. 5



Massifs paléozoïques
Socle peu profond fracturé
Géosynclinal alpin
Plissements de couverture
Plissements de couverture non séismiques
Pyrénées et plis provençaux
Avant Fosse Mollasse
Fossés oligocènes
Axes séismiques
Failles
Bords de fossés
Volcans tertiaires et quaternaires
Anomalie magnétique positive

Légende de la fig. 5.


0
25 km
1° W
0°
46° 30
LA ROCHELLE
CIVRAY
1901
RUFFEC
46°
ROCHEFORT
1939
1936
1905, 1935
1864
SAINTES
COGNAC
La Charente
ANGOULÊME
45° 30
Faille
1901= Epicentre et date