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A large unknown historical earthquake in the Abruzzi region (Central Italy): combination of geological and historical data

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Abstract
The combination of paleoseismological and historical investigation can be used to obtain a complete knowledge of past earthquakes. In Italy the 1000 year-long record of historical earthquakes provides an opportunity to compare data from the catalogue with results from paleoseismologic investigations. Trenching results along the Ovindoli-Pezza Fault (OPF), in the Abruzzi region, showed two surface faulting events. The most recent of these events occurred after 1019 A.D. and should be reported in the Catalogue of Italian Seismicity. Nevertheless, the earthquake appears to be missed or not well located in the Catalogue. In order to define in which century a large earthquake on the OPF should have clearly left a sign in the historical record, we carried out historical investigations back to the XI century. The studies were mainly focused on disclosing possible «negative» evidence for the occurrence of the most recent event along the OPF. No clear records related to this event were found but on the basis of the information we obtained the occurrence of this earthquake can be constrained between 1019 A.D. and the XV century, possibly between 1019 A.D. and XIII century.

Key words *Central Apennines – active faulting – paleoseismicity – historical earthquakes*

1. Introduction

The recognition of active faults and the study of their seismic behaviour are basic tools for modern seismic hazard assessment. In fact, the *characteristic earthquake model* (Schwartz and Coppersmith, 1984), stating that in most cases, large seismogenic faults produce repeated earthquakes of essentially the same size, set the basis for using the past seismic history of faults for predicting their future behaviour. This new approach to seismic hazard increased the awareness of the importance of the geological recognition and dating of large earthquakes of the past (generally referred to as *paleoearthquakes*). As a consequence, information on past seismicity can be obtained following two lines of investigation: historical and geological. On the one hand, the occurrence of large earthquakes may endure in the historical *memory* of a region through historical documentation; on the other, large magnitude earthquakes ($M \geq 6.5$) may leave distinct traces at the surface, that become permanent features of the geomorphology and geology. Based on historical data catalogues of seismicity are compiled including date and location of large earthquakes that occurred within historical time, whereas geological investigation allows the detection of both historical and prehistoric earthquakes well recorded on individual faults and the attribution to each event of an age and a magnitude. Therefore, the seismic history of a fault can be reconstructed by merging information from history and geology. If a paleoearthquake recognized by geological method has occurred during historical time the age of

the paleoearthquake can be precisely constrained by comparing its geological age with the events reported in the catalogue for that particular region. In this case the intrinsic limits of each type of investigation are overcome; a particular historical earthquake can be associated with certainty to its causative fault and *viceversa*. However, this is a very uncommon case because historical catalogues are generally too short with respect to the frequency of large earthquakes on the same fault and thus they are generally not sufficient for reconstructing the long-term seismic behaviour of a fault. Italy has one of the best catalogues of historical seismicity (Postpischl, 1985) in the world that, for large earthquakes, can be considered complete at least for the last millennium. However, recent studies performed along some Italian seismogenic faults show that the average recurrence times are of the order of one to two millennia (Valensise and Pantosti, 1992; Pantosti *et al.*, 1993; Cinti *et al.*, 1992a). Therefore, in most cases the historical catalogue could report only one large event for each fault and possibly none. In this light, the geological investigation appears to be critical for extending back in time the seismic history for hazard evaluations. In this paper we combine the paleoseismological results that we obtained for one of the most clear surface breaking fault in Italy, the Ovindoli-Pezza fault (hereinafter referred to as OPF), with historical investigations. The results obtained allowed us to: 1) make comparisons and correlation between geological and historical data; 2) use the historical information to better constrain the geological results, and 3) better understand limits and potentiality of the historical information.

2. Geological evidence of paleoearthquakes on the OPF

The OPF is a major seismogenic normal fault located in the Abruzzi Apennines about 100 km east of Rome (fig. 1). This structure is about 20 km-long, and is part of the main seismogenic belt that runs along the axis of the Central and Southern Apennines (Valensise *et al.*, 1993). The northern section of the OPF, between Piano di Pezza and Ovindoli village, is a continuous 12 km-long segment that displaces Late Pleistocene (< 0.7 *M*yr) moraine and outwash, and Holocene (< 10000 yr) alluvial fans (Cassoli *et al.*, 1986; Giraudi, 1989). This indicates that this fault segment was active in recent time. South of the Ovindoli village the fault is still evident as an important lineament, however the absence of recent deposits along its trace makes it impossible to define its present activity. The fault scarp is very well preserved at Piano di Pezza. It runs along the northern edge of the basin as a south-southwest facing scarp up to 16 m-high (Biasini, 1966; Giraudi, 1989; Cinti *et al.*, 1992b). The presence of Holocene deposits displaced by the fault and the excellent preservation of the fault scarp, make the Piano di Pezza basin a good site for paleoseismological investigations. We opened three trenches across the Piano di Pezza scarp. Based on detailed logging of the trenches and on a graphic reconstruction of the stratigraphy, we recognized the geological deformation produced by at least two surface faulting earthquakes on the OPF (Cinti *et al.*, 1992a, fig. 2a,b). The most recent event is defined by a 8 m-wide fault zone in alluvial fan deposits and produced about 3 m net vertical slip, suggesting a large magnitude for this earthquake ($M \sim 7$) (Swan *et al.*, 1980; Ambraseys, 1988; Wells and Coppersmith, 1994).

Dendrochronologically corrected radiocarbon dating of buried paleosols and detrital charcoals from the trenches provided geological estimates of the age of the paleoearthquakes. The most recent faulted deposit is an organic A soil-horizon (unit C in fig. 2a,b), dated at 1019-1194 A.D, buried by an unfaulted colluvium. Since the most recent earthquake occurred after this soil was formed, it should have been occurred sometime between 1019 A.D. and today. Unfortunately we did not find any other geological constraint to set a narrower interval of occurrence. The penultimate event is younger than a brown paleosol (unit N in fig. 2b), which appears to be deformed at least twice respect to the deformation recorded by the organic A soil. Based on radiocarbon dating,

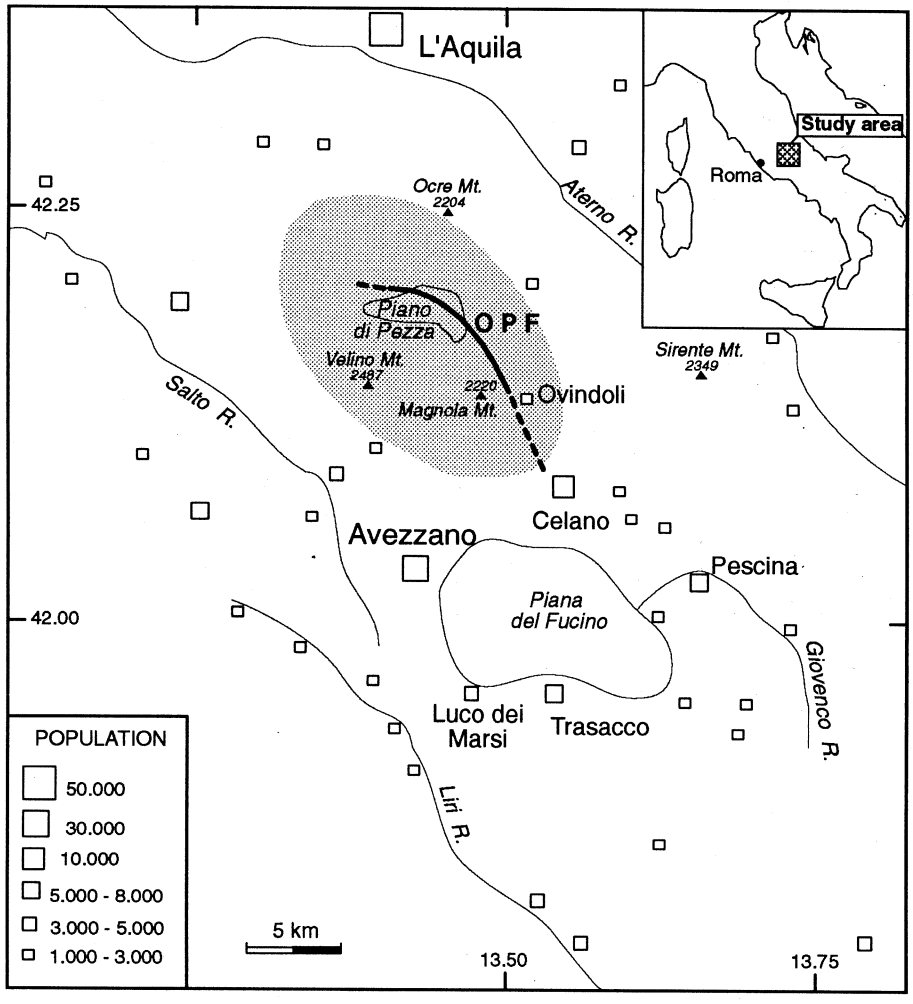

Fig. 1. Location of Ovindoli-Pezza Fault (OPF) (heavy line, dashed where hypothesized) and distribution of the urban centers and population in the zone surrounding Piano di Pezza in 1994. The shaded area represents the expected mesoseismal area for a $M \sim 7$ earthquake on the OPF.

the penultimate earthquake occurred sometime between 2208 B.C. and 401 A.D.

3. Historical constraints on the paleoseismicity of the OPF

Trenching at Piano di Pezza shows evidence for the past two surface faulting ($M \sim 7$) paleoearthquakes on the OPF. The penultimate event is too old to correspond to one of the earthquake reported in the Catalogue of Italian Seismicity (Postpischl, 1985). On the contrary, the most recent event occurred within the interval of time covered by the Catalogue, sometime between 1019 A.D. and the present. However, none of the large events ($I \geq$ VIII) reported in the Catalogue can be directly related

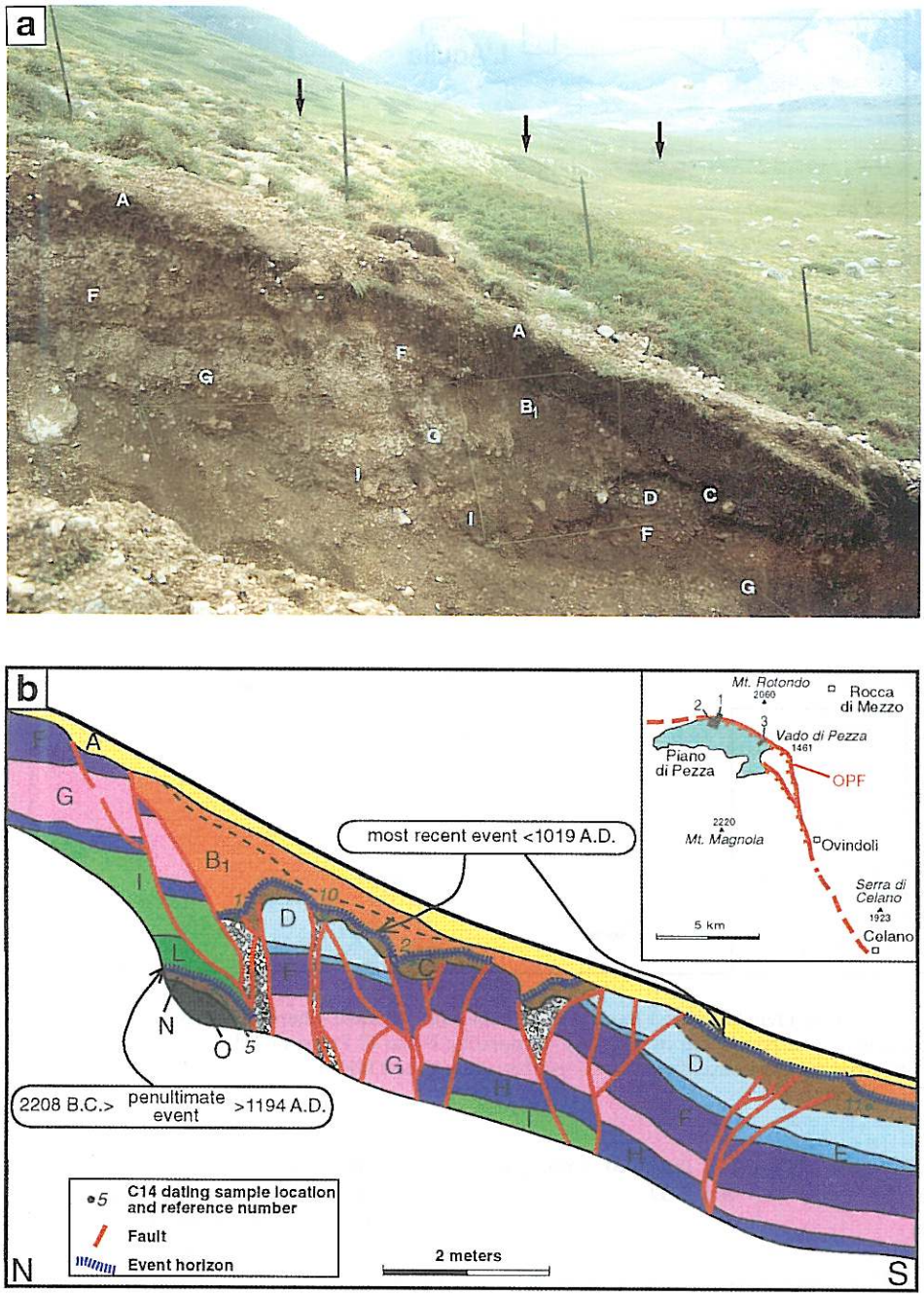

Fig. 2a,b. Photo and log of the fault zone of trench 1 excavated across the OPF at Piano di Pezza (location is shown in the inset). (a) The arrows indicate the fault scarp. The letters correspond to the units in the log of figure (b).

to the OPF (fig. 3). Considering that the OPF is located nearby Rome (fig. 1), some earthquake effects reported in this town during the VIII-XIV centuries, and in particular that one occurred in 1091 A.D. (R. Funiciello, personal communication), could be related to the most recent earthquake produced by the OPF.

A look at the present setting of the area of expected damage from a large earthquake on the OPF suggests a possible reason for the lack of the most recent earthquake on the OPF in the Catalogue: the area is characterized by rough mountains, narrow and steep valleys that made viability and agriculture difficult, consequently it used to be scarcely populated (fig. 1). Although it is not possible to set the exact age of the most recent earthquake on the OPF on the basis of the historical catalogue, we can try to use historical considerations to better constrain the interval of occurrence. Our investigation, instead looking for the evidence of past earthquakes in the historical documentation, is focused on the «negative» evidence for the occurrence of large earthquakes during a particular period of time. Our aim is to define a time since a large earthquake on the OPF should have left a clear sign in the historical record of the region. If no evidence for large earthquakes exists more recently than this time, we can reasonably affirm that the most recent earthquake on the OPF occurred prior to that. As the reliability of the historical record in a region and at a particular time is strictly related to the presence of population, major trade centers, and strategic sites, we concentrated our investigation on the reconstruction of the settlement evolution in the area where we expect important damage for a $M \sim 7$ earthquake on the OPF, starting from the XI century.

3.1 *Settlement evolution of Central Abruzzi since the XI century*

The evolution of settlement in Central Abruzzi starting from the XI century is charac-

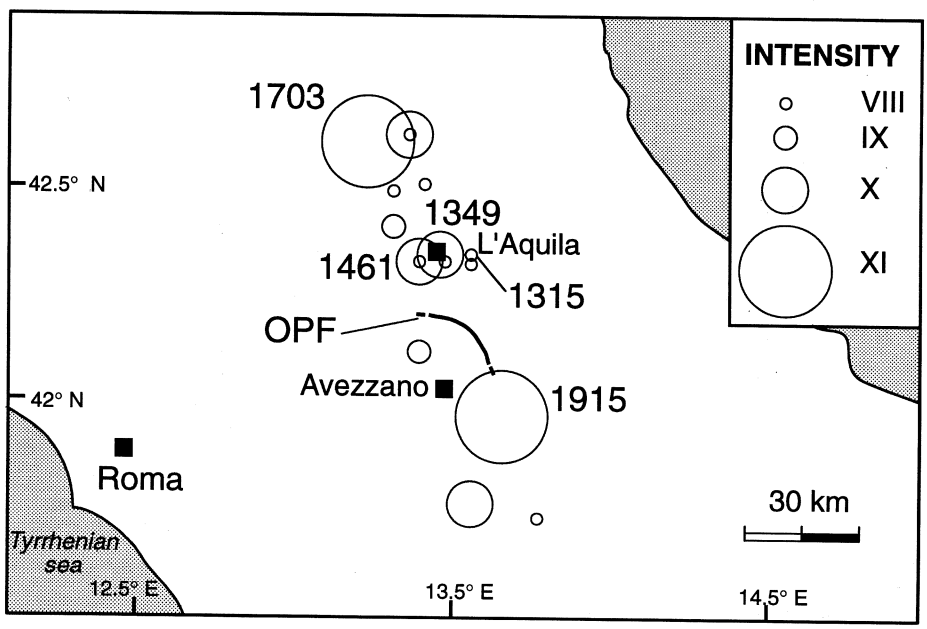

Fig. 3. Historical seismicity of Central Abruzzi (1000 A.D.-1980 A.D.; $I \geq$ VIII) (Postpischl, 1985). No large historical earthquake that can be reasonably associated with the OPF is reported in the catalogue.

terized by two main stages: prior to and after the XV century. In fact, the distribution of villages and strategic sites in the territory after the XV century was very similar to the present one. Whereas the XI-XV centuries show significant differences from the present. Moreover, the period XI-XV centuries can be distinguished in two intervals: XI-XIII centuries and XIII-XV centuries. Before the XIII century the area was sparsely populated and only few rural villages settled around small churches. Development was prevented not only by the geographic setting of the region but also by the repeated barbarian invasions that caused important destruction to the whole Italian peninsula. At that time even important centers like Rome recorded the most significant decrease of population and the poorest conditions of life. Written documentation for that period is very scarce because Latin was known only by clergy and moreover a significant amount of documents has been destroyed. This scarcity should have been even worse in the study area because of the complete absence of Episcopal communities, where cultural activities were concentrated, prior to the XIII century (fig. 4).

Starting from the end of XIII century, a general improvement of cultural and economical conditions tooks place throughout Central Italy. Several defensive structures, such as towers and castles, were built in strategic sites and new villages were established (fig. 5). In the same period the Benedictine communities settled massively in the area; several monasteries were built and most of the pre-existing churches were completely reconstructed (see fig. 6 and Appendix). The Benedictine diffused a wave of renewal in the region that caused the developing of new cultural centers and the increasing of the production of manuscripts, which represent the main source of historical documentation.

3.2 *Interpretation of the historical observations*

According to our reconstruction, during the interval of time between the XI and XV century, the mesoseismal area possibly produced

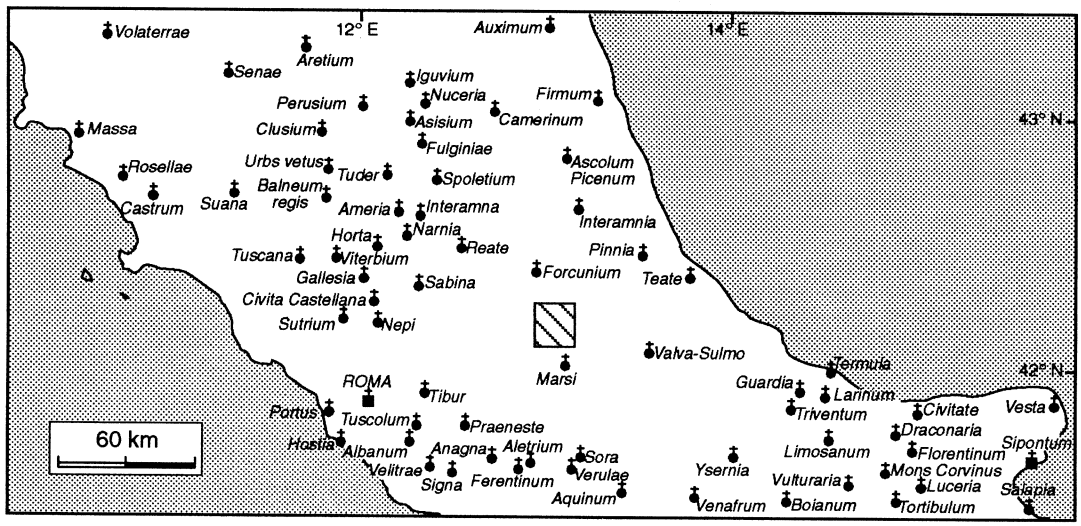

Fig. 4. Distribution of Episcopal sites in Central Italy in 1198 A.D. (from Cammarosano, 1993). The zone surrounding the study area (indicated by the square) is characterized by a complete lack of sites.

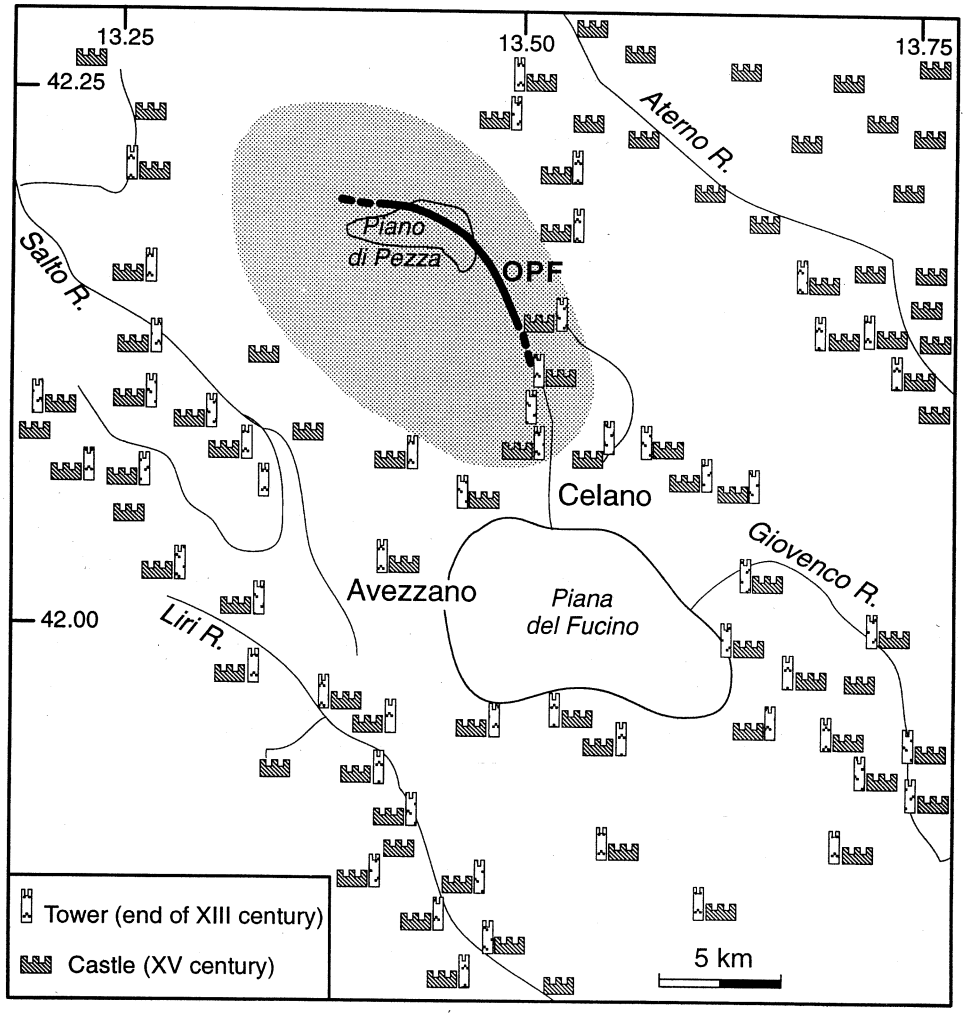

Fig. 5. Distribution of the towers in the XIII century and the castles of the XV century (based on historical reconstruction performed by the Sopr. BAAAS of Celano, personal communication). Today, most of these structures are completely collapsed. The towers were located in strategic points, from which it was possible to control most part of the territory. Some structures were also within the expected mesoseismal zone for an OPF earthquake (shaded area).

by a hypothetical earthquake on the OPF was scarcely populated, and therefore there were few people and structures that would have recorded the traces of a large earthquake. The beginning of the XV century marks a definite cultural and economical development that involves also the mesoseismal area of the OPF. Thus, a large seismic event on the OPF should have been surely felt and should appear in the historical record. In the light of these considerations and on the basis of the geological record it is reasonable to affirm that the most recent OPF earthquake occurred between 1019 A.D. and the XV century. We may reduce further

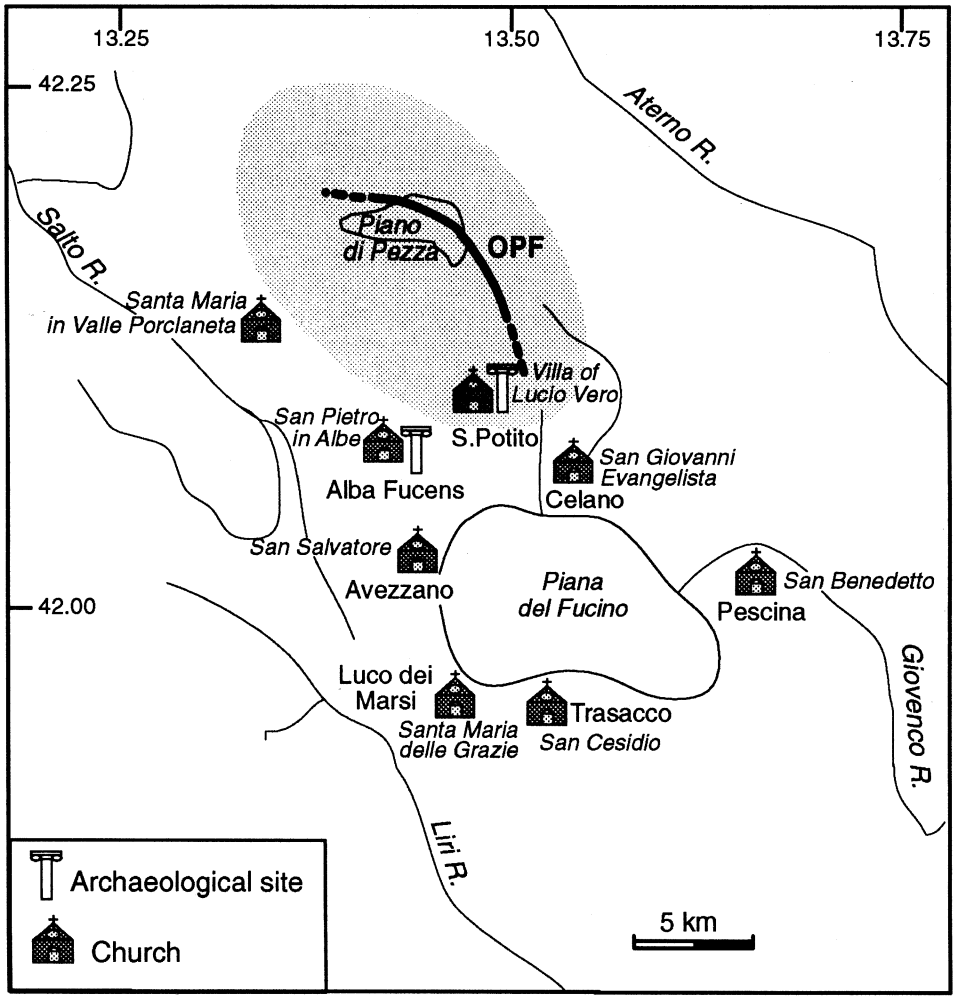

Fig. 6. Archeological sites and churches located in the region surrounding Piano di Pezza prior to the XIII century. We investigated in detail the history of some villages and structures indicated in the figure (see Appendix). The shaded area represents the expected mesoseismal area for an earthquake on the OPF.

the interval of occurrence of this event between the 1019 A.D. and the XIII century. In fact, from the end of the XIII century the presence of many defense sites and the arrival of Benedictines suggest that an earthquake on the OPF would have left a sign in the historical record of the region. The fact that Benedictines completely rebuilt the pre-existing structures makes difficult to discriminate if the churches had to be rebuilt because of the occurrence of a destructive event (*i.e.* earthquake) or just because of the need of the Benedictine community for enlarging and remodelling the structures as a consequence of the general wave of renewal.

Another possibility should be considered for explaining the lack of the most recent OPF earthquake in the Catalogue: the event is re-

ported in the Catalogue but it has been mislocated. In this case, in the light of the previous considerations and of a careful revision of the historical documentation (SGA, 1994), there are only two events not very well constrained that could be related to the OPF activity: the eartquakes of December 3, 1315 (I = VIII MCS) and January 22, 1349 (I = X MCS). They are located north of the study area near the town of L'Aquila (fig. 3) and their causative fault is still unknown. Considering that L'Aquila was built in 1254 and was the main town in the region, it should be expected that the felt reports about these earthquakes were restricted to this town. Following this hypothesis, the earthquake source could have been the OPF, and L'Aquila was only mildly damaged because it is located at a distance of ~35 km from the fault. Moreover, the analysis performed by the SGA (1994) found that the 1315 should be a much larger earthquake than I = VIII. So that, this earthquake could be the most recent event on the OPF.

4. Conclusions

The integration of historical and geological investigations carried out in the area of Piano di Pezza allowed us to set the age of the most recent earthquake on the OPF between 1019 A.D. and the XV century, and possibly between 1019 A.D. and the end of XIII century. This earthquake is not found in the Historical Catalogue of Italy. The lack or mislocation of the most recent OPF event in the seismic catalogue is probably due to the particular conditions that characterized the area in that historical period, such as scarcity of population, confused and poor documentation.

A general conclusion of this study is that conditions similar to those of the Piano di Pezza area may exist in other regions, and therefore other large or moderate magnitude earthquakes may have been missed or mislocated in the Catalogue of the Italian Seismicity. This raises important questions about the use of the historical information as the unique input for seismic hazard analyses and highlights the need for paleoseismological investigations and a closer integration of historical and geological data.

Appendix

We investigated the history of villages and in particular of the ancient buildings existing in the area surrounding Piano di Pezza. In this Appendix we report the information obtained for the most significant sites (for site location see fig. 6).

San Potito – Archeological excavations of the roman *Villa di Lucio Vero* show that the Villa was built at the beginning of the I century and probably abandoned at the end of the II (Gabler *et al.*, 1986; Gabler and Redó, 1988). At the same location there is also evidence of a small village and traces of a church built mainly reusing materials from the roman villa in the IX century and probably reconstructed later. This center was finally deserted in the XI century. The presence in 1074 of a fortress called *Castellum* is also documented (Gabler and Redó, 1988), today it is turned in ruins.

Alba Fucens – The village of Alba Fucens was the most important in the region during the roman period and until the XV century. It dates back to 300 B.C. and was an important strategic center (Mertens, 1981). Although the decline of the village started in the III century, it was never completely abandoned. The restoration of the church of *San Pietro in Albe*, strongly damaged following the 1915 Avezzano earthquake, show distinct phases of reconstruction: 1) the original structure was probably established in the VIII century by the early Benedictines on the ruins of a roman temple (Sopr. BAAAS, 1991); 2) around the XII century it was rebuilt, maybe after being damaged by an earthquake (Mertens, 1981); 3) Benedictines made important remodelling in the XIII century, changing completely the original structure of the building.

Santa Maria in Valle Porclaneta – The monastery was donated at the end of the XI

century by the earl of Marsi to the Benedictines. They restored it, enlarging the structure (Gavini, 1926). The building is now completely destroyed, only the sanctuary is preserved and has been significantly restored following the 1915 Avezzano earthquake.

Villages near the Piana del Fucino – The Piana del Fucino was a lake until the end of the XIX century and it represented the best site for an intense development because of favourable environmental conditions such as temperate climate and flatness of the morphology.

– Celano: the village was the residence of the earls of Marsi, probably until the XI century. The castle of Celano was built on the southern slope of the Serra di Celano and was destroyed by Federico II in 1223; the traces of the original structure are today completely missed. The Castle was rebuilt at lower elevation in 1392, and is now the Castle of Piccolomini. In Celano is located also the church of *San Giovanni Evangelista* (now *Santa Maria delle Grazie*), probably built in the middle of the IX century. The church, even if characterized by different phases of restoring, is at present conform to the XIII century architecture, suggesting at that time a complete changing of the original church.

– Avezzano: the church of *San Bartolomeo* erected around the XIII century, was severely damaged by the 1915 earthquake. The restoration of the church highlighted traces of a preexisting Benedictine church (it was probably the church of *San Salvatore*, dated back to the 870).

– Trasacco: the church of *San Cesidio* is probably dated back to the IX century. In 936, it was destroyed by the Hungarians (Gavini, 1926). The structure was rebuilt in the XIII century.

– Luco dei Marsi: the present church of *Santa Maria* (dated back to the X century) was completely rebuilt before the restoration by the Benedictine in the XIII century.

– Pescina: the church of *San Benedetto*, that was destroyed during the 1915 Avezzano earthquake, preserves some traces of the original Benedictine church dated back to the end of the XI century. The structure was rebuilt and extended upwards in the following centuries.

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