GROUND EFFECTS IN THE SEPTEMBER-OCTOBER 1997 UMBRIA-MARCHE (CENTRAL ITALY) SEISMIC SEQUENCE AND THEIR SIGNIFICANCE FOR SEISMIC HAZARD ASSESSMENT

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SUMMARY

The September-October 1997 seismic sequence in the Umbria-Marche region of Central Italy (main shocks on September 26th , Mw 5.7 and 6.0, and on October 14th , Mw 5.6) left significant ground effects, which were mainly concentrated in the Colfiorito intermountain basin. These effects included surface faulting, ground cracks and settlements, rock falls, slides, hydrological and gas anomalies. Of special interest was the observation of surface ruptures generated along segments of a system of normal faults already mapped as capable, with end-to-end lengths of 12 kilometers and maximum displacements of 8 cm. In this paper it is emphasized that surface faulting due to the 1997 event can be used to infer the threshold magnitude for surface faulting in Central Apennines, allowing to calibrate palaeoearthquake size from fault offsets as seen in trench investigations.

INTRODUCTION

This paper focuses on the September 26th events, named as Colfiorito earthquakes from their epicentral area, which were the strongest ones of the whole sequence and produced the most significant geological effects. A first shock on September 3rd (at 22:07 GMT, Ml 4.5) was followed, on September 26th , by two moderate earthquakes (Figure 1) with epicenter in the Colfiorito area (Mw = 5.7 at 00:33 GMT and Mw = 6.0 at 09:40 GMT), which produced the highest damage (Intensity IX-X MCS) [Camassi et al., 1997], and by two other main shocks on October 3rd (Mw = 5.4) and 14th (Mw = 5.7), the last one with the epicenter more to the South, nearby Sellano [Boschi and Cocco, 1997, Morelli et al., 1998].

Among the surface effects, which included typical features such as ground fractures, slides and hydrogeological anomalies, systematic normal slips in the range of 2 to 8 centimeters inside discontinuous rupture zones with an overall length of ca. 12 kilometers were observed along the west-verging northwest-southeast-trending normal faults bordering the intermontane Colfiorito tectonic basin and its southern prolongation.

The distribution and characteristics of the environmental effects related to the main shocks of the sequence are analysed, as observed in the field (see Cello et al. [1998] and Esposito et al. [1998], for their detailed description), illustrating their relevance for seismic hazard assessment (SHA).

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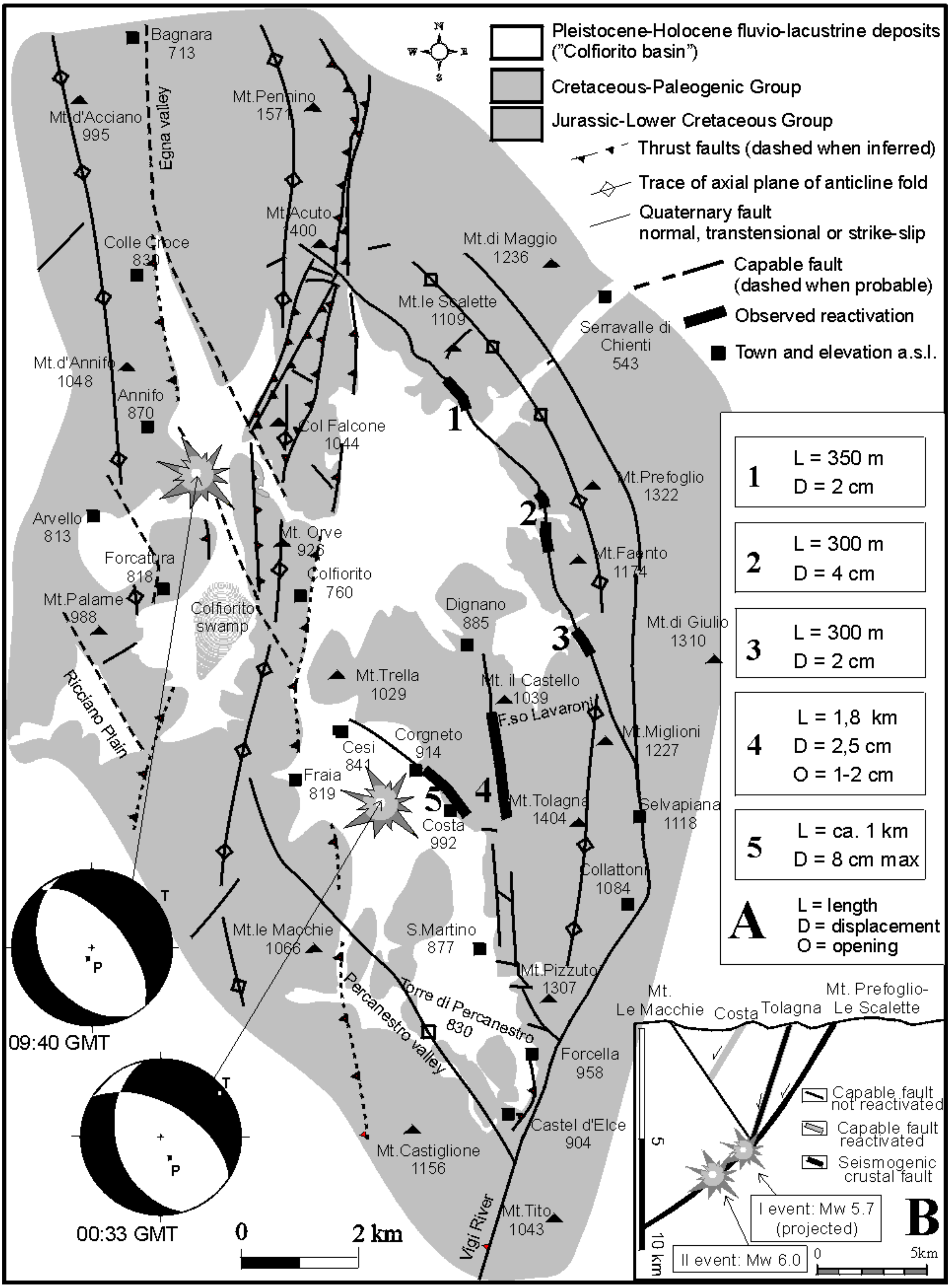

Figure 1: Surface faulting during the September 26th earthquakes drawn over the map of capable faults of the Colfiorito basin (from Cello et al. [1998], modified); (A) observed vertical displacement. Epicenter locations are inferred from preliminary instrumental data and ground effects distribution (see Figure 2); focal mechanisms are after Harvard CMT catalogue; B) Interpretative section showing the inferred prosecution at depth of the main capable and reactivated faults and the hypocenters of the September 26th, 1997 earthquakes.

GEOLOGICAL AND SEISMOLOGICAL BACKGROUND

The Colfiorito basin (Figure 1), elongated in a NNW-SSE direction, is a typical actively expanding, fault-bounded, depression inside the Apennines; its flat valley floor is slightly above 800 m a.s.l. and is now artificially drained toward NE in the Chienti river valley, being the natural drainage hindered by the recent activity of the Colfiorito border fault. The surrounding mountains reach maximum elevations of ca. 1570 m a.s.l. (Mt. Pennino) and are mostly made of mesozoic limestones and marls. The valley fill, not exceeding 120 m, is made of alluvial and lacustrine sediments, whose deposition started about 1 million years ago, slightly before the Jaramillo palaeomagnetic event [Coltorti et al., 1998].

Cello et al. [1997] and Tondi et al. [1997] mapped in detail capable normal faults (sensu IAEA [1991]; i.e., the subset of active faults with the potential for surface rupture, commonly associated to moderate to strong crustal earthquakes) in the region including the Colfiorito basin, also emphasizing their potential for coseismic ground displacement.

Furthermore, historical catalogues show that events of similar and even larger size repeatedly affected the Umbria-Marche region over the last millennium [Boschi et al., 1995, Boschi et al., 1997, Monachesi and Stucchi, 1997 and Camassi and Stucchi, 1998].

The available instrumental data for recent moderate events in the Umbria-Marche region show that typical hypocentral depths are in the order of 6 to 15 km [Haessler et al., 1988 and Deschamps et al., 1992], and that the prevailing focal mechanism solutions suggest mostly normal faulting along roughly NW-SE trending structures [Anderson and Jackson, 1987 and Scarpa, 1992].

GROUND EFFECTS OF THE 1997 UMBRIA-MARCHE EARTHQUAKES

Based on field investigation, we recognized ground effects in a ca. 700 Km^2 wide, roughly elliptical, area around the Colfiorito epicentral zone (Figure 2) [Cello et al., 1998, Esposito et al., 1998 and Esposito et al., 1999]. The observed phenomena were classified as primary effects (surface faulting) and secondary effects (ground fractures, landslides, local ground settlements and hydrological changes). The former result from the propagation up to the surface of the seismogenic slip at depth, giving direct evidence of the size and kinematics of the earthquake. Instead, the presence, activation threshold, spatial distribution, number and size of secondary effects depend on frequency content and duration of seismic shaking, which is a function of the local geology (stratigraphy, water saturation and morphology) and of the travel path of seismic waves, as well as of the source parameters. In the following sections we briefly describe the secondary effects first, because they have been utilized as indicators for the recognition of the most likely location of primary faulting.

Secondary Effects

Ground fractures, either in Quaternary colluvial and fluvio-lacustrine deposits and in rock formations, were concentrated in a NNW-SSE elliptical area (Figure 2) and mainly struck conformably with the reactivated faults. Their highest concentration and dimensions well fit the macroseismic and instrumental epicentral area. About the typology of the phenomena, the open fractures (tension cracks) were prevalent, from a few meters up to hundreds of meters long, generally from some millimeters to a few centimeters wide and with relative vertical displacements ranging from a few millimeters up to 5 centimeters.

The most common landslides were represented by rock falls (ca. 60%), probably due to the relatively high vulnerability of the outcropping formations in the epicentral area, mostly consisting of densely fractured limestone and marly limestone, sometimes interbedded with clay and sandstones. Rotational and translational slides also occurred (ca. 35%), with only a few cases of earth flows. Rotational sliding phenomena mainly occurred in debris deposits. The landslide distribution indicates that the area of maximum density is consistent with the VIII-IX MCS damage level. Most of the landslides occurred within a distance of 10 km (ca. 60 % of the total), their number decreases progressively within a distance of 20-25 Km [Esposito et al., 1998]. It should be noted that, fortunately, the very dry conditions of the late summer season prevented the occurrence of many rotational slides, being most of the area very prone to this phenomenon in wet conditions [Guzzetti and Cardinali, 1989].

For the same reason, no liquefaction was observed, but only localized ground compaction and artificial fill settlements.

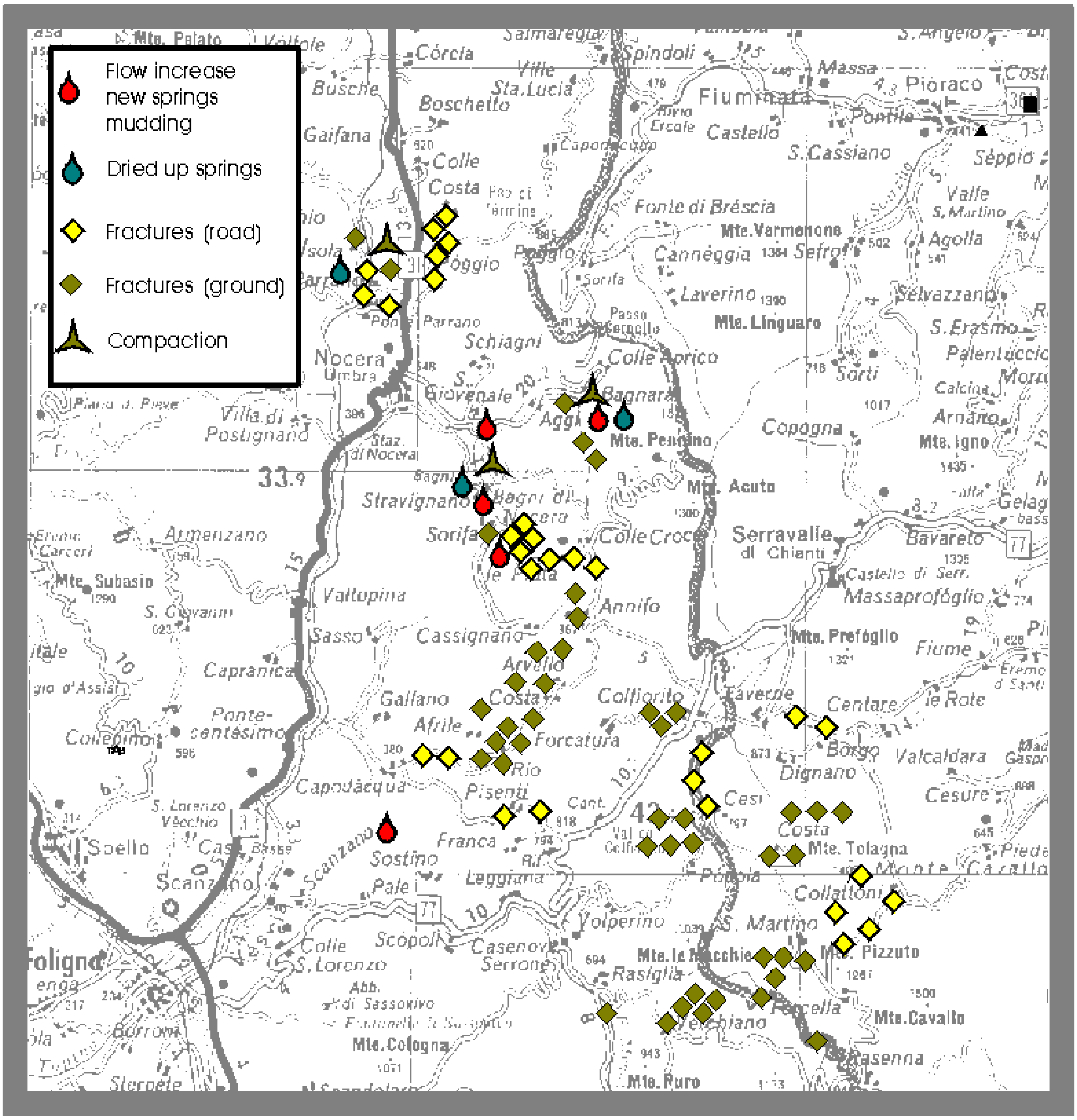

Figure 2: Distribution of ground effects of the 1997 Umbria-Marche sequence [after Esposito et al , 1999].

Several hydrological effects were mainly concentrated in the area around Nocera Umbra, and include flow increase, turbid water and drying up of existing springs, and even creation of new springs.

Finally, gas emissions and some variations in chemical parameters of spring waters were observed at different locations, both inside [Calcara et al., 1997] and outside the epicentral area.

In general, it has been found that the levels of secondary effects are in good accordance [Esposito et al., 1999] with the corresponding levels of intensities based on the historical database [Serva, 1994].

Primary effects

Based on the preliminary appraisal of the distribution of damage and environmental effects, we checked all the already known capable faults located within the epicentral area (Colfiorito basin, Figure 1) in the hours and days following the main shocks, observing a subtle but systematic slip on some of them (see Cello et al. [1998] for a more detailed description). These faults, which border the range fronts, generally mark the interface between the

Meso-Cenozoic calcareous or marly bedrock and the late Quaternary slope deposits, typically related to the latest Glacial age (20 to 15 ka B.P.) [Coltorti and Dramis, 1987]. In general, the scarps carved in calcareous rock are well exposed and often display up to 2-3 meters high well preserved slickensides.

Surface ruptures along several segments of the main faults have been mapped (Figure 1): a) Costa-Corgneto segment of the Cesi-Costa fault; b) Tolagna segment of the Dignano-Forcella fault; c) Mt. Le Scalette, Mt. Faento and La Pintura segments of the Colfiorito border fault. The Costa rupture (Figure 3) occurred during the 00:33 shock, because the road cracks associated to it were observed before the second 09:40 event; for the other cited ruptures we cannot discriminate which was the causative event between the two. The coseismic motion was generally normal dip-slip, with only a minor left-lateral component near the Costa village. These faults have been re-surveyed several times during a period of more than one year to document possible additional slips, which have not occurred, and the morphological evolution of the free-faces. In many cases, along the reactivated fault segments, surface offset is remarkably constant (several centimeters) over tens to several hundreds of meters, while the thickness of slope deposits varies from a few centimeters to tens of meters. Slope deposits were in dry conditions and generally stabilized by the tree root penetration. All these evidences indicate that the observed ground displacement is related to fault dip rather than ground failure due to shaking.

Either on September 26th and October 14th other surface ruptures occurred unrelated to known capable faults, for instance near Fraia, Sellano, Renaro, Mevale and Rasenna (Figure 1).

CONCLUSIONS

Ground effects during events in the range of magnitude of the Colfiorito shocks provide essential information for SHA in the Apennines. They allow to fix the magnitude thresholds above which strong environmental effects, including surface faulting, are to be expected in that specific tectonic setting. Then, accurate long-term geomorphological and short-term paleoseismological and historical studies should verify if such thresholds were exceeded in the past.

The distribution of secondary effects defines the area including the causative faults and allows reliable estimates of the intensity and shape of highest isoseismals, well complementing the intensity assessment based on the level of structural damage. Moreover it contributes to effectively compare our rich catalogue of pre-instrumental earthquakes with recent events.

The significance of the observed slip along faults bordering the Colfiorito basin has caused a great debate among Italian scientists, having been interpreted either as the compaction of the debris deposit, a gravity effect or a true fault reactivation. Many pieces of evidence confirmed that coseismic slip was not a secondary, gravity-induced, phenomenon, but had a tectonic origin [Vittori et al., 1999]. Detailed descriptions of surface faulting for moderate earthquakes are not common, being easily missed or misinterpreted.

Finally, the reactivation of the Colfiorito faults substantiates the robustness of the criteria adopted to classify them as capable, sensu IAEA [1991], before the last earthquakes. These criteria are based [Vittori et al., 1991] on the close resemblance with bedrock fault scarps and slickensides ruptured during historical events, better if in the same tectonic and lithological setting (e.g., Apennines and central Greece: Stewart and Hancock [1990]; Armijo et al. [1992]; Pavlides et al. [1995]; Cello et al. [1997]). The same criteria are the bases for the compilation of the map of capable faults of Italy for the Apennines, while these criteria need be tuned for application to different settings [Vittori et al., 1997].

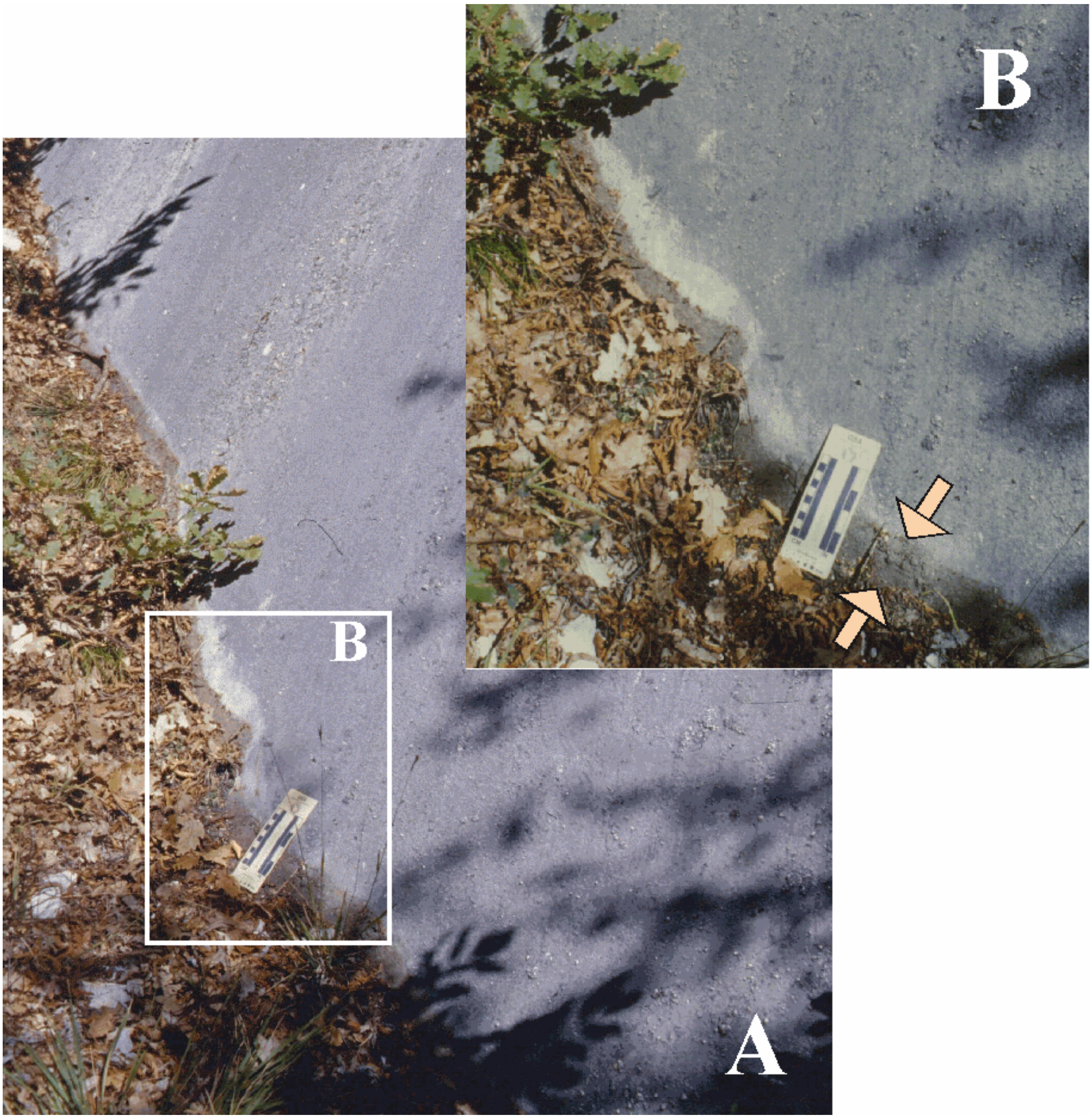

Figure 3: A) Slickenside with basal 7-8 cm high free-face along the Costa bedrock fault scarp; B) Detail of the free-face, marked by a brown soil-coated strip. Photographs taken on September 27th , 1997.

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