

OUTLINE OF THE «MAP OF THE MAJOR ACTIVE FAULTS IN THE HOLOCENE» BETWEEN THE PO AND PIAVE RIVERS AND LAKE COMO (NORTHERN ITALY)

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Abstract

This study consists in the compilation of a «Map of the major active faults in the Holocene» (last 10^4 years) between the Po and Piave rivers and lake Como and in a Catalogue of the faults that appear on the map. Besides the various faults (numbered, classified as «active» and «supposed active» and subdivided into «outcropping» and «buried»), the Map also shows folds (anticlines and synclines), areal movements (uplifting, lowering and tilting), and epicenters of earthquakes with Richter's magnitude ≥ 6 . The Catalogue contains a description of the fault characteristics (type of fault, attitude, displacement, main historical earthquakes, period of activity, classification etc.), which are summarized on special data sheets. Overall, 32 faults have been included on the Map and in the Catalogue. Of these, 9 are «active» faults and 23 are «supposed active faults»; they are concentrated prevalently in the Veneto Pre-Alps and Belluno sector, where several folds also proved to be «active», and in the Lessini M.ts - L. Garda sector. As far as areal movement is concerned, it is possible to distinguish five areas differing in the type of movement. As regards earthquakes, only four seismic events in the study area had characteristics comparable to earthquakes with magnitudes ≤ 6 . The detailed analysis of the hypocentral depths of all the earthquakes recorded instrumentally in the study area since 1982, revealed depths of less than 30 km.

Illustrazione della «Carta delle principali faglie attive nell'Olocene» tra i fiumi Po e Piave e il Lago di Como (Italia Settentrionale)

Riassunto

Lo studio illustrato consiste nell'elaborazione di una «Carta delle principali faglie attive nell'Olocene» (da 10.000 anni a.C. ad oggi) tra i fiumi Po e Piave e il lago di Como e nella preparazione di un Catalogo delle faglie ivi rappresentate. Nella «Map of the major active faults in the Holocene», sono riportate oltre alle varie faglie (numerate, classificate in «attive» e «ritenute attive» e suddivise in «affioranti» e «sepolte») altri elementi di attività tettonica olocenica: pieghe (anticlinali e sinclinali), movimenti areali (sollevamenti, abbassamenti e basculamenti) e gli epicentri dei terremoti con magnitudo maggiore o uguale a 6 gradi della scala Richter. Il Catalogo consiste nella descrizione delle caratteristiche delle faglie; tali caratteristiche sono riassunte in apposite schede che riportano per ciascuna faglia o gruppo di faglie: le coordinate delle estremità, il nome, la bibliografia neotettonica, il tipo di faglia, la giacitura, il rigetto, la lunghezza, i principali terremoti (con indicazione della data degli eventi, della magnitudo), e la profondità ipocentrale massima e più frequente, l'intervallo di attività, la classificazione e le eventuali note. In totale sono state rappresentate in carta e catalogate 32 faglie di cui 9 «attive» e 23 «presunte attive». Esse risultano concentrate nel settore delle Prealpi Venete Orientali e del Bellunese, dove sono indicate come «attive» anche alcune pieghe, e nel settore M. Lessini - L. di Garda. Dal punto di vista dei movimenti areali si possono distinguere cinque settori con diversi tipi di movimento. Per quanto riguarda i terremoti, nella regione studiata, sono avvenuti solo quattro sismi di caratteristiche paragonabili ad eventi di magnitudo ≥ 6 . L'analisi di dettaglio delle profondità ipocentrali di tutti i sismi registrati strumentalmente a partire dal 1982, ha rivelato profondità inferiori a 30 km.

Keywords: Northern Italy, active fault, Holocene.

Parole chiave: Italia Settentrionale, faglia attiva, Olocene.

Introduction

This work has been carried out in the frame of the International Lithosphere Programme (ILP) subproject «World map of major active faults» (Trifonov, 1990) and of the Italian National Project «Geomorfologia strutturale ed evoluzione del rilievo in Italia e in altre aree mediterranea».

The starting point for this study consists in the results of research conducted in 1990 and 1991, and which led to the compilation of an inventory of faults active in the Middle Pleistocene - Holocene (700,000 years b.P.), between the Po and Piave rivers and lake Como (Castaldini & Panizza, 1991).

These data have been re-examined and, in the case of seismological data, supplemented with data taken from the catalogue of earthquakes in Italy since 1000 A.D. (Postpischl

1985), compiled in the frame of the Progetto Finalizzato Geodinamica, as well as with data collected by the seismometric network of the Osservatorio Geofisico Sperimentale of Trieste (OGS, 1982-1990).

Procedures and mapping criteria

Map of the major active faults in the Holocene

The original scale of the «Map of the active faults in the Holocene» (Figure 1) is 1:1,000,000 (a scale which allows for sufficient clarity in spite of the concentration of faults and other records of tectonic activity in certain sectors).

All Holocene faults that are more than 15 km in length (that is, faults reaching a length of at least 3 mm on the final scale of 1:5,000,000 for the map of continents of the ILP Project) are included in the Map.

The faults have been classified as «active» or «supposed active» but there is no indication of the type of movement because in many cases, the data reported in the literature are conflicting (e.g., see Notes in Figures 2a and 2b).

As concerns the activity of the faults, the following classification, derived from Panizza & Castaldini (1987), has been adopted:

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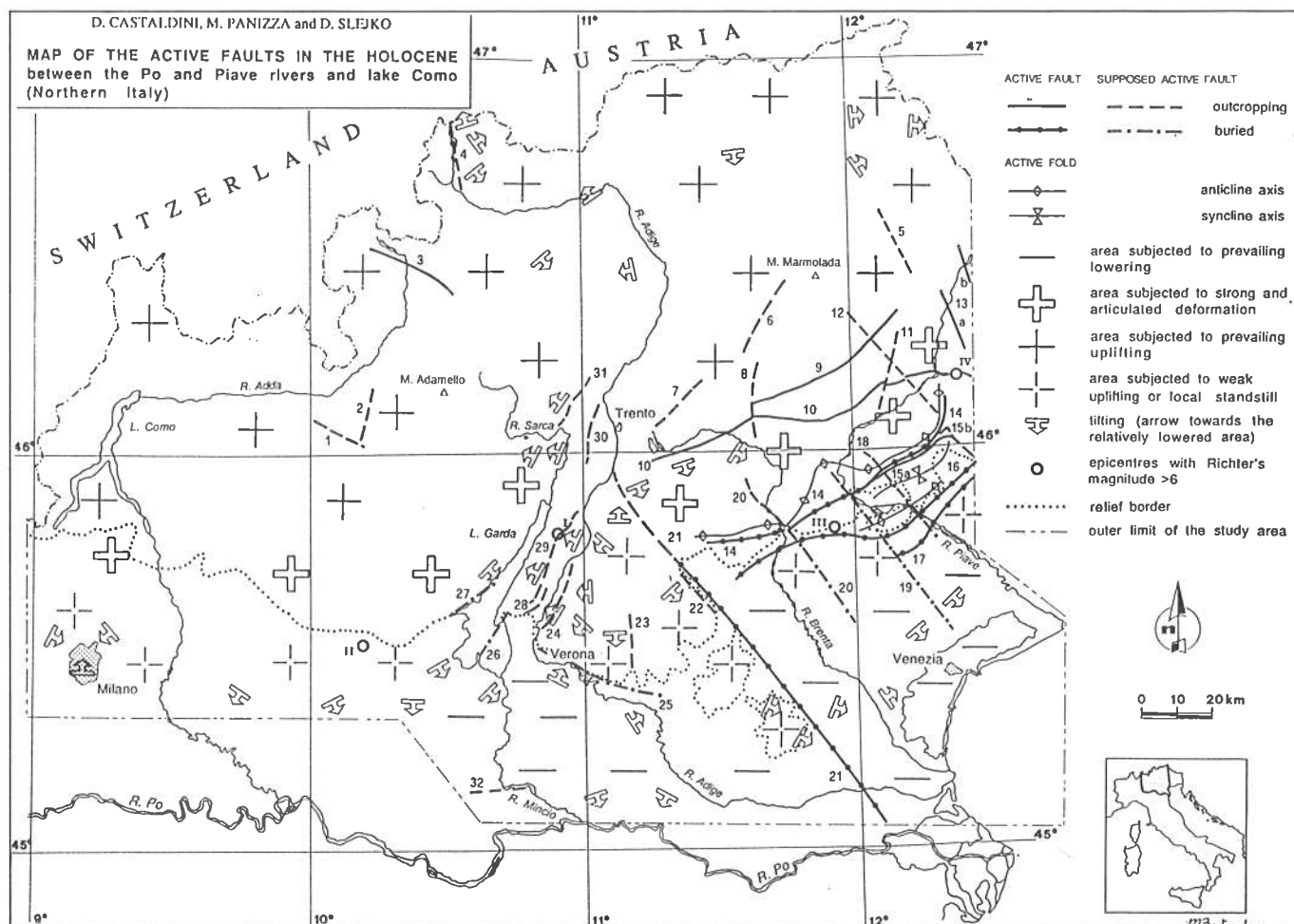


Figure 1 - Map of the major active faults in the Holocene, between the Po and Piave rivers and lake Como (Northern Italy).

- «Active fault»: proven displacement of rocks and/or «significant» forms or on the basis of levelling of precision.

- «Supposed active fault»: on the basis of supporting geomorphological or other evidence (e.g. seismological data), but showing no visible displacement of rocks and/or «significant» forms.

The term «significant» is used for rocks and forms to indicate that their age lies within the neotectonic interval considered (in this research: Holocene, 10,000 years b. P.).

As concerns the other linear elements that appear on the map, that is, the folds, they have been identified as «active», as the literature (Pellegrini & Zanferrari, 1980) have indicated the presence of «deformed continental deposits, of the late upper Pleistocene age», along them.

Both the faults and the folds have been classified as either «outcropping» or «buried».

The identification of areal movements in the Holocene was derived from CNR (1983) and from Slejko et al. (1987), with some changes being made on the basis of detailed studies (ENEL, 1988).

As concerns seismicity, the catalogue of earthquakes in Italy since 1000 A.D. (Postpischl, 1985) reports only four earthquakes with epicentral intensity greater than, or equal to, X on the Mercalli-Cancani-Sieberg (MCS) scale and, therefore, of magnitude greater than 6 (Table 1), when the Karnik (1969) magnitude/intensity relation valid for the Alps is con-

sidered. Hypocentral depth can be estimated from macroseismic data only when a good isoseismal map is available. In the case of the four large earthquakes, only the most recent one of 1873 permitted an estimation of the depth at about 25 km.

Faults Catalogue

The characteristics of the faults to be listed in the Catalogue were summarized on special data sheets (see examples in Figures 2a and 2b).

The significant items making up the data sheets for the Catalogue are described briefly below.

Neotectonic references

The references (indicated by a number in parentheses,

Nr	DATE			EPICENTRAL COORDINATES			D	I ₀	M	EPICENTRAL AREA
	year	month	day	Lat N	Long E	Gr.				
I	1117	JAN	3	45° 48'	10° 54'	-	-	X-XI	6.5	Verona area
II	1222	DEC	25	45° 32'	10° 12'	-	-	XI	6.8	Brescia area
III	1695	FEB	25	45° 48'	11° 55'	-	-	X	6.3	Asolo area
IV	1876	JUN	29	46° 11'	12° 23'	25	25	X	6.8	Belluno area

Table 1 - Earthquakes with epicenter intensities greater than, or equal to, X (MCS) (that is, greater than, or equal to, a magnitude of 6), occurring in the study area from the year 1000 to 1980 (from Postpischl 1985). Nr = number of the epicenter in Figure 2; D = depth of focus; I₀ = MCS epicentral intensity; M = Richter's magnitude obtained from I₀ using Karnik's relation (1969).

Fault n.	Coordinates of both extremities	Name of the fault	Neotectonic references	Type of fault	Attitude			Displacement (m)	Length (km)	Main historical earthquakes in the fault zone and focus depth	Period of activity	Classification	Notes
					Strike	Dip	Dip angle						
14	46°08'-12°19' 45°47'-11°24'	Bassano-Valdobbiadene Line or Flexure	99] 70] 97] 38] 72] 61] 88]	*)	WSW-ENE NNE-SSW	S	from 75° to v	**)	1873/7/6 - M=4.9 ***) 1873/7/27 - M=5.2 ***) Dm = 29 km 9 km < Df < 14 km	Holocene from 72] and 99]	A	*) Various authors have defined this as a flexure, a fault-fold or a S-verging thrust. Through the associated Longhere L. (n.15a), it continues eastward beyond the study area. **) The overall post-Piacenzian uplift of the Bassano-Valdobbiadene Flexure is estimable at 0.5-1 mm/year. 72] and 97] ***) Aftershocks of the M= 6,2 earthquake of the fault zone n.10	
15	45°58'-12°26' 45°54'-12°03'	Longhere F. (a) - Montaner F. (b)	72] 99] 97] 38] 88] 73]	*)	NE-SW	-	-	>100 v**)	36 Dm, Df = n.a.	Holocene from 97]	A sA ***)	*) Reverse: lowering of the N side in correspondence of the Longhere F. and of the W side in correspondence of the Montaner F. Associated with the Bassano-Valdobbiadene L. (n. 14) **) In the Middle Pleistocene-Holocene. 99] ***) 15 a= Active 15 b=Supposed Active	

Figure 2a - Example of a data sheet for the Catalogue of active faults: Bassano-Valdobbiadene L. (n. 14) and Longhere F.-Montaner F. (n. 15). F=fault; L=line; (-)=non indicated; u=undefined; v=vertical and subvertical; h=horizontal; M=Richter's magnitude; Dm=maximum depth of focus; Df=most frequent depth of focus; n.a.=not assessed; A=active fault; sA=supposed fault active.

Fault n.	Coordinates of both extremities	Name of the fault	Neotectonic references	Type of fault	Attitude			Displacement (m)	Length (km)	Main historical earthquakes in the fault zone and focus depth	Period of activity	Classification	Notes
					Strike	Dip	Dip angle						
28	45°40'-10°52' 45°36'-10°46'	Dosso della Croce F.	83] 46] 70] 38] 88] 18] 31] 54] 97]	*)	WSW-ENE	NW	60°	u	15 Dm = 17 km Df = 7 km	1876/4/29 - M=4.7 Dm = 17 km Df = 7 km	Contemporary 54]	sA	*) Various indications: normal fault, reverse fault or thrust. Most studies define it as a reverse fault and all of them indicate uplifting of the NW side. The attitude data are those reported in 31]
29	45°52'-10°59' 45°37'-10°48'	M.Baldo L.	83] 84] 85] 46] 70] 97] 38] 88] 28] 31] 61] 54] 92] 87]	*)	NNE-SSW	WNW	v	u	30 Dm=23 km 7 km < Df < 12 km	1117/1/3 - M=6.5 1334/12/4 - M=5.5 1876/4/29 - M=5.2 Dm=23 km 7 km < Df < 12 km	Holocene 28], 31]	sA	*) Various definitions are provided by the neotectonic literature: reverse fault, normal fault or thrust. However, all the studies indicate uplifting of the W side.

Figure 2b - Example of a data sheet for the Catalogue of active faults: Dosso della Croce F. (n. 28) ad M. Baldo L. (n. 29).

which corresponds to the number used in the «References» section of this research) are limited to publications with a neotectonic orientation. However, publications from other fields of Earth Sciences were also considered and are listed when they contain significant data for the definition of the activity of the elements inventoried.

Type of fault

The type of fault is indicated here, along with the type of movement in the neotectonic period considered. In cases where the movement that took place in the Holocene proved to conflict with the geometric features of the element, it was indicated as such in the Notes.

Displacement

The amount of the displacement proved to be difficult to specify using bibliographical references alone. In the literature one usually finds an indication of the total displacement of the element considered, without any further subdivisions by partial intervals such as the Holocene. However, particular bibliographical references and pertinent data may be supplied for this item in the Notes.

Main Historical Earthquakes and Focus Depth

The dates (year, month and day; 0 indicates that the month and/or day are unknown) are listed here, along with the Richter magnitude (abbreviated as M), of the main historical earthquakes that took place since 1000 A.D. in the fault zone, that is, within a 10 km wide strip centered on the fault trace. These data are based on the Postpischl (1985) Catalogue as well as on the OGS (1982-1990) data file. In cases where the magnitude had not been assessed on the basis of instrumental recordings, it was calculated from the epicentral intensity using the Karnik's relation (1969) for Alpine earthquakes. Moreover, for each fault, the maximum depth of focus (Dm) and the most frequent depth of focus (Df) are indicated and expressed in km. These data were obtained from vertical cross sections (see examples in Figure 3) representing the foci within a 10 km wide strip along the study fault. The seismicity reported is that recorded by the OGS seismometric network during the period 1982-1990. When the number of hypocentral solutions is not sufficient for M, Dm and Df estimates, the notation «n.a.» (not assessed) has been used.

The choice of 10 km for the width of the strip was made in consideration of several factors (e.g., the hypocenter location is sometimes not precise enough to permit consideration of a narrower strip; deep fault geometry must be considered and narrow strips would be suited only to vertical faults).

Period of activity

The period in which the element in question was active, is indicated in this column. However, when significant data were available, the most recent period of activity was specified. Any conflicting reports found in the references are reported in the Notes.

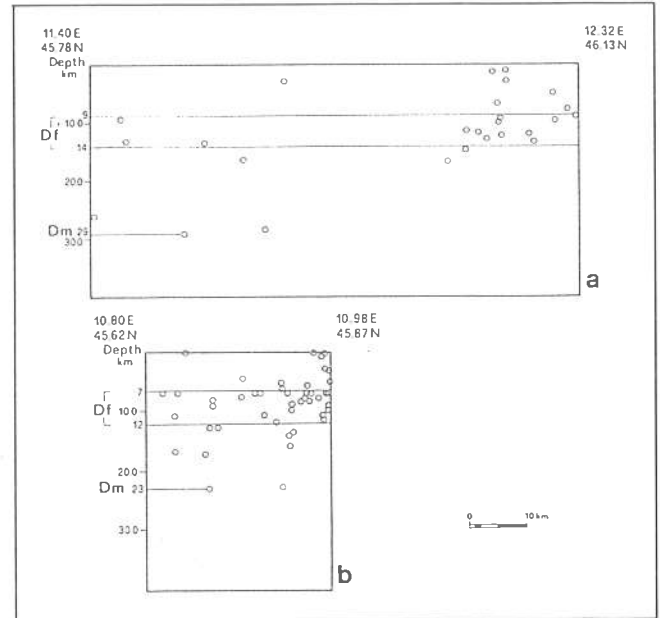


Figure 3 - Examples of a vertical cross sections with foci along the Bassano-Valdobbiadene Line, n. 14, (Fig. 3a) and along the M. Baldo Line, n. 29, (Fig. 3b). The foci (shown as circles varying in size according to magnitude) of earthquakes occurring within a 10 km wide, strip along the study fault and located using data from the seismometer network in Northeastern Italy (OGS, 1982-1990). Dm is the maximum depth of focus. Df is the most frequent depth of focus.

Classification

The faults have been classified as «Active» (abbreviated as A) or «Supposed Active» (SA), according to the above mentioned definitions.

Notes

Any additional notes and observations deemed necessary regarding one or more of the items described above, are included in this column and are marked with an asterisk.

Description of the «Map of the major active faults in the Holocene»

On the base of the results obtained in this study, it is possible to do the following general considerations.

Thirty-two (32) faults (or fault systems) were catalogued and mapped in this study. Nine (9) of these faults were classified as «active faults» (at least for most of their length) on the basis of geologic evidence (displacement of continental deposits which are mainly of the late upper Pleistocene age) and/or levelling of precision data and they are characterized by marked geomorphological evidence (e.g. scarps, rectilinear valleys, reverse slopes, etc...); the classification of the twenty three (23) «supposed active faults» was based, above all, on marked morphoneotectonic evidence and on seismic activity.

They are primarily concentrated in two sectors: 1) the Veneto-Pre-Alps and Belluno sector, where several folds also proved to be active (deformed continental deposits of the late upper Pleistocene); 2) the Lessini M.ts - L. Garda sector. The area between lake Garda and the Brenta river is shown in Figure 4 and it represents part of the two sectors in which

most of the faults inventoried are located. In more detail, Figure 4 a is a sketch of the «Map of active faults in the Holocene» and Figure 4b is a detail from a Large Format Camera (LFC) photograph (scale: 1:770,000 approx.) from Space Shuttle Mission 41 (October 1984). Comparing the two, it is possible to observe morphological evidence of some faults.

Anyway, generally speaking, the absence of faults in some sector of the study area appears to be due to a lower concentration of studies and therefore to a lack of sufficient data for their evaluation, rather than to an absence of neotectonic displacements.

The displacements, which are only of vertical type, vary from a few millimeters (as shown by levelling of precision data), to several meters, (as determined by geologic or geomorphological criteria). For example, the minimum movements were obtained using geodetic data (de Concini et al., 1980) for the Valsugana L., no. 9, (5 mm) and for the Belluno L., no. 10, (3 mm) over a period of about 5 years. One of the most marked displacements was identified along the Malo Fault, no. 22. In fact, a «probable 25 meter displacement of paleosurfaces and Holocene deposits» was reported (Cavallin et al., 1988d).

As far as areal movement is concerned, it is possible to distinguish five sectors: the northern Alpine sector undergoing generalized differential uplift. The uplift and the activity of the disjunctive structure were mainly deduced from morphological data, even though direct geological evidence is not lacking, especially in the Dolomite areas; 2) the Lombard Pre-Alps, the Garda area and Veneto Pre-Alps subject to strong articulated deformation. From a morphotectonic point of view, this evolution is marked by scarps of considerable dimensions, by evident changes in the water network and large landslides (Zanferrari et al., 1982); 3) the Lessini, Berici and Euganei Groups undergoing weak uplifting and/or deformation. A process of articulated uplifting, that divide the area in small blocks, is in progress and general tilting southward is also present.; 4) the upper Lombard and eastern Veneto plain subject to weak uplifting, as shown by the terraces of the main watercourses and their migrations, or local stability; 5) the middle and lower Lombard and Veneto plain sector characterized by constant subsidence in the Quaternary which was more marked towards the Po valley axis and towards the coastal belt.

As regards earthquakes, only four seismic events in the study area had characteristics comparable to earthquakes with magnitudes > 6. More specifically, these events proved to have corresponding magnitudes between 6.3 and 6.8. They occurred between 1117 and 1873 (see Table 1). The first two in particular occurred in a far past and the information available during the preparation of the Postpischl (1985) Catalogue was not suitable to evaluate adequately location and size of the events. Very recently detailed historical investigations have been promoted.

Aside from the earthquake that had its epicenter west of lake Garda, the others are can be tentatively all correlated with the faults or fault systems shown on the «Map of active faults in the Holocene».

The detailed analysis of the hypocentral depths of all the earthquakes recorded instrumentally (OGS, 1982-1990), revealed in all the study region depths of focus less than 30 km.

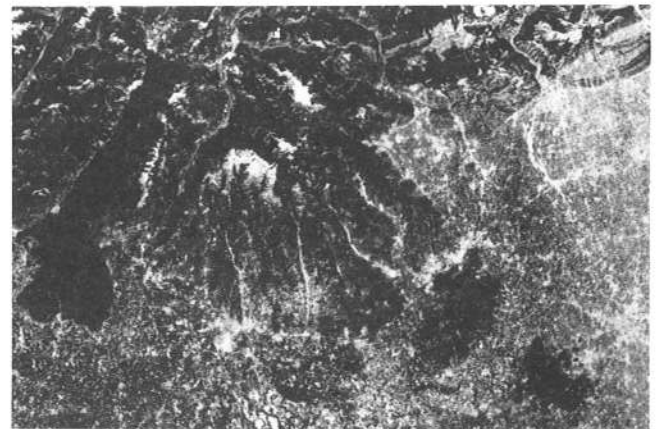
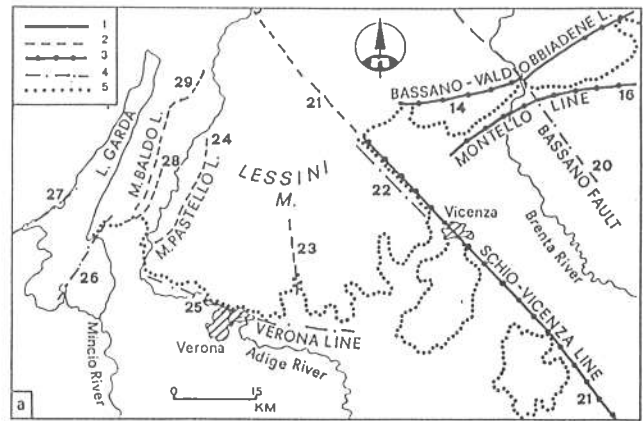


Figure 4 - Area between Lake Garda and the Brenta river (Northern Italy). a: Sketch of the «Map of the active faults in the Holocene». Legend: 1) outcropping or 2) buried active faults; 3) outcropping or 4) buried, supposed active fault; 5) mountain border. b: Section of a LFC photo (scale: 1:770,000 approx.). The comparison of 4a and 4b highlights the morphological evidence of several faults.

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