Internationales Symposion
INTERPRAEVENT 1992 - BERN
Tagungspublikation, Band 2, Seite 181 - 192

DEBRIS-FLOW PHENOMENA IN THE UMBRIA-MARCHE APENNINES OF CENTRAL ITALY

Laves torrentielles dans les Umbria-Marche Apennines en Italie Centrale

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Summary

The results of a research on the distribution and characteristics of debris-flows in the Umbria-Marche Apennines (Central Italy) are presented. Several masses of unsorted debris, mostly sand and gravel with few boulders and fine material, previously mapped as talus, fluvial or glacial deposits are interpreted to be debris-flow deposits. Considerations are made on the morphological and sedimentological characters of the deposits, and a description of some of the largest features in the Monti Sibillini range and in the M. Coscerno area is given. Finally, three main source environments for debris flows are identified; these are: landslide bodies; glacial and periglacial deposits; and talus or scree slopes.

Resumé

L'objectif de nôtre travail a été l'étude des laves torrentielles dans un sector des les Apennins Centrals. Nombreaux masses de debris, consideré précédemment comme depôts fluvial, glacial ou de talus, ont été reconnu comme depôt des laves torrentielles. Ces depôts sont characterizé par une melange de sable, gravier, avec des large blocs et du material fin. Dans deux sectors où les coulées sont plus actives et nombreaux, les sectors des M. Sibillini et du M. Coscerno, nous avons étudié la morphologie des depôts et nous avons fait une description de la leur composition. Nous avons trouvé trois types different des sources pour les laves torrentielles. Elle sont: les glissements du terrain; les depôts glacials et periglacials; et les depôts de talus.

INTRODUCTION

In Italy debris flows have been largely recognized in the Alps (GOVI and SORZANA, 1980; CANCELLI and NOVA, 1985; CROSTA *et al.*, 1990). This report summarizes research carried out in the Umbria-Marche Apennines and shows that in Central Italy debris-flow phenomena are more wide-spread than previously recognized.

In the Umbria-Marche region debris flows were recognized and mapped by GUZZETTI and CARDINALI (1990) during a regional landslide-inventory carried out in the years 1987-1988. Several masses of unsorted debris, mostly gravel with few boulders and some fine material, previously mapped as fluvial or glacial deposits, were reinterpreted as debris-flow deposits. The difference, beside being important for the understanding of the geological and morphological evolution of the region, is essential for assessing the hydrological hazard and for planning effective defensive measures.

During the reconnaissance mapping, two areas, where debris-flow deposits are more abundant, were identified: the M. Bove area, in the Monti Sibillini range; and the M. Coscerno area, in the south-central section of the Nera river valley (Fig. 1). In these two areas research to unravel the complex relationships between debris-flow phenomena and the geological and morphological setting, as well as the local and regional climatological regime, is under way. Through the interpretation of aerial photographs of different vintages and at different scales, extensive field surveys, and the analysis of historical records on inundations, it was possible to identify the geological and morphological environments more prone to the development of debris flows.

REGIONAL SETTING

The Apennines represent the back-bone of the Italian peninsula, crossing the Country in a N-S direction for more than 2000 km from the Po plain to Sicily. The Umbria-Marche Apennines are located in the central section of the Apenninic chain and constitute the divide of the Tyrrhenian and Adriatic sea. They are characterized by mountain ridges as high as 2400 m divided by valleys and intramontane basins with elevation ranging from 400 to 900 m.

The Umbria-Marche Apennines comprise a thrust and fold belt nucleated during the Late Miocene and successively cut by normal faults. A 2200 m thick Meso-Cenozoic sedimentary cover, consisting of massive and thinly bedded limestone, cherty limestone, marl and clay, was deformed by buckling in the Upper Miocene, resulting in a complex *én echelon* set of E-verging anticlines and synclines. Starting with the Lower Pliocene the area underwent isostatic uplift, and from the Late Pliocene was affected by extensional tectonics associated with the opening of the Tyrrhenian sea, resulting in the formation of NNW-SSE trending normal faults (BARCHI *et al.*, 1987).

The morphology of the area is controlled by the geological setting. Flat-topped mountain ridges correspond to the hinge zone of major box-shaped anticlines; whereas valleys oriented N-S are developed along major synclines. Limited sections of the drainage network, mostly deep, narrow canyons, are incised at right angle to the fold axes or in the hinge zone of an anticline: these constitute examples of reverse topography.

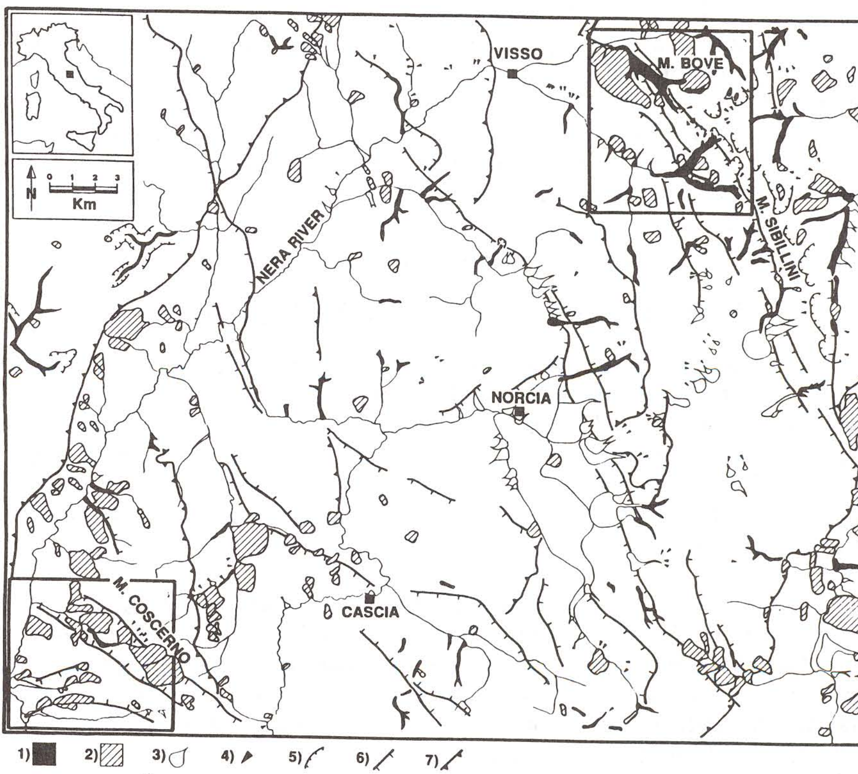

Fig. 1. Map showing mass-movements and tectonic features in a 1200 km^2 area in Central Apennines.
1) Debris flow, 2) Landslide, 3) Debris cone or alluvial fan, 4) Source area of minor debris flow, 5) Escarpment, 6) Normal fault, 7) Thrust or reverse fault.

Fig. 1. Carte des mouvements de terre dans les Apennines-Centrals.
1) Lave torrentielle, 2) Eboulement, 3) Cone d'éboulis, 4) Zone de mobilization de petite coulée, 5) Escarpement, 6) Failles, 7) Chevauchement.

In addition, the landscape is locally controlled by regional normal fault paralleling the Apenninic trend (NNW-SSE) that generate high relative reliefs and very steep slopes (> 45°) where talus deposits, screes, and deep-seated, complex landslides are abundant (BARCHI *et al.*, 1992).

The climate of the area is Mediterranean with the majority of the annual precipitation falling from October through April. Mean annual precipitation ranges from 700 to 1600 $mm \cdot yr^{-1}$, and a 65-years rainfall-record shows a definite increase in the amount of precipitation above 1000 m, where the annual precipitation averages 1200-1400 $mm \cdot yr^{-1}$, whereas below it averages 800 $mm \cdot yr^{-1}$. Snowfall is considerable only above an elevation of 1700 m. Important for the development of debris flows is the local meteorological regime. The characteristic morphology of the area, articulated in high mountain ridges separated by intramontane basins, facilitates the formation of horizontal temperature and pressure gradients that may cause local meteorological instability. Convective thunderstorms 2 to 15 km in radius and with rainfall intensity up to 100 $mm \cdot h^{-1}$ have being recorded in the summer and autumn seasons.

CHARACTERS AND DISTRIBUTION OF DEBRIS-FLOWS

The study area has a long history of inundations. In the last 5 centuries at least 6 catastrophic events have been reported. The last one occurred in the summer of 1906, when several dwellings in the villages of Calcara and Castelsantangelo were damaged and 4 people were killed (GUZZETTI and CARDINALI, 1992). Since then several minor events have occurred. In the last two decades at least three debris-flow events were observed in the Casana valley, the Renari di Capriglia, and Macchie areas.

Research on the origin of such catastrophic inundations goes back to the 17th century. In 1606 Ambrogio Magete, a scientist from Milano that visited the M. Sibillini area, identified four main causes of flooding: the particularly erodible rocks, that could be easily carried away by the waters; the abundant precipitations, especially on the highest peaks; the erosive activity of animals; and the cultivation on the slopes associated with an intense clear-cutting practice (GUZZETTI and CARDINALI, 1992).

Deposits of unsorted, unconsolidated debris abound in the area. Figure 1 is an inventory map, originally prepared at 1:25,000-scale from the interpretation of 1:33,000-scale black and white aerial photographs and field surveys, showing debris deposits and deep-seated landslides in a 1200 km^2 area in the Umbria-Marche Apennines.

Most of these deposits were previously mapped as talus, scree, alluvial or undefined Holocene debris-deposits (SERVIZIO GEOLOGICO ITALIANO, 1941; 1968). It is in fact difficult to distinguish debris-flow from fluvial sediments on alluvial fans or debris cones in temperate regions such as Central Italy. Surface erosion, weathering, the effects of vegetation, and human activity are particularly intense, and such evidences as scars, and lateral or frontal levees, are concealed in a very short time. Nevertheless in the study area numerous deposits exhibit morphological and sedimentological characters that are typical of debris flows.

The largest deposits are spread over several hectares and have a length, from their source area to the deposition zone, exceeding 1 km. Some exhibit a fan-shaped geometry and locally an hummocky topography as the result of the combination of a large number of shallow mass-movements as well as fluvial processes. They develop along valleys with a gradient ranging from 10° to 25°, generally on not organized, low-order sections of the drainage network.

Other seemingly large features develop along narrow, deeply incised, and flat-bottomed valleys. These deposits in places completely fill the valley that exhibits a convex cross-section. In these valleys debris-flows coexist with hyperconcentrated and normal stream-flow processes (PIERSON and COSTA, 1987) as it is indicated by the presence of levees and bars around trees, together with flood-level indicators such as leaves and grass on trunks, or bent and broken trees.

In the few places where the debris deposits are exposed, mostly along gullies, they show a chaotic texture, a poorly stratified mixture of fine material, abundant gravel and pebbles with only few large boulders. This is typical of debris flows that are mass movement phenomena characterized by unsorted, matrix supported deposits (KOSTASCHUK *et al.*, 1986).

In the Monti Sibillini range the largest debris-flow features are concentrated around M. Bove. Two major areas can be identified, respectively on the western and southern slopes of M. Bove: the Calcara and the Macchie debris-flow areas (Fig. 2).

The Calcara deposit has an estimated volume of 25 million m^3 spread over 1.7 km^2, and represents the largest debris deposit in the Sibillini range. It has a convex geometry with an average slope of 16°. The surface is vegetated: shrubs and planted trees prevent erosion and shallow landsliding, that are minor phenomena only along the gullies at the margin of the deposit.

The deposit originated from two distinct sources. The first is located on the western slopes of M. Bicco, on a talus slope developed in the highly fractured shear-zone between two normal faults. Most of the available debris has flowed into the Ussita valley, and today only minor shallow slides occur on the steep slopes of M. Bicco. The second source is located at the mouth of the Val di Bove, in a concentration of debris, primarily landslide deposit, but also talus, glacial and periglacial material. During high-intensity storms or in the case of rapid snow-melting, the bowl-shaped geometry of the Val di Bove concentrates surface and sub-surface flow toward the mouth of the valley, increasing the pore water-pressure in the unconsolidated material, and eventually triggering large debris flows.

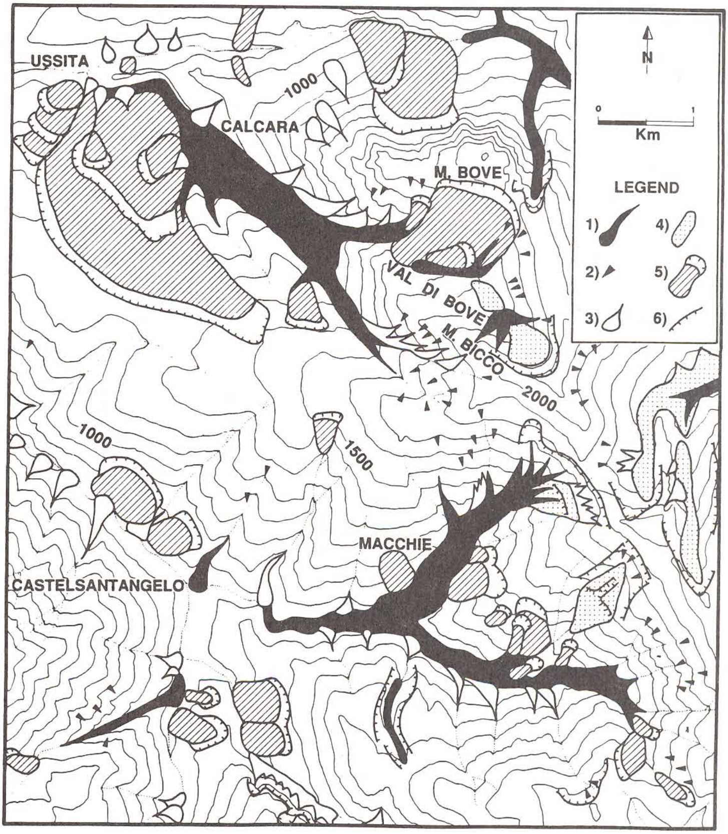

Fig. 2. Map of the Monte Bove area in the Sibillini range. 1) Debris flow, 2) Source area of minor debris flow, 3) Debris cone, 4) Glacial or periglacal deposits, 5) Landslide, 6) Escarpment.

Fig. 2. Carte de la région de Monte Bove dans le massif du Sibillini. 1) Lave torrentielle, 2) Zone de mobilization de petite coulée, 3) Cone d'éboulis, 4) Depôt glacial et periglacial, 5) Eboulement, 6) Escarpment.

The Macchie debris-flow is spread over an area of 1.3 km^2 and its volume can be estimated in the order of 20 million m^3. It has a fan-shaped geometry with a gradient ranging from 25° in the upper part, to 17° in the middle section that decreases to 7° at the toe. The debris lobe, characterized by a convex radial profile, has dammed the Infante valley; the torrent flowing in this valley disappears under the sediments of the fan, reappearing downstream after approximately 500 m of underground course.

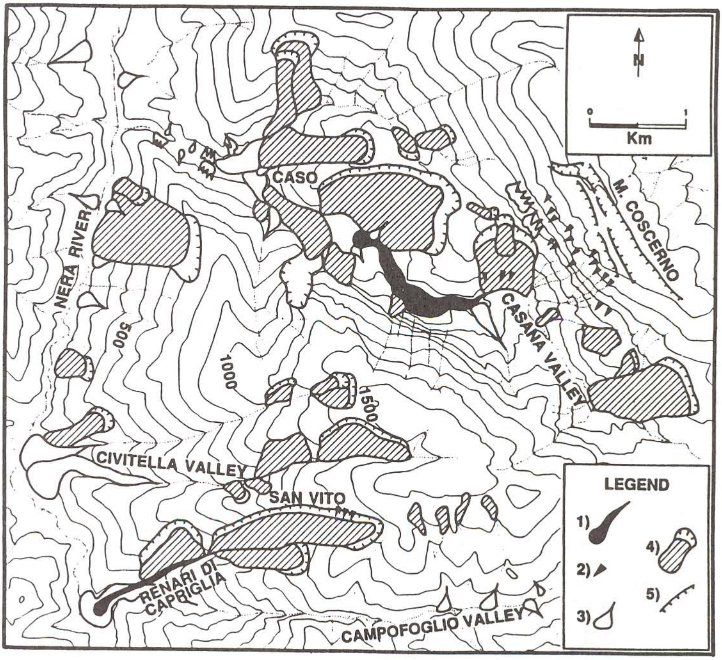

Fig. 3. Map of the Monte Coscerno in the south-central section of the Nera river valley. 1) Debris flow, 2) Source area of minor debris flow, 3) Debris cone, 4) Landslide, 6) Escarpment.

Fig. 3. Carte de la région du Monte Coscerno dans le sector meridional de la vallée du Nera. 1) Lave torrentielle, 2) Zone de mobilization de petite coulée, 3) Cone d'éboulis, 4) Eboulement, 6) Escarpment.

The deposit possibly originated as a landslide-related fan (SORRISO VALVO, 1988), i.e., through the collapse of a rockslide/debris-flow type landslide involving a large wedge of unconsolidated debris of glacial or periglacial origin, located at an elevation of approximately 1700 m on the southern slope of M. Bove. The failure likely occurred through the combination of two different mechanisms: the build up of high water pressures in the debris mass, and gully erosion in the deposit. The former was probably caused by the presence, behind and above the debris wedge, of a regional aquiclude, the marly and clayey Rosso Ammonitico Formation. Numerous springs are present along the outcrop of this aquiclude.

Nowadays the source area is an amphitheatre of approximately 1 km^2 that can be further subdivided into two parts. The western one, a bare scree slope in the shear zone of a normal fault, is quite active, and minor debris flows and debris slides coexist with rill erosion. The eastern part is constituted by a 130 m-high cliff in thinly bedded, cherty limestone cut by joint and cleavage systems. The cliff face is retreating by rockfalls, topples, and minor rock slides. The material accumulates mostly at the base of the cliff, and only occasionally continues downhill coming to rest along the main deposit.

In the M. Coscerno area the largest debris-flow deposits are concentrated in the Casana valley, along the deep, narrow left-tributary valleys of the Nera River (Civitella and Campofoglio valleys), as well as along the steep torrents on the north-western slope of M. Coscerno (di Marte and del Rio torrents) (Fig. 3). Minor debris flows and debris slides are present on talus and scree slopes, that abound in the area mostly along normal faults.

Of particular interest are the processes and related deposits present in the Casana valley. The valley is a narrow graben with a displacement along the normal faults exceeding 800 m that has produced a relative relief of more than 1000 m in less than 2 km. In the area different slope processes are active at the same time (BARCHI *et al.*, 1992).

On the southeastern slope of M. Coscerno a large, complex and potentially still active slide is present. The movement occurred in the partially consolidated talus deposit that developed along the normal fault bordering the northern edge of the graben. Numerous shallow mass movements occur seasonally, particularly at the base of the slope, that has an average gradient of 25°. In this area debris flows and debris slides remove, in successive pulses, minor quantities of debris from the slope. The debris is then redeposited along the Casana valley, forming small, very steep debris cones, visible under the forest that cover the flat-bottomed valley floor.

During particularly intense meteorological events the debris deposited along the valley is eventually remobilized and transported further downstream by debris torrents and hyperconcentrated stream-flow processes (PIERSON & COSTA, 1987). This is particularly clear because of the presence of a rockslide that has dammed the Casana valley in correspondence with the village of Caso, forming a natural retaining basin, where an estimated volume of at least 4 million m^3 of debris has already been deposited. Upstream from the dam the valley has a very low gradient (< 5°) and a convex transverse profile. The surface of the deposit is locally hummocky, and almost completely vegetated by natural and planted trees, that in places are partially submerged by the debris. Levees and bars are visible in places, even if they are not well preserved, possibly because of the occurrence of later flooding events.

DISCUSSION

Debris-flows are possibly the most common type of slope-movement in the world. Their abundance and typological variability have been recognized in different geological, morphological and climatological environments world-wide (RICE and FOGGIN, 1971; CAMPBELL, 1974; MOSER and HOHENSINN, 1983; COSTA and WIECZOREK, 1987; ELLEN and WIECZOREK, 1988).

These highly damaging phenomena appear to be particularly common in areas where the production of debris, colluvium or soil is abundant and rapid, as well as where the local relief is greater. These conditions are best satisfied in tectonically active areas such as the Alps, the Himalaya, the San Andreas fault system in the Western United States, the Canadian Rocky Mountains, and Japan.

The Umbria-Marche Apennines are no exception, and a comparative study of the distribution of landslide and debris-flows with the geological and morphological setting shows that the largest and most active debris-flow deposits concentrate along or nearby faults.

The role played by the faults is twofold. The mainly dip-slip movements along the faults have produced large topographic relief, locally more than 1000 m in less than 2 km; and they have generated conspicuous shear zones, from some tens to some hundred meters wide. In these areas the rock is highly fractured, and talus and scree slopes may easily develop. These constitute preferential sources for debris flows, as in the case of the southeastern slopes of M. Bicco (Fig. 3).

Another frequent source for debris flows is constituted by the numerous deep-seated, complex landslides that are present in the area. Landslides have occurred mostly in bed-rock, and have produced large masses of disrupted rock, from which debris flows frequently develop. This is the case of the Renari di Capriglia debris flow that generates from the San Vito landslide (BARCHI *et al;*, 1992). A still different source of material for debris flows in the study area is constituted by glacial and periglacial deposits (Macchie debris-flow deposit). These are present only in the M. Sibillini range above an elevation of 1700 meters.

The volume of mobilized material differs in each source environment. Debris flows originating from talus and scree slopes rarely exceed a few thousand cubic meters, whereas larger quantities of debris are available from landslide (Casana valley, San Vito), glacial and periglacial deposits (Macchie), allowing for larger debris flows to form.

On talus and scree slopes, that have generally a high permeability, the build-up of high water pressures that can eventually trigger debris flows (CAMPBELL, 1974), occurs only during high-intensity storms, when rainfall largely exceeds the infiltration rate. On low permeability materials, such as landslide bodies and glacial or periglacial deposits, the build-up of water pressure occurs more slowly, and the amount of antecedent rainfall becomes an important factor in triggering debris flows.

Small debris-flow deposits originated mostly from a single or a limited number of failures; whereas the larger deposits (Calcara, Macchie, and Casana valley) are the result of many events. On the largest features landsliding, debris flows, hyperconcentrated floods, and stream-flow processes coexist. Even if landsliding and debris-flow processes may predominate in the source and transport area, and hyperconcentrated or stream-flow processes are more common in the toe or in the more distal areas, it is not possible to draw a definite boundary between the different processes. The predominance of mass-movements versus fluvial processes during an inundation depends on hydrogeological (i.e., discharge, antecedent and total rainfall, rainfall intensity, etc.) and geomorphological (i.e., availability of debris, steepness of slope, morphology of the source area, etc.) characteristics, and therefore can not be generalized.

ACKNOWLEDGEMENTS

Research was supported by CNR-IRPI and CNR-GNDCI grants. We wish to thank V.H. Garduno, G. Crosta, and M. Barchi.

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