Netherlands Journal of Geosciences / Geologie en Mijnbouw 80 (3-4): 273-296 (2001)

Major active faults in Italy: available surficial data

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Manuscript received: July 2000; accepted: October 2001

Abstract

An inventory of the available surficial data on active faults in Italy has been compiled by gathering all the available information on peninsular Italy (project by CNR, National Group for the Defense against Earthquakes), the central-eastern Alps and the Po Plain (EC 'PALEOSIS' project). Such information has been summarised in maps (reporting surficial expressions of faults with length L≥11 km) and in a table where fault parameters relevant for seismic hazard assessment (e.g. slip rates, recurrence intervals for surface faulting events, etc..) have been reported. Based on the geological characteristics of the Italian territory, a fault has been considered as active if it shows evidence of Late Pleistocene-Holocene displacements. Active faults in Italy are distributed throughout the entire Apennine chain, in the Sicilian and Calabrian regions and in some Alpine sectors, but knowledge is not homogeneously distributed through the territory. The largest amount of data is related to the central Apennines. In contrast, fault geometries and parameters are less well defined in the southern Apennines, Sicily and Calabria, where investigations have started more recently. Knowledge is sparse in the northern Apeninnes, where data necessary to define fault parameters are lacking and also the chronology of the activity has to be considered cautiously. Abundant blind faulting in the Po Plain hinders the detection of active faults by means of the classical surficial investigations and therefore the present knowledge is limited to the Mantova fault. Blind faults and the peculiar recent geological history of the Alpine areas, which is strongly conditioned by the erosional and depositional activity during and after the last glacial maximum, also hinder the identification of active faults in the central-eastern Alps. Some faults in this Alpine sector are believed to be active, but data on their segmentation are still missing. Available information indicates that Italian active faults are usually characterised by slip rates lower than 1 mm/yr. Recurrence intervals for surface faulting events are longer than 1,000 years in the central and southern Apennines. This review on the Italian active faults represents the first step to produce a map of the major seismic sources in Italy, which in turn will result from the merge of surficial data with seismological and geological subsurficial data. The available knowledge gathered in this paper indicates those areas where data are presently sparse. It should be, therefore, possible to better plan future geomorphological and paleoseismological investigations.

Keywords: active fault, active tectonics, fault parameters, Italy

Introduction

The role of geologically derived active fault parameters in seismic hazard assessment has increased in the last years (e.g. WGCEP, 1995; Boschi et al., 1996; Field et al., 1999). Quantitative data on the behaviour of faults are used in regional and more 'local' investigations that aim at siting critical engineering works, such as nuclear power plants (e.g. U.S. N.R.C., 1975; IAEA, 1991). This increasing attention to the 'problem' of active faulting is not only evidenced by the number of works summarising active faulting data on maps and tables (e.g. Kaizuka et al., 1992; Trifonov & Machette, 1993; WGNCEP, 1996), but also by the rich literature on methodology (e.g. McCalpin, 1996; Yeats et al., 1997) and nomenclature problems (e.g. Slemmons & McKinney, 1977; Vittori et al., 1997; Machette, 2000).

Studies on active faults in Italy began more than 25 years ago (Bosi, 1975), paleoseismological investigations have been performed since the second half of the 80s (e.g. Giraudi, 1989; Pantosti et al., 1993) and fault parameters have already been used in experiments of seismic hazard assessment (Peruzza et al., 1997; Peruzza, 1999). Databases on active faults are being prepared by ING (Istituto Nazionale di Geofisica; Valensise & Pantosti, 1999) and by ANPA (Italian Agency for the Protection of the Environment; Vittori et al., 1997).

The ING database reports information on the geometry and kinematics of seismic sources responsible for earthquakes with M≥5.5. Geometries have been partly derived by processing macroseismic data reported in historical catalogues, following the method published by Gasperini et al. (1999). This method yields sources which are represented as rectangles ('seismogenic boxes') and permits to fill the knowledge gap related to the lack of surficial geological data on active faults responsible for moderate earthquakes. Beside sources derived from seismological data, the database reports some information on the major faults gathered in the last decade through studies on active tectonics and paleoseismology.

The ANPA database reports a large quantity of information on 'capable faults' (e.g. IAEA, 1991) and therefore gathers surficial information on active structures. Any fault segment which may be responsible for a surficial displacement has been reported in the database, thus giving a final product which is substantially different from the ING map of seismic sources.

During 1998-99 a huge amount of work has been made by researchers involved in CNR-GNDT (National Group for the Defense against Earthquakes) to gather information on the surficial evidence of primary active faults in peninsular Italy. The main purpose of the project (coordinated by F. Galadini and E. Vittori) was the production of an inventory of fault surficial expressions, by gathering all data available in the literature and through new GNDT works. This was considered as the first step to produce a map of seismic sources. Unlike the ANPA database, not all the active or potentially active faults have been reported, but only those representing the surficial expressions of seismic sources related to earthquakes of M≥6.2. At the same time, the EC PALEOSIS project gave the opportunity to carry out a similar work for the central-eastern Alps, where GNDT works were only aimed at defining the seismogenic source of the 1976 Friuli (NE Italy) earthquake (Aoudia et al., 2000). Considering that the available literature on active faulting in the central-eastern Alps is not very recent, some fieldwork was carried out during the PALEOSIS project to investigate the recent activity of faults in the Adige River-Lake Garda sector (Galadini, 2000) and in the central Alps (Tibaldi et al., 1999; Onida et al., 2000a).

The present paper summarises the data on the surficial expressions of active faults in Italy, merging the information derived from the literature and from investigations carried out during the GNDT (peninsular Italy) and PALEOSIS (central-eastern Alps) projects. After the sections dedicated to the recent kinematic framework, the mapping criteria, the definition of a map legend, specific sections will summarise the knowledge on active faults of different sectors of the Italian territory. The resulting picture of the present-day knowledge will be finally discussed.

Recent kinematic framework

Different kinematic styles are co-existing in Italy as a result of the complex geodynamic processes which have conditioned the building of the Alpine and Apennine chains.

Continent-continent convergence between the Adria and the European plates during the Alpine orogeny has been responsible for the formation of the Alps and the main compressive structures affecting the different Alpine sectors (Fig. 1; e.g. Dewey et al., 1973; Castellarin, 1981; Laubscher & Bernoulli, 1982; CNR-PFG, 1983; Doglioni & Bosellini, 1987; Polino et al., 1990). Thrusts and transpressional structures are considered the main active features in the Alps (e.g. CNR-PFG, 1987; Castaldini & Panizza, 1991).

In contrast, plate divergence between the European and the Adria plates has been responsible for the tectonic evolution of peninsular Italy during post-Tortonian times. During this process, the Adria plate was involved in passive slab sinking. Backarc basins formed in the Tyrrhenian sea, and the thrust belt-foredeep system migrated towards the foreland located at the western extension of the Adria plate (Malinverno & Ryan, 1986; Royden et al., 1987; Patacca et al., 1990; Doglioni, 1991; Meletti et al., 2000a). The Apennine chain is located west of the migrating thrust fronts and is affected by mainly extensional tectonics (e.g. CNR-PFG, 1983 and 1987). Presently, two Apennine arcs can be distinguished (Fig. 1): 1) the northern arc, still affected by the flexural retreat of the lithosphere plate (Adria) and related migration of the thrust belt-foredeep system and 2) the southern arc (including the Calabrian arc), not entirely affected by the active flexural retreat of the Adria plate (Patacca et al., 1990; Meletti et al., 2000a). The end of the flexural retreat in the southern Apennines may have occurred in very recent times, i.e. during the

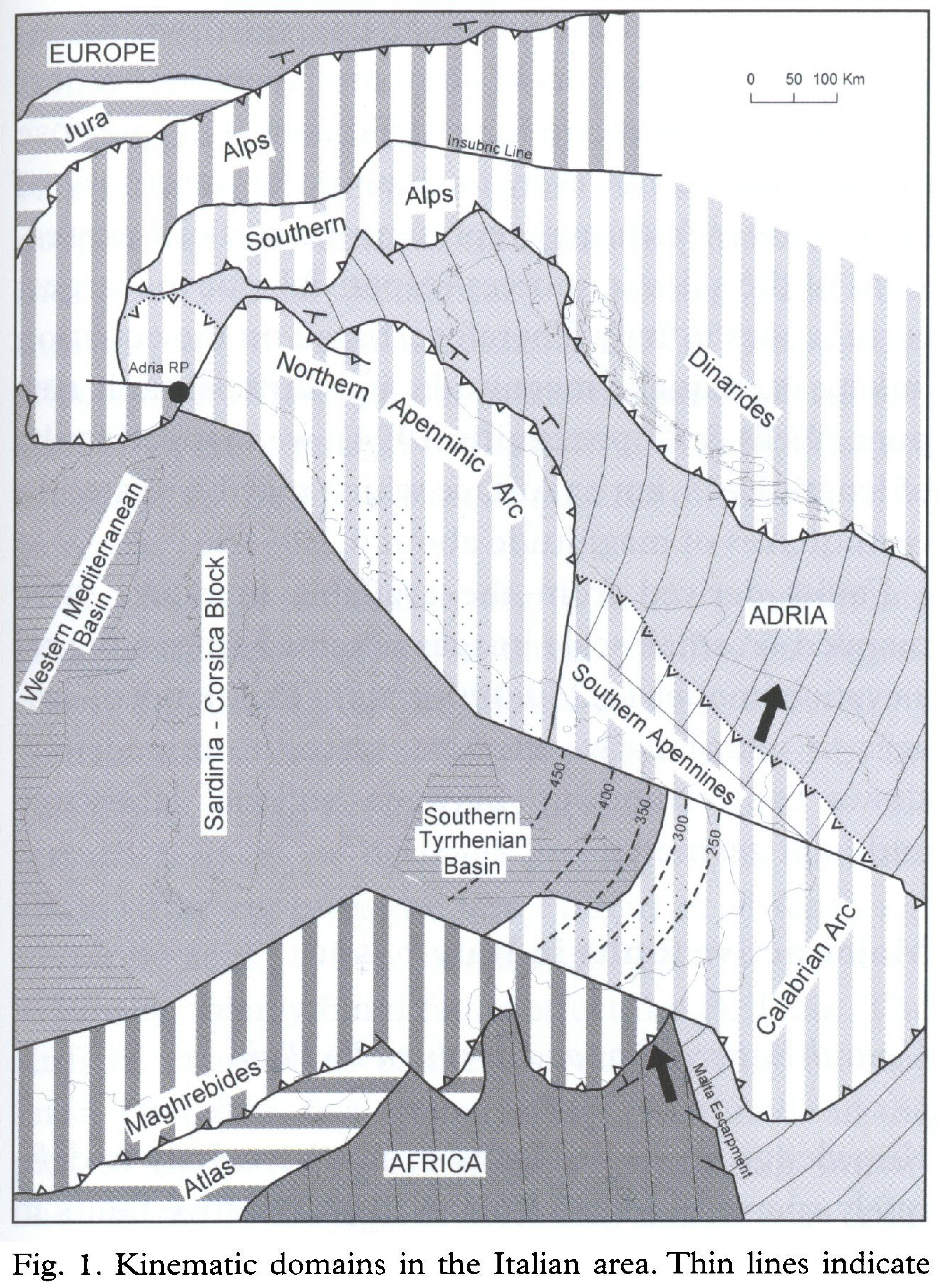


Fig. 1. Kinematic domains in the Italian area. Thin lines indicate the slip vectors of the Africa-Europe and Adria-Europe convergence. Arrows indicate the slip vectors derived from VLBI observations at the Matera (Adria) and Noto (Africa) stations; RP, rotation pole of the system. From Meletti et al. (2000a).

Quaternary (Patacca et al., 1990; Cinque et al., 1993). Since this time rift processes may have affected this portion of the chain. In contrast, the Calabrian arc is probably still experiencing a tectonic regime related to the sinking of the Ionian lithosphere and the presence of a Wadati-Benioff zone beneath the Southern Tyrrhenian Sea (Meletti et al., 2000a).

As indicated in Figure 2, the largest earthquakes (Ms≥6.2) affect the inner portion of the Apennine chain (along an approximately NW-SE trending belt), the Calabrian area, Eastern Sicily and the Central-Eastern Alps. These sectors should, therefore, be characterised by the most striking geological and geomorphological evidence of recent fault activity.

The complex structural evolution due to the abovementioned major geodynamic processes is, however, just one of the factors which renders the identification of active faults quite problematic, particularly in the Apennines. This chain, presently affected by mainly extensional tectonics, has previously experienced the deformation related to the forelandward migration of the compressive fronts. The presence of inherited structures related to the old tectonic regime (sometimes re-used during the Plio-Quaternary extensional regime, e.g. Faccenna et al., 1995) gives a complex structural mosaic hardly decipherable in terms of recent tectonic activity. Quaternary structural changes in the Apennines (not yet fully understood) are indicated by the end or beginning of activity of some faults and modifications of the fault kinematics (Hyppolite et al., 1994; Galadini, 1999; Giano et al., 2000; Cinque et al., 2000) and contribute to complicate the definition of the structural framework related to the present tectonic regime.

Mapping active faults in Italy: methodological aspects

Definition of the map legend

The chronology of the fault activity is crucial for the definition of structural schemes related to the present tectonic regime. We decided to use the Late Pleistocene-Holocene (after the last glacial maximum, about 24000-16000BP; e.g. Orombelli, 1983; Fliri, 1988; Giraudi & Frezzotti; 1997) as the chronological interval which permits to consider a fault as active. Faults which have been active during this short time interval in Italy are definitely related to the present tectonic regime. In contrast, larger Quaternary time intervals of activity do not rule out the possibility that the analysed structural features are due to older and inactive tectonic regimes.

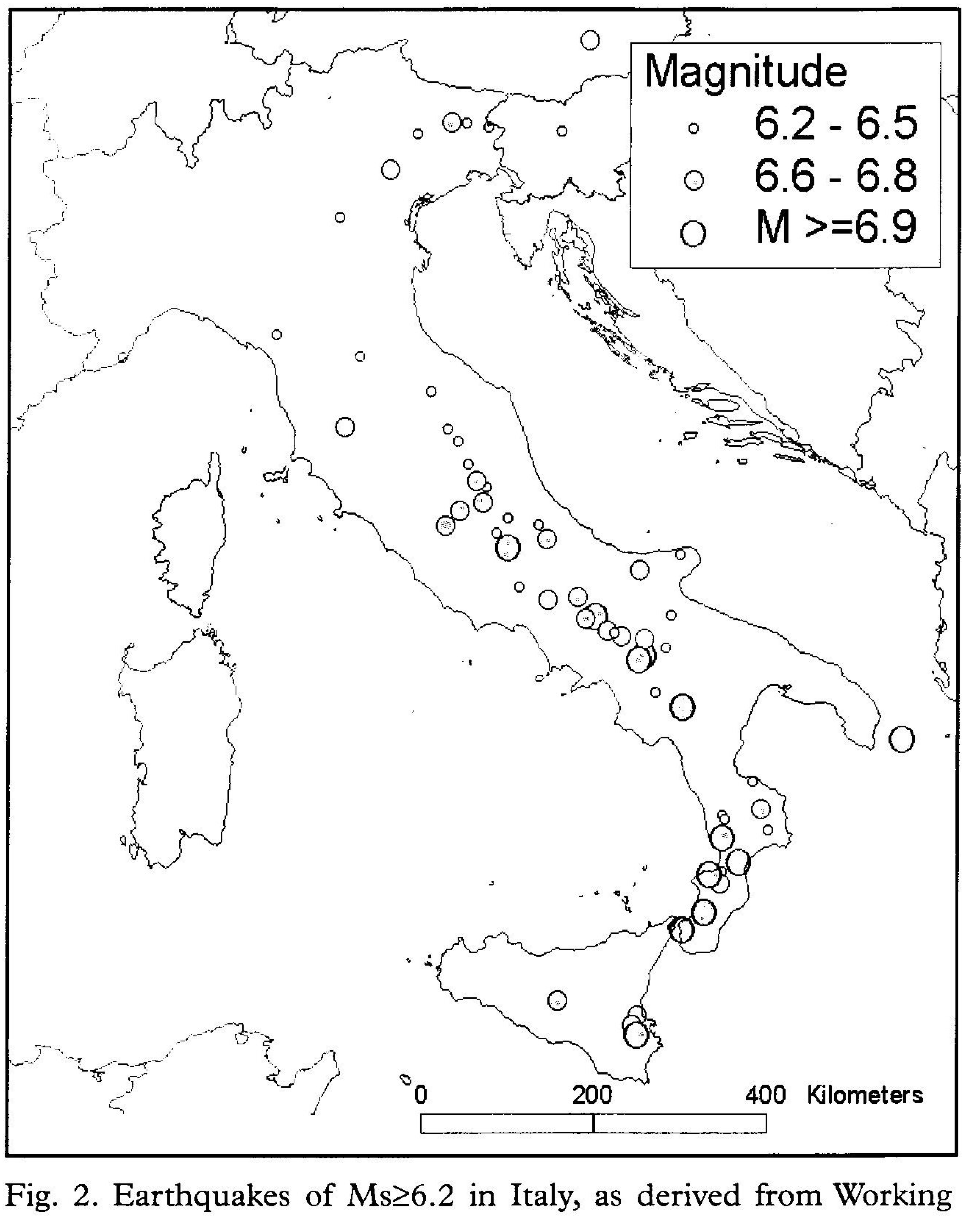


Fig. 2. Earthquakes of Ms≥6.2 in Italy, as derived from Working Group CPTI (1999).

The choice of the above-mentioned chronological interval is also related to the geological and geomorphological features of the sectors affected by recent faults. In most cases faults affect mountain slopes and are responsible for the displacement of slope deposits. It is generally accepted that the most significant morphogenetic events affecting mountain slopes in peninsular Italy (and probably at least in some Alpine sectors) occurred close to the Last Glacial Maximum in periglacial environments (e.g. Dramis, 1983; Blumetti et al., 1993; Giraudi, 1996). Therefore, thick successions of slope deposits related to the above mentioned chronological interval are significant sources of information on the fault activity during the last millennia. Mapped faults have been reported in the next sections with the symbols generally used to define the fault kinematics (Fig. 3). Different colours have also been used to summarise the available knowledge. Faults active during the Late Pleistocene-Holocene (responsible for the displacement of deposits and/or landforms related or subsequent to the Last Glacial Maximum) have been reported in red colour (Fig. 3).

We have reported faults affected by Pleistocene activity in light-blue (Fig. 3). The chronology is, however, not detailed and it is not possible to hypothesise or exclude a Late Pleistocene-Holocene activity.

We have reported faults whose recent activity is still debated among researchers in yellow (Fig. 3). In these cases geomorphic features related to recent activity are differently interpreted.

Finally, we have reported a large category of fragile structures of doubtful interpretation, i.e. in terms of kinematics, geometry or origin (tectonic vs. gravitational), in green (Fig. 3).

Mapping criteria

Data on the fault activity have been derived from the literature produced since the 70s. Only part of the available works (basically the most recent ones) directly deals with the identification of active faults (most of these works being related to paleoseismological investigations). A large number of papers is related to the reconstruction of the recent tectonic history of areas affected by Quaternary faults or to the definition of Quaternary structural frameworks. This category of works may provide some elements to attribute Late Pleistocene-Holocene activity to a certain fault.

Some attention has been dedicated to a few significant faults located in sea areas. In these cases the faults have been reported on the basis of data derived from subsurface investigation techniques (high resolution reflection seismic).

Many works on the western Alps, northern Apennines and some sectors of southern Apennines report data on few-kilometre-long structures. The purpose of our work is, however, to draw up an inventory of active faults which may represent the surficial expressions of the seismic sources responsible for the largest earthquakes in Italy. Therefore, based on the equation linking earthquake magnitude and surficial fault rupture (Wells & Coppersmith, 1994), we mapped faults of length $L \geq 11$ km at surface which may be related to earthquakes of magnitude about 6.2.

Faults derived from the available literature were mapped on small scale images obtained from a digital elevation model (1:250,000 scale). This kind of images is particularly effective since it immediately shows the relationship between regional landscape and fault geometry.

Major active faults in Italy

Central-Eastern Alps and northern Po Plain

Knowledge on active faults in northern Italy is definitely sparse. A great effort to identify active faults in northern Italy was made during the 80s, thanks to the 'Progetto Finalizzato Geodinamica', sponsored by the National Research Council. The results of this important project can be found in the Neotectonic Map of Italy (CNR-PFG, 1987), and in works at regional and local scale (Zanferrari et al., 1982; Carton & Castaldini, 1987; Forcella & Sauro, 1988; Slejko et al., 1989; Castaldini & Panizza, 1991).

After this research phase, however, only few works were produced during the 90s (particularly in the western Alps, e.g. Collo, 1994; Carraro et al., 1994) and only very recent publications testify to a renewed interest for this argument (e.g. Ferrarese et al., 1998; Malaroda, 1998; Galadini & Galli, 1999a; Sauro & Zampieri, 1999; Aoudia et al., 2000; Benedetti et al., 2000).

The identification of active faults in northern Italy is difficult, owing to: 1) the geomorphological evolution of the Alps, 2) the kinematics of the presumably active faults and 3) the presence of blind faults both in the Alpine area and the Po Plain.

The recent geological evolution of the Alps and the present Alpine landscape have been conditioned by morphogenic processes related to the Late Pleistocene glacial cycles. Therefore, landforms and deposits are generally too young to define a 'tectonic trend' for the last few hundred thousand years. Moreover, the intense erosional-depositional activity which affected the mountainous areas during and after the Last Glacial Maximum was responsible for erasing geomorphic features which may be related to the recent activation of faults.

The glacial retreat and the de-buttressing effect on valley slopes is the main cause of the widespread deep-seated gravitational movements (subsequent to the Last Glacial Maximum) involving huge rock masses (e.g. Mortara & Sorzana, 1987). The surficial effects of gravitational deformations are misleadingly similar to those related to the activation of faults (see for example the discussion at the end of the paper by Forcella, 1984).

The fault kinematics is also a factor conditioning the identification of active faults. Unlike the Apennines, a large part of the Alpine areas is affected by thrusts, whose recent activity has been defined by investigating areal geomorphic features, such as deformed terraces or drainage anomalies. In contrast, along-strike ruptures are less evident or absent (e.g. Ferrarese et al., 1998; Aoudia et al., 2000).

Finally, mainly blind faults affect the Po Plain. The surficial expressions of these structures may be very faint. Therefore, few attempts have been made in the past to search for morphologic evidence (e.g. anomalies in the hydrographic network) which may indirectly confirm the recent activation of such faults (Baraldi et al., 1980; Ciucci et al., 1999).

A summary of the available data on active faults is proposed in Figure 4 and Table 1. The reported faults are definitely fewer than those proposed in previous works (Zanferrari et al., 1982; CNR-PFG, 1987; Castaldini & Panizza, 1991) and are the result of both the critical review of the available literature and the original fieldwork made during the PALEOSIS project (Galadini, 2000). The latter has been mainly carried out in the Adige River area (faults 11 to 16) and in the Valtellina region (faults 19 and 20).
Faults have been reported in Figure 4 with different styles, due to the different degree of knowledge. Fault geometry has been precisely defined in the eastern sector (Friuli region, faults nos. 1 to 4). This is mainly due to the great attention this sector received from scientists after the 1976 earthquake (Ms=6.5 in Working Group CPTI, 1999). Therefore, a number of works reported data which are fundamental to define the geometry of active faults (e.g. Bosi et al., 1976; Martinis, 1977; Cavallin et al., 1977; Carulli et al., 1981; Zanferrari et al., 1982; Arca et al., 1985; Slejko et al., 1989; Venturini, 1990; Aoudia et al., 2000).

The structural framework changes drastically towards west (faults nos. 5 to 9). Knowledge is sparse, although many works on this sector have been published (Zanferrari et al., 1982; CNR-PFG, 1987; Castaldini & Panizza, 1991; Castellarin et al., 1992; Ferrarese et al., 1998). Moreover, no data on the segmentation are available. The information on slip rates reported in Table 1, mainly derived from Castaldini & Panizza (1991 and references therein), needs a careful re-evaluation.

Evidence of Late Pleistocene-Holocene activity is related to the Mt. Baldo thrust (no. 11; Magaldi & Sauro, 1982; Forcella & Sauro, 1988; Castellaccio & Zorzin, 1996; Galadini et al., in press) and to the Sirmione-Garda fault (no. 10; Baroni, 1985; Carton & Castaldini, 1985). Faults for which Quaternary activity is probable (but data on the Late Pleistocene-Holocene activity is lacking) have been reported in Figure 4 with numbers 12 to 16 based on the available literature (e.g. Cavallin et al., 1988a; 1988b; 1988c; Petrucci & Cavazzini, 1997) and the fieldwork made during the PALEOSIS project (Galadini, 2000).

Knowledge on active faults is more sparse in the central Alps. A recent attempt to summarise available data has been made by Onida et al. (2000b), who tried to classify the faults following the criteria proposed in Figure 3. The results of this work have been used to draw the map of Figure 4.

Only one fault has been reported which may have been affected by Late Quaternary activity, i.e. the Zebrù fault (no. 19), based on the works by Forcella et al. (1982), CNR-PFG (1987) and Castaldini & Panizza (1991).

Most of the lines drawn in Figure 4 have been classified by Onida et al. (2000b) as 'Structures of uncertain interpretation, in terms of both origin and kinematics' after a review of the mentioned works. The evidence of recent activity is probably the result of deep-seated gravitational movements, as observed in the case of the Mortirolo Pass (no. 20; Forcella, 1984; Onida et al., 2000a). Gravitational deformations also affected some secondary structures related to the Ze-

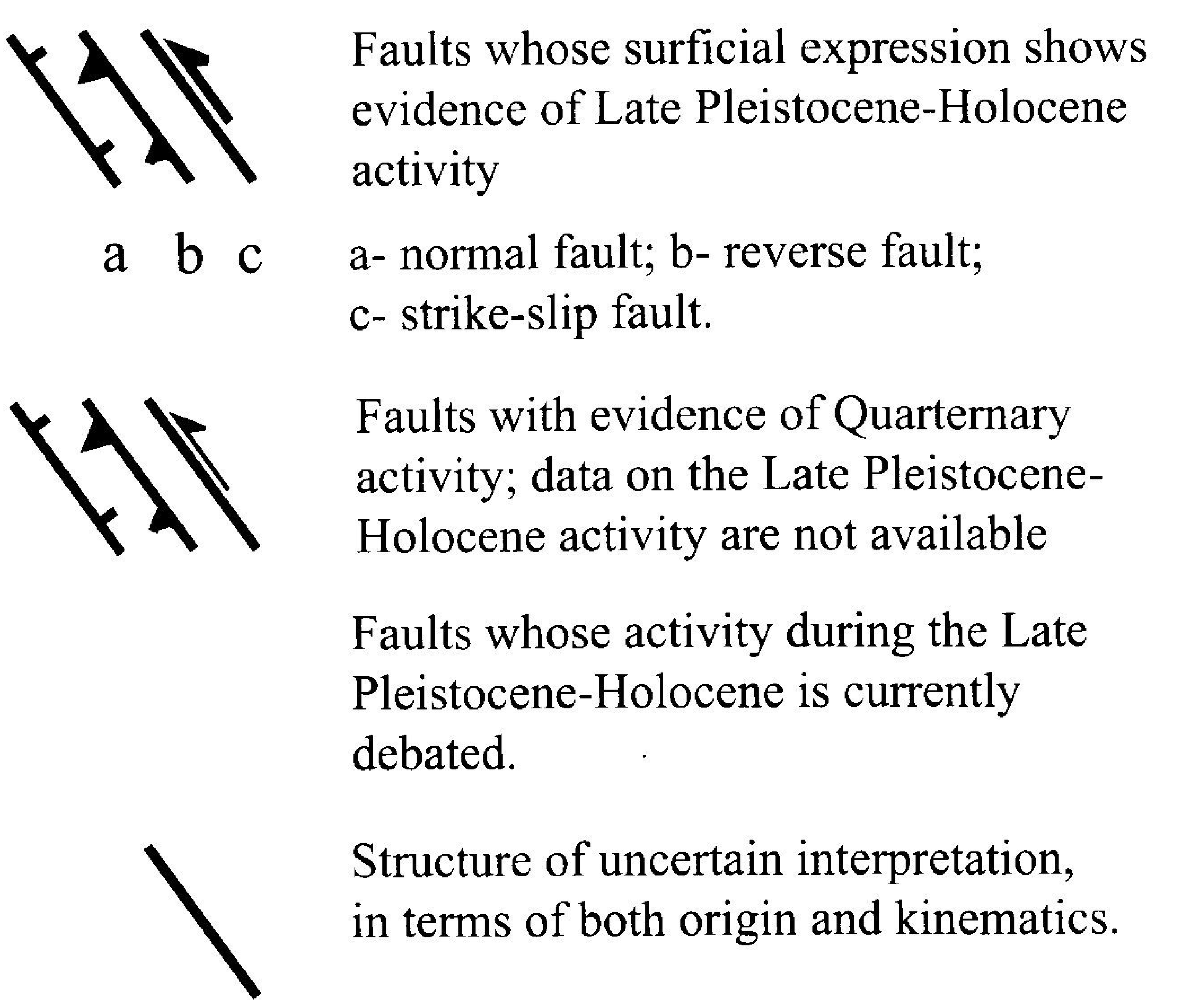


Fig. 3. Legend of the maps reported in Figures 4 to 8.

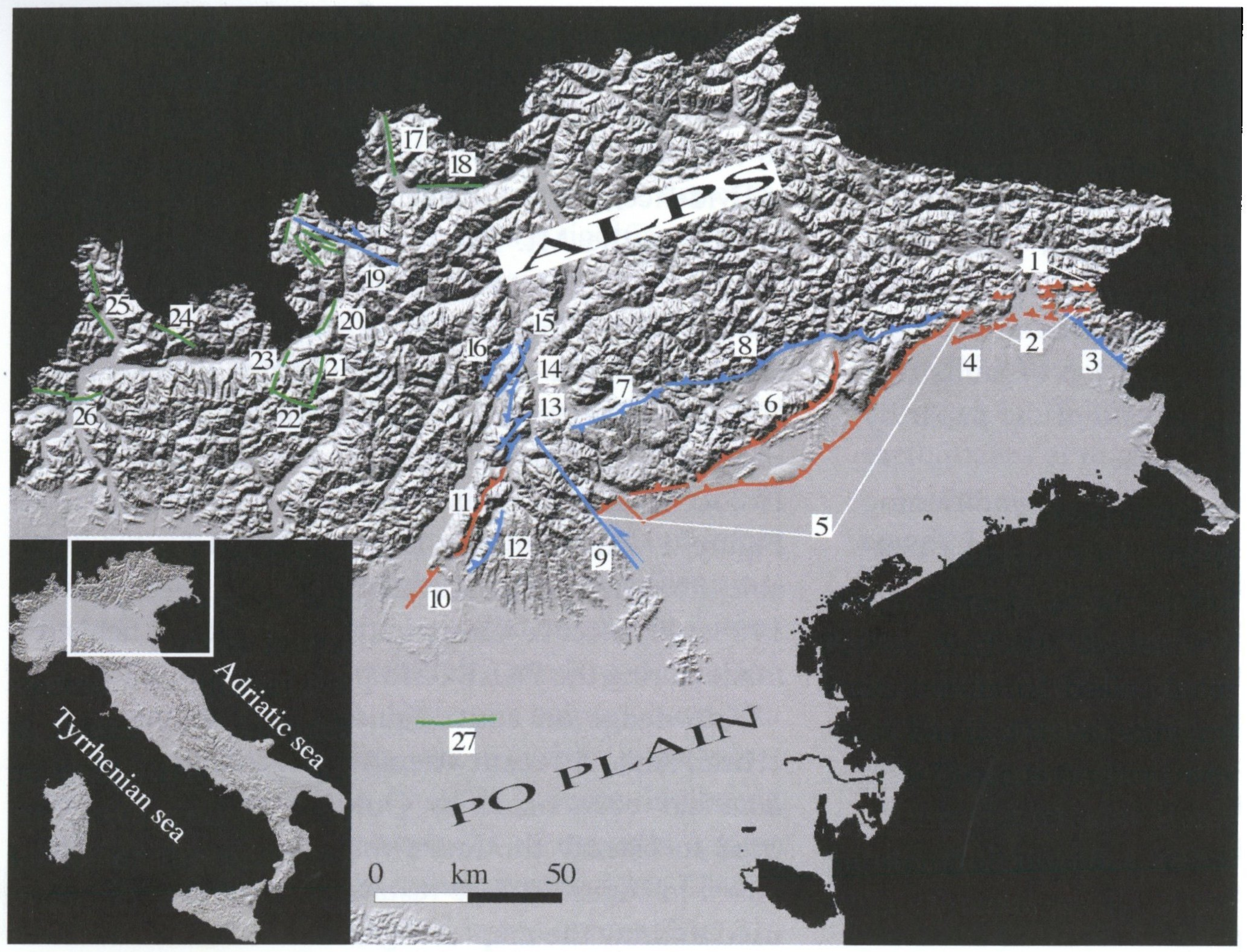


Fig. 4. Active faults in central-eastern Alps and Po Plain. Numbering of faults is the same of Table 1, first column.

brù fault (no. 19). Trenching investigations along one of these structures have shown Holocene gravitational displacements along pre-existing shear planes (Forcella et al., 1998; Tibaldi et al., 1999).

Surficial data which may be possibly related to the recent activity of buried faults in the Po Plain are only available for the Mantova fault (no. 27), based on the analysis of the present river drainage (Baraldi et al., 1980; Castaldini & Panizza, 1991).

Data on major active faults in the western Alps are absent (and for this reason western Alps are not reported in Fig. 4). Few works are available which report evidence of recent activity along short structures or faults of unknown length (Collo, 1994; Carraro et al., 1994; Giardino & Polino, 1997; Malaroda, 1998) or indicate Quaternary faulting based on displacements affecting pre-Quaternary deposits (Mantelli & Vercesi, 2000).

Northern Apennines

Knowledge is sparse also for this Apennine sector (Fig. 5 and Tab. 1). Therefore, the data given here have been derived from works mainly dedicated to neotectonics and structural geology. Moreover, the lithology of the bedrock (mainly clayey-arenaceous formations) does not help to decipher the surficial geometries of active faults, due to the rapid erasing of the tectonic landforms.

As a result of these problems, available works (Bartolini et al., 1982; Raggi, 1985; Antiga et al., 1988; Moretti, 1992; Meletti et al., 1993; Benvenuti, 1995; Cattuto et al., 1995; Benvenuti e Papini, 1997; Piccardi et al., 1997; Borghini et al., 2000) give scarce information on the activity during the Late Pleistocene-Holocene. Moreover, the definition of a major fault among those bordering an intermontane basin is usually questionable. For this reason, in some cases we preferred to report the actual traces of the fault surficial expressions in Figure 5 (faults nos. 33 to 37) and did not draw hypothetical continuous lines.

Most structures have been drawn as 'Faults with evidence of Quaternary activity; data on the Late Pleistocene-Holocene activity are not available' (Fig. 3). This testifies to the presence of a number of faults which have been clearly active during the Quaternary and have been responsible for the formation of the major intermontane basins, i.e. the Lunigiana (faults nos. 28 to 30; Bartolini et al., 1982; Bernini et al., 1993; Meletti et al., 1993; Moretti et al., 1993; Borghini et al., 2000), Garfagnana (faults no. 31; Antiga et al., 1988 and 1993; Moretti, 1992; Meletti et al., 1993), Mugello (faults nos. 32 to 34; Benvenuti, 1995; Benvenuti & Papini, 1997; Piccardi et al., 1997), Casentino (fault no. 35; Meletti et al. 1993) and Tiber depressions (faults nos. 36, 37 and related transfer fault no. 38; CNR-PFG, 1987; Cattuto et al., 1995; Boncio et al., 1998; Boncio & Lavecchia, 2000). Surficial evidence of recent activity along faults bordering basins located to the west (e.g. Florence basin, SW of faults nos. 32 and 34; Piccardi et al., 1997) needs further investigation.

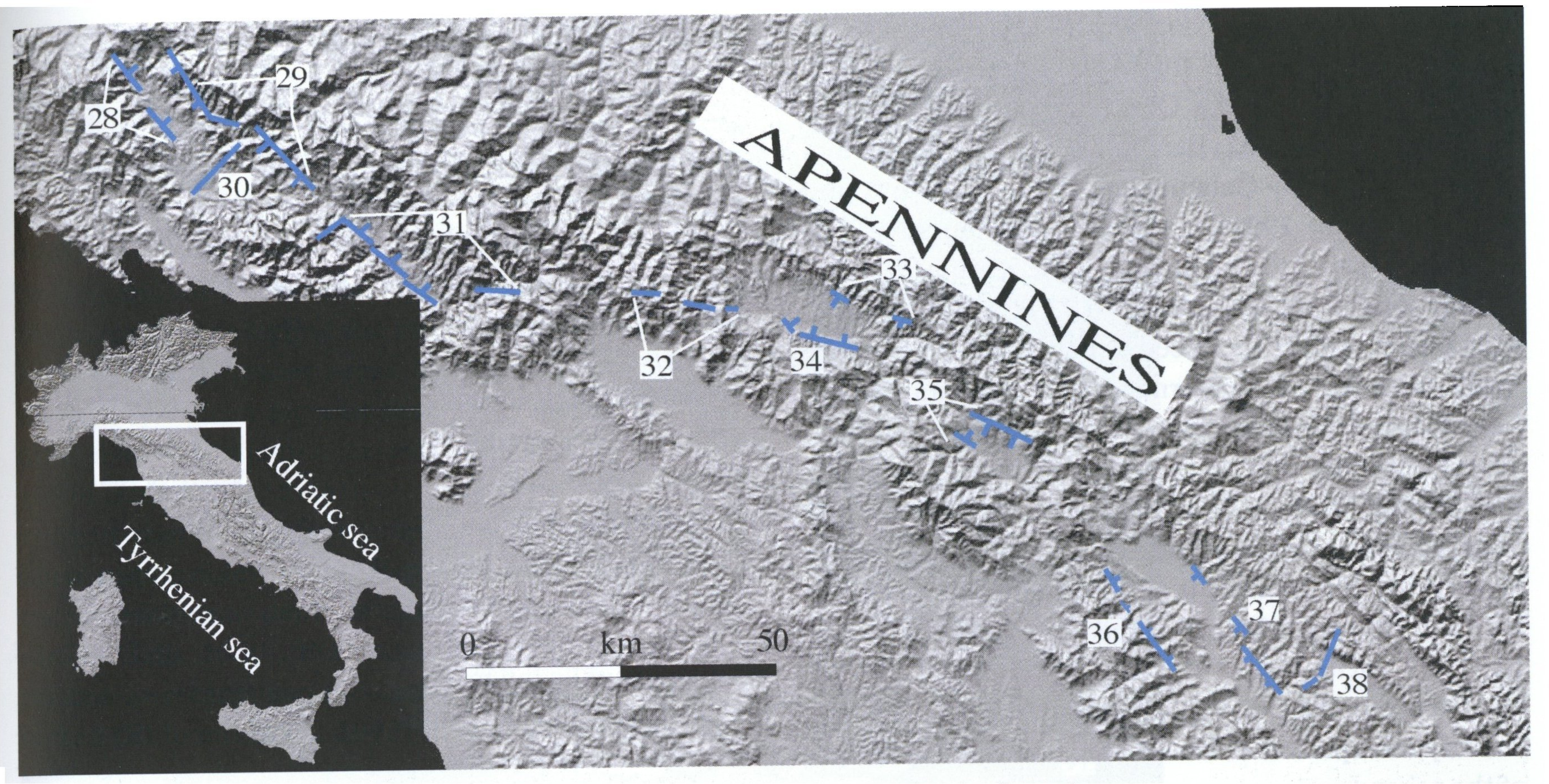


Fig. 5. Active faults in the northern Apennines. Numbering of faults is the same of Table 1, first column.

Evidence of Late Pleistocene-Holocene activity in the northern Apennines has only been indicated for few-km-long faults not reported in Figure 5 (Borghini et al., 2000).

Active faults are also expected north of the Apennine area represented in Figure 5, at the limit or below the southern Po Plain. Based on subsurface data, this area is affected by thrusts involving (in some cases) Quaternary deposits (e.g. Montone & Mariucci, 1999 and references therein). However, as already reported for the northern Po Plain, these presumably active structures are blind and clear evidence of recent activity at surface is lacking.

Table 1 indicates that no parameters are available for the faults of the northern Apennines and therefore this sector is probably the least known in terms of active faulting in Italy.

Central Apennines

Most information on active faults in Italy is related to this Apennine sector. Fault geometries and parameters necessary to define the fault behaviour are better known than in other areas and therefore some attempts have been recently made to summarise available data for seismic hazard evaluations (Peruzza, 1999; Barchi et al., 2000).

Most part of the faults reported in Figure 6 have been responsible for the displacement of Late Pleistocene-Holocene deposits and landforms (e.g. Galadini & Galli, 2000). Bedrock (carbonate) fault scarps related to recent tectonic activity have also been detected (Blumetti et al., 1993; Bosi et al., 1993). Parameters such as the slip rates or the recurrence intervals for surface faulting events are often available (Tab. 1) through paleoseismological investigations performed since the second half of the 80s by different institutions (e.g. Giraudi, 1989; Blumetti, 1995; Giraudi & Frezzotti, 1995; Michetti et al., 1995a; Pantosti et al., 1996; Galadini & Galli, 1999b).

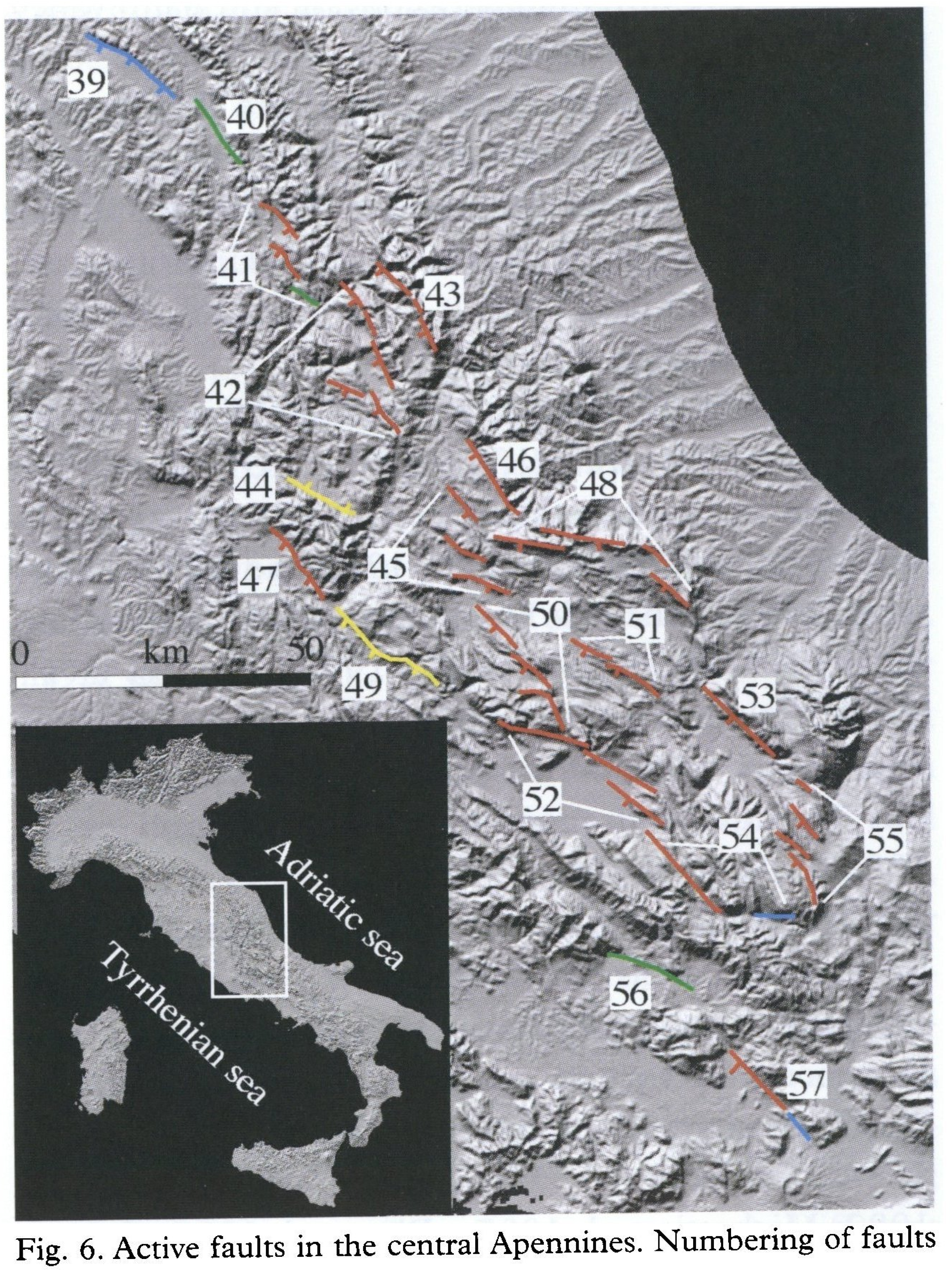


Fig. 6. Active faults in the central Apennines. Numbering of faults is the same of Table 1, first column.

Recent faults usually border Plio-Quaternary intermontane basins whose study has been fundamental for the definition of the Quaternary tectonic history (e.g. Menichetti, 1992; Bertini & Bosi, 1993; Galadini & Messina, 1994; Calamita et al., 1982, 1995 and 1999; Galadini, 1999), necessary to understand the characteristics of the present tectonic regime.

Only one fault (Gubbio, no. 39 in Fig. 6; e.g. Menichetti, 1992) has been reported as a structure 'with evidence of Quaternary activity; data on the Late Pleistocene-Holocene activity are not available'. The constraints on the geometry of two other faults (i.e. Gualdo Tadino and Sora, nos. 40 and 56) are poor, while the origin of the southernmost segment of fault no. 41 (Colfiorito) is still debated. In this case, a surficial rupture which formed during the October 14, 1997 earthquake (M_L=5.5, Amato et al., 1998) has been reported in Figure 6. This rupture was differently interpreted either as the surficial expression of the seismogenic structure or as the result of a deep-seated gravitational movement (e.g. Galli & Galadini, 1999; Vittori et al., 2000). This issue is still unsolved, although recent paleoseismological investigations showed that this coseismic feature formed along a pre-existing fault and that more displacement events affected this structure in the last millennia (Pantosti et al., 1999).

Authors have different opinions about the recent activity of two other faults (Leonessa and Salto Valley, nos. 44 and 49) and some works report these structures as being characterised by Late Pleistocene-Holocene activity (Bosi, 1975; Michetti & Serva, 1990) while other data seem to indicate a Quaternary activity prior to the Late Pleistocene (Chiarini et al., 1997; Galadini et al., 2000; Bosi, Galadini, Messina, unpublished data).

A number of works have been published on the Colfiorito fault system (no. 41) before and after the 1997-98 earthquake sequence (Mmax=6.0) (Calamita & Pizzi, 1992; Cello et al., 1997 and 1998a; Basili et al., 1998; Boncio & Lavecchia, 1999; Galli & Galadini, 1999; Meghraoui et al., 1999; Messina et al., 1999; Calamita et al., 2000; Vittori et al., 2000). Though the origin of the surficial breaks produced by this earthquake is controversial (e.g. Basili et al., 1998; Cello et al., 1998a, Cinti et al., 1999), the fact that the main shocks of the sequence were produced by this structure is undisputed.

A large amount of data is also available for the Late Pleistocene-Holocene activity of the Rieti and Mt. Vettore faults and Norcia fault system (nos. 47, 43 and 42 respectively) (Pizzi, 1992; Calamita & Pizzi, 1992; Michetti et al.,1995a; Blumetti, 1995; Coltorti & Farabollini, 1995; Cello et al., 1998b).

Data on the other faults reported in Figure 6 have been recently summarised by Galadini & Galli (2000). Almost all the faults and fault systems (nos. 45, 46, 48, 50, 52, 54 and 55) have been paleoseismologically investigated (Blumetti, 1995; Giraudi & Frezzotti, 1995; Pantosti et al., 1996; Michetti et al., 1996; Galadini et al., 1998; Galadini & Galli, 1999b and 2000; Doumaz et al., 1999; D'Addezio et al., in press), while geomorphological evidence of Late Pleistocene-Holocene activity has been reported for the Middle Aterno Valley, Sulmona and San Pietro Infine faults (nos. 51, 52 and 57; Bosi & Mercier, 1992; Vittori et al., 1995; Galadini & Galli, 2000).

As for the fault parameters, data derived from paleoseismological works indicate slip rates lower than 1 mm/yr and recurrence intervals for surface faulting events usually longer than 1,000 years.

One of the main structural features of the central Apennines is the Altotiberina fault, a low-angle detachment fault plane dipping towards E to NE and more than 120 km long (Barchi et al., 1998a and 1998b; Boncio & Lavecchia, 2000). The fault is located just east of the belt affected by the Colfiorito, Gualdo Tadino and Gubbio faults (nos. 39 to 41 in Fig. 6). Its northernmost portion coincides with fault no. 36 in Figure 5. According to Boncio & Lavecchia (2000), this structure (detected through seismic reflection profiles) represents the detachment of the above-mentioned SW-dipping faults. Although the Altotiberina fault is clearly detectable from subsurface data, it does not have a clear surficial expression with evidence of recent activity. For this reason, this regional structure has not been entirely mapped in Figure 6.

Southern Apennines and Gargano Promontory

A summary of the available data on the southern Apennine active faults has been recently proposed by Cinque et al. (2000). We used this work as a starting point and further checked the available literature. Information has been summarised in Figure 7 and Table 1.

The 'visibility' of the recent faults in this Apennine portion is strongly influenced by the lithology of the bedrock. For example, an impressive bedrock (carbonate) fault scarp is related to the Boiano fault (no. 63 in Fig. 7). The fault plane is usually exposed along the scarp and places the carbonate bedrock in contact with displaced slope deposits. In contrast, the 'visibility' of the Ufita Valley fault (no. 68) is definitely scarce, because it affects Pliocene sands and clays and Pleistocene alluvial deposits.

A problem common to the entire Apennine chain

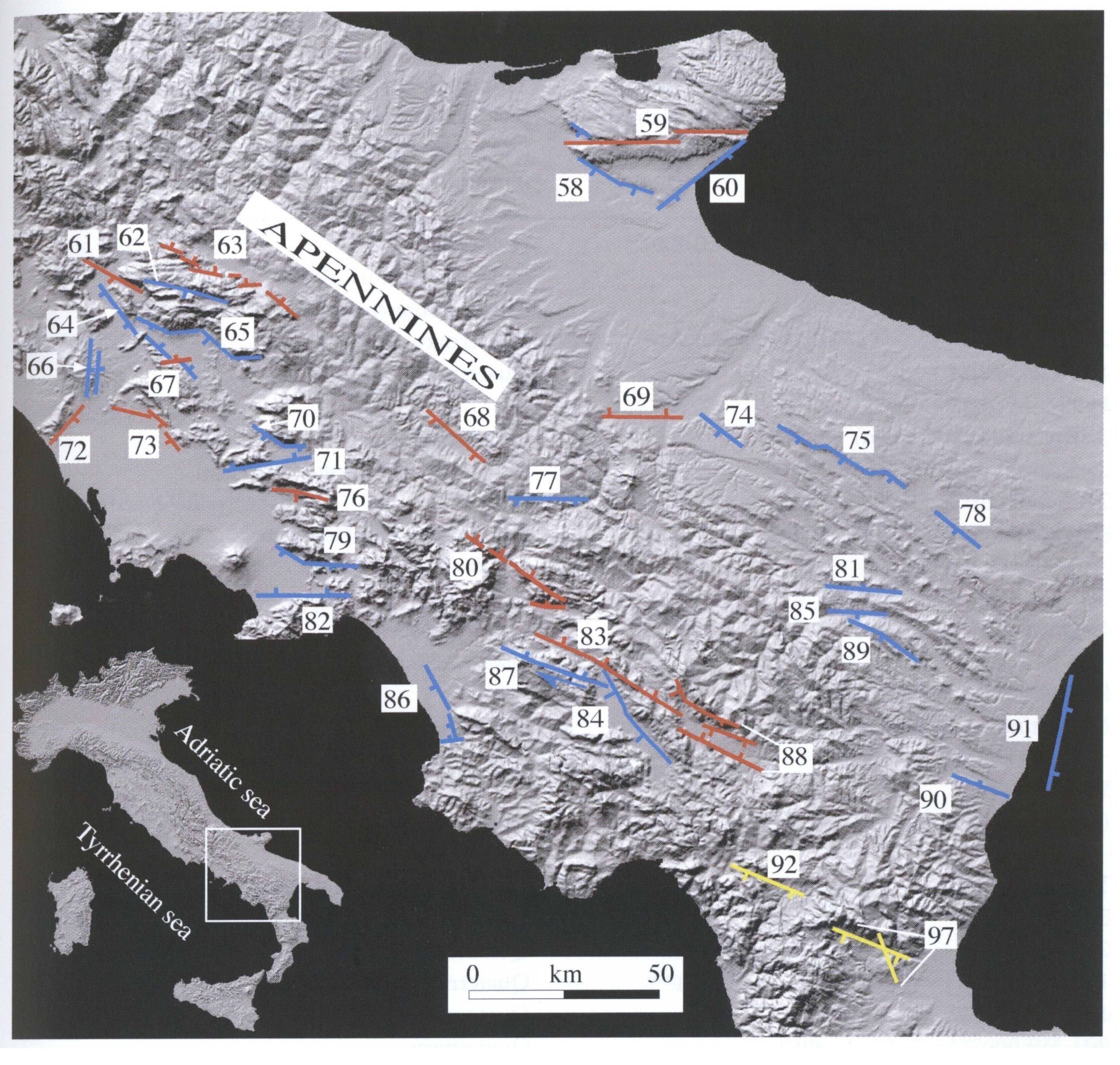


Fig. 7. Active faults in the southern Apennines and the Gargano Promontory. Numbering of faults is the same of Table 1, first column.

(whose effects are probably more evident in the southern Apennines) is related to the age of the present tectonic regime. According to works dealing with kinematics, some changes have affected the tectonic history of this Apennine sector since the beginning of the Middle Pleistocene. In particular, the flexural retreat of the lithosphere plate (located east of the Apennines, in the Adriatic Sea), responsible for the eastward migration of the entire chain, probably ended at this time (Patacca et al., 1990; Cinque et al., 1993). Some kinematic changes affected the portion of the chain where recent faults are located (e.g. Hyppolite et al., 1994; Giano et al., 2000; Cinque et al., 2000) and movements along the presently active faults are likely to have begun in the Middle Pleistocene (see for example the discussion in Pantosti et al., 1993 and Pantosti & Valensise, 1995). Therefore, considering the low slip rates (Tab. 1), active faults may have faintly conditioned the present landscape (inherited from the older tectonic regimes). This tectonic history evidently makes the identification of the active faults and the definition of the fault parameters more difficult.

Western areas close to the Tyrrhenian margin are affected by volcanic activity and by faults (nos. 72, 73 and 76) which have been responsible for the displacement of volcanic deposits dated at 36000 BP (Cinque et al., 2000). The relationship between volcanic and fault activity (i.e. the influence of volcanic paroxisms on fault displacements) has not, however, been addressed so far. Therefore the role played by the reported structures in the local seismotectonic framework is unclear.

Further problems are related to faults nos. 65 (Matese south; Brancaccio et al., 1997; Cinque et al., 2000) and 83 (Tanagro Valley-Agri Valley; CNR-PFG, 1983 and 1987; Scandone, pers. com.), for which we have no data on the segmentation. Fault no. 84 (Vallo di Diano; Ascione et al., 1992; Ferreli et al., 1995; Cinque et al., 2000) has been reported as active during the Late Pleistocene-Holocene by Cinque et al. (2000), but data on the recent activity do not seem to be conclusive. As for the fault system no. 88 (Val d'Agri; Di Niro & Giano, 1995; Benedetti et al., 1998; Giano et al., 2000), the location of the master fault (along the SW or the NE border of the Val d'Agri depression) is still debated. The Late Pleistocene-Holocene activity of fault no. 92 (Mercure Valley) is not indicated by all the available literature (Schiattarella et al., 1994; Marra, 1998; Michetti et al., 2000; Galli et al., in press; Scandone, pers. com.). Different geometries have been proposed for the master fault in

Table 1. Available parameters for the Italian active faults. Numbering of faults in the first column is the same of Figures 4 to 9.

Faults and fault systems	Length of the fault system (km)	Vertical slip rate (mm/yr)	Minimum vertical slip rate (mm/a)	Timing of the most recent activity and *chronological interval to which the slip rate is related*	Recurrence interval for surface faulting events (years)
Mt. Cuar-Mt. Cuarnan (1)	32	–	–	Holocene	–
Mt. Bernadia-Ragogna (2)	30	0.8	–	Holocene (historical)	
				Middle Pleistocene-Present	–
Cividale (3)	26	–	–	Quaternary	–
Meduna River (4)	13	–	–	Quaternary	–
Meduna River-Schio (5)	130				
	(segmentation unknown)	0.1-1	–	Late Pleistocene-Holocene	
				Early Pliocene-Present	–
Bassano-Valdobbiadene (6)	77				
	(segmentation unknown)	0.5-1	–	Late Pleistocene-Holocene	
				Middle Pliocene-Present	–
Valsugana Lineament west (7)	30				
	(segmentation unknown)	0.1-1	–	Late Pleistocene	
				Quaternary	–
Valsugana Lineament east (8)	88				
	(segmentation unknown)	0.1-1	–	Late Pleistocene	
				Quaternary	–
Schio-Vicenza (9)	52				
	(segmentation unknown)	0.1-1	–	Quaternary	
				Quaternary	–
Sirmione-Garda (10)	16	–	–	Late Pleistocene-Holocene	–
Mt. Baldo (11)	31	–	–	Late Pleistocene-Holocene	–
Mt. Pastello-Mt. Pastelletto (12)	21	–	–	Quaternary	–
Mt. Stivo (13)	15	–	–	Quaternary	–
Terlago (14)	13	–	–	Quaternary	–
Mt. Paganella (15)	20	<0.1	–	Quaternary	
				Quaternary	–
Molveno (16)	16	–	–	Quaternary	–
Venosta Valley north (17)	19	–	–	Quaternary	–
Venosta Valley south (18)	20	–	–	Quaternary	–
Zebrù Lineament and secondary structures (19)	36	0.1-1	–	Quaternary	
				Quaternary	–
Mortirolo Pass (20)	13	–	–	Late Pleistocene-Holocene	–
Mt. Bognaviso (21)	14	–	–	Late Pleistocene-Holocene	–
Pizzo Recastello (22)	15	–	–	Late Pleistocene-Holocene	–
Aprica (23)	14	–	–	Late Pleistocene-Holocene	–
Mt. Gruf (24)	14	–	–	Late Pleistocene-Holocene	–
San Giacomo Valley-Chiavenna (25)	23	–	–	Late Pleistocene-Holocene	–
Orobian Lineament (26)	21	–	–	Quaternary	–
Mantova (27)	25	–	–	Late Pleistocene-Holocene	–
Codolo-Tresana (28)	17	–	–	Pliocene-Quaternary	–
Compione-Mommio (29)	35	–	–	Pliocene-Quaternary	–
Taverone (30)	13	–	–	Late Pleistocene	–
Garfagnana (31)	23	–	–	Pleistocene	–
Mugello transfer (32)	20	–	–	Pleistocene	–
Mugello north (33)	15	–	–	Pleistocene	–
Mugello south (34)	16	–	–	Pleistocene	–
Casentino (35)	13	–	–	Pleistocene	–
Upper Tiber Valley west (36)	23	–	–	Pleistocene	–
Upper Tiber Valley east (37)	28	–	–	Pleistocene	–
Mt. Civitello (38)	13	–	–	Pleistocene	–
Gubbio (39)	21	–	–	Pleistocene	–
Gualdo Tadino (40)	16	–	–	Pleistocene	–
Colfiorito (41)	20	0.3-0.4	–	Late Pleistocene-Holocene	
				Quaternary	–

Table 1. Contenious

Faults and fault systems	Length of the fault system (km)	Vertical slip rate (mm/yr)	Minimum vertical slip rate (mm/a)	Timing of the most recent activity and *chronological interval to which the slip rate is related*	Recurrence interval for surface faulting events (years)
Norcia (42)	30	0.5-0.7[1]	0.2[2]	Late Pleistocene-Holocene *[1]Quaternary* *[2]0.1 Ma-Present*	–
Mt. Vettore (43)	18	0.5-0.6	0.25-0.3	Holocene *12000-3600 BP-Present*	≥1,650
Leonessa (44)	21	0.3	–	Early-Middle Pleistocene/Late Pleistocene(?)-Holocene(?) *Late Pleistocene-Holocene (?)*	–
Upper Aterno Valley (45)	25	0.47-0.86	–	Late Pleistocene-Holocene *31710+760 BP-Present* *23330+300 BP-Present*	–
Laga Mts. (46)	18	0.73-0.9[1]	0.3-0.36[2]	Holocene *[1]20000-30000 BP-Present* *[2]6395-6175 BC-Present*	>1,000
Rieti (47)	27	0.5	–	Late Pleistocene-Holocene *LatePleistocene-Holocene*	–
Campo Imperatore-Assergi-Mt. Cappucciata (48)	40	0.67-1		Holocene *18000-13000 BP-Present*	2,500-7,000
Salto Valley (49)	24	0.3	–	Early-Middle Pleistocene/ Late Pleistocene(?)-Holocene(?) *Holocene (?)*	–
Campo Felice-Colle Cerasitto*/ Ovindoli-Pezza** (50)	*16/**12-20	*1.1/**0.8-1.2[1] **1.2-2.3[2]	–	Holocene *18000 BP-Present **7000 BP[1]-Present **7000-10000 BP[2]-Present	**2,760-3,200
Middle Aterno Valley (51)	21	0.33-0.43	–	Late Pleistocene-Holocene *1.5 Ma-Present*	–
Fucino (52)	33	0.7-0.8[1]	0.4-0.5[2] 0.37-0.43[3]	Holocene (historical) *0.8-1 Ma[1]-Present* *19100+650 BP[2]-Present* *0.4 Ma[3]-Present*	1,400-2,600
Mt. Morrone (53)	20	–	0.5-0.66	Late Pleistocene-Holocene *0.9-1.0 Ma-Present*	–
Upper Sangro Valley (54)	20	–	0.17-0.21	Late Pleistocene *0.8-1 Ma-Present*	–
Aremogna-Cinquemiglia (55)	16	–	0.2	Holocene *10000 BP-Present*	1,000-4,000
Sora (56)	18	–	–	Quaternary	–
San Pietro Infine (57)	17	–	–	Late Pleistocene	–
Candelaro (58)	28	–	0.2	Quaternary *Quaternary*	–
Mattinata (59)	47	0.8–1.2	–	Late Pleistocene-Holocene *Holocene*	–
Manfredonia (60)	28	–	–	Quaternary	–
Pozzilli–Capriati (61)	18	0.2-0.4	–	Holocene *Middle Pleistocene-Holocene*	–
Matese Lake (62)	22	–	–	Quaternary	–
Bojano (63)	34	0.1–0.5	–	Late Pleistocene-Holocene *Late Pleistocene-Holocene*	–
Mastrati (64)	15	> 0.1	–	Quaternary *Middle Pleistocene (upper part)* *Holocene(?)*	–
Matese south (65)	41 (segmentation unknown)	–	0.5	Quaternary *Quaternary*	–

Table 1. Contenious

Faults and fault systems	Length of the fault system (km)	Vertical slip rate (mm/yr)	Minimum vertical slip rate (mm/a)	Timing of the most recent activity and *chronological interval to which the slip rate is related*	Recurrence interval for surface faulting events (years)
Roccamonfina (66)	15	~0.1	–	Quaternary *Middle Pleistocene (upper part) Holocene(?)*	–
Baia e Latina (67)	18	0.2-0.3	–	Late Pleistocene-Holocene (central segment) *36000 BP -Present (central segment)*	–
Ufita Valley south (68)	22	0.2	–	Late Pleistocene-Holocene *Late Pleistocene-Holocene*	–
Ofanto Valley (69)	20	0.5	–	Late Pleistocene-Holocene *Late Pleistocene-Holocene*	–
Mt. Taburno (70)	15	–	–	Quaternary	–
Maddaloni-Caudina Valley (71)	22	–	–	Quaternary	–
Mt. Massico (72)	13	*2-2.5 **0.2-0.5	–	Late Pleistocene-Holocene **1.45 Ma -Present* ***36000 BP -Present*	–
Volturno Plain (73)	22	*0.5-1.5 **0.2-0.5	–	Late Pleistocene-Holocene **1.45 Ma – Present* ***36000 BP – Present*	–
Matinella River (74)	12	<0.1	–	Quaternary *Middle Pleistocene – Holocene(?)*	–
Gravina di Puglia (75)	35 (segmentation unknown)	<0.1	–	Quaternary *Middle Pleistocene – Holocene(?)*	–
Avella Mts. (76)	15	0.2–0.5	–	Late Pleistocene-Holocene(?) *Middle Pleistocene – Holocene(?)*	–
Mt. Cervaro (77)	20	–	–	Quaternary	–
Santeramo in Colle (78)	14	<0.1	–	Quaternary *Middle Pleistocene – Holocene(?)*	–
Sarno Mts. (79)	22	–	–	Quaternary	–
Irpinia (80)	30	0.2-0.4	–	Holocene (historical) *Holocene*	1,470-2,245
Calciano (81)	20	<0.1	–	Quaternary *Middle Pleistocene – Holocene(?)*	–
Lattari Mts. north (82)	23	1-2	–	Quaternary *Middle Pleistocene – Holocene(?)*	–
Tanagro Valley-Agri Valley (83)	43 (segmentation unknown)	–	–	Late Pleistocene-Holocene	–
Vallo di Diano (84)	30	0.5-1.0 1.0	–	Quaternary *Quaternary* *0.4 – 0.6 Ma- Present*	–
Bilioso River (85)	15	<0.1	–	Quaternary *Middle Pleistocene – Holocene(?)*	–
Ponte Barizzo (86)	20	>0.1	–	Quaternary *Middle Pleistocene (upper part) – Holocene(?)*	–
Mt. Alburno (87)	28	–	–	Quaternary	–

Table 1. Contenious

Faults and fault systems	Length of the fault system (km)	Vertical slip rate (mm/yr)	Minimum vertical slip rate (mm/a)	Timing of the most recent activity and *chronological interval to which the slip rate is related*	Recurrence interval for surface faulting events (years)
Agri Valley (88)	34	1.0	–	Late Pleistocene-Holocene	
				Late Pleistocene-Holocene	–
Codola Plain (89)	20	<0.1	–	Quaternary	
				Middle Pleistocene –	
				Holocene(?)	–
Lower Sinni Valley (90)	15	<0.2	–	Late Pleistocene	
				Late Pleistocene – Holocene(?)	–
Taranto Gulf (91)	30	–	–	Quaternary	–
Mercure Valley (92)	20	0.5	–	Quaternary/Late	
				Pleistocene(?)-Holocene(?)	
				Holocene(?)	–
Mt. Pollino (93)	20	0.5	–	Holocene	
				Holocene	1,170
San Marco Argentano –					
Domanico (94)	35	0.5-2	–	Holocene	
				Quaternary	–
Corigliano-Rossano (95)	47	1-5	–	Quaternary	
				Quaternary	–
Tarsia-Zumpano (96)	40	0.1-0.5	–	Quaternary	
				Quaternary	–
Mt.Fuscaldo (97)	16	0.1-0.3	–	Late Pleistocene-Holocene	
				Quaternary	–
Piano Lago-Savuto Valley-					
Decollatura (98)	25	0.2-0.5	–	Late Pleistocene-Holocene	
				Quaternary	–
Marchesato (99)	33	0.5-1.5	–	Late Pleistocene-Holocene	
				Middle Pleistocene-Holocene	–
Lamezia-Catanzaro (100)	35	–	–	Late Pleistocene-Holocene	–
Catanzaro Graben south (101)	21	–	0.2	Quaternary	
				Quaternary	–
Mesima Valley west (102)	33	–	0.2	Late Pleistocene-Holocene	
				Quaternary	–
Serre (103)	37	*0.8-1			
		**0.7	–	Late Pleistocene-Holocene	
				*0.24 Ma – Present	
				**0.12 Ma- Present	–
Nicotera (104)	14	–	0.2	Late Pleistocene-Holocene	
				Quaternary	–
Serre east (105)	26	–	0.2	Quaternary	
				Quaternary	–
Gioia Tauro (106)	23	–	–	Late Pleistocene-Holocene	–
Sant'Eufemia (107)	26	0.7	–	Late Pleistocene-Holocene	
				0.12 Ma – Present	–
Cittanova (108)	48	*0.6-0.9			
		*1	–	Late Pleistocene-Holocene	
				*0.12 Ma – Present	
				**0.24 Ma – Present	–
Reggio Calabria (109)	21	0.6	–	Late Pleistocene	
				0.12 Ma – Present	–
Pellaro-Mosorrofa (110)	17	–	–	Quaternary	–
Tindari-Novara di Sicilia (111)	26	–	–	Quaternary	–
Messina – Giardini (112)	50				
	(segmentation unknown)	–	–	Holocene (historical)	–
Castellammare del Golfo (113)	13	–	–	Quaternary	–
Malta Escarpment,					
Catania Gulf (114)	26	–	2.0	Late Pleistocene-Holocene	
				0.7 Ma – Present	–

Table 1. Contenious

Faults and fault systems	Length of the fault system (km)	Vertical slip rate (mm/yr)	Minimum vertical slip rate (mm/a)	Timing of the most recent activity and *chronological interval to which the slip rate is related*	Recurrence interval for surface faulting events (years)
Malta Escarpment, northern portion (115)	25	–	–	Holocene	–
Malta Escarpment, central portion (116)	54	–	–	Holocene	–
Malta Escarpment, southern portion (117)	20	–	–	Holocene	–
Scordia (118)	12	–	–	Quaternary	–
Lentini Graben (119)	18	–	–	Quaternary	–
Climiti Mts. (120)	15	–	–	Quaternary	–
Comiso (121)	31	–	–	Quaternary	–
Avola-Noto (122)	19	0.6	–	Quaternary *0.7 Ma – Present*	–
Marina di Ragusa (123)	20	–	–	Quaternary	–
Rosolini – Pozzallo (124)	25	0.5	–	Late Pleistocene-Holocene *0.12 Ma – Present*	–

paleoseismological works related to the Mt. Pollino area (no. 97; Cinti et al., 1997; Michetti et al., 1997).

Four faults which were active during the Late Pleistocene-Holocene have been investigated in the inner portion of the Apennine chain: no. 61 (Pozzilli-Capriati; Cinque et al., 2000 and references therein); no. 63 (Boiano; Russo & Terribile, 1995; Cucci et al., 1996; Basili et al., 1999; Guerrieri et al., 1999; Corrado et al., 2000); no. 68 (Ufita Valley; Brancaccio et al., 1981; Basso et al., 1996) and no. 80 (Irpinia, paleoseismologically investigated by Pantosti et al., 1993). Other faults are located east of the chain and available data generally indicate activity during the Quaternary, without clear evidence of movements during the Late Pleistocene-Holocene (nos. 74, 75, 78, 81, 85, 89, 90; Cinque et al., 2000). Fault no. 69 (Ofanto Valley) is reported as active during the Late Pleistocene-Holocene by Cinque et al. (2000). Evidence of activity during the same chronological interval for fault no. 59 (Mattinata) can be derived from the works by Piccardi (1998) and Cinque et al. (2000).

Available fault parameters indicate a tectonic behaviour similar to that of the faults affecting the central Apennines, i.e. slip rates lower than 1 mm/yr and recurrence intervals for surface faulting events longer than 1000 years (Tab. 1).

Calabria

This sector of peninsular Italy has been affected by a recent tectonic history which is different from that of the southern Apennines. According to current kinematic interpretations, the flexural retreat of the lithosphere plate in the Calabrian area may still be active (e.g. Patacca et al., 1990).

Faults reported in Figure 8 and Table 1 often show impressive evidence of recent activity, consistent with the occurence of some of the largest earthquakes ever recorded in Italy in the last centuries (e.g. the 1783 earthquake sequence; Working Group CPTI, 1999).

The faults of the northern portion have been taken from Moretti (2000 and references therein). Faults no. 94 and 96 (San Marco Argentano-Domanico and Tarsia-Zumpano; Lanzafame & Tortorici, 1981; Carobene & Damiani, 1985) border the Crati Valley, but evidence of Late Pleistocene-Holocene activity has only been recognised along the western fault. The other faults active during the Late Pleistocene-Holocene (nos. 97 to 100) have been mapped on the basis of data collected by Moretti (2000) along structures partially reported in CNR-PFG (1987). Paleoseismological data are still lacking.

Data on the southern sector of the area represented in Figure 8 are controversial and therefore it is still impossible to define the major faults (responsible for the strong Calabrian earthquakes) among those dipping in opposite directions (nos. 102, 103, 106 and 108). The available literature reports evidence of activity during the Late Pleistocene-Holocene for all the mentioned faults (Cotecchia et al., 1986; Valensise et al., 1993; Valensise & D'Addezio, 1994; Monaco & Tortorici, 1995; Tortorici et al., 1995; Bosi & Galli, 2000). Ongoing investigations by different institutions will probably cast light on this fundamental issue.

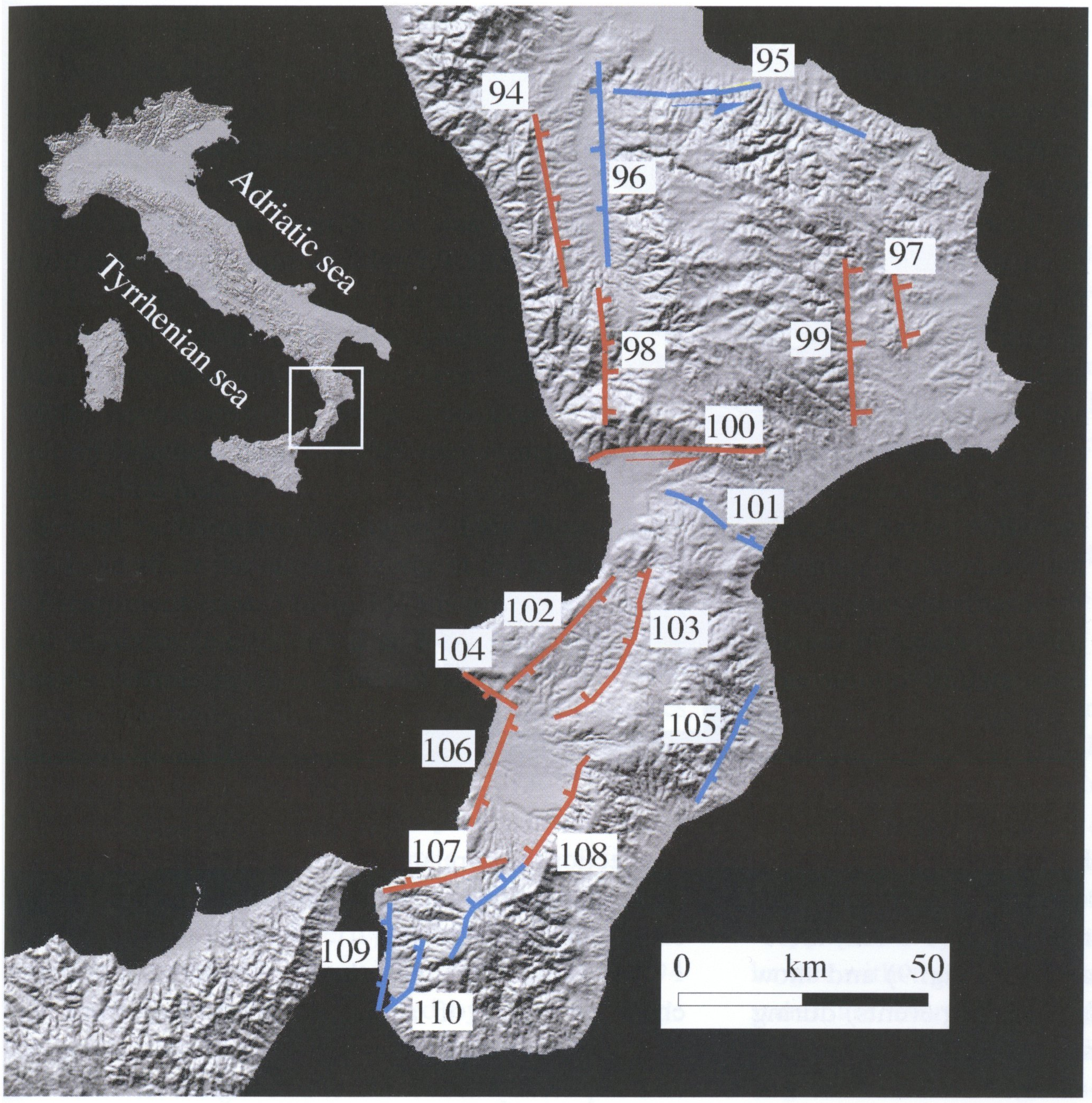


Fig. 8. Active faults in Calabria. Numbering of faults is the same of Table 1, first column.

Sicily

A summary of the available data related to the active faults of Sicily is reported in Azzaro & Barbano (2000). We further checked the available literature and produced the map of Figure 9 and summarised the data in Table 1.

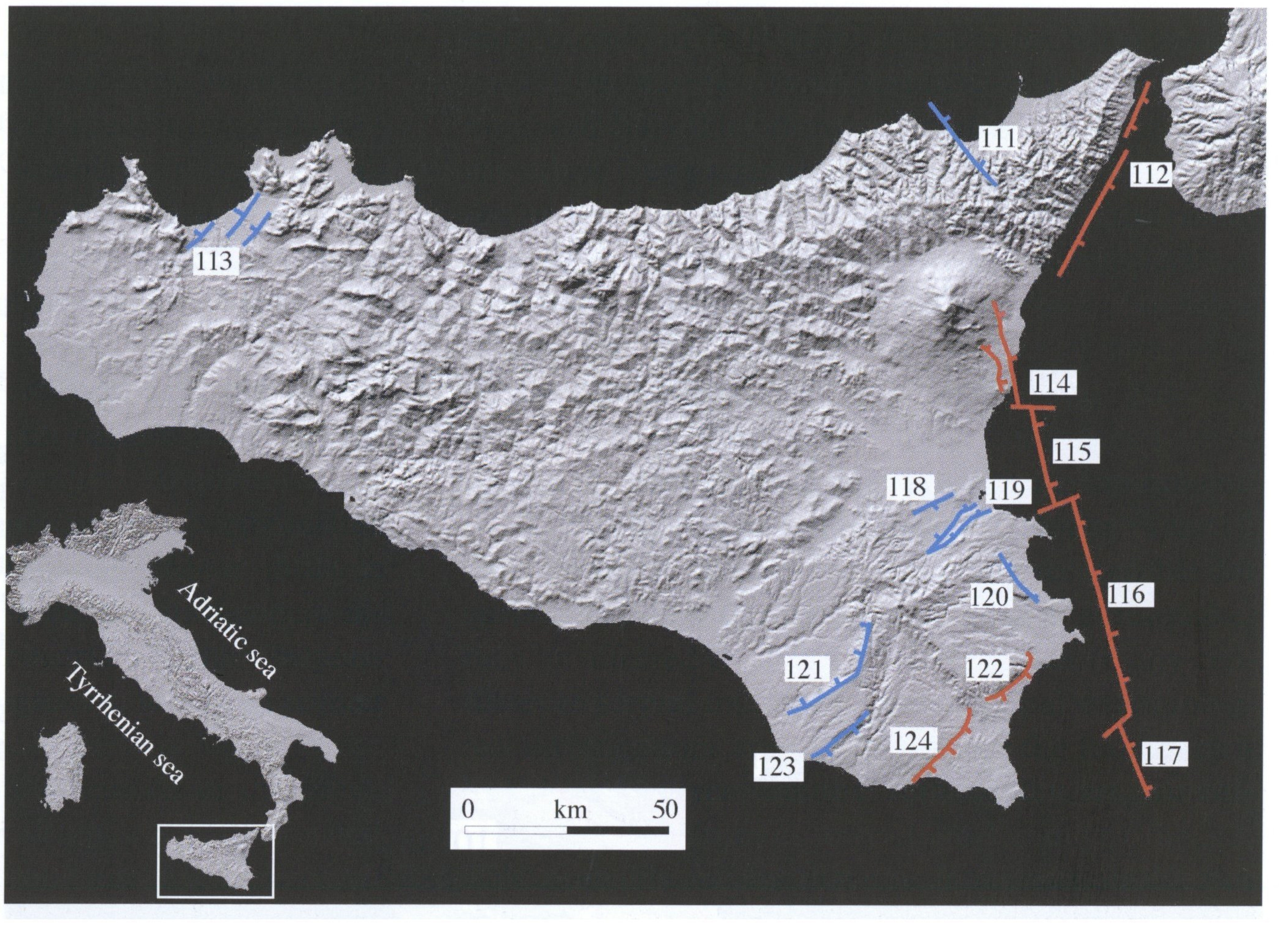
In western Sicily, Pleistocene faults (for which no data are available on the Late Pleistocene-Holocene activity) have been mapped (no. 113, Castellammare del Golfo; Mauz & Renda, 1995).

In 1968 south-western Sicily was affected by an earthquake of magnitude Ms=5.9 (Working Group CPTI, 1999). Geological works on the earthquake area did not provide conclusive data on the geometry of the fault responsible for this event (Michetti et al., 1995b; Monaco et al., 1996). The lack of surface faulting (Michetti et al., 1995b) may indicate activity along a blind fault.

Several faults active during the Late Pleistocene-Holocene affect the eastern sector of Sicily. The Malta Escarpment (nos. 114 to 117) is generally considered as active (e.g. Monaco & Tortorici, 1995). Reflection seismic profiles (Hirn et al., 1997) confirm the activity during the Holocene. This fault has been considered as a possible source of the 1693 earthquakes (Hirn et al., 1997; Sirovich & Pettenati, 1999; Zollo et al., 1999); the geometry reported in Figure 8 has been taken from CNR-PFG (1983). The Messina-Giardini fault (no. 112) has also been defined through the interpretation of unpublished reflection seismic profiles (Finetti & Del Ben, 1995; Scandone, pers. com.). The activity in the Messina Strait area is demonstrated by further geological data (Ghisetti, 1984; Valensise and Pantosti, 1992). Faults nos. 122 and 124 (Avola-Noto and Rosolini-Pozzallo) have been reported in Figure 8 on the basis of the work by Monaco & Tortorici (1995). Fault no. 111 (Tindari-Novara di Sicilia) may have been affected by Late Quaternary activity (Ghisetti, 1979; Lanzafame & Bousquet, 1997); yet, data on the Late Pleistocene-Holocene behaviour are not available. Other Pleistocene faults (nos. 118 to 121 and 123) have been reported in Azzaro & Barbano (2000).

A map of the minor active faults affecting the Mt. Etna region (northern portion of fault no. 114) is reported in Azzaro (1999). This map testifies to the large amount of data which has been collected in this

Fig. 9. Active faults in Sicily. Numbering of faults is the same of Table 1, first column.



area (Monaco et al., 1995; Bella et al., 1996; Monaco, 1997; Azzaro et al., 1998a and 1998b; Azzaro et al., 2000). The faults are generally short (1-5 km, therefore they have not been mapped in Fig. 9) and show evidence of activation (surface faulting events) during low magnitude seismic events (M=3.0-4.5).

Discussion

The state of the art

The review of the surface data on active faults gives a picture of the knowledge distribution throughout the Italian territory. Knowledge is, in our opinion, far from being satisfactory.

Considering the high quality and amount of the data on the central Apennines, this sector probably represents an exception. In the southern Apennines, Calabria and Sicily, the geometries of active or possibly active structures have been reported, but little is known in terms of fault parameters. Knowledge is also poor on the geometrical aspects of the northern Apennine faults and it is sparse and generally related to old works as regards central-eastern Alps and the Po Plain.

The reason for such inconsistency is partly related to research organisation problems. Most research groups are, in fact, located in central Italy, where investigations on active faults began more than 25 years ago (e.g. Bosi, 1975). Investigations have been scarcer or even absent in other areas.

Further problems (already discussed in the previous sections) are related to the difficulties in performing investigations on active faults due to the geological setting and history.

A significant factor hindering the identification and characterisation of active faults derives from the lithology of the surficial formations affected by the active or possibly active faults. The high level of knowledge in the central Apennines and the lack of knowledge in the northern Apennines are also the effect of a more reliable use of geomorphological methods in areas where the bedrock is made of carbonate rocks (central Apennines) instead of clayey-arenaceous successions (northern Apennines).

Moreover, the distribution of the moderate-large earthquakes in Italy (Fig. 2) indicates a magnitude trend decreasing from southern-central Italy to northern Italy. Therefore, the surficial expressions of the active faults affecting the northern Apennines and the Alps may be fainter than those affecting the rest of peninsular Italy as a response to the lower surficial coseismic displacements.

Kinematic aspects

Kinematic data indicate that Italian faults are generally affected by slip rates lower than 1 mm/yr (Tab. 1). This probably means that the faults responsible for surface faulting during moderate-large earthquakes may be affected by long recurrence times (many centuries to several millennia). Although paleoseismological investigations are still sparse over the Italian territory, long recurrence intervals (>1,000 years) for surface faulting events have been paleoseismologically demonstrated for the central Apennine faults (Galadini and Galli, 2000 and references therein) and for the Irpinia and Mt. Pollino faults in the southern Apennines (Pantosti et al., 1993; Michetti et al., 1997; Cinti et al., 1997). This behaviour may therefore be typical of the faults affecting central-southern Italy.

Data on the overall deformation in the areas affected by the mapped faults may permit to evaluate the role of seismogenic processes in regional tectonics. However, extended GPS measurements (giving precise information about the overall deformation) only began few years ago and available data are preliminary.

Data on the ongoing overall deformation in the central Alps indicate a shortening of 3 mm/yr in NW-SE direction, resulting from GPS measurements in the second half of the 90s (Caporali & Martin, 2000). Therefore, considering that no strong earthquakes have affected the Alps in recent times, the seismogenic deformation related to the activation of the mapped major faults (to which slip rates lower than 1 mm/yr may be related) represents a minor fraction of the overall deformation.

GPS data for the southern part of the central Apennines indicate an extension of 6±2 mm between 1994 and 1999 in an area not affected by moderate-large earthquakes in the last years (D'Agostino et al., in press). Extension related to the major normal faults and derived from the estimated surficial coseismic slip has been assessed in 0.7-1.6 mm/yr across the Apennine chain (Galadini & Galli, 2000). A comparison between GPS data and 'coseismic' extension indicates that the portion of the overall deformation not related to large magnitude earthquakes may be comparable to that resulting from the coseismic displacement along the major faults.

Implications for seismic hazard assessment

Available geological information on the central Apennines (were the most complete dataset is available) has strong implications in seismic hazard evaluations. Galadini & Galli (2000) compared the active faulting framework of the central Apennines (Fig. 6) with the seismological data (earthquakes with M>6 occurred since 1000 AD) derived from historical catalogues (Boschi et al., 1995 and 1997; Camassi & Stucchi, 1997; Working Group CPTI, 1999). Earthquakes were associated to specific faults on the basis of the available paleoseismological data, historical reports on the occurrence of surface faulting and the distribution of the damage. This permitted to hypothesise that faults nos. 43, 46, 48, 51, 53, 54 and 55 (Fig. 6) have probably been dormant in the last 1,000 years (Galadini & Galli, 2000). Paleoseismological and archaeoseismological data indicate that for two of these faults (43 and 53 in Fig. 6) the elapsed time since the last fault activation may be very large (≥1,650 years and about 1,800 years for nos. 43 and 53, respectively). The high level of hazard associated to the mentioned faults has been indicated by the seismic hazard assessment tests performed by Peruzza (1999), who used linear structures (faults) and non-poissonian processes for probabilistic hazard evaluations.

However, as previously reported, the amount of geological information on the faults of the other Italian sectors is not comparable with that available on the central Apennines. Active faulting data are too sparse for seismic hazard analyses similar to those performed in the central Apennines.

The importance of the available data is, however, demonstrated by the attempts to propose new seismogenic zonations of the Italian territory (Stucchi et al., 2000), propaedeutic to traditional hazard evaluations (e.g. Cornell, 1968). Meletti et al. (2000b) associated a maximum expected magnitude to each fault, through the application of the equation by Wells & Coppersmith (1994) linking the fault surficial rupture length with the earthquake magnitude. Seismogenic zones are therefore being drawn as polygonal domains, each affected by the same kinematic regime (e.g. normal faulting) and by seismic sources for which the maximum expected magnitude is the same (Stucchi et al., 2000). This procedure should permit to define seismogenic zones closely related to the active tectonic processes.

Conclusions

The available information on the active faults affecting the Italian territory has been reviewed in order to define the state of the art on this issue. Knowledge is not homogenously distributed throughout Italy's active zones. A detailed knowledge of the fault geometry and kinematics is only available for the central Apennines, as a result of investigations which started more than 25 years ago. Information is less abundant in southern Italy, where detailed investigations (including paleoseismology) have been made along few of the faults considered as active. In contrast, evidence of active faulting is sparse in the northern Apennines, the Po Plain, and the Alps.

Paleoseismologically inferred data on the age of displacement events indicate that the recurrence interval of surface faulting episodes along a specific fault is longer than 1,000 years in the central and southern Apennines. Available slip rates are generally lower than 1 mm/yr in the different active structural domains (extensional in the Apennines, compressive in the Alps). This may indicate long recurrence intervals (>1,000 years) for large magnitude earthquakes per fault also in domains that have not been paleoseismologically studied.

In terms of seismic hazard assessment the amount of active tectonic data in the central Apennines can contribute to probabilistic hazard evaluations involving the use of seismogenic sources and related kinematic parameters (recurrence interval, elapsed time since the last fault activation, slip rate). Some attempts have already been made which show high hazard levels for some faults quiescent in the last 1,000 years (Peruzza, 1999; Galadini & Galli, 2000; Barchi et al., 2000). The information available for the rest of Italy is having a prominent role in the drawing of a new seismogenic zonation, propaedeutic to seismic hazard evaluations with traditional computational procedures (Stucchi et al., 2000; Meletti et al., 2000b).

As for the development of the geological research on active faults, the proposed review clearly indicates the areas affected by the largest knowledge gaps (northern Apennines, Po Plain, Alps), urgently needing investigations. In contrast, studies on active faults should be reduced in the central Apennines.

Acknowledgements

The GNDT researchers involved in investigations on active faults in Italy collected and published data on active tectonics in specific areas. The EC financed investigations on central-eastern Alps (ENV4-CT97-0578). The merge of the available data has permitted the drawing up of the present paper summarising the knowledge on the entire Italian territory. We are grateful to P. Scandone (University of Pisa) for the discussions on the Italian active tectonics and the useful suggestions during the preparation of the maps. We are also grateful to A. Cinque (University of Napoli) who dedicated some days to discuss the Quaternary tectonics of the southern Apennines. The review by G. Michel and S. Vandycke contributed to improve the paper.

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