The Database of Individual Seismogenic Sources (DISS), version 3: summarizing 20 years of research on Italy's earthquake geology

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Abstract

This paper describes the main characteristics, the evolution, and the current structure of the Database of Individual Seismogenic Sources (DISS) and particularly of its most recent release (version 3.0.2). The Database contains the results of the investigations of the active tectonics in Italy during the past 20 years. The first two sections of this paper document the recent evolution in mapping and archiving Italian active fault data in relation to important achievements in the understanding of Italian tectonics, some of which were spurred by significant earthquakes. The central sections describe the current structure of the Database, the reasons for its assumptions and data categories, its current contents, its evolution through several years of improvements. The last section describes how the current contents of the Database correspond with the existing strain and stress data available from focal mechanism, borehole breakout, and GPS data for the whole of Italy. The Database supplies a fresh and unified view of active and seismogenic processes in Italy by building on basic physical constraints concerning rates of crustal deformation, on

the continuity of deformation belts and on the spatial relationships between adjacent faults, both at the surface and at depth.

1. Introduction: 20 years of Earthquake Geology in Italy

The Database of Individual Seismogenic Sources (DISS; Fig. 1) is a repository of geologic, tectonic, and active fault data for the Italian territory. The Database highlights the results of several decades of research work, with special emphasis on data and conceptual achievements of the past 20 years. This paper intends to present an overview of the Database, both in terms of structure and data content, and can not substitute for a complete in-depth visit of its web site (www.ingv.it/DISS).

To understand the process that led to the development of DISS we will first recall a few essential facts in the recent course of earthquake geology in Italy (below in this Section) and how the need for systematically organized tectonic information has developed in recent years (Section 2). We then describe the current structure of the Database (Section 3) and its improvements over previous versions (Section 4). Finally, we briefly discuss how DISS may contribute to an improved understanding of the past and current geodynamics of the Italian peninsula.

Until about 20 years ago in most European countries, the main contribution of the geological community to assessing seismic hazard usually included the identification of "Quaternary faults" (or even "Neotectonic faults") and the preparation of fault maps, generally at regional if not national scale. Italy was no exception. In the early 1980s, a large group of geologists from various disciplines compiled a series of maps culminating in the "Structural model of Italy" [*Bigi et al.*, 1983] and the "Synthetic structural-kinematic map of Italy" [*Bigi et al.*, 1989], representing a massive yet careful effort to map active tectonic features for the whole of Italy. These maps formed a fundamental basis for a large number of applications in the earth sciences but were generally unfit for seismic hazard purposes because they contain potential seismogenic sources along with probable inactive faults. In addition the maps can not be used to infer earthquake rates and magnitude distributions. They were largely unsuitable also in deterministic applications, as they generally did not provide the 3D geometry and extent of earthquake sources that are potentially relevant for the site or infrastructure to be protected. For all these reasons, traditional fault maps were largely ignored by Italian seismic hazard practitioners, who resorted to a combination of historical seismicity catalogues and loosely drawn "seismogenic areas" encircling the epicenters of the largest earthquakes.

Things took a sharp turn starting with the middle of the 1980s, when various independent groups started investigating the catastrophic yet geologically obscure 1980 Irpinia earthquake (Mw 6.9), one of the largest Italian earthquakes of the XX century. Four years after the earthquake *Westaway and Jackson* [1984] published the first account of indisputable primary surface faulting following an Italian earthquake. Meanwhile, *Serva et al.* [1988] conducted a detailed investigation of surface ruptures generated by the 1915 Avezzano earthquake, which included field mapping and direct interviews of survivors. In addition, *Ward and Valensise* [1989] confirmed normal faulting kinematics and the extent of the earthquake rupture using historical leveling observations. The 1908 Messina Straits earthquake (Mw 7.2) also was investigated using leveling observations by *Capuano et al.* [1988] and several other workers.

Following the positive identification of a limited number of surface breaks, the development of a simplified fault segmentation model for the most active portion of southern Italy by *Pantosti and Valensise* [1989] marked the onset of Paleoseismology in Italy. *Pantosti et al.* [1989, 1993] uncovered a record of at least four 1980-type paleoearthquakes from trenching at different sites along the surface rupture. *Giraudi* [1989] trenched the Aremogna fault in the central Apennines, and found evidence for prehistoric surface rupture of a previously unrecognized major tectonic feature. Paleoseismology, which became standard practice, yielded the first direct observations of repeated earthquakes to suggest surprisingly long (ultramillenary) recurrence intervals for most Italian faults. Overall, the 1990s recorded a spectacular growth in direct investigation of fault scarps on young sediments, reconstruction of the near-fault landscape evolution, and the analysis of the long-term deformation of young geological markers (e.g., Late Pleistocene sediments and fluvial or coastal terraces) at a scale of a few to tens of kilometers. This trend led to the development of new strategies for paleoseismological investigation: for instance, *Valensise and Pantosti* [1992] used coseismic displacements and the total amount of deformation of a Late Pleistocene marine terrace to infer an average repeat time for 1908-type earthquakes in the Messina Straits.

The early 1990s were, thus, a time of optimism for the Italian active tectonics community that was slowly becoming an earthquake geology community. Investigators focused on more and more faults, both previously known and newly identified. However, the basic knowledge of seismogenic faults in Italy was still very spotty and recurrence intervals from trenching or other techniques too few and too scattered for any use in the seismic hazard assessment procedure. All throughout the 1990s most practitioners continued to ignore the potential impact of the geological community, not only in Italy but everywhere in Europe, except for specific applications in the deterministic assessment of seismic hazard.

In 1996 the Italian GNDT (Gruppo Nazionale per la Difesa dai Terremoti) launched a new countrywide effort to systematically identify end characterize seismogenic faults (sub-task 5.1.1 "*Zone sismogenetiche e probabilità degli eventi associati*", coordinated by P. Scandone and M. Stucchi: see *Galadini et al.* [2000a]). This effort was initiated to provide the raw data for more geology-based assessment of the earthquake potential in a new seismic hazard map of Italy. Unfortunately, all subsequent seismic hazard analyses did not utilize the new geologic data (e.g., *Albarello et al.* [2000]; *Akinci et al*. [2004]) or retained loosely drawn seismic source zones based on large-scale geologic data (e.g., *Gruppo di Lavoro MPS* [2004]).

The late 1990s and early 2000s was also marked by the development of "fault catalogues" and "fault databases", extensive compilations that attempt to blend conventional tectonic and fault information with paleoseismological results and, in some cases, with historical and instrumental earthquake data. Unfortunately, during the same time Italy and its conterminous regions experienced a number of significant (M 5.5 – 6.0) earthquakes generated by blind faults (e.g., 26 September 1997, Colfiorito, Mw 5.7 and Mw 6.0; 9 September 1998, Lauria, Mw 5.7; 12 April 1998, Bovec-Krn, Mw 5.7; 6 September 2002, Palermo, Mw 5.8; 31 October and 1 November 2002, Molise, Mw 5.7 and Mw 5.7; 29 March 2003, Jabuka Island, Mw 5.5). In fact, out of 13 XX century earthquakes larger than Mw 6.0 [*CPTI Working Group*, 2004], positive evidence for surface faulting exists only for the 13 January 1915, Avezzano (Mw 7.0) and the 23 November 1980, Irpinia (Mw 6.9) events, although all of them certainly qualify as "morphogenic earthquakes" (*sensu Caputo* [2005]). These circumstances brought to light that fault compilations based on near-fault geological observations will necessarily be incomplete; therefore as much as 60-70% of the potential earthquake sources in Italy, and nearly 100% in large portions of central and northern Europe, will most likely be missed.

The earliest attempt to document information on seismogenic sources is the Database of Italy's Seismogenic Sources, version 1.0 (DISS 1.0), a compilation prepared by scientists of Istituto Nazionale di Geofisica (ING; now INGV) and presented in July 2000 [*Valensise and Pantosti*, 2000; 2001a] (Fig. 2). DISS 1.0 blended seismogenic sources identified by geological and geophysical data with sources based purely on instrumental and macroseismic data. Meanwhile, GNDT completed sub-task 5.1.2 "*Inventario delle faglie attive e dei terremoti ad esse associabili*" (coordinated by F. Galadini and E. Vittori: see *Galadini et al.* [2000a, 2000b, 2001]; *Meletti et al.* [2000]) (Fig. 3). This effort used geologic evidence to map and characterize a large number of active faults, but did not attempt to provide a segmentation model. ITHACA [*Michetti et al.*, 2000], another database prepared by scientists with ANPA (Agenzia Nazionale Protezione Ambiente; now APAT), was also essentially geology-based and focused specifically on faults that are expressed at the surface and the associated potential hazard for infrastructures and critical facilities (Fig. 4).

The database we describe here provides more accurate, better organized, and more quantitative descriptions of the seismogenic potential of faults in Italy. Recently, the international geological community finally has been acknowledged as a major participant in seismic hazard assessment and risk mitigation strategies. However, our data is limited and XXI century Quaternary geologists must adopt a multidisciplinary approach. Cooperation with marine geologists, experts in the interpretation of subsurface data, seismologists, and geodesists will help to identify elusive earthquake sources in the future. This paper describes how this goal can be achieved by (a) exploiting a broader range of geological observations, including those that apparently lie very far from conventional active faulting and paleoseismology studies (e.g. gravimetric data, coastal uplift data, drainage anomalies, anomalous crustal fluids); and (b) by developing new forms of incorporating strictly geological observations and all other evidence of tectonic activity and secular strain accumulation.

2. The Database: systematic information for supporting multiple seismic hazard applications

In the previous section we briefly discussed 20 years of fault mapping efforts in Italy. The investigation of active faulting and characterization of seismogenic processes in Italy is a difficult and controversial task, probably more difficult than in many other earthquake-prone countries. Paradoxically, progress has been slowed also by the exceptional quality and quantity of historical data, which prevented the Italian geological and seismological communities from collaboration. As a consequence, the study of seismogenic sources in Italy has been traditionally based on the analysis of felt reports of historical earthquakes. The historical approach provides a satisfactory mapping of point-sources, which generally reveal the main active tectonic trends, and is good at constraining the size of the largest historical earthquakes. However, historical data alone do not provide information on the physical properties of a specific earthquake source (e.g. length, width, dip, strike, etc.) , and hence can not be used to calculate ground shaking scenarios.

The difficulties inherent in the identification of active faults and seismogenic sources in Italy have been extensively discussed [*Galadini et al.*, 2001; *Valensise and Pantosti*, 2001b; *Valensise et al.*, 2003] and will not be repeated in this paper. Here we wish to emphasize that DISS was planned and designed in the second half of the 1990s to highlight the experience gained in the previous decade and summarized in Section 1. It was developed as a permanent interface between the data providers (geologists and seismologists who identify and characterize seismogenic sources) and the final users (a vast category that includes other Earth scientists, earthquake engineers, planners, and insurers).

DISS is an original tool that was developed in Italy by Italian scientists (INGV). Nevertheless, it builds on ideas developed in the most earthquake-prone countries worldwide and compares well with similar ongoing efforts by colleagues from Japan (AIST), USA (USGS), and New Zealand (GNS), who all developed their own database of active faults (Tab. 1). The compilers of DISS are establishing permanent links with their counterparts in these countries, on the grounds that they aim at similar goals and they all operate within institutions that are strictly government-based or are funded with public resources. These databases have several features in common. They are developed by national scientific institutions and cover the entire country; tend or aspire to completeness, explicitly or implicitly, inside the area they cover; exploit to the maximum possible extent the available scientific literature; have been, or are intended to be, used in the assessment of seismic hazard at national and local level. There are indeed several differences among them. They use different minimum magnitude thresholds (if any); define different maximum ages for fault activity (if any); place different emphasis in reconstructing the history of movements on identified faults; attach different importance to the ability of the fault in rupturing at the surface; use different strategies to map, represent, and characterize faults.

Identifying individual earthquake sources is universally recognized as a fundamental step towards more accurate assessment of regional seismic hazard and that of critical facilities, for effective urban planning, and for developing suitable risk mitigation plans. But seismic hazard and society-oriented applications are not the only reasons to compile and progressively update a database of seismogenic sources. Many recent earthquakes worldwide have supplied a unique opportunity to understand geodynamic processes that can not be easily appreciated through conventional geological observations. In particular, earthquakes of magnitude 5.5 and larger provide evidence for the highest-hierarchy level of active crustal deformation, reducing and summarizing the geological complexity created by the interplay of secondary tectonic processes, local stress fields and strictly surficial processes. They also justify and explain the evolution of the youngest geological deposits and processes and of landscape features at the scale of large crustal faults (10-50 km). Potential applications of DISS to the understanding of the geodynamics and recent evolution of Italy form the object of Section 5 of this paper.

The need for compiling information on potential seismogenic sources stems from the consideration that the hazard associated with active faults has multiple facets that may affect adversely different elements of the natural and of the human environment. There are three types of effects of a significant crustal earthquake: (a) strong ground shaking, (b) surface deformation, and (c) surface rupture. The first occurs always but is transient. It affects the widest area (roughly, fault size x10) and is responsible for most of the damage. It may also trigger secondary geological effects (liquefaction, landslides, and minor ruptures). The second also occurs always and is permanent. It affects a wide area (roughly, fault size x2) and produces limited damage (critical facilities), and may trigger secondary geological effects, either permanent (stream avulsion, slope instability) or transient (tsunami). The third occurs only when fault daylights but is permanent. It affects a limited area (shorter than fault length and only tens of meters-wide) and may produce significant damage or collapse even in earthquake-resistant buildings, infrastructures and critical facilities. It may trigger permanent geological effects (water ponding, damming).

The fundamental purpose of any seismic hazard analysis is to predict the location, magnitude and spatial extent of some or all of these undesirable earthquake effects. This is accomplished through different types of deterministic and probabilistic modeling and by assigning a probability of occurrence to all expected phenomena. DISS was conceived and progressively developed as a foundation for many of these calculations through its key-element, the "seismogenic source". The following section describes in some detail the various types of seismogenic sources, their parameters and the criteria for qualifying and assigning uncertainties. Here we wish to briefly recall that DISS data allow for direct or nearly direct estimation of many of the effects summarized above.

The most obvious use of DISS data is in the prediction of the geological effects of a significant earthquake. DISS data may be used to predict the approximate location of surface ruptures, either from direct reports taken in the literature or by extrapolation of the fault geometry; to anticipate the pattern of expected ground subsidence or uplift and of the ensuing landscape and drainage modifications; and to predict the scenario of earthquake-induced tsunamis. For example, *Lorito et al.* [2006, 2007] have extensively used seismogenic sources taken from DISS 3 to deterministically model the threat represented by large earthquake-generated tsunamis in the Mediterranean basin and to assess the expected maximum water elevation along the coasts of southern Italy.

Many recent seismic hazard studies that focused on predicting the ground shaking component have used DISS data. Most of these analyses are currently documented only by abstracts presented at international meetings or by internal reports:

(a) *Conventional time-independent probabilistic seismic hazard assessment (SHA)*. The distribution, depth, and kinematic properties of seismogenic sources from DISS version 2.0 were used to constrain the seismogenic zonation ZS9 [*Meletti et al.*, 2004, 2007] that forms the basis for the new Seismic Hazard Map of Italy, completed in 2004 [*Gruppo di Lavoro MPS*, 2004].

(b) *Non-conventional time-independent probabilistic SHA analyses*. A subset of Seismogenic Areas (see Section 3) for northern Italy was used in a project that represents a follow-up of the activities that led to the Seismic Hazard Map of Italy [*Calvi and Stucchi*, 2006]. The new approach explores the variability of seismic hazard estimates obtained using a conventional seismogenic zonation vs. the more detailed zonation that can be obtained from DISS 3.

(c) *Time-independent probabilistic SHA in terms of displacement spectra*. In the framework of a project funded by the Italian Department for Civil Protection [*Faccioli and Rovelli*, 2006], DISS Individual Seismogenic Sources (see Section 3) were used to assess seismic hazard in terms of D_{10} (displacement at 10 s period) [*Faccioli et al.*, 2004].

(d) *Probabilistic SHA analyses that include time-dependency*. Version 2.0 of DISS has been used by *Pace et al.* [2006] in the framework of a hybrid model to calculate time-dependent seismic hazard for central Italy. Other similar applications are underway within a project funded by the Italian Department for Civil Protection to assess the entire country [*Slejko and Valensise*, 2006];

(e) *Deterministic SHA for specific areas, settlements, or major infrastructures (earthquake scenarios)*. Within the framework of numerous research programs funded by various agencies at state or regional level, DISS is being used to simulate scenario earthquakes and replicate recent and historical earthquakes. For example, *Faccioli and Vanini* [2004] used the DISS source for the 1908 Messina Straits earthquake to verify the design earthquake for the planned Messina Straits Bridge. *Mucciarelli et al.* [2005] used DISS sources for 3-D modeling of wave propagation in the area of the 1930 Senigallia, central Italy earthquake (Mw 5.9). *Franceschina et al.* [2006] modeled the source of the 31 October, 2002, Molise, southern Italy, earthquake. DISS source data are also being routinely used by consulting firms for modeling other Italian historical earthquakes.

(f) *Stochastic finite-fault modeling to quantify near field and the directivity effects*. *Zonno and Carvalho* [2006] used the parameters supplied by DISS 3 for the seismogenic sources of the 1980 Irpinia earthquakes to evaluate a new approach for investigating the effects of a finite fault on details of the ground shaking.

(g) *Mid- and short-term earthquake predictions based on real-time analyses of seismic moment release (AMR-type techniques)*. DISS seismogenic sources have been used by *Barba and Grondin* [2004] to identify accelerating moment release prior to large historical Apennines earthquakes.

Most of the above mentioned applications (a, b, e, f, g) use only a geometric and kinematic description of the seismogenic sources, thus taking advantage of the most robust information supplied in DISS, which now includes accuracy parameters introduced with DISS 3. Only a few applications attempt fully to exploit the time-dependent information, which includes fault slip-rates, the recurrence interval of individual earthquakes, and the timing of the most recent earthquake, which requires proper assignment of the known historical earthquakes to their causative source. Due to the intrinsic ambiguity of Italy's active tectonics and to ongoing inability to accurately identify active faults, this part of the Database content is less robust and reliable than the more descriptive, time-independent data. This disparity is not likely to improve significantly in the near future. Tests are underway [*Barba*, 2006] to determine whether the time-independent information in DISS may be effectively complemented by strain rate patterns calculated using a combination of GPS and tectonic data. These calculations involve finite-element 3D numerical modeling using the software SHELLS [*Bird*, 1999].

3. Rationale, structure and content of the Database

In this section we illustrate Version 3 (release 3.0.2) of the Database of Individual Seismogenic Sources (DISS), providing an overview of its current structure and of the ideas and accomplishments that guided its most recent development.

3.1. Conceptual framework I: types of seismogenic sources

DISS' main object is the Seismogenic Source. In Version 3 we distinguish three main categories of Seismogenic Sources based on their attributes, their expected use, the nature and reliability of data used to define them:

- "Individual Seismogenic Sources" (Fig. 5) are defined by geological and geophysical data (see Tab. 2) and are characterized by a full set of geometric (strike, dip, length, width and depth), kinematic (rake), and seismological parameters (single event displacement, magnitude, slip rate, recurrence interval). Each parameter is then rated for accuracy. Individual Seismogenic Sources are assumed to exhibit strictly-periodic recurrence with respect to rupture length/width, slip per event, and expected magnitude. They are compared to worldwide databases for internal consistency in terms of length, width, single event displacement and magnitude, and can be augmented by fault scarp data when available. This category is intended to supply the most accurate information available for the best identified sources, but it can not guarantee the completeness of the sources themselves. As such, Individual Seismogenic Sources can be used for calculating earthquake and tsunami scenarios and for tectonic and geodynamic investigations, but are not meant to comprise a complete input dataset for probabilistic assessment of seismic hazard.

- "Seismogenic Areas" (Fig. 6) also are based on geological and geophysical data (see Tab. 2) and characterized by geometric (strike, dip, width, depth) and kinematic (rake) parameters. The length of "characteristic" rupture, however, is poorly defined or unknown, thus the source spans an unspecified number of Individual Sources. They are not assumed to be capable of a specific size earthquake but their seismic potential can be estimated from existing earthquake catalogues. A Seismogenic Area is essentially an inferred structure based on regional surface and subsurface geological data that are exploited well beyond the simple identification of active faults or youthful tectonic features. As opposed to the previous case, this category of sources was conceived to achieve completeness of the record of potential earthquake sources, although this may imply a smaller accuracy of source description. In conjunction with seismicity and modern strain data, Seismogenic Areas can thus contribute to the development of regional probabilistic seismic hazard assessment (i.e. the new Seismic Hazard Map of Italy, *Gruppo di Lavoro MPS* [2004]; *Calvi and Stucchi* [2006]) and for investigating large-scale geodynamic processes.

- "Macroseismic Sources" are based on automatic processing of macroseismic data of earthquakes with M 5.5 and larger using the algorithm developed by *Gasperini et al.* [1999]. They are subdivided into three categories (Macroseismic-Well Constrained, Fig. 7a; Macroseismic-Poorly Constrained, Fig. 7b; Macroseismic-Deep, Fig. 7c) depending on the quality of the macroseismic dataset and on the parameters supplied for each of them (*Gasperini et al.* [1999]; *Valensise and Pantosti* [2000]). The main purpose for including macroseismic sources is to better define the previous two categories of sources and to constrain the seismogenic properties and potential of poorly known areas.

3.2. Conceptual framework II: additional info and management of uncertainties

Seismogenic sources of all types are characterized based on the available literature or unpublished original work. This information is organized in summaries of published papers and commentaries on critical issues; original figures, pictures, diagrams, maps, and sections from the literature or drawn by the compiler; lists of pertinent references keyed to a physical repository of papers, reports, conference proceedings.

We require only fully parameterized records to appear in the Database; in other words, no field in any record can be null. Therefore, compilers must make inferences regarding parameters that are unknown. Our decision has obviously pros and cons. On the one hand, end users will find this useful because they do not need to supply the unknown information. On the other hand, end users must be aware of the uncertainty associated with some sets of parameters.

A further outstanding issue, related only with the Individual Seismogenic Sources, stems from the awareness that length (L), width (W), single event displacement (D), and magnitude (M) are interconnected by seismological scaling relationships. Therefore, compilers verify the internal consistency of these parameters. The ideal case is when L, W, D, and M are all known from independent observations. In this case the different estimations can be used alternately with the scaling relationships, and the consistency of a seismogenic source with some generalized model can be analyzed. Most likely, only one or two of these parameters are known with confidence and can then be used to determine the others. In case only M is known (e.g., the source is based on an instrumentally recorded earthquake), L, W, and D can be calculated from scaling relationships. Conversely, M can be estimated if one or more of the other parameters are known. The compiler may decide to choose a specific relationship or averages the results of multiple relationships. When only one among L, W, or D is known and M is known, the compiler first verifies if they agree with one another, then determines the other parameters. If they do not agree, the compiler must choose the best constrained data through independent observations and all other parameters are based on it. This procedure guarantees that our characterization of seismogenic sources does not differ significantly from present knowledge of the earthquake process while preserving at least some seismologic and geologic observations.

Unlike the previous versions, DISS 3 compilers also assess the accuracy with which each individual seismogenic source is depicted in the Database. The accuracy factor contains two principal components of uncertainty: epistemic and stochastic. The first has to do with the mere existence of the seismogenic source, that is equivalent to answering the question “how did the source become known?”. The second has to do with the way the source was parameterized. The stochastic accuracy is divided into four principal components, namely: Location (centroid coordinates); Geometry (fault plane and slip vector orientation); Size (length, width, slip, magnitude); Behavior (slip rate, recurrence).

Each component of accuracy is given a score based on *a priori* statements. Scoring reflects quantitative estimations taken from well-established practices or statistics. Location, geometry, size, and behavior are respectively compared with: location of the associated earthquake as it appears in seismic catalogues; statistics on focal mechanisms [*Helffrich*, 1997] or with current practice in geologic mapping; empirical relationships [*Wells and Coppersmith*, 1994]; predictions of the strictly-periodic recurrence model.

We are still testing this procedure and a similar scheme will also be implemented for the Seismogenic Areas.

Every parameter of each Individual Seismogenic Source or Seismogenic Area is qualified according to the type of analyses that were done to determine it. The qualifiers are defined as follows:

- *Literature Data* (LD): data taken from studies published in scientific journals, Master or PhD theses, and technical reports of research projects or internal reports of major research institutions or universities.
- *Original Data* (OD): unpublished original measurements and interpretations for the purposes of this Database.
- *Empirical Relationship* (ER): values derived from empirical relations such as those of moment magnitude vs. fault size [*Wells and Coppersmith*, 1994] or vs. seismic moment [*Kanamori and Anderson*, 1975; *Hanks and Kanamori*, 1979].
- *Analytical Relationship* (AR): values derived from simple equations relating the geometric properties of a rectangular fault plane or the equation relating seismic moment with rigidity, fault area, and average displacement.
- *Expert Judgment* (EJ): assignments made by the compiler on the basis tectonic information or established knowledge at a scale broader than that of the seismogenic

source under consideration.

These qualifiers give an assessment of the parameters reliability, which decreases from the first to the last. Fig. 8 shows the distribution of qualifiers within the Database. Notice that ER and AR are not applicable to Seismogenic Areas. In addition to the qualifier, a short note describes the type of observation or empirical relation used to determine each parameter. More detailed information is usually presented and discussed in the "Comments and Open Questions" or in the "Explanatory Notes" sections.

Finally, DISS 3 also stores different support datasets such as bibliographic references, literature data, geographic and administrative data, geological, seismological or paleoseismological data, and various historical and instrumental earthquake catalogues, as did earlier versions of DISS. All information is organized as GIS layers that enable the user to explore all data types at different scales and to perform spatial analyses and complex statistical computations. DISS 3 is available both as a standalone application and as an Internet-based cartographic server (http://www.ingv.it/DISS/).

3.3. Information Technology (IT) framework

The architecture of the new DISS 3 provides three different modes of access: (1) a specifically designed cartographic (ArcIMS) and alphanumeric web interface that only requires a web browser and a fast (640 kbps or faster) Internet connection (Fig. 9a); (2) a web interface based on the Google Earth application (Fig. 9b), that requires a browser, a fast Internet connection and the Google Earth software (available free for Mac, PC and Linux computers at http://earth.google.com/download-earth.html); (3) standalone mode, which uses a custom application based on MapBasic. This access mode requires MapInfo 6.5 or higher and is available only for PC computers. It is intended for database developers and for selected users that wish to contribute their own data and interpretations to the database. It allows users to access several information levels not available on the web versions of the database, including georeferenced cartography in raster format, stress data, and several types of geophysical data (Fig. 9c and d). This version, including the dedicated software, is available upon request to sophisticated users and potential collaborators.

The main difference between the system available to developer-users (access mode (3) on desktop PC) and those available to all other remote users (i.e. those who use DISS 3 by access modes (1) and (2) through the Internet) is the number and functionality of supported tools. Built-in GIS tools on remote platforms are not, and will likely not be for long, as efficient as those on desktop computers. Thus, as of today, advanced spatial analyses and statistical computations can not be performed directly within the Internet user interfaces. To facilitate users we then distribute the main data tables in several GIS proprietary formats, such as MapInfo (mif/mid), ESRI ArcInfo Export (E00), ESRI Shape (shp), AutoCAD (DXF), and Google Earth (kml). All the information on accessing DISS 3 is available at the Internet site http://www.ingv.it/DISS.

As inferred from the statistics of the web site, users who routinely visit the Database belong to various categories. They come not only from Italian and non-Italian research institutions and universities, but also from several regional administrations and private consulting companies. Between July and September 2006 the DISS web site was accessed by users from over 30 foreign countries. Returning visitors were almost 50 percent, and a significant part of them visited the web pages more than 10 times each. This implies that the use of DISS extends well beyond the community of sibling researchers and that we may expect to meet an ever increasing demand.

4. Progress with respect to previous versions and data validation

Although the development of DISS and its related activities have experienced a substantial acceleration in the past two years, its foundations were laid out in 1994, when seven of the most representative seismogenic sources of the southern Apennines were organized in a simplified paper catalogue [*D'Ajello Caracciolo*, 1995]. Tab. 3 summarizes the main benchmarks of the Database and its evolution in terms of data content to present. Apart from the very early prototypes, all successive versions of DISS are available through its web site (www.ingv.it/DISS/Downloads/); therefore, users can easily verify the improvements between different versions. More importantly, this access also guarantees that results obtained by using different database versions at different times can be reproduced.

In the late 1990s, data collection became more systematic. To help with data collection and representation, the early archive was moved to a GIS platform that was being developed within the E.C.-funded project "Scenario" [*Salvaneschi et al.*, 1996]. A prototype of this early GIS version, provisionally termed "CAIFA" (Catalogo Italiano Faglie), was presented in July 1999. The GIS data structure was further improved in the framework of the E.C.-funded project "FAUST" (Faults as a Seismologists' Tool [*Mucciarelli and FAUST Working Group*, 2000]). In 2000, the name was changed to DISS (Database of Italy's Seismogenic Sources); the Database was presented to the seismological community and distributed in several tens of copies through a CD-Rom. Eventually, the DISS was extended to other seismic-prone countries of Europe in the framework of Faust. This effort resulted in the development of a simple but effective web-GIS interface that allowed access to the content of the Italian database plus a number of other seismogenic sources in Greece, Spain, Portugal, France, Switzerland, and other countries. This European database contained only individual seismogenic sources, either obtained from geological/geophysical data or from intensity data, and was prepared thanks to the cooperation of several institutions and individuals [National Observatory of

Athens, for Greece (scientist in charge *George Stavrakakis*); University of Barcelona, for Spain (scientist in charge *Pere Santanach*); University of Chieti, for Greece (scientist in charge *Riccardo Caputo*); INGV-Milan Section, for Albania, Algeria, Austria, Belgium, Bosnia, Bulgaria, Croatia, Czech Republic, France, Greece, Hungary, Macedonia, Montenegro, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Switzerland, Turkey, United Kingdom (scientist in charge *Paola Albini)*].

At the end of the Faust project (January 2001) the database maintenance was assumed by INGV as "Database of Potential Sources for Earthquakes Larger than M 5.5 in Europe" [*Valensise et al.*, 2002]. Fig. 10 shows the layout of the web-GIS interface and its main functionalities. The same database also was incorporated in the working materials of the project SAFE (Slow Active Faults in Europe: *Sebrier and SAFE Consortium* [2003]).

DISS v. 2.0 [*Valensise and Pantosti*, 2001a] was made available in July 2001 and published in December of the same year. It was distributed through a CD-Rom to over 1,000 scientists and presented at several meetings worldwide. The interest generated by DISS 2.0 led to a "grace period" that lasted for nearly three years, ending with the presentation of the prototype of DISS 3 in September 2004. DISS 3 is profoundly different from all its predecessors, both in terms of structure and data content. A new, faster and substantially more powerful web-GIS interface was designed and tested. Finally, a new fast and effective interface was created using Google Earth.

DISS is now at the core of a series of projects coordinated by INGV and funded by Italy's Department for Civil Protection. The projects deal with several aspects of seismic hazard and will be completed at the end of 2007. For this reason, DISS is constantly maintained and updated; frequent exchanges with seismic hazard practitioners who are using it are providing feedback for further improvements of the data content.

The widespread use of DISS in the framework in the assessment of seismic hazard at a national level is emphasizing the need for validation of its data content. Ideally, validating a seismotectonic scheme and its predictions in term of seismic hazard requires a time interval of at least a few complete seismic cycles (e.g., 10,000 years). Any other means of validation must be considered as pure inferences. Global validation of the Database aims at verifying the correct spatial representation of the earthquake potential, the appropriateness of the predictions in terms of annual moment rate budget, the internal consistency of all spatial and time estimates. Most seismic hazard applications at national and regional scales are extremely sensitive to these parameters and generally more tolerant to inaccuracies such as the exact location of a fault, its dip direction, or minor exaggeration of its slip rate. Conversely, such large-scale applications are most sensitive to the completeness of the seismogenic source record, that is to say, their predictions may be heavily jeopardized by seismogenic sources that are omitted. A typical example is given by the 2002 Molise earthquakes (southern Italy), that struck a region located between the Gargano promontory and the axis of the Apennines where no seismogenic potential had been envisioned (this can be verified in Figs. 2, 3, 4).

In contrast, the validation of individual sources is crucial for deterministic applications of seismic hazard, where the predictions of ground motion are extremely sensitive even to the slightest changes in the fault geometry and kinematics. In addition to providing preferred parameters of any given seismogenic source, compilers of DISS strive to supply all the background information (including papers that support completely different interpretations) to help the end user to grasp the data uncertainty. For instance, calculations made for evaluating the expected ground shaking at the site of the planned bridge across the Messina Straits [*Faccioli and Vanini*, 2004] have taken advantage of information supplied by DISS, not only on the preferred but also on alternative solutions, for the causative fault of the 1908 earthquake. In other cases, an implicit validation may be supplied by modeling of the ground shaking associated with significant historical earthquakes. For example, *Mucciarelli et al.* [2005] showed that the seismogenic source identified by DISS compilers as the causative fault of the rather controversial 1930 Senigallia, central Italy earthquake (Mw 5.9) provides the best fit to the reported damage.

5. Learning about Italy's active tectonics from a regional seismotectonic view

In the previous sections we have illustrated that DISS is not simply an archive of outcrop-scale field data, but rather a tool that allows the seismogenic process to be represented and investigated in 3D at various scales, and particularly at regional scale. One of the key goals of the Database design was to fully exploit basic physical constraints concerning the rates of crustal deformation, the continuity of deformation belts, and the spatial relationships between adjacent faults, both at the surface and at depth.

An easy way to outline major regional tectonic trends is to look at (1) seismogenic sources grouped by faulting types and (2) their slip vectors in map projection (Fig. 11). The sources illustrate the lateral continuity of the normal fault system along the backbone of peninsular Italy and the different styles of compression in the outer parts of the mountain belt: thrusts in the south-eastern Alps, northern Apennines, Calabrian Arc, and Sicilian-Maghrebian chain; predominant strike slip east of the southern Apennines axis and in southeastern Sicily. The change in slip vector direction shows the continuous tectonic flow that extends through zones with different tectonic regimes. These two views also facilitate the comparison between the information on faulting contained in DISS and other types of geophysical data. Kinematics and tectonic flow predicted by DISS can be compared with the results of moment tensor summation of a few decades of seismicity located within the Seismogenic Areas of DISS in terms of average focal mechanisms (Fig. 12a) and P and T axes (Fig. 12b). Normal faulting in the inner Apennines is well represented. Conversely, and apart from the southern Tyrrhenian and the eastern Alps, compression is less well documented, with the exception of the thrust faulting earthquakes in the outer northern Apennines and the strike-slip faulting earthquakes in the Apulia foreland. However, borehole breakout (Fig. 12c) and GPS data (Fig. 12d) augment the picture of the stress field in areas where focal mechanism data are rare. For instance, note the improved characterization of the compressional stress field in most part of the areas previously mentioned. If taken alone, GPS and borehole breakouts mainly help with defining the geometrical properties of the stress field and tell little, if not nothing at all, on the potential for large earthquakes. This is where the knowledge about active faults illuminates the picture.

All these analyses show that the kinematic view based on geophysical observations agrees very well with that obtained from the DISS seismogenic sources. Comparing fault data, such as those contained in DISS, with other geophysical data may look inappropriate at times because the different datasets are not strictly independent. However when they are all put together, one gets at least two immediate benefits. The first is the enhanced capability of exploring the information from geographically scattered point data (focal mechanisms, borehole breakouts, GPS measurements) over the spatial domain. The second is the longer time window that can be analyzed; few years to few decades for geophysical data compared to thousands of years for geologic data on active faults.

Given the general picture, we conclude by illustrating a few examples on recent advancements in understanding the regional tectonic process at a smaller scale.

(a) There is growing evidence that fault segmentation is a long-lived feature that controls the length of long seismogenic faults, and hence the expected earthquake size (e.g. *Valensise and Pantosti* [2001b]) along major extensional belts, such as along the crest of the Apennines. An ongoing regional-scale appreciation of historical and pre-historical earthquakes has already helped locating a number of "aseismic" sections of the belt (also studied at local scale, e.g. *Boncio et al*. [2000]; *Galadini and Galli* [2003]; *Piccinini et al*. [2003]; *Pucci et al*. [2003]; *Cucci et al*. [2004]; *Vannoli et al*. [2004]; *Lucente et al*. [2005]). It is likely that these historically aseismic sections will experience significant earthquakes before a large event is repeated on the adjacent, historically activated sections.

(b) The seismicity of the outer northern Apennines arc has always appeared rather scattered and apparently random. The area is characterized by reverse faulting at widely different depths. A careful reassessment of the typical depth of instrumental earthquakes and an "educated guess" of the depth of the main historical events allowed us to match the location of the main earthquakes with geologically-documented parts of the same major thrust belt. In particular, deeper earthquakes concentrate along the western portion of the arc, whereas shallower events generally occur along the outer front [*Vannoli et al*., 2004; *Burrato et al*., 2004; *Meletti et al*., 2004; *Piccinini et al*., 2006].

(c) The Eastern Southern Alps and Northern Dinarides have long been known as characterized by a compressional stress field due to the convergence between the Adriatic and the European plates. This area has intermediate to strong earthquakes that have caused severe damage even in the recent past (e.g., 6 May 1976, Friuli, Mw 6.4; 12 April 1998, Bovec-Krn, Mw 5.7); local geological studies have already addressed several active faults (e.g. *Aoudia et al.* [2000]; *Benedetti et al*. [2000]; *Zanferrari et al*. [2003]; *Fitzko et al.* [2005]). Recent studies have brought together an internally consistent regional seismotectonic picture of low-angle north-dipping thrusts at the Southern Alps piedmont and high-angle dextral strike-slip faults in the Northern Dinarides with interspersed seismically quiescent faults (*Galadini et al.* [2005]; *Poli et al.* [2007]; *Burrato et al.*, this volume).

(d) The current views of the tectonics of southern Italy imply that the region is subjected to a well-established far-field tectonic stress, but also that it exhibits widely different local stress fields within different structural units at correspondingly different depths. In particular, NW-SE compression dominates below 12-14 km, while NE-SW extension acts above this level. The existence of such a dual tectonic system was first highlighted by the 2002 Molise earthquakes (Mw 5.7), an isolated and relatively minor event [*Di Bucci and Mazzoli*, 2003; *Valensise et al*., 2004]. Therefore, full 3D regional perspective is still needed (e.g. *Di Bucci et al*. [2006]) to capture the evidence for a deeper contractional stress field and for setting the boundaries of the region that is experiencing it.

(e) Mediterranean and Italian permanent GPS networks are beginning to return meaningful estimates of the strain rate across the peninsula (e.g. *Hunstad et al*. [2003]; *D'Agostino and Selvaggi* [2004]; *Jenny et al*. [2006]; *Serpelloni et al*. [2005]). The data are very interesting as it confirms or modifies current interpretation regarding contraction and extension trends. However, the GPS network is not dense enough to be of use for estimating slip rates on individual faults, and hence for understanding where and how elastic crustal strain is accumulating to generate future earthquakes. By providing 3D fault geometries and partitioning the GPS-documented strain on discrete and independently identified faults, DISS aids all GPS practitioners, who can explore strain accumulation anomalies and plan detailed surveys or permanent networks on a sound basis.

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Figure captions

Figure 1 – DISS 3, v. 3.0.2 (standalone version) devoted to developers. DISS uses the MapInfo GIS. Figure shows location of "Individual Seismogenic Sources" (in yellow) and "Seismogenic Areas" (in red; see Section 3 for the definition of terms) and the location of all earthquakes mentioned in the text (Moment magnitudes of historical earthquakes are from *CPTI Working Group* [2004], those of recent earthquakes are from various sources).

Figure 2 – Map of the GIS-based Database of Italy's Seismogenic Sources (DISS), version 1.0 [*Valensise and Pantosti*, 2000]. The database was developed as a prototype between 1997 and 1999, presented to the public in July 2000 and distributed to scientists and institutions on CD-ROM. The map shows sources for earthquakes of M 5.5 and larger based on geological and geophysical data (in yellow) or intensity data (in black and blue).

Figure 3 – (a) Map of surface tectonic elements ("elementi geologici di superficie") prepared by Italy's GNDT between 1996 and 1999. The image shows a detail of the southern Apennines. A set of parameters contained in a data table is assigned to each fault (from *Galadini et al.* [2001]). (b) Map of potential earthquake sources ("sorgenti potenziali") for earthquakes of M 5.5 and larger, obtained from field mapping and interpretation of intensity data (from *Meletti et al.* [2000]).

Figure 4 – Map of the GIS-based ITHACA database ("Italy Hazard from Capable Faults"; *Michetti et al.* [2000]). The main goal of this database was to identify capable faults. ITHACA was distributed to scientists and institutions on CD-ROM. An updated version of ITHACA can be found at http://www.apat.gov.it/site/it-IT/Progetti/ITHACA_-

_Catalogo_delle_faglie_capaci/.

Figure 5 – Schematic representation of an Individual Seismogenic Source and its characteristics.

Figure 6 – Schematic representation of a Seismogenic Area and its characteristics.

Figure 7 – Schematic representation of macroseismic sources and their characteristics (as defined in *Gasperini et al.* [1999] and *Valensise and Pantosti* [2000]): (a) well-constrained; (b) poorly-constrained; (c) deep-focus.

Figure 8 - Graphs showing the qualifiers relative to each parameter of seismogenic sources. (a) Individual Seismogenic Sources (total = 115); (b) Seismogenic Areas (total = 81). See text for the definitions of qualifiers.

Figure 9 – DISS 3 user interfaces. (a) Web interface provides navigation tools to users through a web application based on ArcIMS GIS engine; (b) Google Earth interface provides interactive navigation through the free Google Earth software; (c) standalone version for developers, uses the MapInfo GIS engine; (d) FaultStudio, an additional tool for manipulating fault data, also devoted to developers using standalone mode with the MapInfo GIS engine.

Figure 10 - Home page of the web-GIS interface and main functionalities of the "Database of Potential Sources for Earthquakes Larger than M 5.5 in Europe" [*Valensise et al.*, 2002].

Figure 11 - (a) Individual Seismogenic Sources and (b) Seismogenic Areas shown by color

coded faulting mechanisms. Blue: reverse or thrust; red: normal; dark green: right-lateral strike slip; light green: left-lateral strike slip. (c) Slip vectors with their angular variability from Individual Seismogenic Sources and Seismogenic Areas projected on the horizontal plane.

Figure 12 – (a) Average focal mechanisms and (b) P and T axes from moment tensor summation of earthquakes within the Seismogenic Areas of DISS (original elaboration by Vannucci G. using the EMMA database by *Gasperini and Vannucci* [2003] and *Vannucci and Gasperini* [2004]). (c) Smoothed Sh_{min} orientation and inferred faulting mechanisms from *Montone et al*. [2004]. (d) Horizontal strain rates (red: extension; blue: contraction) from GPS data published by *Serpelloni et al*. [2005].

Table captions

Table 1 - Major country-size databases of active faults or seismogenic sources for use in seismic hazard assessment.

Table 2 – Principal types of data and methods used to determine the parameters of seismogenic sources. The lists in the second column are not intended to be exhaustive. Parameters in italics apply to Individual Seismogenic Sources only.

Table 3 – Synoptic view of the evolution of the Database of Individual Seismogenic Sources (DISS).

Table 1

Country	Database name	Institution in charge	Institution type	Web address
Japan	Behavioral Segment-Based Active Fault Database of Japan	National Institute of Advanced Industrial Science and Technology (AIST)	Public institution	http://unit.aist.go.jp/actfault/ http://www.aist.go.jp/RIODB/activefault2005/cgi-bin/Search_e.cgi?TYPE=S
New Zealand	New Zealand Active Faults Database	GNS Science Limited	Government-owned research company	http://data.gns.cri.nz/af/
United States	Quaternary Fault and Fold Database of the United States	United States Geological Survey (USGS)	Public governmental (federal) institution	http://earthquake.usgs.gov/regional/qfaults/
Italy	*Database of Individual Seismogenic Sources*	*Istituto Nazionale di Geofisica e Vulcanologia - INGV*	*Public governmental institution*	*http://www.ingv.it/DISS/*

Table 2

Parameter	**Appropriate data and methods**
Location	• Location of historical and/or instrumental earthquakes. • Geological maps. • Analysis of geologic, geomorphic, geodetic deformation.
Length (L)	• Geological maps of faults expressed at the surface. • Geological cross sections across the active fault system. • Length of the area deformed by slip at depth identified as displaced or warped geological layers (folds) or geomorphic features (e.g. alluvial and coastal terraces), anomalous drainage pattern (e.g. allogenic stream/river migration/avulsion). • Scaling relationship between length and moment magnitude (e.g., LogL = a + b × Mw).
Width (W)	• Geological sections across the active fault system. • Width of the area deformed by slip at depth identified as displaced or warped geological layers (folds) or geomorphic features (e.g. alluvial and coastal terraces), anomalous drainage pattern (e.g. allogenic stream/river migration/avulsion). • Combined analysis with the estimation of depth. • Scaling relationship between width and moment magnitude (e.g., LogW = a + b × Mw).
Depth	• Depth distribution of instrumental earthquakes. • Geological sections across the active fault system. • Rheological profiles of the region. • Seismic tomography of the region. • Combined analysis with the estimation of width.
Strike, Dip, and Rake	• Displacement components of geological markers in maps and cross sections. • Measurements of faults exposed at the surface. • Focal mechanisms of the larger associated earthquakes or other physical properties such as principal stress and strain axes.
Slip Rate (SR)	• Displacement of dated geological markers. • Displacement observed through geodetic measurements. • Displacement calculated from seismic or geodetic strain. • Derivation from recurrence interval and slip (SR = D / RI).
Recurrence Interval (RI)	• Time lag between successive event horizons identified in paleoseismological trenches. • Derivation from long-term slip rate (RI = D / SR).
Slip per Event (D)	• Displaced geologic or geomorphic markers. • Analytical formulation of seismic moment based on the double-couple model ($D = M_0 / \mu S$, where μ is rigidity, S is fault area, and M_0 is seismic moment).
Magnitude (Mw)	• Largest magnitude of associated earthquake(s) measured instrumentally. • Largest magnitude of associated historical earthquake(s) estimated from intensity data. • Magnitude inferred from the area of the largest associated fault or fault set. • Magnitude inferred from a physical model that includes deformation data of any sort (e.g. geodetic, seismic, and geological). • Scaling relationship between magnitude and fault size (e.g. Mw = a + b LogS, where S is fault size) or magnitude and single event displacement.

Table 3

	Nameless prototype	**CAIFA prototype**	**DISS 1.0**	**DISS 2.0**	**DISS 3 prototype**	**DISS 3.0.0**	**DISS 3.0.1**	**DISS 3.0.2**
Date Released	Jun 1995	Jul 1999	Jul 2000	Jul 2001	Sep 2004	Jan 2005	Nov 2005	Sep 2006
Significant improvements	-	Implemented on GIS	Several utility functions added	• Finalized for distribution to scientific community • 200- page descriptive manual published on Annals of Geophysics • Over 1,0000 copies of database distributed through CD-ROM	• New categories of seismogenic sources introduced: non-segmented sources, non parameterized sources • Graphic representation of fault kinematics • All parameters are assigned Qualifiers & Explanatory Notes	• Seismogenic Areas introduced • Web version implemented	• First stable release of version 3	• Google Earth version implemented • 6 non-Italian sources added
Individual Seismogenic Sources	7	25	54	60	100	100	107*	115**
Seismogenic Areas	---	-	-	-	-	43	67	81
Support data: References[1]	173	~500	715	1,256	1,720	1,720	1,944	2,063
Support data: Images[2]	---	216	264	450	550	550	683	794
Support data: Texts[3]	41	~63	~135	~150	~250	~250	~270	~300
Additional materials	---	• 22 Previous fault compilations[4] • 98 Tectonic lineaments[6]	• 28 Previous fault compilations[4] • 142 Tectonic lineaments[6]	• 41 Previous fault compilations[4] • 10 Additional data[5] • 142 Tectonic lineaments[6]	• 41 Previous fault compilations[4] • 12 Additional data[5]	• 41 Previous fault compilations[4] • 12 Additional data[5]	• 41 Previous fault compilations[4] • 16 Additional data[5]	• 41 Previous fault compilations[4] • 20 Additional data[5]

[1] Number of independent references attached to the seismogenic sources.
[2] Number of independent images (original of from published literature) documenting the seismogenic sources.
[3] Number of equivalent pages of original texts documenting the seismogenic sources.
[4] Previous fault compilations: georeferenced fault maps from previous papers/investigators.
[5] Additional data: georeferenced sets of geophysical, geological data from various investigators.
[6] Tectonic lineaments: georeferenced sets of linear tectonic features from various papers/investigators.
* 14 sources added; 7 sources removed; 8 sources modified with respect to previous version.
** 9 sources added; 1 source removed; parameters of 1 source modified; 34 sources improved.

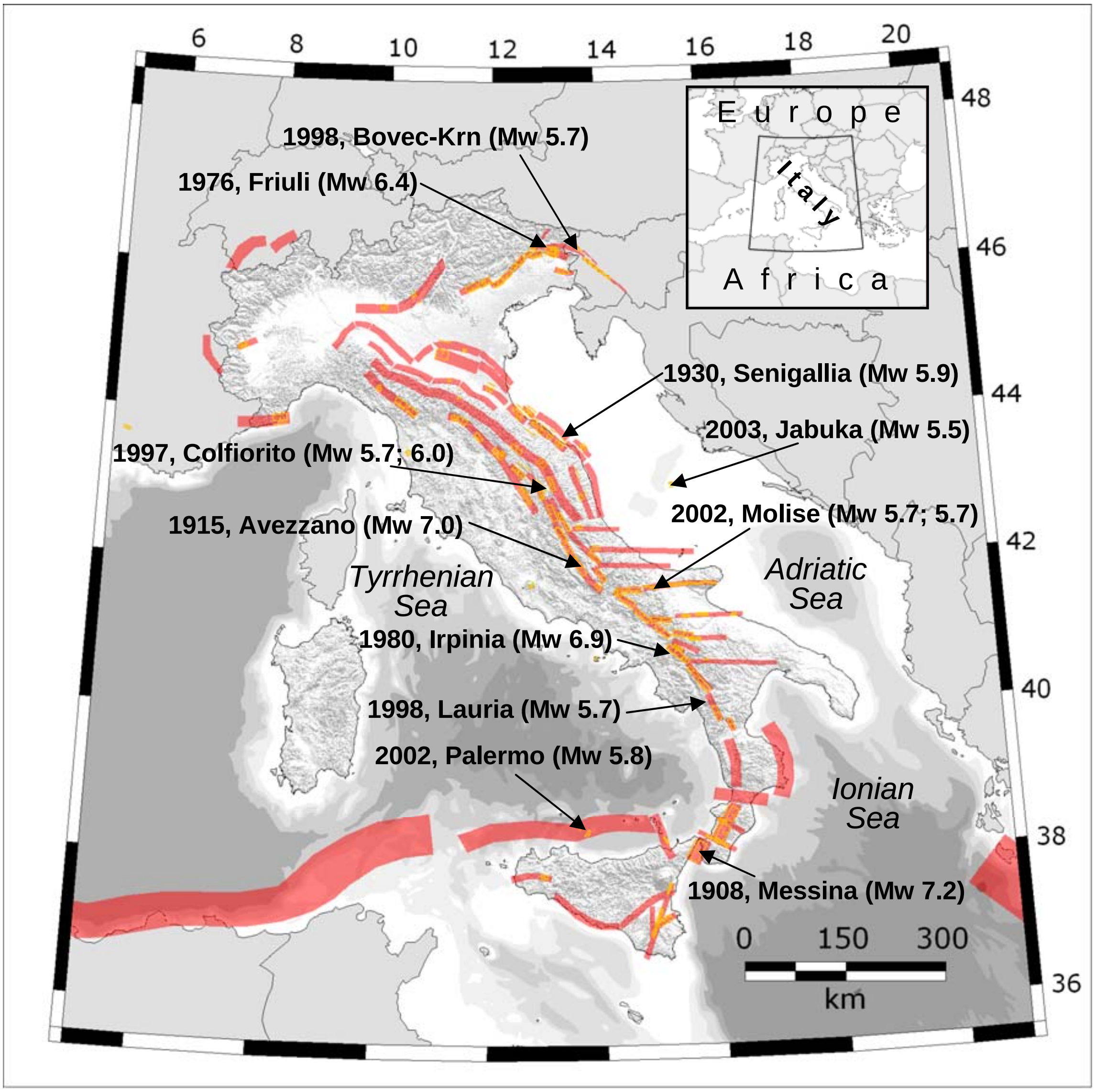


Figure 1

Basili et al.

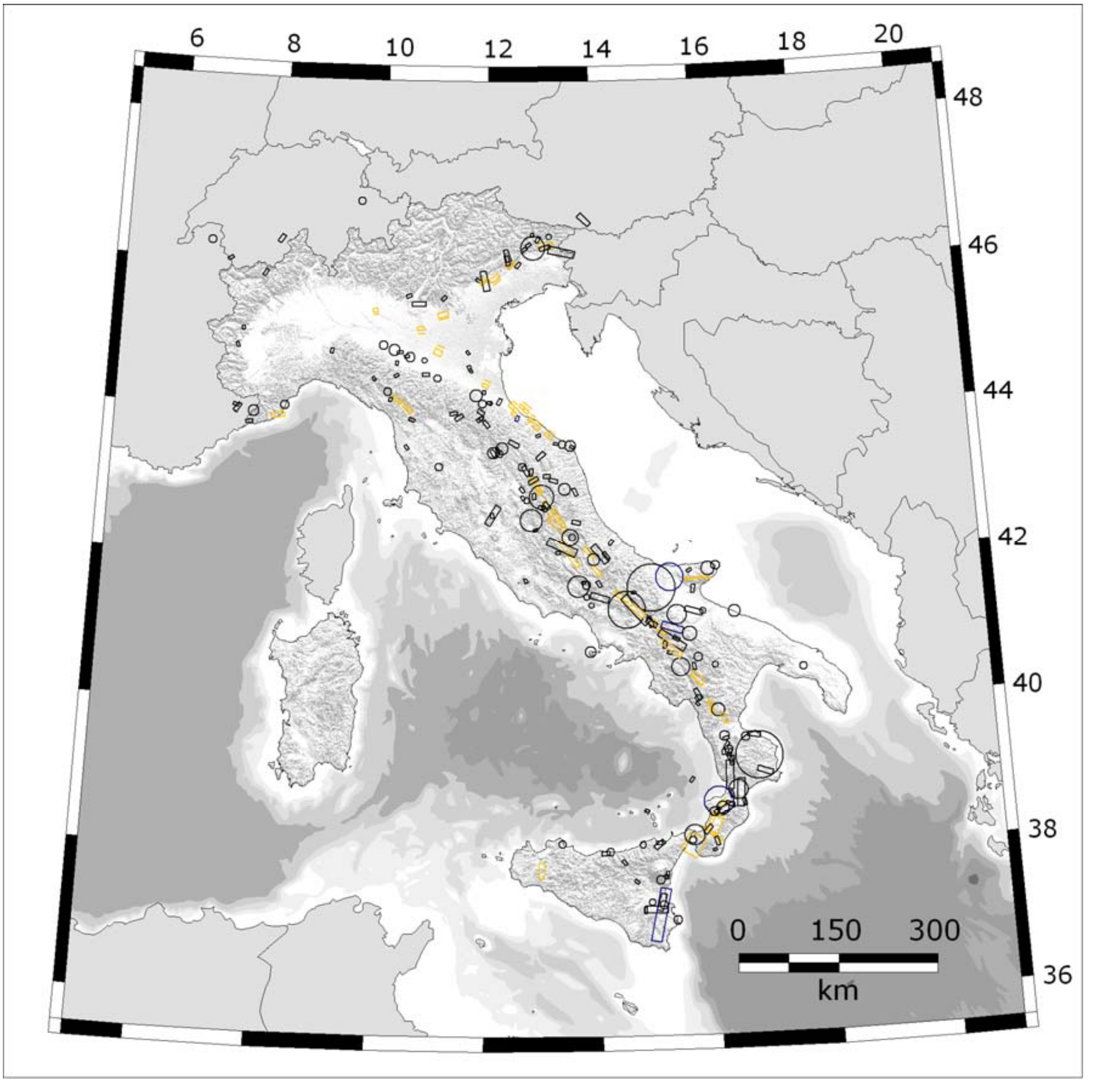


Figure 2

Basili et al.

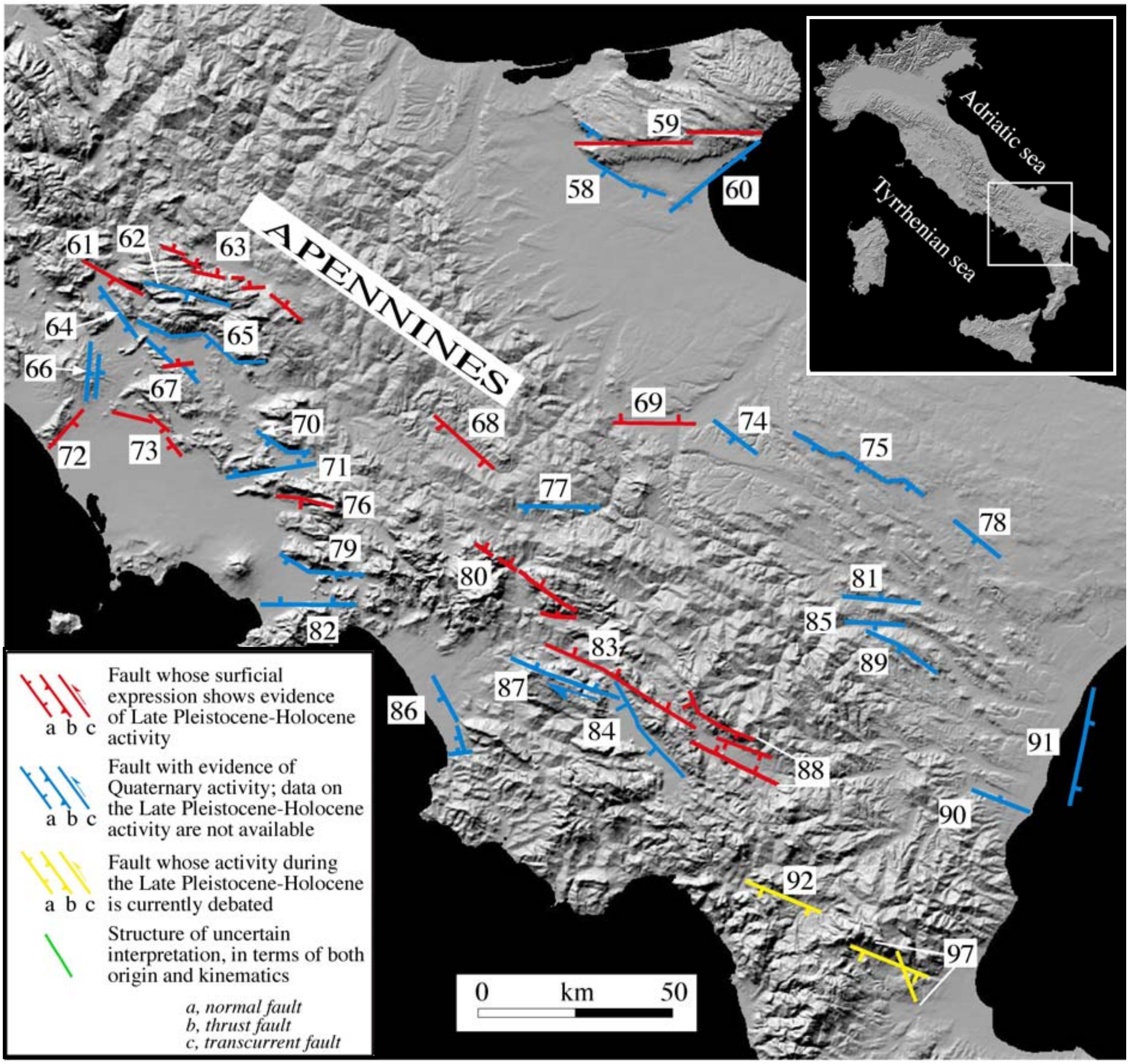


Figure 3a

Basili et al.

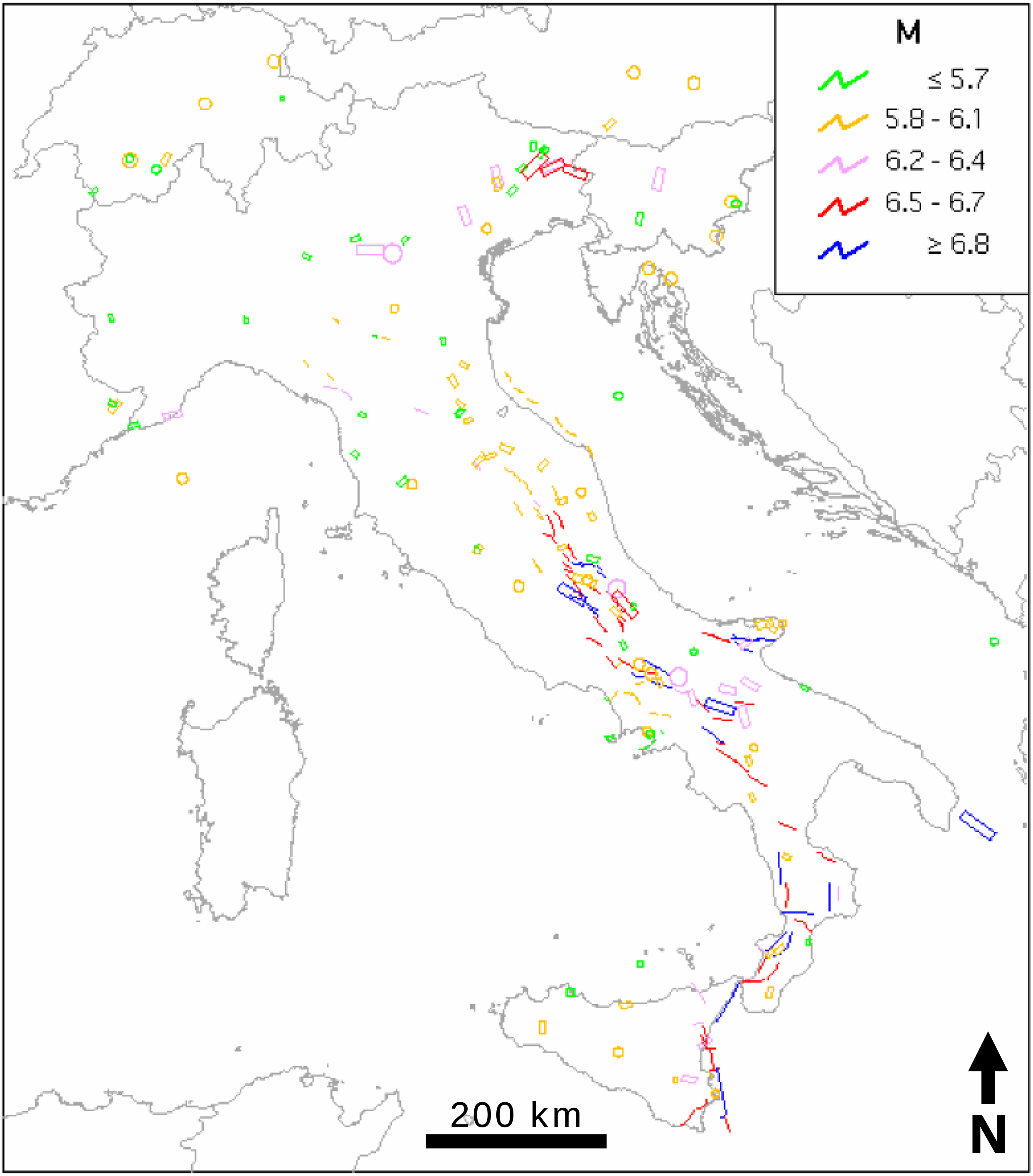


Figure 3b
Basili et al.

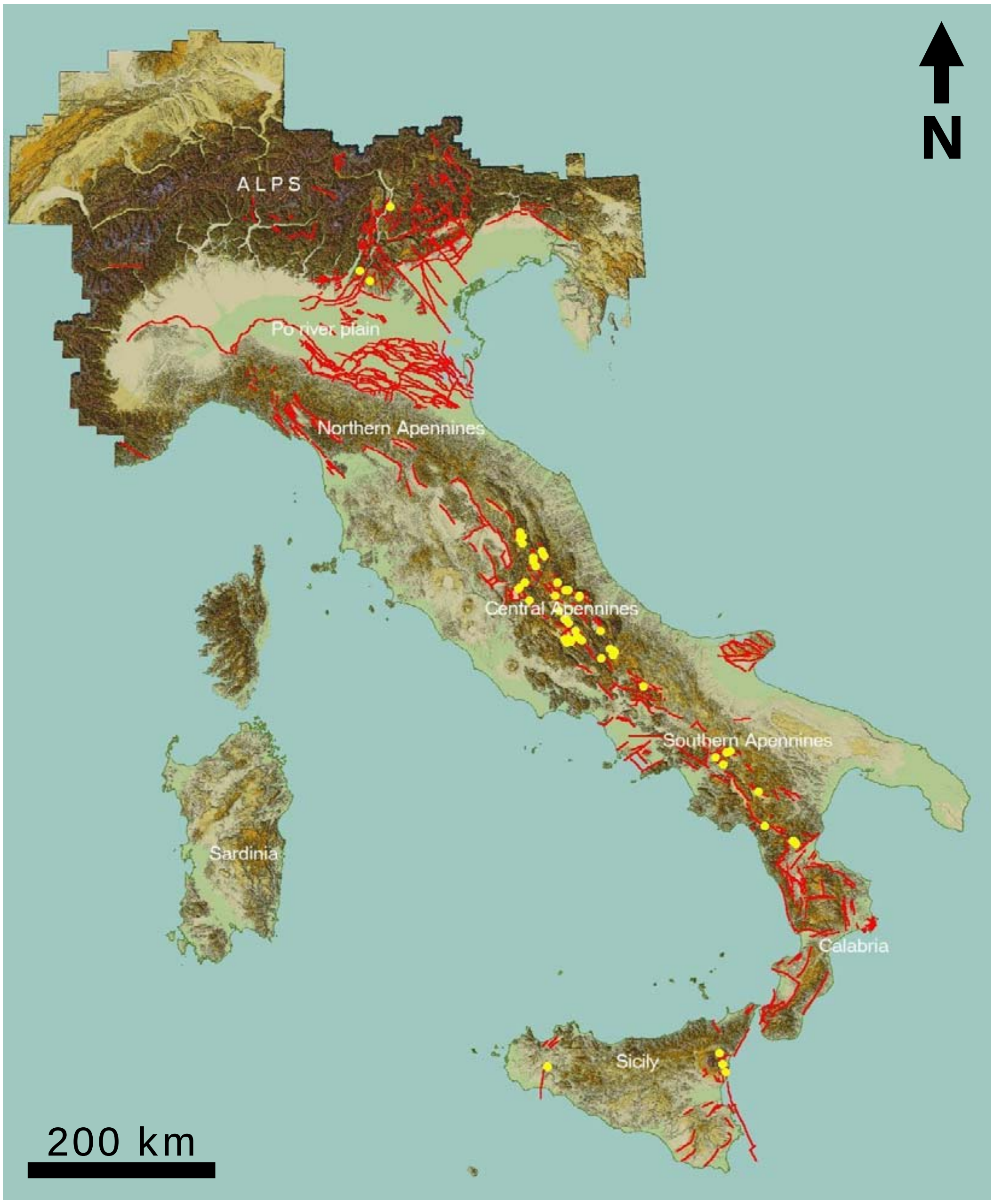


Figure 4

Basili et al.

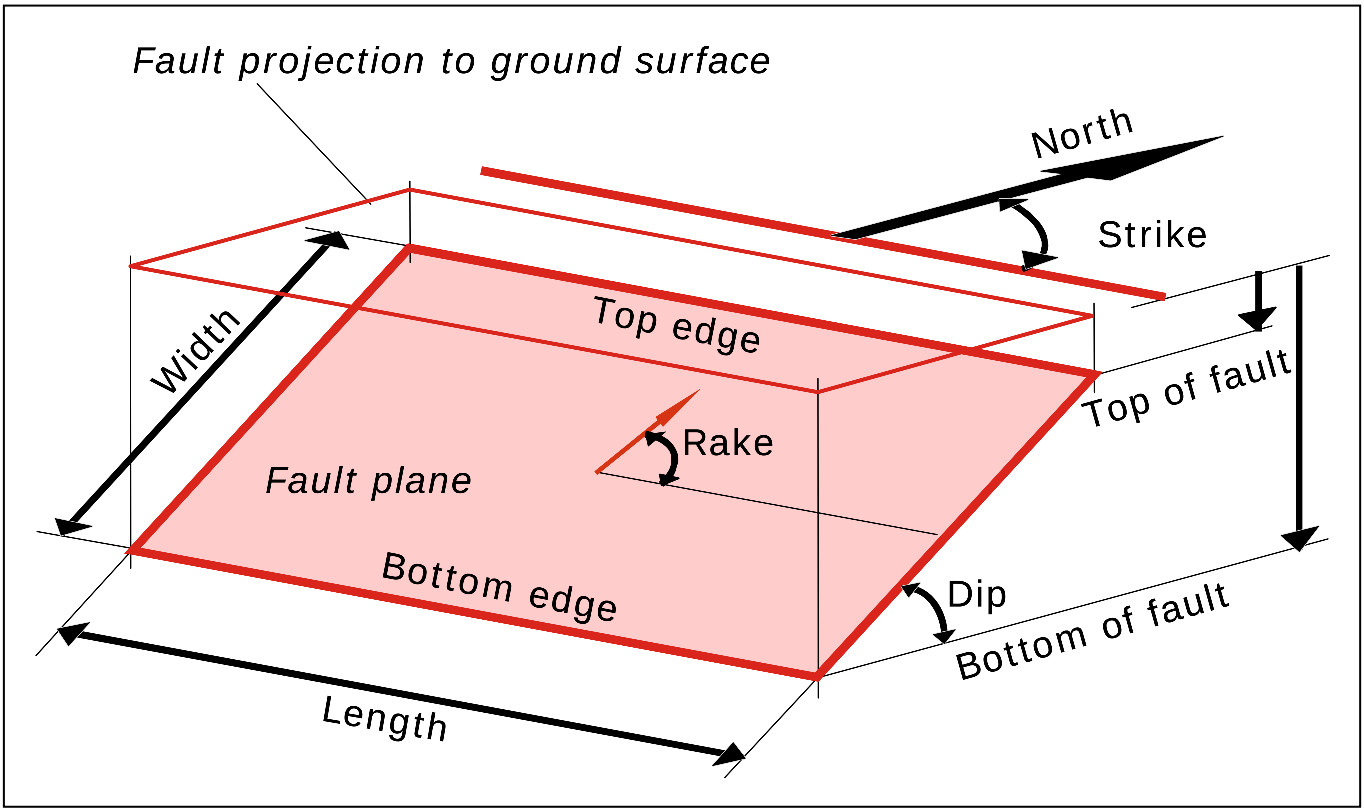


Figure 5

Basili et al.

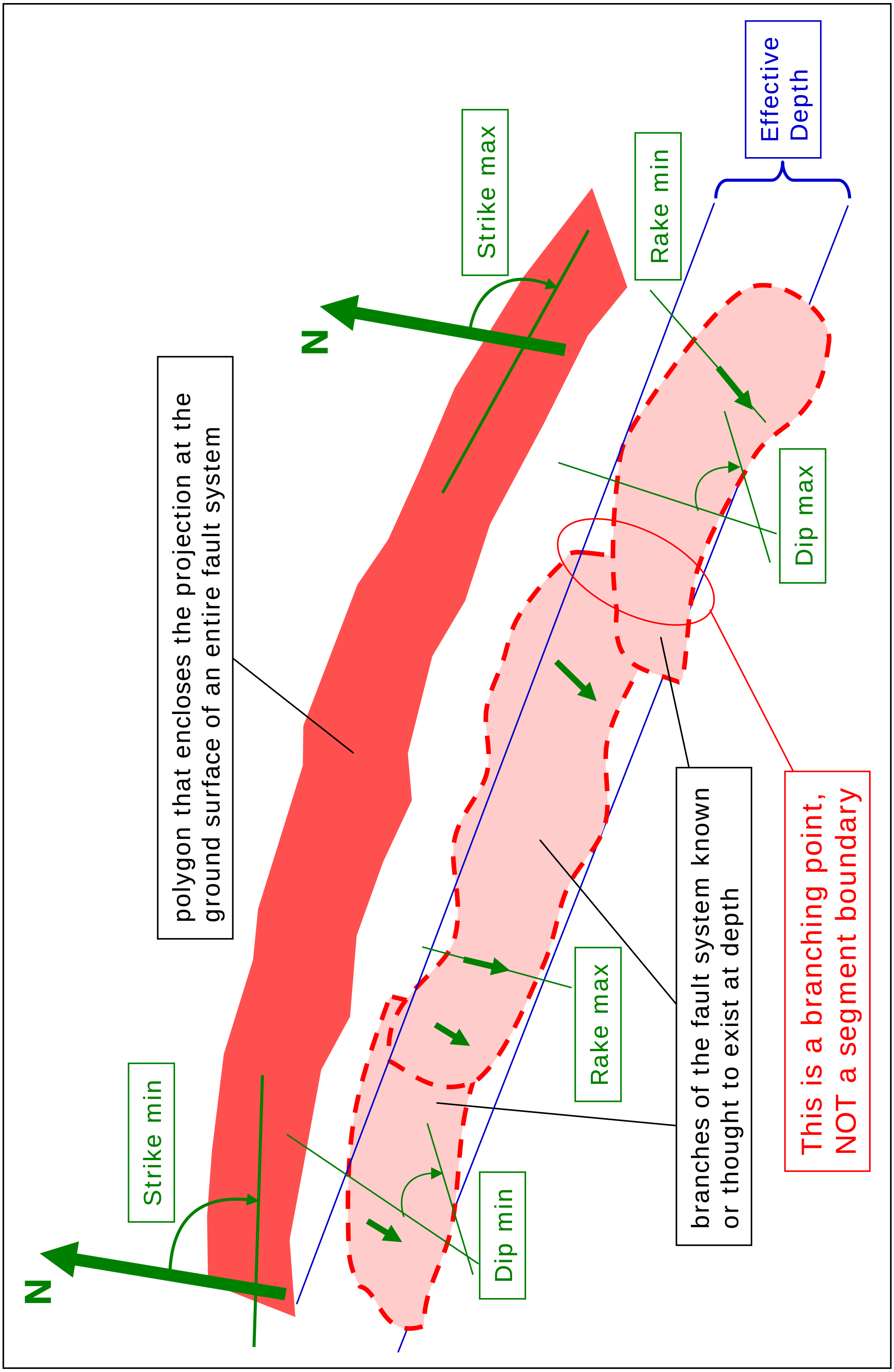


Figure 6
Basili et al.

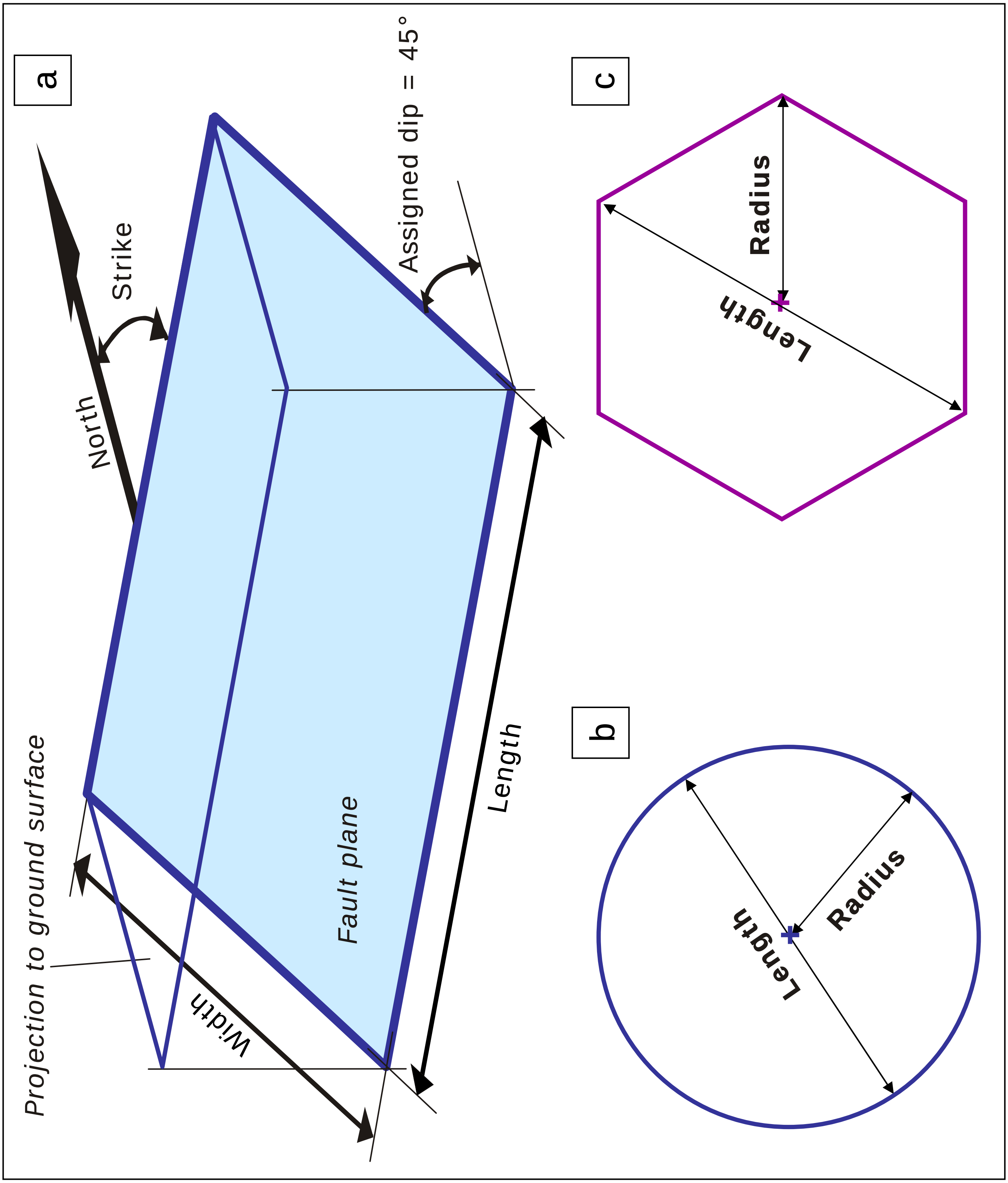


Figure 7

Basili et al.

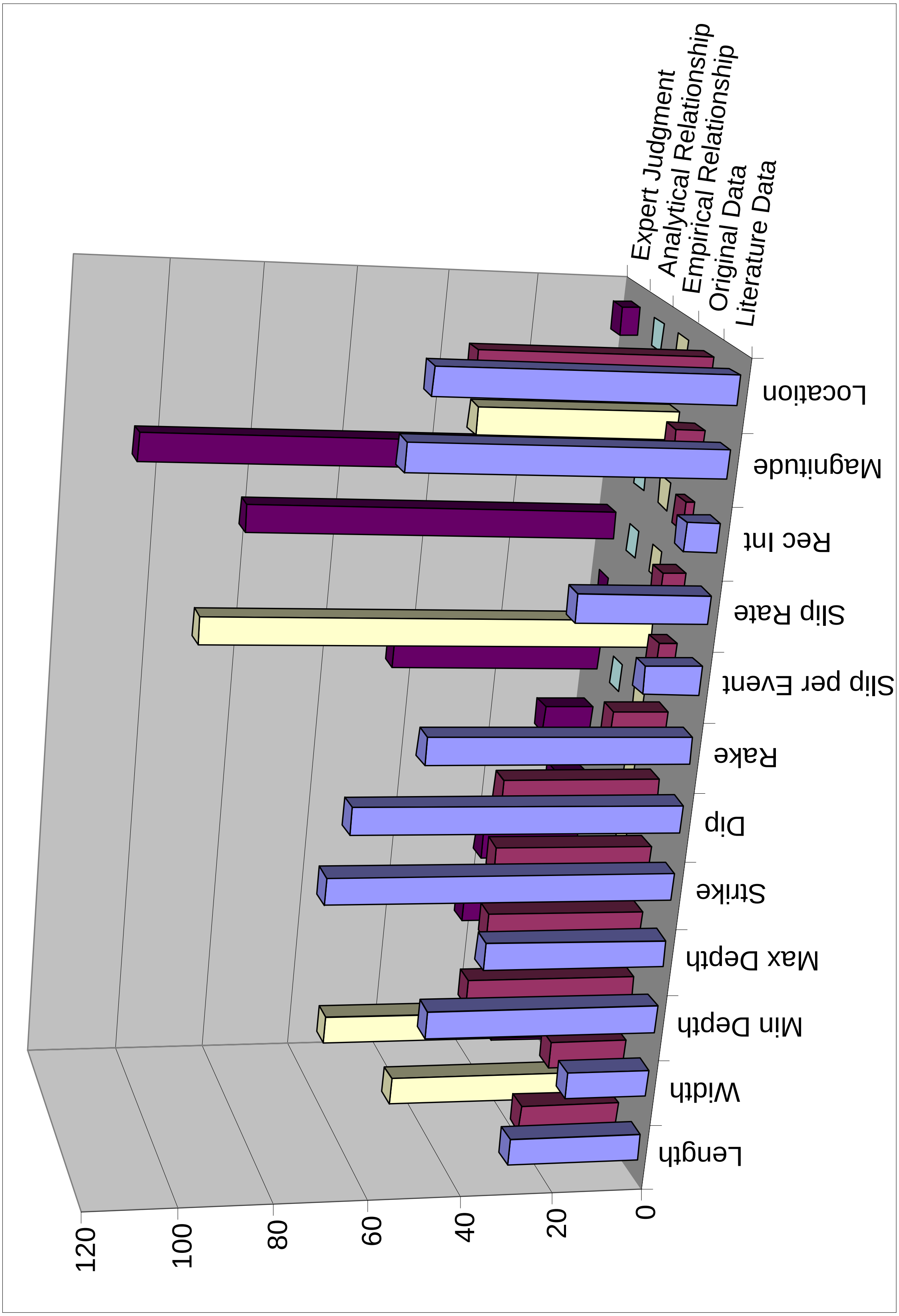


Figure 8a

Basili et al.

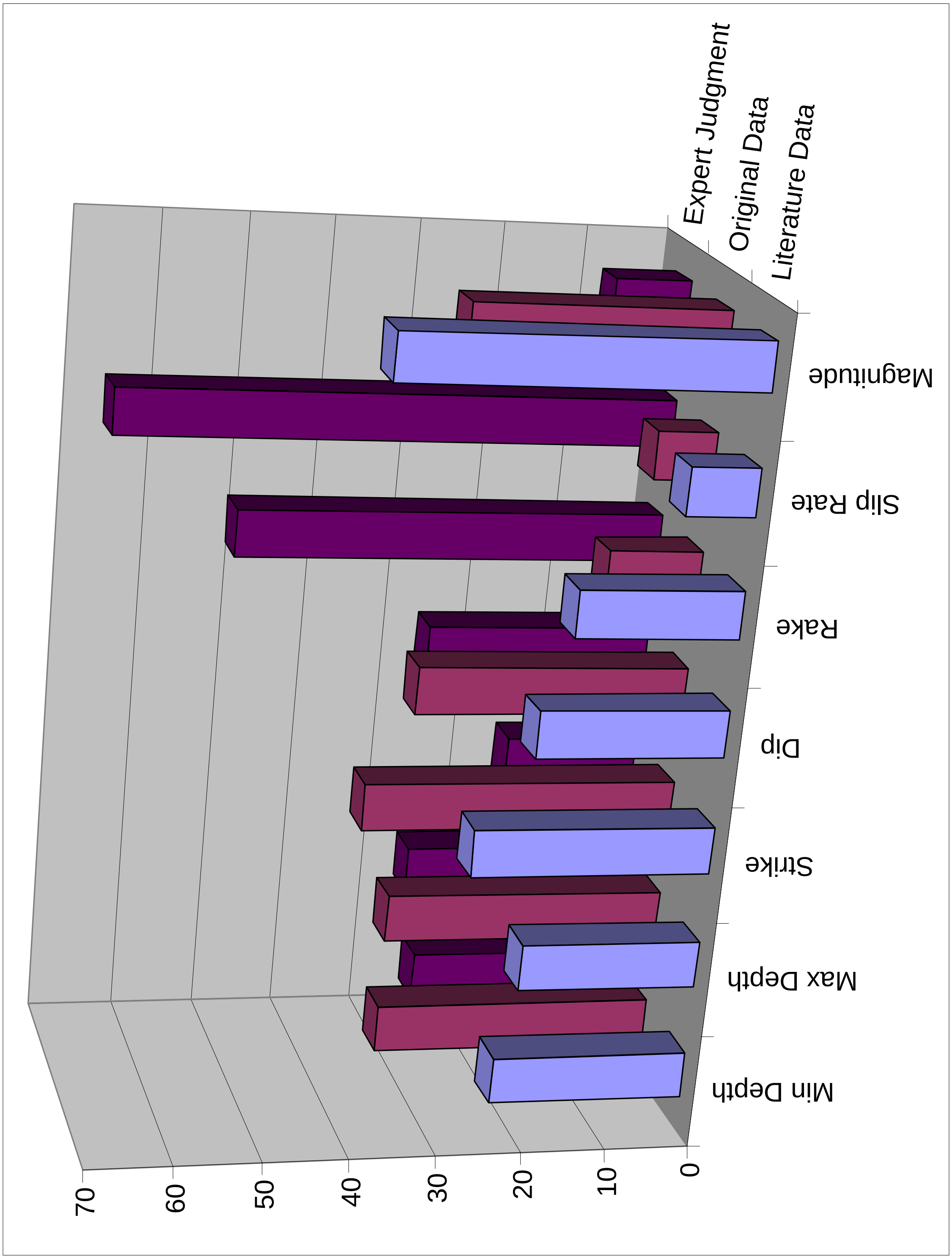


Figure 8b

Basili et al.

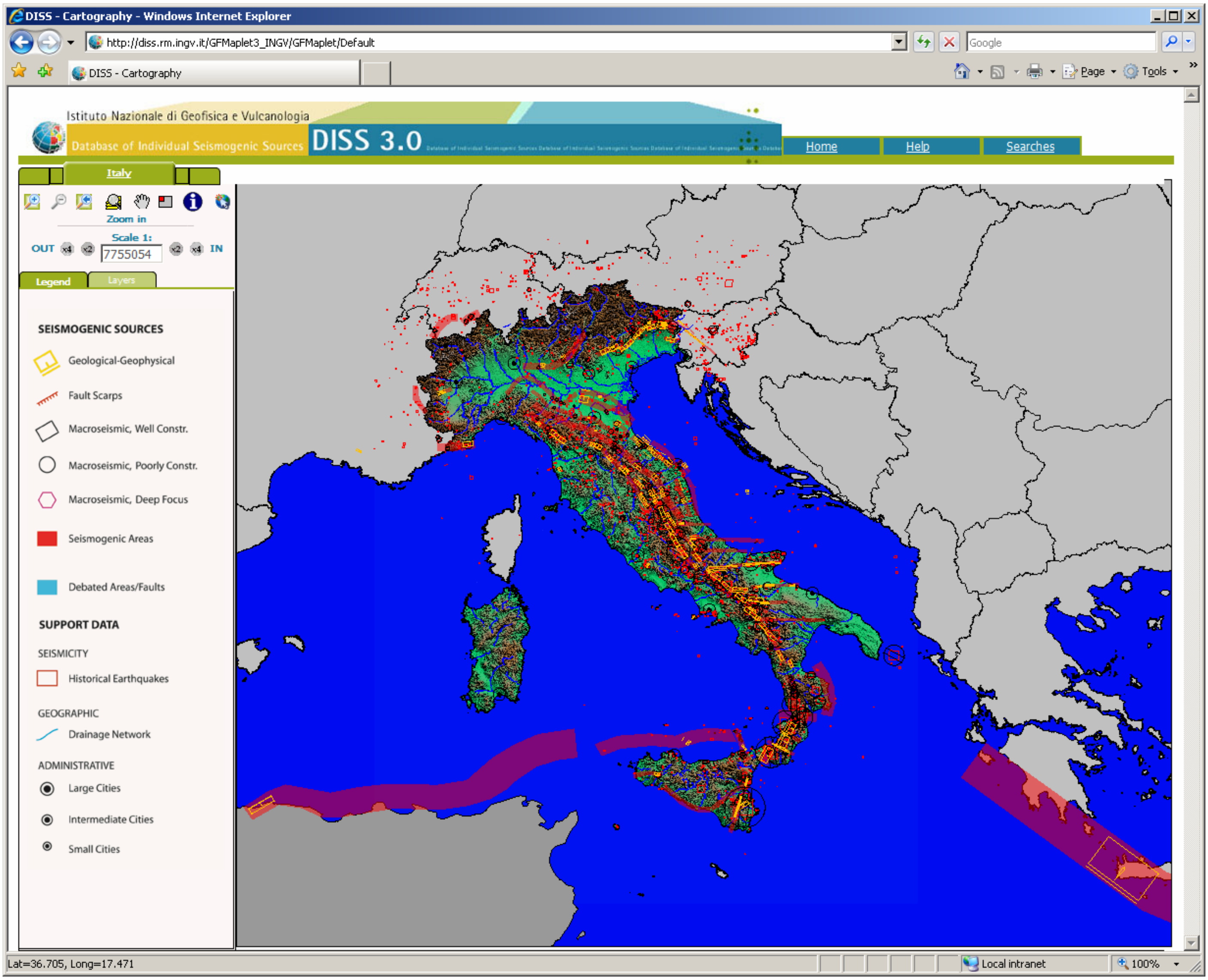


Figure 9a

Basili et al.

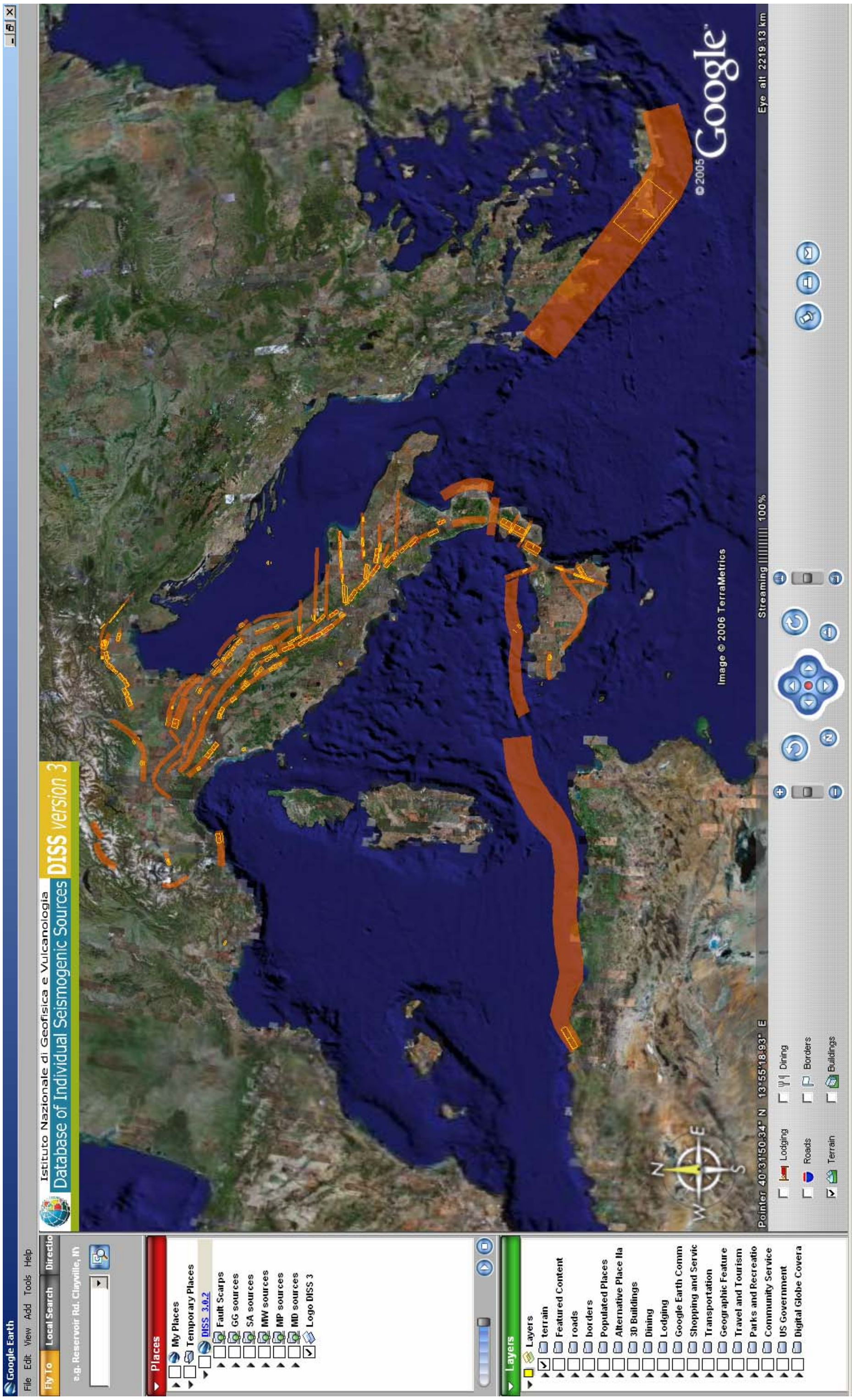
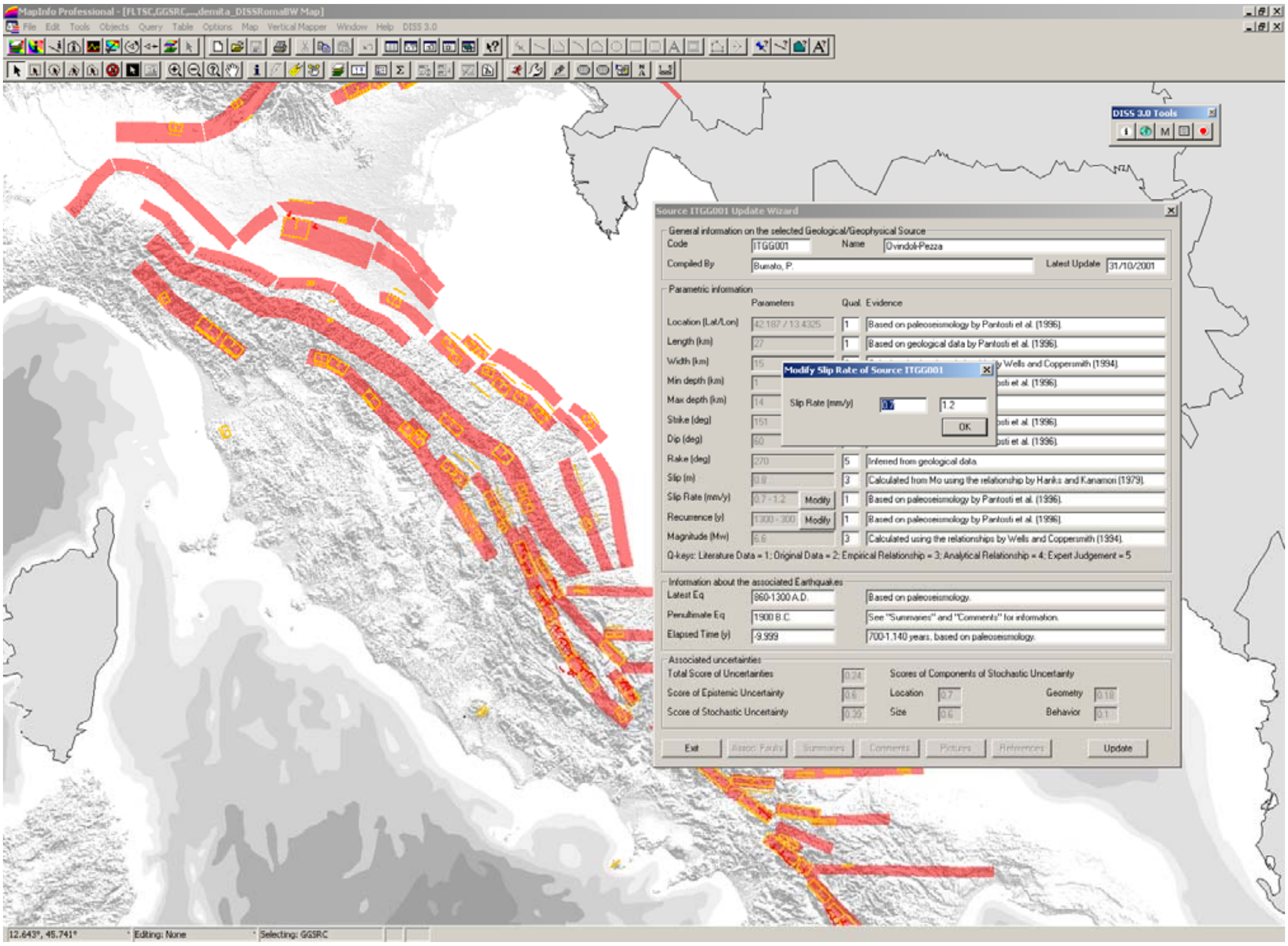


Figure 9b

Basili et al.



General information on the selected Geological/Geophysical Source

Code: ITGG001
Name: Ovindoli-Pezza
Compiled By: Burrato, P.
Latest Update: 31/10/2001

Parametric information

	Parameters	Qual.	Evidence
Location (Lat/Lon)	42.187 / 13.4325	1	Based on paleoseismology by Pantosti et al. (1996).
Length (km)	27	1	Based on geological data by Pantosti et al. (1996).
Width (km)	15		y Wells and Coppersmith (1994).
Min depth (km)	1		osti et al. (1996).
Max depth (km)	14		
Strike (deg)	151		osti et al. (1996).
Dip (deg)	60		osti et al. (1996).
Rake (deg)	270	5	Inferred from geological data.
Slip (m)	0.8	3	Calculated from Mo using the relationship by Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.7 - 1.2	1	Based on paleoseismology by Pantosti et al. (1996).
Recurrence (y)	1300 - 300	1	Based on paleoseismology by Pantosti et al. (1996).
Magnitude (Mw)	6.6	3	Calculated using the relationships by Wells and Coppersmith (1994).

Q-keys: Literature Data = 1; Original Data = 2; Empirical Relationship = 3; Analytical Relationship = 4; Expert Judgement = 5

Slip Rate (mm/y): 0.7 1.2

Information about the associated Earthquakes

Latest Eq	860-1300 A.D.	Based on paleoseismology.
Penultimate Eq	1900 B.C.	See "Summaries" and "Comments" for information.
Elapsed Time (y)	-9.999	700-1,140 years, based on paleoseismology.

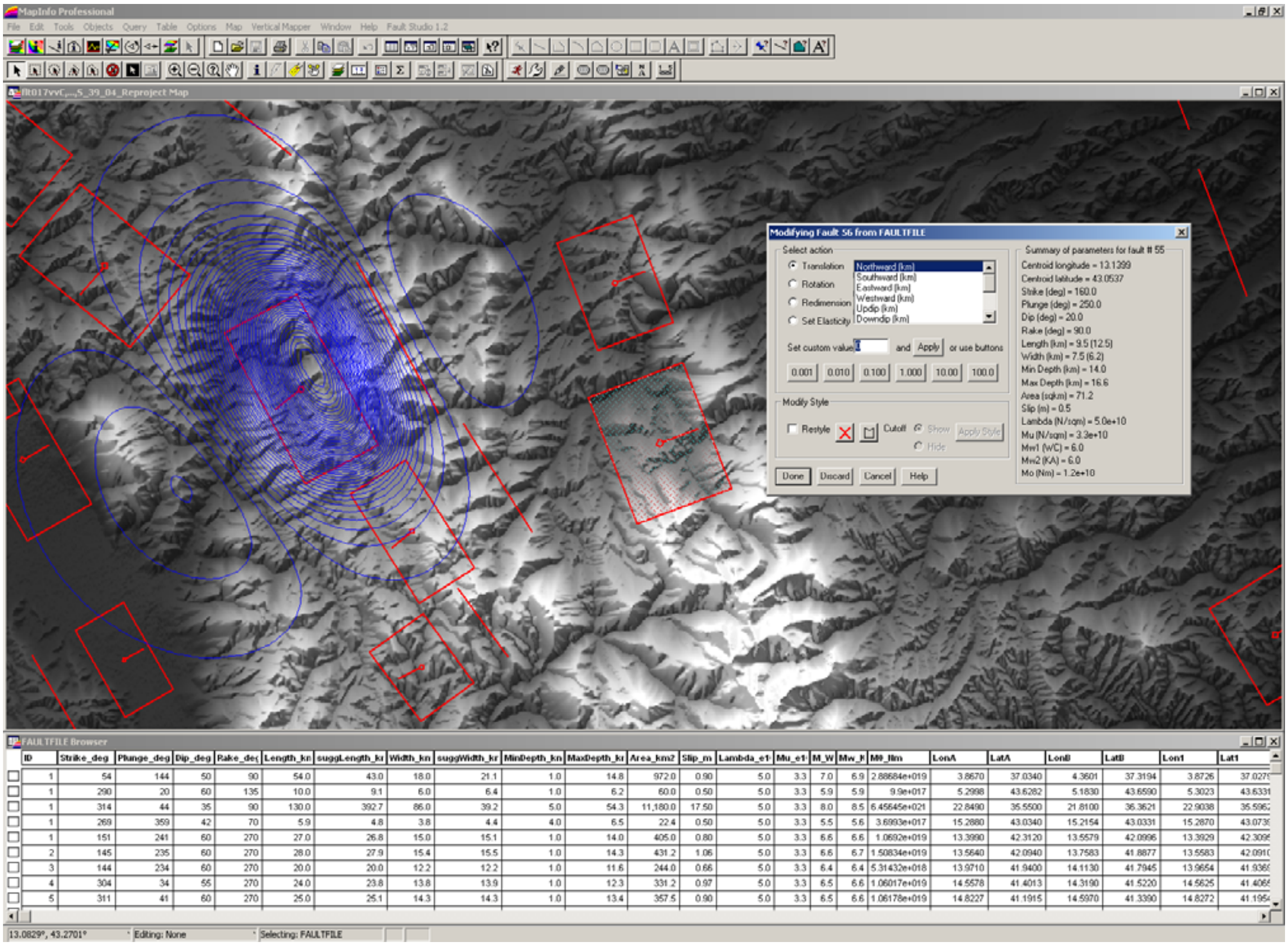
Associated uncertainties

Total Score of Uncertainties: 0.24
Score of Epistemic Uncertainty: 0.6
Score of Stochastic Uncertainty: 0.39

Scores of Components of Stochastic Uncertainty
Location: 0.7
Size: 0.6
Geometry: 0.18
Behavior: 0.1

Figure 9c

Basili et al.



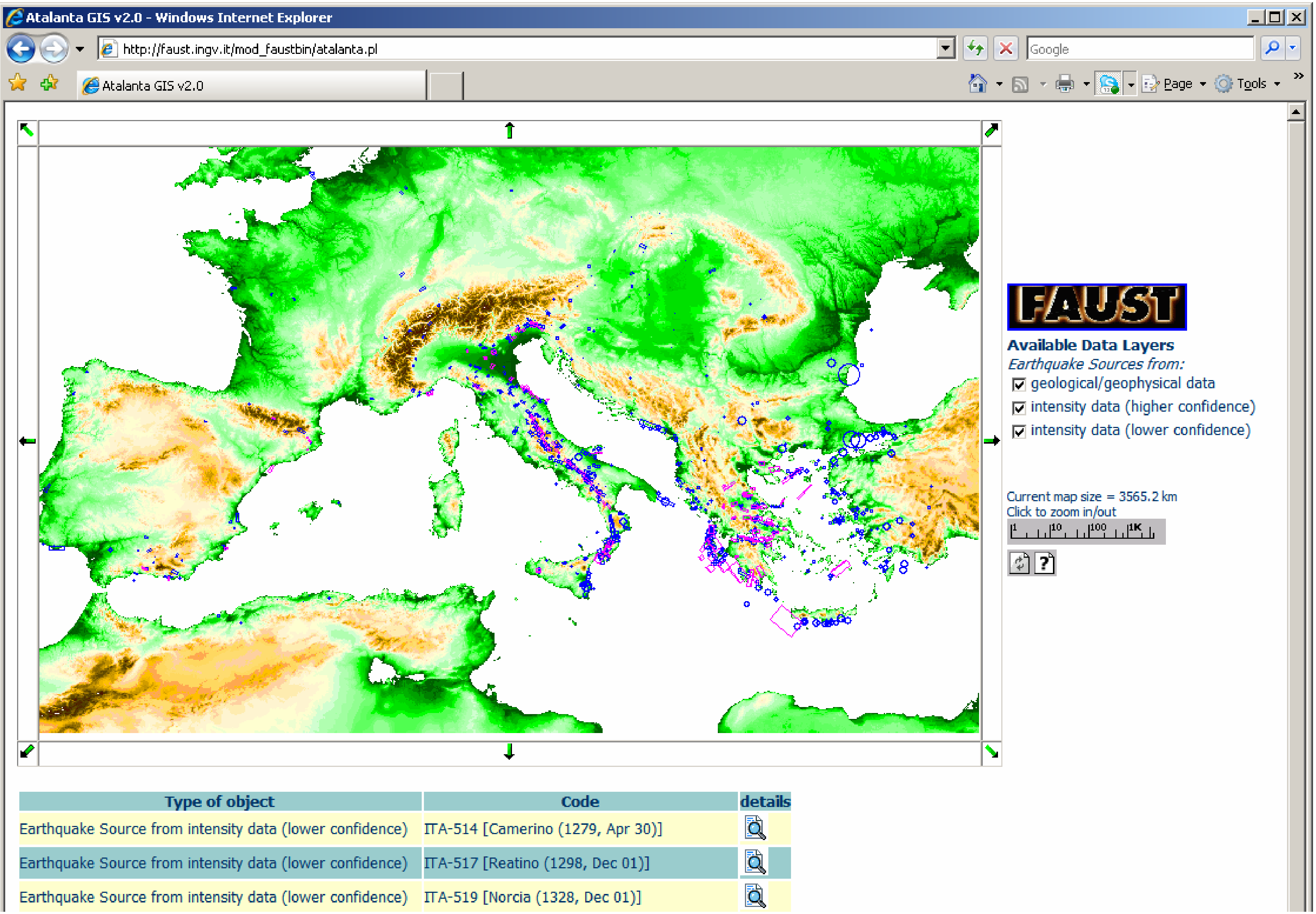
Summary of parameters for fault # 55
Centroid longitude = 13.1399
Centroid latitude = 43.0537
Strike (deg) = 160.0
Plunge (deg) = 250.0
Dip (deg) = 20.0
Rake (deg) = 90.0
Length (km) = 9.5 (12.5)
Width (km) = 7.5 (6.2)
Min Depth (km) = 14.0
Max Depth (km) = 16.6
Area (sqkm) = 71.2
Slip (m) = 0.5
Lambda (N/sqm) = 5.0e+10
Mu (N/sqm) = 3.3e+10
Mw1 (WC) = 6.0
Mw2 (KA) = 6.0
Mo (Nm) = 1.2e+10

	ID	Strike_deg	Plunge_deg	Dip_deg	Rake_de(	Length_kn	suggLength_kr	Width_kn	suggWidth_kr	MinDepth_kn	MaxDepth_kr	Area_km2	Slip_m	Lambda_e1	Mu_e1	M_W	Mw_K	M0_Nm	LonA	LatA	LonB	LatB	Lon1	Lat1
☐	1	54	144	50	90	54.0	43.0	18.0	21.1	1.0	14.8	972.0	0.90	5.0	3.3	7.0	6.9	2.88684e+019	3.8670	37.0340	4.3601	37.3194	3.8726	37.027
☐	1	290	20	60	135	10.0	9.1	6.0	6.4	1.0	6.2	60.0	0.50	5.0	3.3	5.9	5.9	9.9e+017	5.2998	43.6282	5.1830	43.6590	5.3023	43.633
☐	1	314	44	35	90	130.0	392.7	86.0	39.2	5.0	54.3	11,180.0	17.50	5.0	3.3	8.0	8.5	6.45645e+021	22.8490	35.5500	21.8100	36.3621	22.9038	35.596
☐	1	269	359	42	70	5.9	4.8	3.8	4.4	4.0	6.5	22.4	0.50	5.0	3.3	5.5	5.6	3.6993e+017	15.2880	43.0340	15.2154	43.0331	15.2870	43.073
☐	1	151	241	60	270	27.0	26.8	15.0	15.1	1.0	14.0	405.0	0.80	5.0	3.3	6.6	6.6	1.0692e+019	13.3990	42.3120	13.5579	42.0996	13.3929	42.309
☐	2	145	235	60	270	28.0	27.9	15.4	15.5	1.0	14.3	431.2	1.06	5.0	3.3	6.6	6.7	1.50834e+019	13.5640	42.0940	13.7583	41.8877	13.5583	42.091
☐	3	144	234	60	270	20.0	20.0	12.2	12.2	1.0	11.6	244.0	0.66	5.0	3.3	6.4	6.4	5.31432e+018	13.9710	41.9400	14.1130	41.7945	13.9654	41.936
☐	4	304	34	55	270	24.0	23.8	13.8	13.9	1.0	12.3	331.2	0.97	5.0	3.3	6.5	6.6	1.06017e+019	14.5578	41.4013	14.3190	41.5220	14.5625	41.406
☐	5	311	41	60	270	25.0	25.1	14.3	14.3	1.0	13.4	357.5	0.90	5.0	3.3	6.5	6.6	1.06178e+019	14.8227	41.1915	14.5970	41.3390	14.8272	41.195

13.0829°, 43.2701° Editing: None Selecting: FAULTFILE

Figure 9d

Basili et al.



Available Data Layers

Earthquake Sources from:

☑ geological/geophysical data
☑ intensity data (higher confidence)
☑ intensity data (lower confidence)

Current map size = 3565.2 km
Click to zoom in/out

Type of object	Code	details
Earthquake Source from intensity data (lower confidence)	ITA-514 [Camerino (1279, Apr 30)]	🔍
Earthquake Source from intensity data (lower confidence)	ITA-517 [Reatino (1298, Dec 01)]	🔍
Earthquake Source from intensity data (lower confidence)	ITA-519 [Norcia (1328, Dec 01)]	🔍

Figure 10
Basili et al.

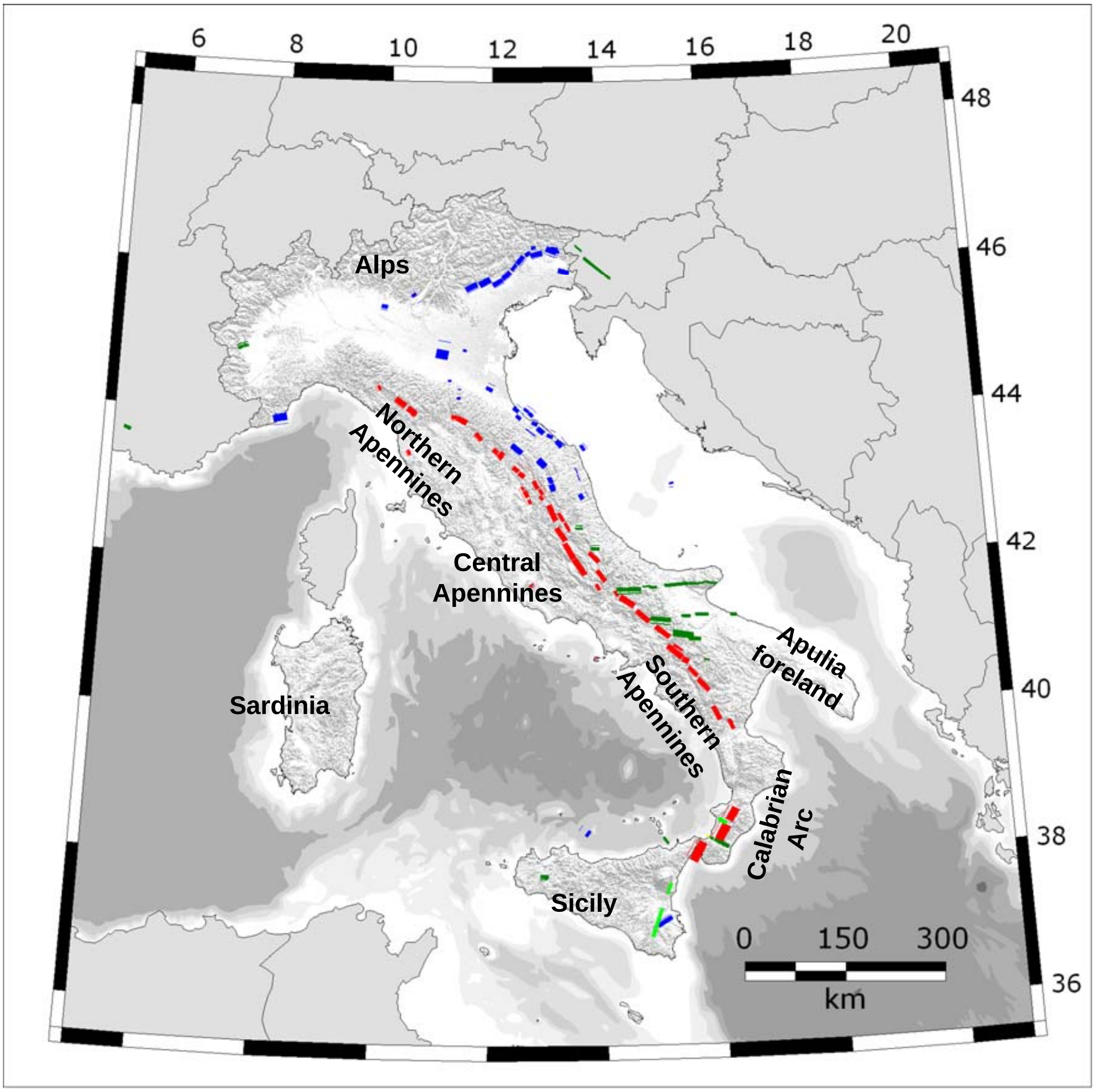


Figure 11a

Basili et al.

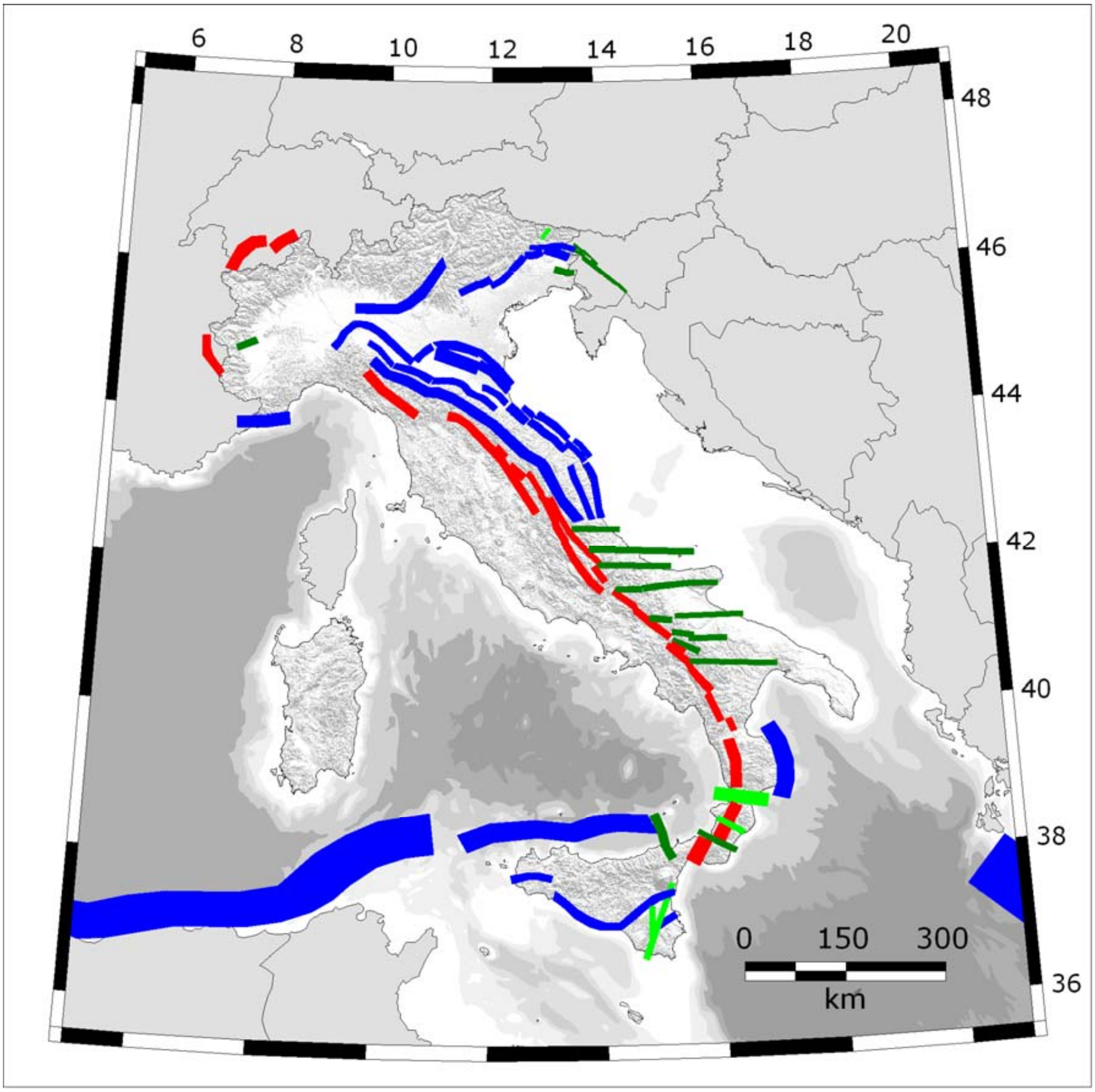


Figure 11b

Basili et al.

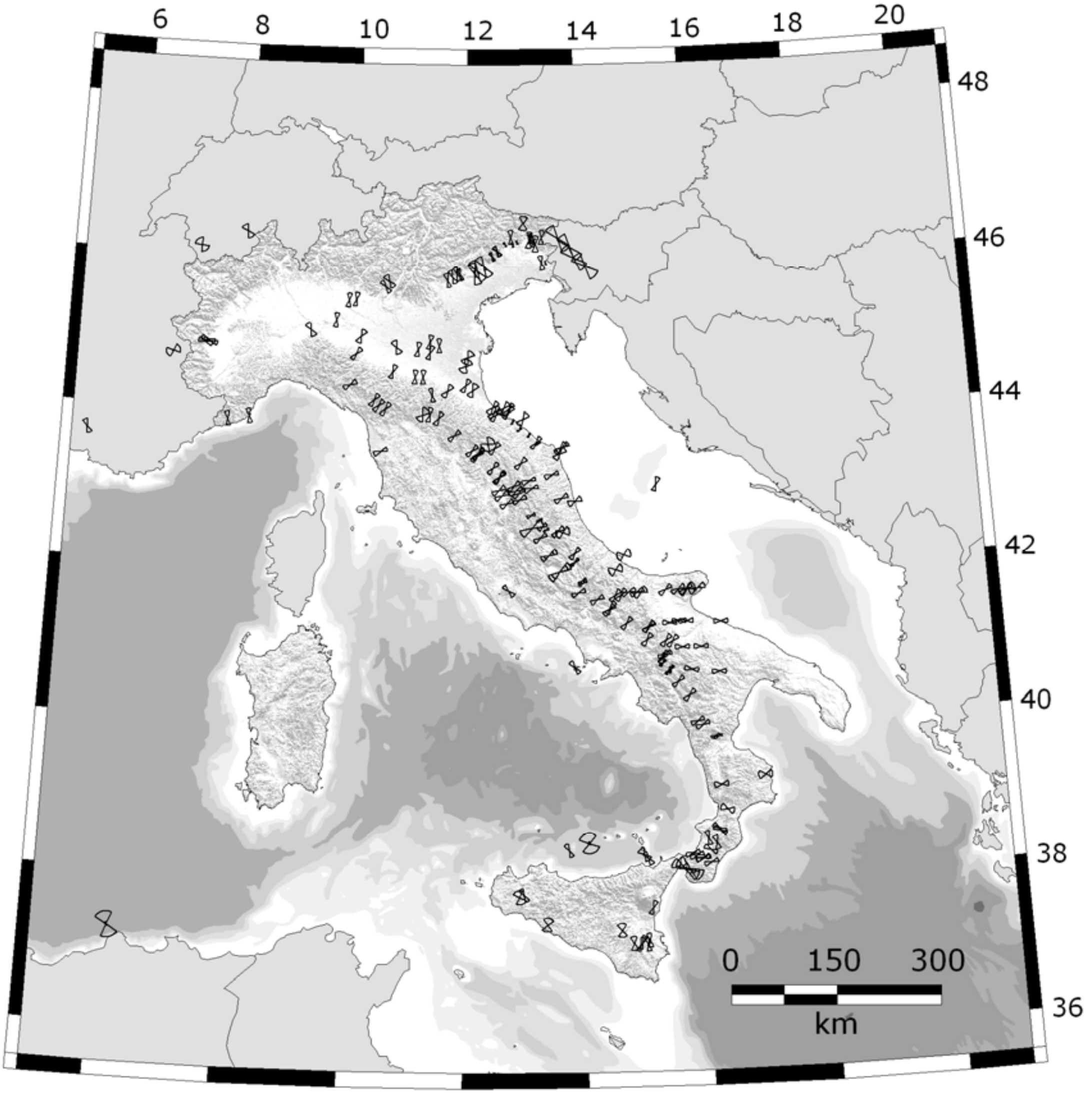


Figure 11c

Basili et al.

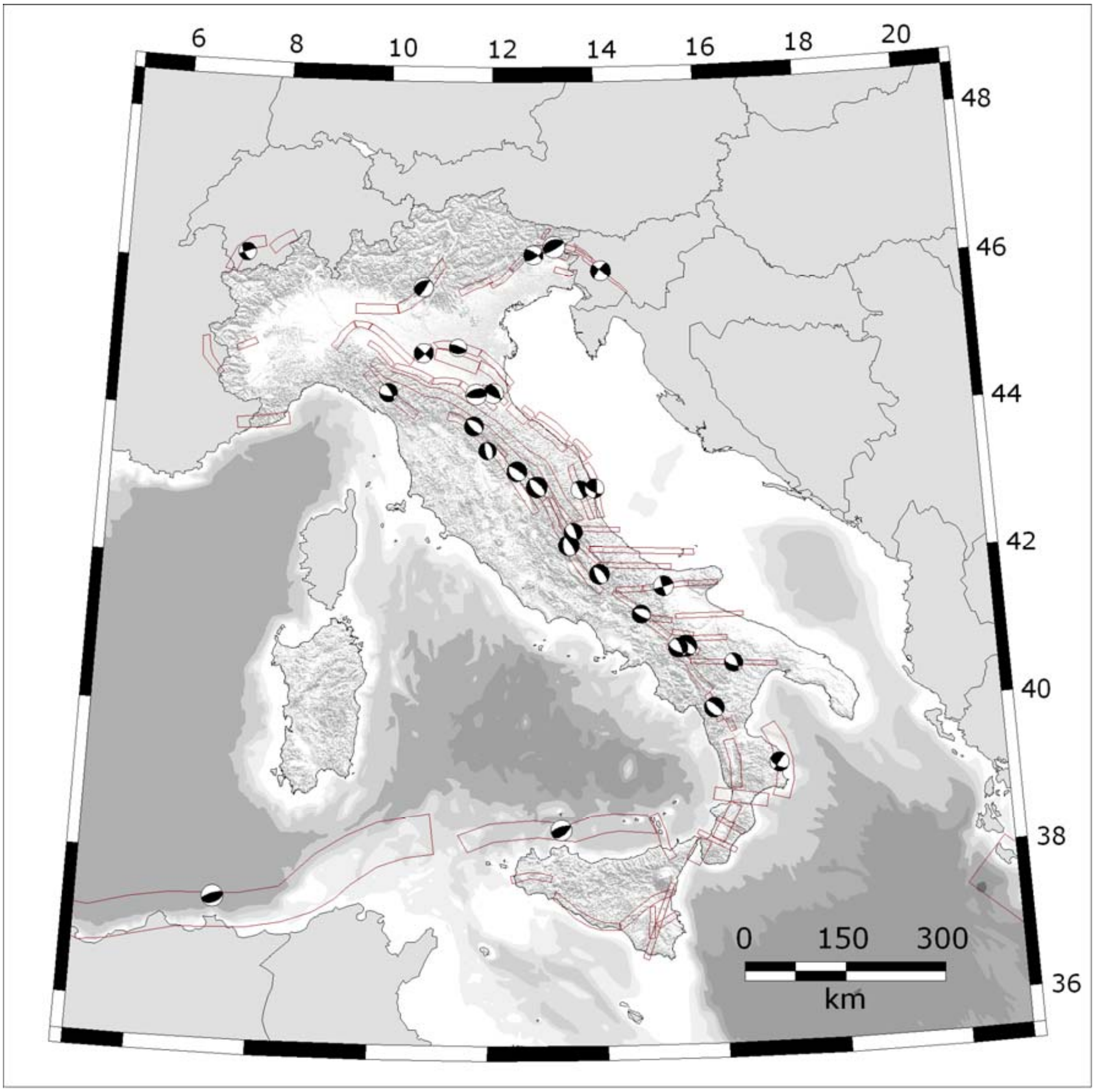


Figure 12a

Basili et al.

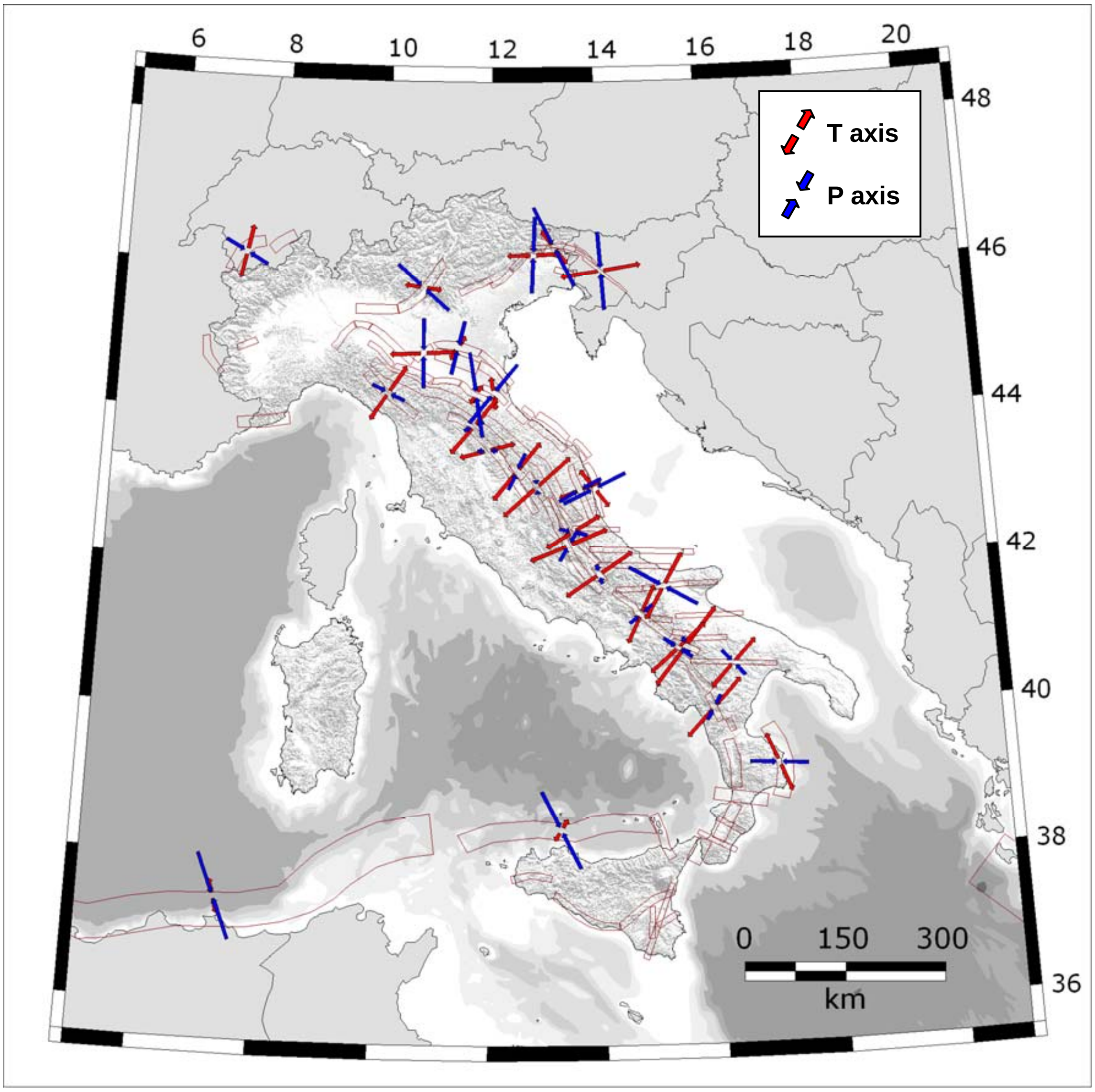


Figure 12b

Basili et al.

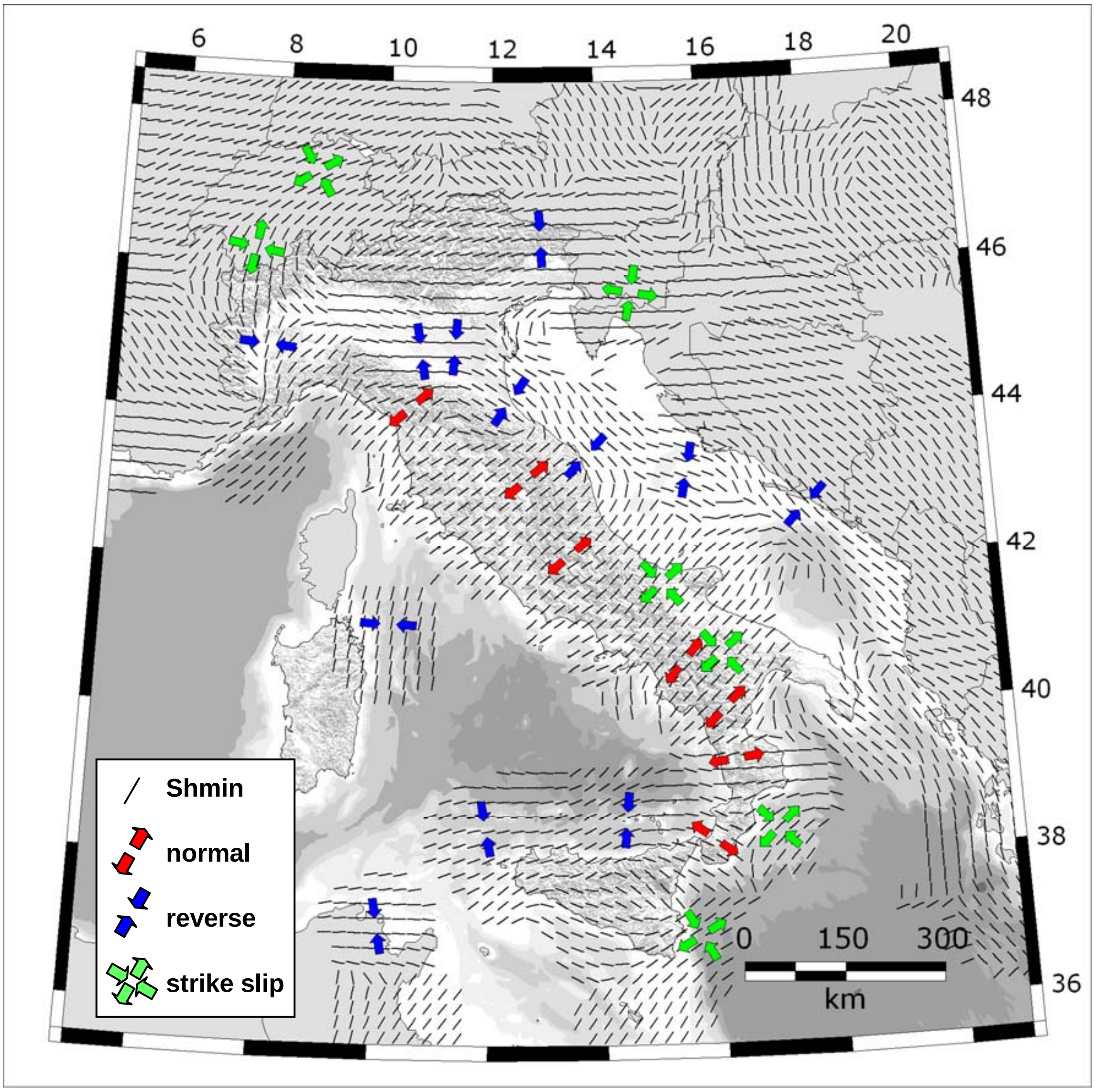


Figure 12c

Basili et al.

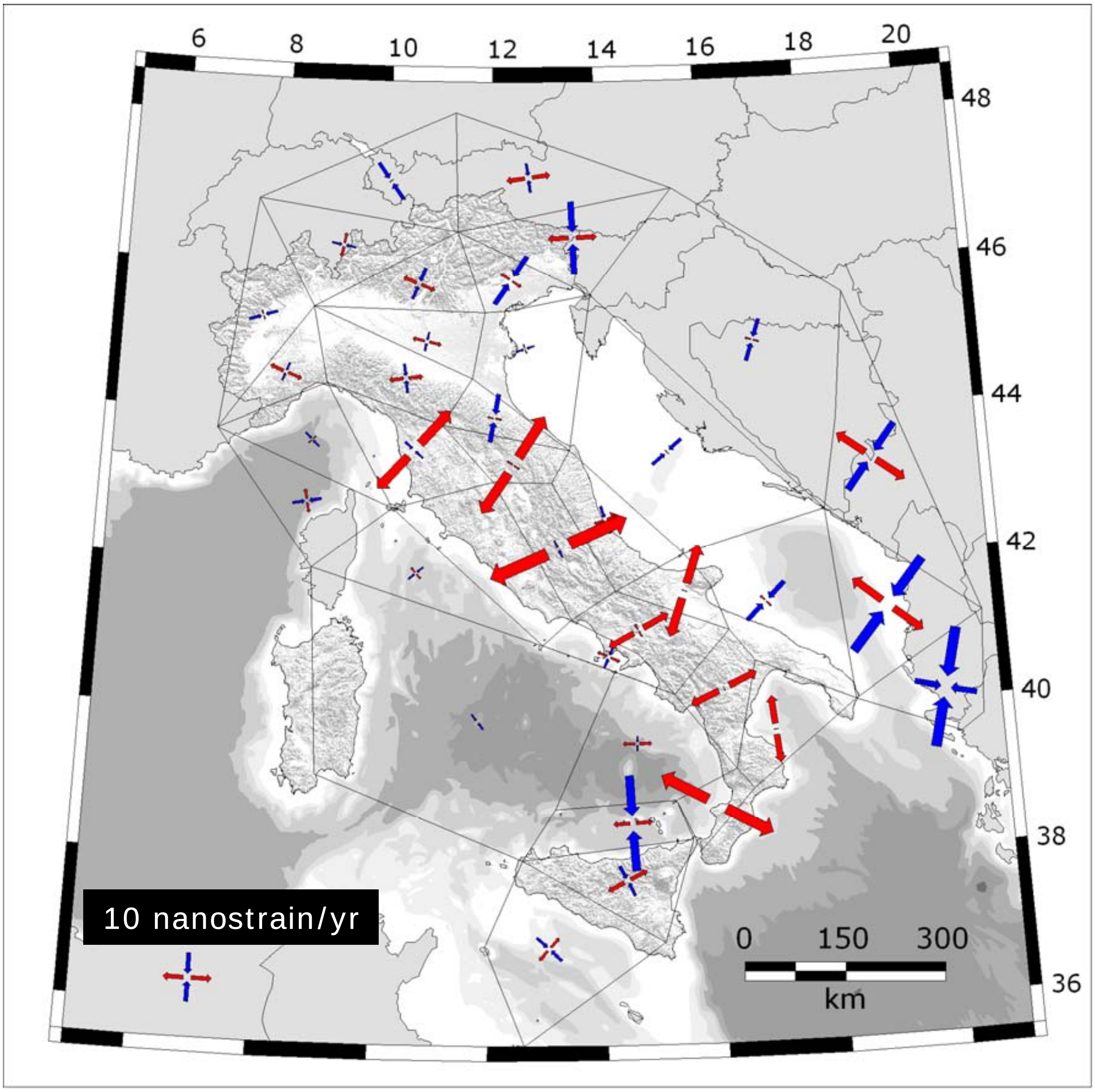


Figure 12d

Basili et al.