Available online at www.sciencedirect.com
ScienceDirect
C. R. Geoscience 340 (2008) 203–210
Comptes Rendus Geoscience
http://france.elsevier.com/direct/CRAS2A/

Internal Geophysics

On some electrical effects of the 1887 Ligurian earthquake

Jean-Paul Poirier *, Frédéric Perrier, Jean-Louis Le Mouël

Équipe de géomagnétisme, Institut de physique du Globe, 4, place Jussieu, 75005 Paris, France

Received 29 September 2007; accepted after revision 10 December 2007
Available online 18 March 2008

Presented by Claude Jaupart

Abstract

Significant electrical effects were observed in association with the 23 February 1887 Ligurian earthquake. Magnetic oscillatory signals, recorded in several locations in France and England, are inconclusive, as they can be interpreted as a consequence of the shaking of the magnetometers induced by the seismic waves. While observations in a telephone switch in Cannes could suggest the presence of electrical currents during the earthquake, evidence that is more convincing was reported near Monaco, where a telegraph operator received an electric shock that caused muscular tetanisation. This could be the first reliable evidence of a strong coseismic electrical potential. The minimal ground electric potential difference able to generate this condition is estimated to be of the order of 40 V. These observations, combined with similar accounts in Italy and in Martinique during early operation of telegraph networks, also suggest the existence of electrical phenomena occurring seconds or minutes before the main shock. ***To cite this article: J.-P. Poirier et al., C. R. Geoscience 340 (2008).***

Résumé

Sur quelques effets électriques du séisme ligure de 1887. Des effets électriques significatifs ont été observés lors du tremblement de terre du 23 février 1887, en Ligurie. On ne peut tirer de conclusions valables des signaux magnétiques enregistrés, qui peuvent être dus à l'agitation des magnétomètres par les ondes sismiques. En revanche, l'existence de courants électriques cosismiques est suggérée par des observations dans un standard téléphonique à Cannes. Un soldat télégraphiste, près de Monaco, reçut un fort choc électrique au moment du séisme. Cette observation, bien documentée, constitue probablement la première évidence de l'existence d'un potentiel électrique cosismique. La différence de potentiel par rapport à la terre qui a pu causer les effets observés sur le soldat est estimée à 40 V environ. Des effets électriques observés en Italie et en Martinique lors de l'utilisation des premiers télégraphes électriques conduisent à suggérer l'existence de phénomènes électriques cosismiques et peut-être se manifestant quelques secondes ou minutes avant le séisme. ***Pour citer cet article : J.-P. Poirier et al., C. R. Geoscience 340 (2008).***

Keywords: Coseismic electric potential; Earthquake precursor; Telegraph; Tetanisation

Mots clés : Potentiel électrique cosismique ; Précurseur de tremblement de terre ; Télégraphe ; Tétanisation

* Corresponding author.
E-mail address: poirier@ipgp.jussieu.fr (J.-P. Poirier).

1631-0713/$ – see front matter © 2007 Académie des sciences. Published by Elsevier Masson SAS. All rights reserved.
doi:10.1016/j.crte.2007.12.004

1. Introduction

The association between electrical phenomena and earthquakes has remained a recurring subject in the 18th and 19th centuries [13,17,18]. In the 1980s, the VAN group claimed to be able to predict earthquakes in Greece by detecting anomalous electric signals referred to as Seismic Electrical Signals (SES) (e.g., [26]). This proposal caused a great deal of heated and often unproductive controversy (e.g., [12]). Some signals identified by the VAN group were indeed of dubious origin [21]. The scepticism was augmented by the fact that no clear model could be demonstrated for the generation of electrical earthquake precursors. Despite the fact that observations are still being made repeatedly, SES, if they exist, do not appear systematic and they remain hard to measure and difficult to separate from anthropogenic phenomena. Unambiguous observations of electrical and magnetic phenomena during large earthquakes remain rare occurrences. It is therefore interesting to revisit early observations performed at the end of the 19th century, which appear reliable and were, for the most part, recorded in the *Comptes rendus de l'Académie des sciences*.

In this paper, we review the observations collected in association with the 23 February 1887 Ligurian earthquake. We first recall the available information about the earthquake. We then describe the reports from magnetic observatories as well as from telephone and telegraph stations. We give particular attention to the report of an electrical shock suffered by a telegraph operator, which we use to estimate the electric potential difference generated by the earthquake.

2. The 1887 Ligurian earthquake

In the morning of Wednesday 23 February 1887, the Ligurian Riviera, in Italy, was shaken by three successive earthquake shocks, at 5:22, 5:29, and 7:51 (UT) [5]. Offret [19] reports the times of arrival of the shocks at various Italian cities, given by seismographs; at Genoa, only 100 km away from the epicentre, the time of arrival of the first shock is given as 5:41:25. This time is obviously inconsistent with the carefully corrected time given by [5], which may be attributed to the use of various local times in Italy (as well as in France).

The epicentre (Fig. 1) was located in the sea, offshore from Imperia, at 43.90° N and 8.03° E, on a system of normal faults [8,9]. The epicentral intensity was IX for the first shock, VII for the second and VIII for the last one [9]. The maximal intensity I_0 of the first shock was IX–X at Diano Marina and Diano Castello, near Imperia. A magnitude m can be approximately calculated using the formula $m = 0.481\ I_0 + 1.407$ for Italy [14], which gives $m \approx 6.2$. The number of victims in Italy was estimated between 630 and 640.

The earthquake was felt with intensity VII at Nice, about 70 km away from the epicentre, where 900 houses were damaged, one child was killed, and eight persons were wounded. At Cannes (about 90 km away) and Toulon (about 190 km away), the intensity was only V. Although the damage in France was slight, the earthquake caused considerable emotion in the public, due, in part, to the fact that it had occurred at the end of the Nice Carnival, and perhaps that it came only two years after another strong earthquake, which had made a thousand victims in Andalusia, on 25 December 1884.

Numerous reports were sent to the Paris Academy of Sciences, and printed in the *Comptes rendus* [10,16,19,20,22,23,25]. Five days after the earthquake, on 28 February, the Academy established a 'Commission des tremblements de terre' in charge of gathering all the reports about the earthquake and drawing, if possible, general conclusions (which it did not). There were in Europe several magnetic observatories where disturbances of various magnetic instruments were reported at times close to those of the seismic shocks. Some of them were presented or commented upon by Offret [19] and by a leading physicist and magnetician of the time, Éleuthère Mascart (1837–1908), professor of physics at the 'Collège de France', director of the 'Bureau central météorologique' and a member of the French Academy of Sciences [16].

3. Reports from magnetic observatories (1887)

In this section, we examine the magnetic disturbances reported at times close to those reported for the seismic shocks. The director of the observatory of Perpignan, in southern France, noticed (Fig. 2) that the magnetic instruments were strongly perturbed at 5:47 [10]. Mascart noted that the instruments were set in oscillations at the observatory of Parc de Saint-Maur, near Paris, at 5:45 (Fig. 2) and at Lyons at 5:55 [16]. Offret [19] gives identical times of the magnetic perturbations for Lyons, Perpignan, and Paris, at 5:45. However, Mascart insists on the remarkable simultaneity of the disturbances, since the clocks in Perpignan and Lyons were ahead of those in Paris by 2 minutes and 10 minutes, respectively.

In a letter to *Nature*, dated 3 March 1887 (pp. 419–421), the curve given by the bifilar magnetograph of the Kew observatory (near London) is reproduced, showing

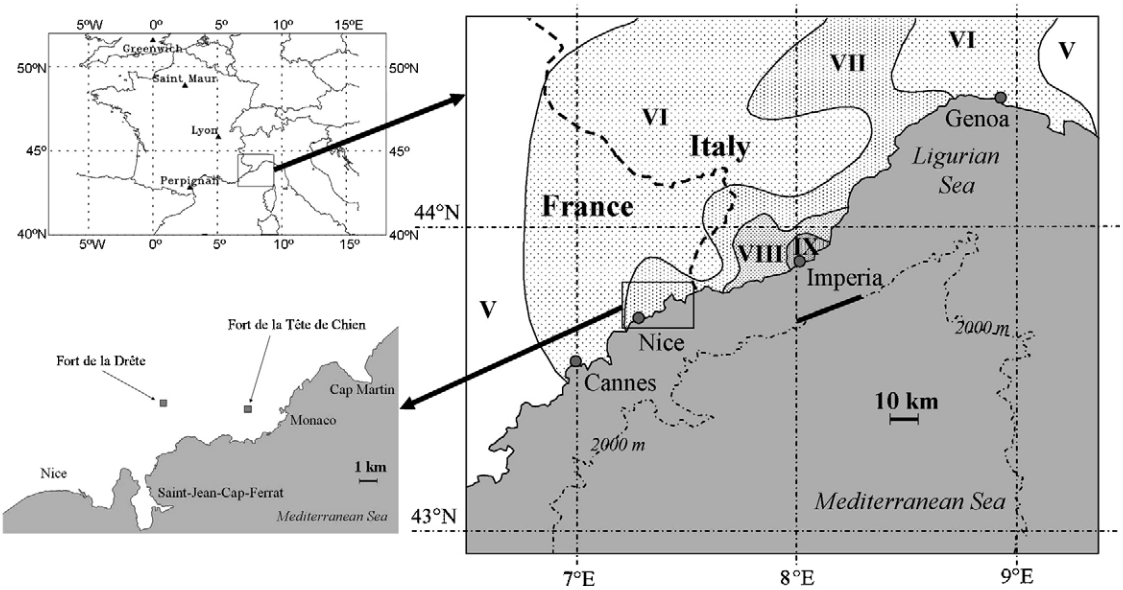

Fig. 1. Isoseists of the 23 February 1887 earthquake (right, after [9]). The upper inset (left) shows the location of the magnetic stations discussed in the text. The lower inset (left) shows the location of the telegraph stations involved in the reported electrical shock.

Fig. 1. Isoséistes du séisme du 23 février 1887 (à droite, d'après [9]). En haut à gauche, emplacement des stations magnétiques discutées dans le texte. En bas à gauche, emplacement des bureaux télégraphiques.

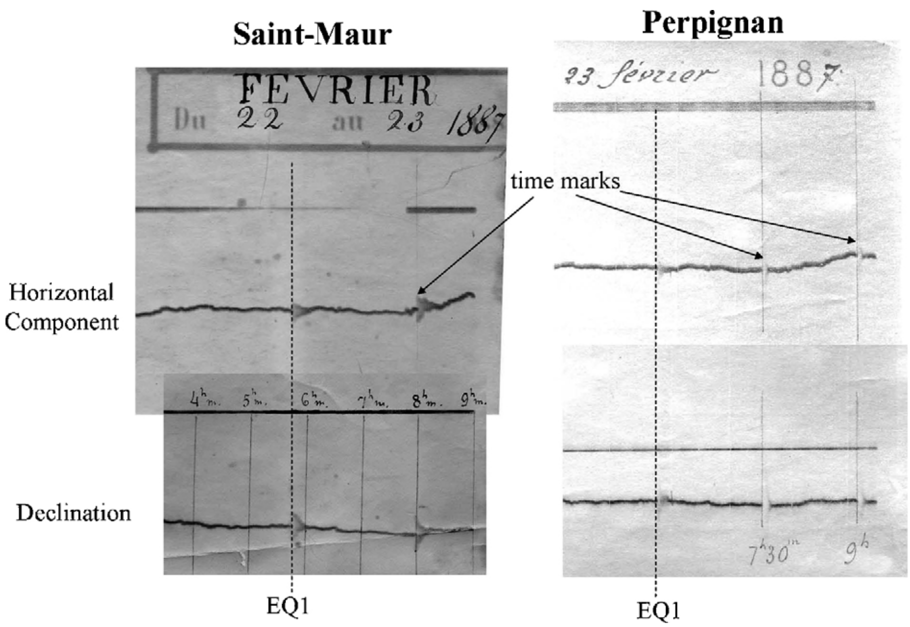

Fig. 2. Magnetic intensity and declination signals recorded during the 23 February 1887 earthquake at the Saint-Maur and Perpignan magnetic observatories (archives of the French National Magnetic Observatory, Chambon-la-Forêt).

Fig. 2. Intensité du champ magnétique et déclinaison enregistrées pendant le séisme du 23 février 1887 par les observatoires magnétiques de Saint-Maur et de Perpignan (archives de l'Observatoire magnétique national de Chambon-la-Forêt).

a disturbance of the instrument at about 5:40 am (UT). This is confirmed by a report from the Royal Observatory, Greenwich [6], stating that ‘‘at 5:38, Greenwich civil time, the declination and horizontal force magnets were suddenly thrown into vibration by some cause not magnetic.’’ The time of arrival of the signal in Kew cannot be compared with the time of arrival in French observatories, since before 14 March 1891, there was no unique legal time in France, where the Greenwich civil time (UT) became legal on 9 March 1911.

An important problem was deciding whether the suspended magnetic needles or bar magnets were set in motion by the shaking of the ground, in the way of a pendulum seismograph, or whether they registered the passage of electric currents. Offret [19] rejects the latter possibility on the grounds of the discrepancy between times of arrival of the perturbation in various stations and the fact that some magnetic apparatus in the same stations did register the perturbation while others did not.

From the shape of the curves at Parc de Saint-Maur, Mascart [16] remarked that the motions were different from those due to usual magnetic perturbations, but were more like those induced by pulses of electrical currents used to produce time marks on magnetograms (Fig. 2). He concluded that the magnetic instruments probably registered, not the motions of the ground, but the passage of electric currents produced in the ground at some stage of the earthquake.

We re-examined the recordings of Perpignan, Lyons, and Saint-Maur observatories, all of them equipped with the same Mascart magnetometers, and we found that, while the perturbations superficially resemble those corresponding to the time marks, there are slight differences that can be attributed to a difference in excitation. The time marks are caused by the isolated mechanical impulsion due to the sudden establishment of the pulse of current. In the case of the perturbations, however, there was a longer excitation with a time constant of the order of that of the oscillations of the bar. We are therefore led to the conclusion, opposite to that of Mascart, that the magnets were indeed set in motion by the shaking of the ground. Actually, magnetometers were available before seismometers and could be used to evaluate the magnitude for earthquakes at the end of the 19th century and the beginning of the 20th century [2].

In the following, we will focus on some intriguing electrical phenomena that occurred at the time of the 1887 earthquake, as well as on previous earthquakes in Italy and in Martinique.

4. Reports from telephone exchanges (1887)

In Cannes, about 90 km away from the epicentre of the 1887 earthquake (Fig. 1), the telephone operators arriving at the exchange at 8:00 am noticed that all the flaps covering the numbers of the customers were down, as normally happened when an electric current was received, corresponding to a call from a customer. However, the flaps of numbers not yet connected were still up [25]. This suggested that an electric current had been produced earlier in the morning, possibly at the time of the first shock.

In contradiction to this interpretation, it was suggested [25] that the flaps corresponding to numbers not yet connected were probably adjusted not to fall easily, and that they could stay up even when the building was shaken. Besides, no flaps had fallen in the telephone exchange of Nice. However, the argument might work the other way round, for if the flaps had been shaken down by the shock in Cannes, they should have fallen even more easily in Nice, where the shocks were felt with a higher intensity.

5. Reports from a telegraph bureau near Nice (1887)

An intriguing phenomenon was reported in a letter to the Academy from the Artillery Committee of the French Ministry of War, communicating a report from the lieutenant-colonel Benoît, director of the Artillery at Nice [22]. In the morning of 23 February, at 8:50 (7:50 UT), the soldier Muller, at the Fort de la Tête-de-Chien, east of Nice and 1.5 km west of Monaco (Fig. 1), was reporting by telegraph on the effects of the first two shocks to a colleague at the Fort de la Drette, about 5 km away westward, above Èze. The transmission being interrupted by his correspondent, the soldier was watching the paper coming out, when suddenly the telegraph apparatus went creaking and jerking. When, at the moment of the third shock, the soldier put his hand to the manipulator to resume the transmission, he saw the wall oscillate and he felt a strong electric jolt in the right arm. He was standing, as was his habit when manipulating, and he was thrown back to his chair, where he remained for a few minutes without being able to move. He was so shocked that he could not resume his service before late in the afternoon.

The day before, about 6 pm, during the reception of a dispatch, similar creaking of the clockwork and jerky motions of the paper had been observed. The letter ends with these words: ‘‘This electrical phenomenon, appearing to be the result of the earthquake, has seemed worth mentioning.'' A month later, a second letter from the lieutenant-colonel Benoît [20] gave details on the incident, which had been deemed sufficiently important to be worth an inquest ''as it was excessively rare (it being difficult for a person to be brought in contact with telegraphic wires buried in the ground at the exact moment of an earthquake, by pure chance).'' It was ascertained that the soldier usually manipulated with the back of his hand resting on the table, his thumb on the insulated knob and two fingers in contact with the metallic parts of the apparatus.

The psychological examination of soldier Muller confirmed the reliability of his testimony. The possibility that he had been thrown back by the earthquake shock rather than by an electric jolt was also dismissed: the soldier had remained in a daze on his chair for ten minutes; after coming to, he had felt like drunk all day long and his right arm had remained numb, as paralysed. Since then, he has had ''tremulations'' in the body and especially in his right arm.

Medical examination showed that the sensitivity of his fingers, especially of the one that was in contact with the manipulator, had considerably decreased. The left side of his face was agitated by spasms and his left eyelid often fell down. It therefore could be affirmed that it undoubtedly was a strong electric shock that the soldier Muller had received at the time of the earthquake. The letter concluded: ''This observation seems to us of an exceptional importance, as it indicates that earthquakes are accompanied by intense electrical currents.''

6. Reports from Italian telegraph bureaus (1873, 1879, 1880, 1887)

The existence of electrical phenomena during and before earthquakes had already been the subject of an interesting series of observations, made in telegraph bureaus in Italy, between 1873 and 1887. They were reported by Giovanni Luvini (1818–1892), professor of physics at the Military Academy in Turin [15]. From the wording of the reports, it appears that the telegraph in use in Italy at this time still was the early 'single-needle telegraph', invented by Wheatstone and Cooke in 1836–1837. The transmitter sent to the line a series of pulses of current of positive or negative polarity, and the receiver had an indicating magnetic needle, which deviated in one direction when a (conventionally) positive current was received in the line and in the opposite direction when the current was negative. The deflection of the needle left or right corresponded to dots or dashes of the Morse code. In France, however, the better known Morse telegraph had been in use since 1854.

Luvini first recalls that, on 12 March 1873, a telegrapher in Savignano was receiving a dispatch from Cesena when a strange alteration occurred in the apparatus; the earthquake was felt a few minutes later. Savignano sul Rubicone is a small town, about 14 km southeast of Cesena, in Emilia-Romagna, and the epicentre of the earthquake was near Camerino in the Marche, halfway between Macerata and Foligno, about 120 km southeast of Cesena [1].

A few months later, following a recommendation of Father Alessandro Serpieri (1823–1885), a noted meteorologist and seismologist, professor of physics at the University of Urbino, the Director of Telegraphs issued a circular instructing the telegraph operators to observe and note the abnormal deviations of the galvanometric needle of their apparatus. A number of observations were thus made [24]:

- on 1 August 1879, at Castrovillari (Calabria), the needle deviated by 8°, indicating the presence of a negative current, immediately after an earthquake, and the needle took 13 minutes to return to zero;
- on 9 August 1879 at Urbino (Marche), the needle deviated by 5°, indicating the presence of a negative current. The telegrapher checked that all bureaus on the line were silent; 25 minutes later, an earthquake was felt;
- on 3 February 1880 a S. Godenzo (Toscana), the telegrapher was observing a sudden agitation of the needle, when he felt an earthquake. The needle had deviated by 14°;
- on 2 March 1880, the telegrapher at Spezzano Albanese (Calabria) saw the needle deviate by 10°, indicating the presence of a negative current, 4 or 5 s before an earthquake.

From the reported sign of the current, Serpieri concluded that the ''electro-seismic current'' (*corrente elettro-sismica*) manifested at one station seemed to originate at the ground of a distant station.

The passage of currents of presumably high intensity in telegraphic lines seems confirmed by observations made at Corleone (Sicily) during the 1876 earthquake [1], reported by Milne [17]: ''On July 9th, at 8.35 pm, a shock occurred during the time a dispatch was being sent to Palermo. This was stopped and the signal 'Earthquake! Earthquake! Earthquake!' was sent. The operator not understanding the signal, replied 'Lift up the *tasto*, the current is too strong.' It was raised but the current was still too strong. The Palermo line was then thrown out of circuit and the Prizzi line put in. The galvanometer oscillated for 7 seconds and came to rest after 15 seconds.''

Unfortunately, over the years, the 1873 circular was mostly forgotten or neglected by telegraph operators, so that when the 1887 earthquake struck, only two observations were reported [15]:

- on 23 February 1887, in Milan, during the earthquake, the operator observed a deviation of 5° corresponding to a current in a wire in north–south orientation. The same experiment was made on another wire quasi-perpendicular to the first one, but no current was observed;
- on 11 March 1887, in Bra (Piedmont), the needle deviated by 3°, indicating the presence of a negative current, during 7 minutes at the time of an earthquake (an aftershock of the 23 February earthquake).

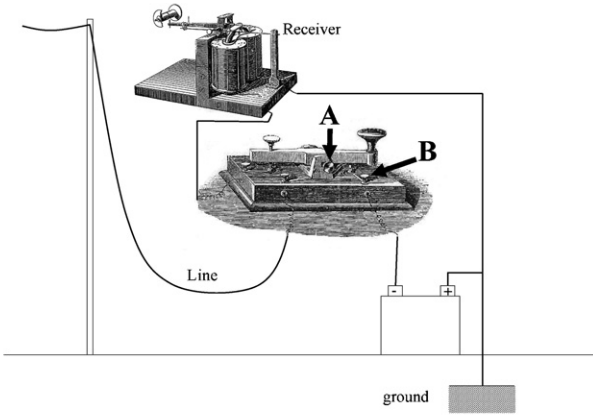

Fig. 3. Sketch of a Morse telegraph station. The electric shock was received when the operator touched the part A of the manipulator.

Fig. 3. Schéma d'une station de télégraphe Morse. L'opérateur a reçu la commotion électrique en touchant la partie A du manipulateur.

7. Reports from the telegraph bureau at Fort-de-France (1875)

Similar observations were made by M. Destieux, chief of the telegraph bureau at Fort-de-France (Martinique) before several shocks of earthquake, on 17 September 1875 [23]. At 10:25 am, he noticed that ''the needle of the galvanometer after an abnormal deviation became wildly agitated and pointed toward the ground conductor.'' Touching the screws and the coil, which were grounded, he found that they produced electric discharges. At 10:53, the first shock of the earthquake was felt. A short time later, the needle went back to its initial position.

The same phenomena were observed before subsequent shocks. The shocks followed the agitation of the needle and its deviation toward the ground after intervals of time between 15 mins and 2 h.

8. Discussion

These various observations indicate that a significant electric potential can be generated at the time of an earthquake, or seconds to minutes before its occurrence. The case of soldier Muller is particularly interesting, because it has been quite precisely documented and it allows a semi-quantitative estimate of the electric potential.

A typical telegraph configuration is illustrated in Fig. 3. The cable line enters the manipulator through its axis A. Thus, point A of the manipulator is always at the potential of the remote station. At rest, a spring maintains point B in the up position and the line is connected to the receiver. When the operator wants to send a signal, he presses point B down, disconnecting the receiver and connecting the line to the minus pole of the battery. A similar set-up exists at the remote station. If some voltage appears at the remote ground, it is transmitted to the line via the remote battery. While axis A is connected to the receiver, the current flows through the receiver, which records the signal. If a signal persists for a long time, due for instance to some voltage at the remote ground, then the receiver remains blocked, which might account for the reported creaking. If now the operator wants to send a message, or acknowledge receipt, he presses down the manipulator and part A stays at the high voltage; no current flows until the manipulator touches down. If, during this process, and before the manipulator touches down, the hand of the operator touches by accident point A, current can flow through his body, explaining muscular tetanisation of the arm, provided it is somehow grounded. This hypothesis is supported by the fact that the soldier was standing, and that he had the habit of manipulating with the back of the hand on the table, underneath points A and B (Fig. 3), as mentioned above.

An estimation of the lower limit of the electric potential difference between the two telegraph stations compatible with the observations can be attempted. Commonly quoted values of the current intensity necessary to trigger muscular tetanisation in the hand and forearm vary from about 20 mA [3] to higher values [7]. We will assume the lower threshold value of 10 mA, given by the International Electrotechnical Commission (IEC). The resistance through the hand can also vary from about 10,000 to 30,000 Ω for a dry hand, and from

3000 to 5000 Ω for a wet hand [7]. The resistance of the line itself can be estimated using data from iron telegraph cables [11] and is about 360 Ω, which is thus negligible compared with the hand and body resistances. We also assume that the contact resistance in the soil is negligible. The minimum necessary potential difference then varies from 40 to 100 V.

Incidentally, as soldier Muller did not apparently suffer from cardiac fibrillation, an upper limit of about 50 mA for the current intensity can also be given. Thus, an upper limit of about 200 to 1000 V can also be inferred for the voltage.

We can reasonably conclude that, during the 1887 earthquake, an electric potential difference of 40 to 100 V was generated between the two stations. The mechanism by which such potential differences can be possibly produced is still not clear. The electrokinetic effect, associated with the flow of an electrolyte through a porous matrix, is a potential candidate (e.g., [4]).

The calculation of the electrical potential generated by electrokinetic phenomena is unfortunately almost impossible, as it depends on too many unsubstantiated assumptions on the seismic source. Even if an electrical potential of the right order of magnitude could be generated at the epicentre, which does not seem impossible, it could not have been transferred to the telegraph station, unless heterogeneous conduction channels existed in the crust, between the source and the Fort de la Tête-de-Chien, where soldier Muller experienced the shock. It is also premature to conclude, based on the observations collected during the operation of Italian telegraph networks, unfortunately stopped before the 1887 earthquake, that precursory electrical signals did exist.

9. Conclusions

The electric phenomena reported in association with the 23 February 1887, and previously in Italy and Martinique in association with other earthquakes, have to be taken into account seriously. The medical examination of soldier Muller has been conducted with the utmost care and the incident has been documented and analysed in details. The occurrence of an electric shock is therefore beyond reasonable doubt. The association with the earthquake can also hardly be questioned in this case.

The documented case of soldier Muller suggests that electric potentials as high as 40 V were generated in the crust during, and possibly before, a relatively modest earthquake, even though the mechanisms able to generate such an electric potential are unknown.

However, the reported observations raise some concern about an important part of the physics of earthquakes, still poorly known, and which definitely deserves detailed and careful new investigations, which could perhaps be performed on telephonic lines.

Acknowledgments

We gratefully acknowledge the constructive reviews of Dominique Gibert and Jacques Zlotnicki, which led to an improvement of the paper.

References

[1] M. Baratta, I terremoti d'Italia, Turin, Italy, 1901.
[2] J.D. Batlló, D. Arrazola, A. Ugalde, Using magnetograms for earthquake magnitude evaluation, EOS Trans. AGU 86 (2005) 498.
[3] W. Benenson, J.W. Harris, H. Stocker, H. Lutz, Handbook of Physics, Springer-Verlag, New York, 2000, p. 609.
[4] P. Bernard, Plausibility of long distance electrotelluric precursors to earthquakes, J. Geophys. Res. 97 (1992) 17531–17546.
[5] E. Boschi, Catalogue of strong Italian earthquakes from 461 BC to 1997, Ann. Geofis. 43 (2000) 609–868.
[6] W.H.M. Christie, The earthquake, Nature (17 March 1987) 462.
[7] C. F. Dalziel, Deleterious effects of electric shock, Report of the World Health Office and International Electrotechnical Commission, Geneva, Switzerland, 1961.
[8] C. Eva, A.B. Rabinovich, The February 23, 1887 tsunami recorded on the Ligurian coast, western Mediterranean, Geophys. Res. Lett. 24 (1997) 2211–2214.
[9] G. Ferrari, The 1887 Ligurian earthquake: A detailed study from contemporary scientific observations, Tectonophysics 193 (1991) 131–139.
[10] M. Fines, Sur le tremblement de terre du 23 février, enregistré à l'observatoire de Perpignan, C. R. Acad. Sci. Paris 104 (1887) 606–608.
[11] A. Ganot, Traité élémentaire de physique, Hachette, Paris, 1887.
[12] R. Geller (Ed.), Debate on VAN, Special issue, Geophys. Res. Lett. 23 (1996) 1291–1452.
[13] E. Guidoboni, J.-P. Poirier, Quand la terre tremblait, Odile Jacob, Paris, 2004.
[14] V. Kárnik, Seismicity of the European area, D. Reidel, Dordrecht, The Netherlands, 1969, p. 65.
[15] G. Luvini, Perturbazione elettrica foriera del terremoto, Riv. Sci.-Ind. (1887) 3–5.
[16] E. Mascart, Remarques de M. Mascart au sujet de cette communication [Fines], C. R. Acad. Sci. Paris 104 (1887) 606–608.
[17] J. Milne, Earthquakes in connection with electric and magnetic phenomena, Trans. Seismol. Soc. Jpn 15 (1890) 135–162.
[18] J. Milne, Seismology, Kegan Paul, Trench, Trübner & Co Ltd, London, 1898.
[19] A. Offret, Tremblements de terre du 23 février 1887. Heures de l'arrivée des secousses en dehors de l'épicentre, C. R. Acad. Sci. Paris 104 (1887) 1238–1242.
[20] M. Onimus, Étude des effets d'une commotion électrique ressentie pendant le tremblement de terre du 23 février, C. R. Acad. Sci. Paris 104 (1887) 1244–1245.

[21] V.N. Pham, D. Boyer, J.-L. Le Mouël, G. Choukiaras, G.N. Stavrakakis, Electromagnetic signals generated in the solid Earth by digital transmission of radio waves, as a plausible source for some so-called electro-seismic signals, Phys. Earth Planet. Inter. 114 (1999) 141–163.

[22] H. Résal, Sur un fait qui s'est produit près de Nice lors de la dernière secousse de tremblement de terre, C. R. Acad. Sci. Paris 104 (1887) 950–951.

[23] R. Rivet, C. R. Acad. Sci. Paris 81 (1875) 693–694.

[24] A. Serpieri, Elettricità e terremoto, Rend. Ist. Lomb. Sci. Lett. (1880) 193–194.

[25] J.-L. Soret, Sur le tremblement de terre du 23 février 1887, C. R. Acad. Sci. Paris 104 (1887) 1088–1089, excerpt from a letter to Mascart.

[26] P. Varotsos, K. Alexopoulos, M. Lazaridou, Latest aspects of earthquake prediction in Greece by seismic electric signals, II, Tectonophysics 224 (1993) 1–37.