Chapter

Translational Rock-Block Slides in a Tertiary Flyschoid Complexes of Southern Piedmont Region (North-West Italy)

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Abstract

The southern Piedmont Region (north-west Italy) is characterized by a hilly zone called "Langhe" that covers an area of about 2300 km^2 and is bordered by Tanaro River at north and west, by Orba River at east, and by Apennine mountains at south. The Langhe is rolling hills famous for their excellent wine, populated by many small inhabited centers since ancient times. An idea of the Langhe geomorphology can be gained by studying the word "Langa": it may have been derived from either "landa," which means a wild and uninhabited place or from "lingua," which means a strip of land. The morphology of the Langhe hills is characterized by asymmetrical valleys with steep south-east facing slopes and more gentle north-west facing slopes: their profile is defined "saw toothed" by local inhabitants. The asymmetric shape is clearly conditioned by the geology. Severe hydrological events occurred in the last 100 years in Piedmont in particular on May 1926, February and March 1972, February 1974, and November 1994. During these long rainy periods, on the gentler slopes, translational rock-block slides involve tertiary flyschoid complexes represented by rhythmic series of deposits with varied grain size. These landslides often damage or destroy buildings and roads, even if rarely claim human lives.

Keywords: translational rock-block slides, tertiary flyschoid complexes, damage, Piedmont, north-west Italy

1. Introduction

Translational rock-block slides (TRBSs) are mass movements that involve the displacement of material along one or more discrete shearing surfaces. The sliding can extend downward and outward along a broadly planar surface (a translational slide). They are less common than complex landslides, rotational landslides, and shallow landslides. With reference to the TRBSs studied in the world that are not strictly correlated to the Langhe landslides, the casuistry is varied, just as there are many potentially involving rocks. The TRBS phenomenon has been addressed by several authors who have studied them in very different geological contexts due to various trigger causes.

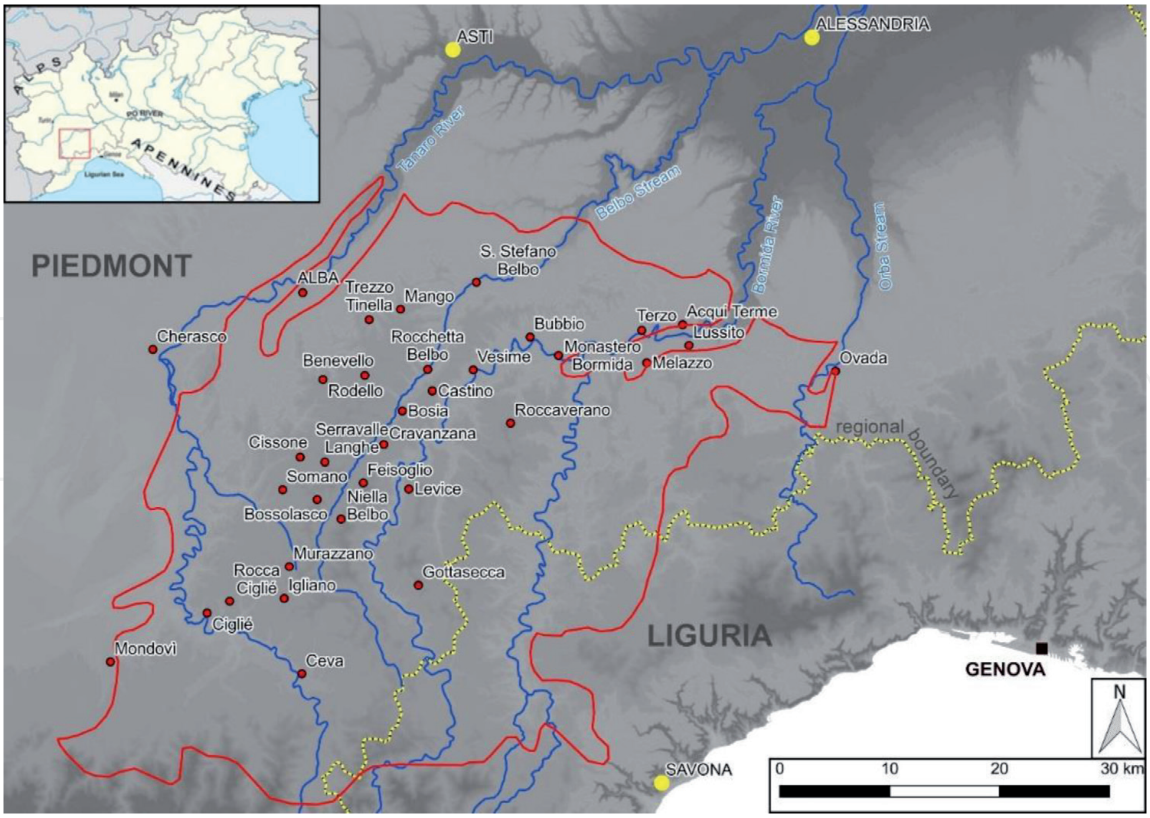

Figure 1.
Langhe hills, a large area in Southeast Piedmont (northern Italy). All place names mentioned in the text and in the captions are marked with colored dots (red limit from Ref. [1], modified).

The singularity of the Langhe planar landslides is well known in Italy, less abroad. In effect, typing in Google Scholar "rock-block slides" 382 links may be found; but if we wanted to refine the search by including the "marly silty" and "arenaceous-sandy" voices, the search would provide only five published papers.

The Langhe Hills, particularly renowned for the cultivation of fine vineyards, are bordered by the Tanaro River to the north and west, the Orba River to the east, and the Apennines to the south [1]. Langhe covers an area of about 2300 km^2 in southeast Piedmont (northern Italy): the main city of the area is Alba, which lies on the banks of the Tanaro River. Alba, a town famous for the confectionery industry, is located about 150 km southwest from Milan and 65 km SSE from Turin and 70 km north-west from Genoa. Tanaro originates in the Apennines and flows north along the western boundary of the region until it reaches the small town of Cherasco, where, due to old capture phenomenon, it bends right and flows on to Alba and Asti, after which it joins the Po River downstream from Alessandria (**Figure 1**).

The Langhe is rolling hills famous for their excellent wine, populated by many small inhabited centers since ancient times: Alba is the largest and most important city. An idea of the Langhe geomorphology can be gained by studying the word "Langa": it may have been derived from either "landa," which means a wild and uninhabited place or from "lingua," which means a strip of land.

The geological characteristics of the layers, the geomorphology of the hills, the mineralogical composition of some levels, and the predisposition for translational movement mean that the Langhe hills can truly be considered a particular area that lends itself much to be studied.

During intense rainfall events, Langhe hills are usually affected by translational rock-block slides [2]. These are particular interesting in terms of:

- their typical attributes: the landslides occur in tertiary flyschoid complexes represented by a rhythmic series of marly silty and sandy-arenaceous rocks; sliding surfaces correspond to a thin marly clayey level, where infiltrating water deeply penetrates extensive systems of discontinuities;

- their widespread distribution during major rainfall events; and

- their high repetitiveness: some slopes have been affected several times in the last 100 years, the period over which reliable rainfall data are available.

2. Geological and geomorphological framework of the Langhe hills

The Langhe hills form the southern part of the Piedmont Tertiary basin, which is bounded by the Alps to the south and west, the Apennines to the east, and the Po Plain to the north. The basin's complex structural and stratigraphic history results from the post-Eocene phases of the Alpine orogeny and the opening of the north-western sector of the Mediterranean Sea [3]. The Langhe basin is composed of an Oligocene-Miocene sequence of terrigenous deposits that lie in unconformity above a pre-Cenozoic bedrock formed by Alpine and Apennine metamorphic units and characterized by a complex crustal geometry. The sedimentary sequence is more than 3500 m thick and is differentiated in time with respect to syn-sedimentary tectonics that are mainly associated with tensional forces [3]. Sedimentation begins with the deposition of continental deposits in alluvial fans and fan-deltas, followed by shallow marine transgressive deposits of the Late Eocene to Early Oligocene. The drowning of the area was marked by the deposition of open-sea units composed of alternating high-density flow deposits and hemipelagic sediments dating from the Early Oligocene to the Tortonian. The sedimentation ended in the Messinian with deposits that marked a sudden drop in sea level [4]. The main rock types are marls, silty marls, mudstones, sandstones, and conglomerates. The sequence forms a monocline that has a regional dip of 10–12° toward the northwest and is displaced at different stratigraphic levels by normal or strike-slip faults with a NE-SW orientation. Fault throws are usually in the range of 10–50 m, but locally they reach values of over 200 m [5].

The morphology of the Langhe hills is clearly affected by its structural setting. The area is characterized by the asymmetrical profile of the valleys, which results from isoclinal bedding in marly silty and arenaceous-sandy facies. Long, gentle slopes dip toward the northwest in the same direction as the bedding planes, although the inclination of the strata is usually lower than the slope surface. Short, steep slopes dip toward the southwest at about 25–40° in the opposite direction to the dip of the bedding. The morphological instability of the area is reflected in the common occurrence of landslides, which represent the main morphogenetic factors on the slopes. The gentler hillsides are prone to translational rock-block slides that involve the bedrock to a maximum depth of 20 m, while landslides due to saturation and fluidification of the eluvio-colluvial cover, the so-called "soil slips" [6] occur on the steeper slopes.

3. Past severe events and respective studies in the Langhe area

Since immemorial time, translational rock-block slides have been very common in the Langhe hills. In spite of this, in Italy, the scientific community started to show a certain interest in these phenomena only in the 1960s of the twentieth century. In the preceding period, the studies and surveys had been completely casual, despite the preeminent control role that these phenomena have always played on the morphological evolution of an extensive portion of the Piedmont territory and the reflexes for the safety of numerous inhabited centers, as the above chronology of **Table 1**. Some of the major movements of the past century are still remembered by old people in the Langhe villages. In an extensive analysis of instability, Forlati and Campus [7] identified over 2000 active and quiescent planar slides. Their morphostructural elements, which are mostly scarps and cracks, correspond clearly with those of old landslides. Govi and other authors [8–9] have demonstrated that, on many unstable slopes in the Langhe hills, instability along the bedding planes represents the same kind of evolution: in November 1994 meteorological event, for example, 44% of them were considered as a reactivation of a past movement [10].

The first historical events of which we have certain and documented information were two, those that at the end of March 1679 destroyed, respectively, the town of Bosia and part of the famous baths of the Acqui city [11]. They were two destructive TRBSs, which were mentioned in the local chronicles. Then for almost two centuries, there was no news, although it cannot be excluded that other episodes have happened in the meantime. But on the other hand, it is always difficult to find historical finds of the eighteenth century: since there are no large cities in the Langhe, but only small towns, the only documents that can be found are often those produced by the parish priests of the churches that reported the misfortunes that occurred in the villages.

The first events of the nineteenth century remembered by written documents are those that occurred in the period of 1853–1861 (three cases).

The first contributions of the twentieth century are due to the naturalist-geologist Sacco, who on 1901 and 1903 described the landslides of Mondovì [12] and Cherasco [13] advancing, for the latter, acute observations on the possible evolution and on the possibility of arresting the translational movement.

A few years later, De Alessandri published a very valuable study on the landslides of the Acqui area [14]. The author illustrated very carefully the historical planar slides of the Monte Stregone Mountain, underlining the tendency of the phenomena to reproduce in the same localities, noting that “it is an established principle that the landslides occurred are in their turn the main cause of further landslides and that their quiescence is often temporary, with intervals that can extend to a century, before resuming the movement phase.”

During an intense rainfall period on May 16, 1926, a translational landslide occurred near the village of Levice [15], involving a surface area of 3 ha (**Figure 2**). According to eyewitness accounts, long cracks appeared less than an hour before large fractures 20–25 m in depth opened in the slope. There were no victims, and no buildings were destroyed, but meadows and vineyards were damaged.

Ten years later, on March 6, 1936, in the municipality of Castino, the small village of Vernetta was comprehensively damaged by a rock-block slide with a surface area of 35 ha. The blocks moved 150 m at an average velocity of 60 cm/h: a stretch of highway and seven houses were destroyed, and 38 people were evacuated [16].

On April 7, 1941, following a rainy period after an especially snowy winter, a sudden translational landslide destroyed the Cascina Bric farmhouse, near the village of Cissone: the mass movement killed three people and destroyed several buildings. The width of the main scarp was about 300 m, and the rock blocks were about 30 m deep (**Figure 3**). The phenomenon was carefully studied by Boni [17], with a good report accompanied by excellent photographs. The author highlighted the conditioning role, for the purposes of stability, of the geological-structural structure of the region and of the lithological characteristics of the rocks involved;

Year/mm/dd	Municipality/place	Brief description	Source
1679/03/31	Bosia	A large translational landslide devastated much of the ancient town. The landslide will be reactivated again in 1853 and more recently in November 1994.	[11, 26]
1679/03/31	Acqui	An “extraordinarily voluminous” landslide, slipped from Monte Stregone Mountain, buried the thermal establishments of Acqui Terme.	[14]
1860 approx.	Cigliè	“Half a hill collapsed, swallowing several houses in the disrupted clods.”	[15]
1861/10/??	Rocchetta Belbo	A landslide caused “an unforgettable catastrophe.”	[15]
1876/05/23	Mango	A rock-block slide of about 40 ha shifted a house for 120 m. The moved clods had a depth of up to 13 m.	[11]
1876/spring	Acqui	From the slope of Monte Stregone Mountain another great landslide broke off, adjacent to that of 1679, which destroyed houses, claiming human victims (number unknown).	[14]
1879/05/26	Igliano	Some witnesses observed the opening of a large fracture close to the church and then the sliding of an area of 2 ha for 15–20 m, with disarticulation in clods 15–20 m high. They were warned “a huge roar and a wobble of soil,” and “flames, accompanied by a sulfurous smell” were observed.	[11, 53]
1892/03/31	Roccaverano	“Large planar landslide.”	[12]
1892/03/31	Vesime	One rock-block slide moved 60 m together with a house causing two victims.	[53]
1901/03/20	Trezzo Tinella	A landslide with an area of several hectares swept over a farmhouse.	[11]
1901/03/20	Mondovì	A slippage about 20 m deep originated with a “general cracking” of the mass (probably over 200,000 m^3).	[11, 12]
1902/spring	Acqui area	Period sadly remembered for the large number of landslides. On the Monte Stregone Mountain, great dislocations were reported with “a fracturing and an overlapping of layers.”	[13, 14]
1902/spring	Melazzo	Two houses were overwhelmed by a planar landslide.	[13]
1902/spring	Cherasco	A translational block slide with a width of over 300 m and a length of about 700 m involved the slope on which stood a cluster of farmhouses causing serious damage to the buildings.	[13]

Year/mm/dd	Municipality/place	Brief description	Source
1905/05/15	Lussito	Exceptionally abundant rainfall triggered numerous landslides. On the southern slope of Monte Stregone Mountain, there was "a slippage of a large fractured mass … on a marly surface … made extremely slippery."	[14]
1907/04/06	Acqui	Another landslide on the Monte Stregone Mountain that devastated an area adjacent to that collapsed in 1876. The mass involved (area 0.35 ha, volume 30,000 m^3) slipped on a marly stratification plane that "after the phenomenon had a highly laminated mirror surface." There were five casualties.	[14]
1917/05/29–31	Vesime	A 3-ha landslide swept over a building.	[53]
1917/05/29–31	Terzo	Another landslide removed a road for a length of about 80 m.	[53]
1926/05/16	Levice	During the severe alluvial event that hit the Tanaro and Bormida river basins, a landslide extended for about 3 ha, 10–15 m deep, marginally involved the Levice little town.	[15]
1926/05/16	Benevello	A "massive landslide" was reported.	[11]
1936/03/05–06	Castino	Sudden landslide of about 35 ha with damage to buildings, while the state road was moved by 150 m. The landslide will be reactivated later in 1953, but it moved only a few meters.	[11]
1941/04/07	Cissone	A small hamlet was moved about 60 m and destroyed (three casualties) by a sudden 30 m deep slide and about 300 m wide in the detachment area.	[17]
1951/02/10–12	Zone between the Belbo and Uzzone streams close Levice	An alluvial event hit the area between the Belbo and Uzzone torrents with particular gravity, causing "a very large number of landslides, subverting in many points the age-old stability of extensive cultivated and inhabited slopes. There are numerous cases in which entire vineyards … they literally glided down the valley for tens and hundreds of meters, leaving theirs place a shiny reflecting surface."	[53]
1956/03/26–28	Niella Belbo	A translational landslide extended over 4 ha cut down two farmhouses.	[11]
1957/04/07–13	Trezzo Tinella	Important reactivation of the 1901 landslide.	[11]

Year/mm/dd	Municipality/place	Brief description	Source
1963/01/05–06	Cigliè	Progressive aggravation of the conditions of stability of the great phenomenon of Cigliè (surface 25 ha, thickness 15–25 m, volume 3.5–4 million m^3) with destruction of 16 houses.	[15]
1968/11/01–04	Gottasecca, Prunetto, Niella Belbo, and Bossolasco	During this serious event, numerous important planar landslides were activated, recognizable on aerial photographs of 1969 or documented by photographs from the ground. The largest was that of Bossolasco slide, extended 15 ha.	[11, 19, 54]
1971/ April–May	Castino	An extensive planar landslide involved some rural buildings.	[11]
1972/02–03 and 1974/03	Somano and Cherasco	These two events, which took place into a period of only 24 months, activated or reactivated numerous planar landslides in the Belbo, Tanaro, and Bormida valleys. We recall the great slide of Somano (10 million m^3) and that of Cherasco (4–5 million m^3). The 1972 event, with over 130 identified cases, associated with that of 1974, which reactivated numerous landslides that had arisen 2 years earlier, can be considered in terms of diffusion of phenomena, the second-greatest event in the Langhe after the November 1994.	[8, 11, 20, 21, 22, 54]
1977/10/07	Ovada area	Numerous deep TRBSs with an area of up to 1 ha originated between the Ovada area and the Scrivia River basin.	[53]
1985/03/08	Ovada area	One large rock-block slide involved a farm.	[54]
1994/02/06	Monastero Bormida	Planar landslide destroyed two buildings and part of an aqueduct.	[37, 54]
1994/11/05–06	Several dozen municipalities	A very intense and prolonged rainfall event produced more than 450 TRBSs in the Langhe hills. In the Ceva territory up to 10 TRBSs occurred in 1 km^2.	[26]
2019/11/26	Bubbio	Area involved equal to 1 hectare; translation of the clods about 20 m with maximum 7 m in height. Significant damage to the vineyards and the municipal road (removed 100 m).	Personal communication
2019/11/26	Santo Stefano Belbo	Landslide triggered in a vineyard. Rejection of only 70–80 cm, but sufficient to severely damage a farmhouse.	Personal communication

The words in the "quotation marks" are original of the reference document.

Table 1.
Most famous past translational rock-block slides in the Langhe hills for which at least one report has been found. These landslides are historically documented since the second half of the seventeenth century: in this chronology, briefly reported, the most significant cases for dimensions and effects produced are reported.

Figure 2.
May 16, 1926: Levice rock-block slides, top view. The large disjointed clods are evident.

Figure 3.
Cissone, Cascina Bric farmhouse. The large rock-block slide that caused three casualties on April 7, 1941.

he reconstructed the phases preceding the collapse and put forward some hypotheses on the determining causes of the landslide, recognizing and analyzing the triggering role of the rain that had fallen in the previous days and the preparatory role of the melting waters of the abundant snowfalls of the winter.

On January 9, 1963, the Cigliè rock-block slide destroyed 10 buildings, and 17 others had to be evacuated. The landslide had been known since the late eighteenth century and was reactivated in 1860, in the early twentieth century, and in 1954, 1956, and 1958, but the movements that occurred during the spring of 1960 were somewhat larger than previous ones. The total surface involved was about 25 ha, with a depth of 15–25 m and a volume of 4 million m^3 (**Figure 4**). The approach of Cortemiglia and Terranova [18] to this TRBS was mainly morphological-geological with marginal references to the role of rains. In the work, some data related to the geotechnical characterization of the rock mass were also exposed.

During the first week of November 1968, intense rainfall hit the Langhe area: many important planar landslides were activated, recognizable on aerial photographs of 1969 or documented by photographs from the ground. The largest was that of Bossolasco slide, extended 15 ha. Grasso [19] in a study dedicated to the Belbo Valley seriously affected by extensive flooding and numerous landslides in the aforesaid period, defined “landslides by plasticity” or “plastic-gravitational deformations in the eluvial cover located on the marly silty substrate” phenomena that, from what can be observed from the published photographs, they were presumably planar slides in the incipient stage. Only in the chapter, “geomorphological observations” were made an explicit but very brief reference to these landslides, which are considered “generally of limited extension.”

In February and March 1972 and February 1974, several translational landslides occurred in the Langhe hills [8, 20]. Some of the movements affected entire slopes and caused severe damage to rural buildings, main highways, secondary roads, and agricultural activities (in particular vineyards and wineries). Two of these landslides, the Somano and Arnulfi rock-block slides, were extensively studied. The Somano landslide occurred on March 13, 1972 and was reactivated on February 18, 1974. With an area of almost 1 km^2 and a volume of about 10 million m^3, it was the largest rock-block slide to occur in the Langhe in the twentieth century (**Figure 5**).

Figure 4.
Detail of the landslide phenomenon of January 1963 in the crown area, in a photograph of the time. There are clearly visible bedrock structure dip slope of tertiary-age sedimentary rocks (on the left) and part of a slipped clod (on the right).

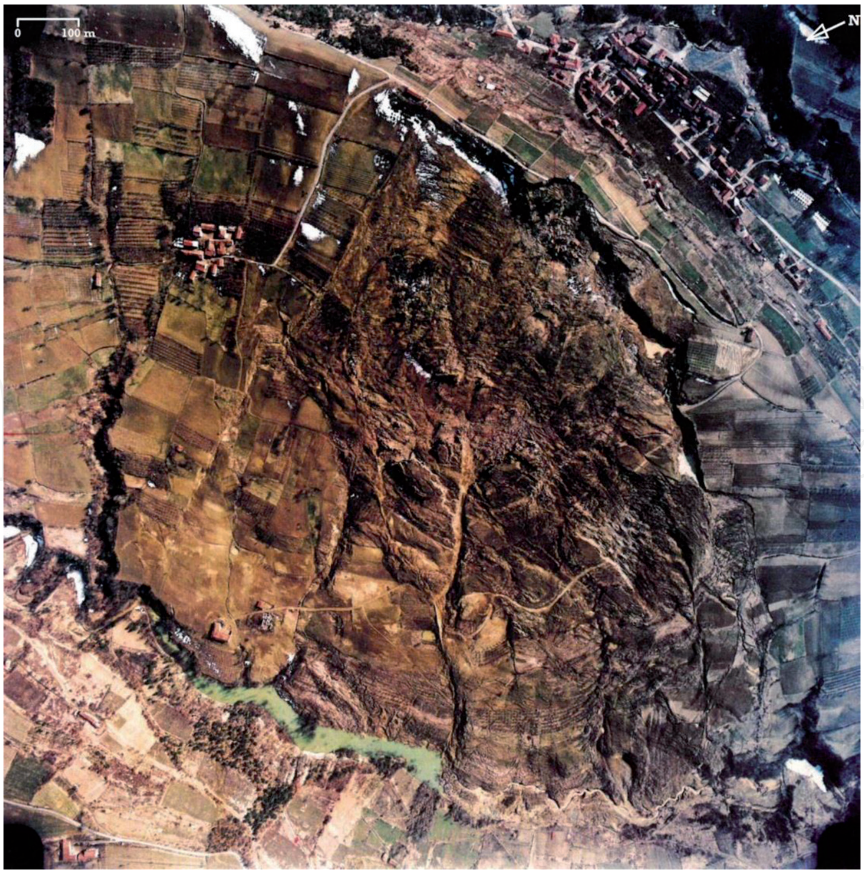

Figure 5.
Aerial photograph of the huge translational rock-block slide at Somano (February 1974). The movement stopped at the opposite slope causing a dam and consequent small lake of the Gamba stream.

Of more than 200 slopes identified as having been subject to translational movements, in 1972, some 130 showed clear signs of instability, although a smaller number manifested similar signs in 1974. The Arnulfi rock-block slide had a volume of about 5 million m^3 and affected a slope that showed signs of past instability.

The large number of TRBSs altogether triggered or reactivated by two pluviometric events close together over time (February to March 1972 and February 1974) gave inspiration to some researchers from the CNR-IRPI of Turin to focus attention on these phenomena. The first planar landslide studied in order of time was that of Altavilla di Somano of which Govi [8, 21] reconstructed with extreme accuracy the evolution on a multitemporal photointerpretation basis, while Sorzana [20], with reference to the Arnulfi landslide near Cherasco, underlined the role of hydrological-climatic parameters in play, between which the evaporation-transpiration.

The studies of Biancotti on the geomorphology of the Langhe [22–25] highlighted the important morphogenetic role of landslides on dip slopes, for which models of dynamic evolution were illustrated by the author. Particular attention to these landslides was dedicated in the study on the Rea Stream basin, which also included a map of slope dynamics "which reported some slides (e.g., Somano, Cissone) and indicated some sectors of dip slopes prone to 'creeping and soliflux.'"

The investigations jointly undertaken by the CNR-IRPI of Turin together with the Geological Service of the Regione Piemonte in the years 1978–1980 for creating a systematic cartography of the Piedmont instability phenomena were another opportunity to expand and deepen the state of knowledge on sliding landslides. For the first time, the detailed picture of these phenomena was outlined, the actual areal distribution and the state of activity indicated with appropriate symbologies on maps at the scale of 1:100,000. The result of a decade of research carried out by the CNR-IRPI of Turin on the subject materialized into two summary papers:

- the first by Govi and Sorzana [8], valuable for its methodological approach, pointed out above all the kinematic-evolutionary aspects, highlighting how most of the slides analyzed had occurred on the slopes that had already been the site of similar phenomena in the past and

- the second by Govi et al. [9] identified the minimum cumulative rainfall threshold of an event lasting from 1 to 3 days capable of triggering a slide, in 100 mm, provided that the rainfall in the previous 60 days exceeded variable values from 150 mm to 300 m, depending on the season in which slides occur (usually between November and May).

In 1993, the book "Atlante dei Centri Instabili piemontesi" ("Atlas of unstable Piedmontese inhabited centers") was published by Luino et al. [15], in which some detailed illustrative sheets of important landslides appeared of sliding.

Then, in 1994, the most important event in the history of the Langhe hills took place: it was defined by experts as "secular." The event was devastating due to the flooding of the valley bottoms heavily urbanized causing enormous damage and 44 victims along the Tanaro Valley. But landslides on the slopes also made a notable contribution in terms of destroyed roads, damaged houses, and removed aqueducts. Many countries were totally isolated, and there were great problems in order to restore a certain normalcy.

On 5–6 November, after days in which rainfall reached maximum intensities of 50 mm/h and 200–250 mm/day, more than 450 translational landslides of various size occurred in the Langhe slopes (**Figure 6**) with a top of 10 rock-block slides within only 1 km^2 in an area around the Ceva town [26]. In terms of areas involved by various landslide typologies, the November 1994 event was similar to the February 1972 and February 1974 events.

In the years immediately following the serious event of November 1994, several authors addressed the study of these characteristic landslides, examining different aspects, in particular geology, morphology, hydrogeology, and predisposing and triggering factors. We remember Del Monaco et al. [27], Aleotti et al. [28], Polloni et al. [29], and Ayala et al. [30], who described some rock-block slides occurred during the event into a synthesis report of the field mission of a CEC research group carried out in the Langhe within the framework of the EU project MeFISSt.

A photointerpretation work was instead undertaken by Susella [31] on a large landslide that occurred not in 1994, but many centuries earlier, in a period difficult to define. Using of aerial photographs and field surveys, he identified the largest movement known to date, which occurred near the town of Cravanzana. Here, a landslide moved blocks 40–45 m in depth, over 2 km wide and 700 m long. The estimated volume exceeded 10 million cubic meters.

Again referring to the landslides of November 1994, the physical-mechanical parameters of TRBSs were studied by Lancellotta and Scavia [32], while in the 2-year period of 1997–1998, Aleotti together with other authors addressed the issue of TRBSs with two papers, which, starting from the November 1994 event, examined geological, structural, morphological, and meteorological conditions of the Langhe hills. In the first paper [33], the authors demonstrated that the cause of the original process is flexural slip between layers of different competencies. Murazzano rock-block slide was deeply analyzed and confirmed the validity of this hypothesis showing the possibility that large flexural slip displacement could have occurred in a thick incompetent unbonded sandy silt layer. In a second paper [34], the authors suggested that, based on the results of studies performed to point out the location of the prone areas, the typology of the expected phenomena, and their frequency, adequate hazard management policies could have been

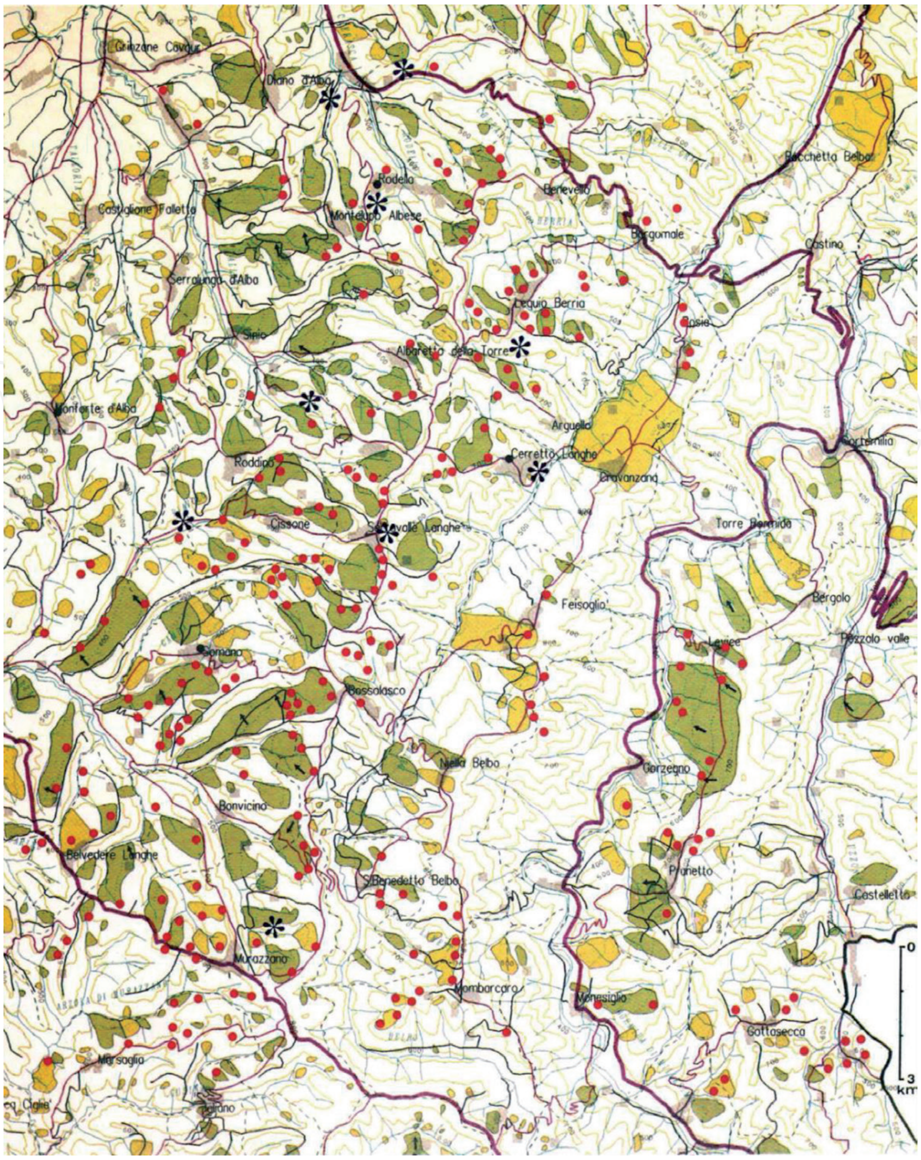

Figure 6.
Location of the main landslides of November 1994 in the Langhe area reported on the map of landslides (by CNR-IRPI and Regione Piemonte). The red spots indicate the TRBSs, and the blue asterisks indicate the areas in which there was the largest concentration of shallow landslides (soil slips). On the map, the quiescent TRBSs are indicated in yellow color; landslides active in the previous 30–40 years in green color (the small blue arrows indicate the most active sectors). In purple color, the roads are indicated.

undertaken especially in hilly area. They underlined that prevention or stabilizing measures are not always effective and in any case involve high costs; they concluded that for the elements that were already exposed at risk, monitoring and warning system with data teletransmission and real-time elaboration could have been a valid solution.

On 1998, Lollino et al. [35] sought to identify some factors capable of triggering and accelerating planar phenomena with the aim of a more in-depth understanding of the kinematic mechanisms and any related risks.

The TRBSs of the Langhe hills in the second half of the 1990s became the main topic study of the Regione Piemonte Geological Service. Its geologists and engineers deeply analyzed the geological, kinematic, and physical characteristics of the landslides: the papers of Forlati et al. [36–37], Forlati et al. [38], Campus [39], Forlati and Tamberlani [40], Susella [41], and Forlati and Campus [7] are noteworthy. In this period, the experts of the Geological Service produced in particular: (1) cartographies of active and quiescent landslides (in collaboration with the CNR-IRPI of Turin, see **Figure** 7), (2) monographs of individual landslides, and (3) research on the geotechnical characterization of the slopes.

Figure 7.
Sliding surface of the Monastero Bormida landslide (February 6, 1994): The following days, the glossy surface was extremely slippery. It created great difficulties for geologists during the survey.

Other studies on rock-block slides of the Langhe hills were produced by Heiland and Stemberk [42], with an interesting comparison between these Piedmontese slides and similar phenomena in Czech Republic (Beskydy Mountains), Aiassa et al. [43], and Bandis et al. [44]. In 1999, Luino [26] presented the results of 4 years of studies on the Langhe and surveys carried out as a result of the aforementioned event in 1994, describing the triggering rains and the processes that occurred on the ground, both in the hydrographic network and on the slopes.

Mason and Rosembaum [45] used Landsat Thematic Mapper and multitemporal SPOT-Panchromatic image data to identify slope instabilities generated by the storm that struck Piedmont in November 1994. Slope angle and slope aspect data were derived from a Digital Elevation Model (DEM) produced from stereo air photographs. The geohazard map was then compiled by merging digital slope data with geotechnical characteristics, utilizing map algebra within a Geographical Information Systems (GISs).

Mandrone with some colleagues, in the period of 2000–2004 [46–48], assessed the risk conditions of the historic centers of the Langhe by analyzing the influence of precipitation on the triggering mechanisms of the instabilities, presenting a forecast model for the triggering of planar sliding landslides based on monitoring of the aquifer level and its correlation with meteorological data.

In the period of 2002–2004, with the aim to map all the existing landslides in Piedmont (including both results of monitoring data and available historical data), the Geological Service of Regione Piemonte participated at the so-called IFFI national project (Inventario dei Fenomeni Franosi in Italia – Inventory of Landslides in Italy) [49]. This landslide inventory represents a fundamental base of knowledge, is a very basic tool for land planning, and strongly helps the local authorities in their decision making. At the same time, the Agency for Environmental Protection of Regione Piemonte (ARPA) carried out new systematic surveys using aerial photo interpretation and created a specific alphanumeric GIS-based database to store and process all the collected data.

In 2005, Luino [50] published an article in which he analyzed the sequence of instability processes triggered by heavy rainfall with a particular focus about the rock-block slide of the Langhe hills triggered during the 1994 event. Luino analyzed the different periods of the event putting in evidence the highest concentration of mass movement trigger moment.

In 2013, Tiranti et al. [51] underlined the importance to establish a warning system capable of providing announcement of activation of the TRBSs with sufficient advance. For this reason, ARPA Piemonte developed a precipitation-threshold-based model setup on an extensive collection of historical data about the landslide movements (since 1917) and the related complete meteorological dataset. The output model can be tested by observations derived by the regional landslide monitoring network consisting of inclinometers and groundwater gauges managed by ARPA Piemonte.

TRBSs were also tackled by Notti et al. [52]: they studied very slow large landslides and the new generation of Persistent Scatterer PSI that allows to increase the density and the time series quality of interferometric data. They analyzed landslides belonging to different geological, geomorphologic, and land-use contexts and with different monitoring systems, in Western and Ligurian Alps, Langhe hills, and a portion of Northern Apennines.

4. Main physical characteristics of the translational rock-block slides

Throughout Europe, flyschoid rocks are commonly unstable. In Italy, the highest concentration can be found in the Langhe hills, which is the reason, in particular after 1994, it has become one of the areas most studied by geomorphologists. As they involve large sectors of slope and completely alter the previous morphological shape, translational rock-block slides are recognized as the phenomena that cause the greatest degree of displacement. We can briefly analyze the most important characteristics of these landslides.

4.1 Gradient of the slipping plane

TRBSs develop along bedding planes on slopes with gradients that vary from 8 to 15°, with 11° as the most common angle (**Figure 7**). They usually correspond to joints that form the interface between sandy-arenaceous and marly silty levels. The dominant direction of translation is nearly always parallel with the dip of the strata, even when the dip direction of the slope face is different. In the latter case, landslides develop at right angles to the slope. At the end of the movement, the sliding surfaces appear as a smooth, inclined plane that sometimes shows the shallow tracks left by the sliding rock block (**Figure 8**).

Sliding surfaces correspond to a thin marly clayey level, where infiltrating water deeply penetrates along systems of discontinuities. Forlati and other authors have discovered that the planar instability phenomena can be ascribed to swelling and to the mineralogy of the material involved. Laboratory testing of specimens immersed in water has revealed that cracks open parallel to the sliding surface. Diffractometric and mineralogical analyses performed on the same samples have shown that in such cracks, the smectite content is similar to the one of the sliding surface as measured in the field. In addition, scanning electron microscope revealed the importance of the fabric, and hence of interparticle links, in the failure mechanism [37]. Moreover, Lollino and Lollino [55], analyzing the landslide of Somano, claimed that the swelling pressure that develops on the sliding surface because of the clay mineral content is a factor that enables the blocks to slide for remarkable

Figure 8.
Sliding surface of the Murazzano landslide taken from uphill: The shallow tracks left by the sliding rock blocks are evident.

distances. These results suggest that the presence of smectite is a decisive factor in predisposing block for sliding that then occurs when there is a sudden increase in rainfall and ensuing hydration processes.

4.2 Area of the slope involved in the landslide

Rock-block slides can extend from a few tens to several thousand square meters. In fact, 46.6% of the landslides studied vary in area from 0.16 to 1.28 ha [5]. Many other rock-block slides triggered in the past are memorable as a result of their dimensions and their consequences for human settlements and activities (**Figure 9**). The Ciglìè landslide (1963) had an area of about 25 ha, while Castino (1936) rock-block slide reached 35 ha. Somano landslide on March 1972 reached an area of almost 100 ha [21].

4.3 Thickness and volumes

About 58.3% of the landslides detected have thicknesses <5 m, 30.1% is between 5 and 10 m, while it significantly decreases for those between 10 and 15 m (10.3%)

Figure 9.
Murazzano Cascina Fascinea farmhouse, one of the most evident landslides of the 1994 event with an area of about 7.4 ha. The clods detached and moved for over 80 m had a height of 8–10 m.

and further decreases for landslides with thicknesses greater than 15 m (1.5%) [10]. In this last category, we can count the landslide of San Benedetto Belbo (**Figure 10**), which was the maximum known depth of any instability that occurred in November 1994 event.

The resulting volumes vary considerably, depending on the areal extent of movements and the thickness of bedrock involved. Volumes are estimated to range from a few hundreds to millions of cubic meters. For example, the Somano landslide in the period of 1972–1974 moved a rock-block slide of a volume of about 10 million m^3.

4.4 Velocity

During the main phase of the movements, obviously, instrumental data are missing; however, the information obtained on the spot and the few bibliographic data available agree in affirming the suddenness of events (developed and exhausted in a span of time included between a few minutes and a few hours). During the paroxysmal phase, the movement can take place at speeds ranging from 0.5 m/h (less than 1 cm/min, Vernetta landslide) to a few hundred m/h (about 5–6 m/min, landslides of Somano and San Benedetto Belbo). The landslide of Somano in 1972 moved involving a farmhouse: in spite of its speed, during the sliding of the rocky mass, the inhabitants were at the table for dinner. The building, in solidarity with the rocky clod, moved gently, and the householders barely noticed the movement only hearing the clink of glasses in the cupboard.

4.5 Displacements

In the wide range of cases recorded over the years, there have been landslides that have been translated by a few meters, but most of them by several tens of meters (**Figure 11**). The systematic analysis of the summary sheets and the results

Figure 10.
San Benedetto Belbo rock-block slide. This landslide is the one with the maximum known thickness: The clods in some points were 22–23 m high, a value that can be deduced from the presence of the geologist on the top. During the late evening of November 5, 1994, eyewitnesses interviewed in the following days said that on the slope of the landslide, they saw many flashes originating from the rubbing of the rock on the sliding surface.

of the aerial photography interpretation analysis made it possible to classify the planar slides typologically, considering the geometry of the sliding surface and the geometry of the landslide body. Forlati and Campus [7] correlated the thickness of the shifted masses and the different types of landslide noting that the thicknesses most at play reached up to 4 m in the case of open plane (70% of the cases) and free over-current (65%) slips in free evolution, while in the case of confined evolution, they increased to 6 m (70%). They are therefore landslides that, although involving the substrate, do not deepen much, remaining on average values of thickness of mobilized clods within 6 m.

All types of sliding are therefore joined by rather modest thicknesses, without indicating a predominant trend compared to the others. An examination of Forlati and Campus [7] summary sheets yielded a population of 108 measures useful for assessing elongation, that is, the distance between the main slope and the lower limit of the accumulation. **Figure 12** shows that 65% of the measurements correspond to an elongation within 100 m. The passage from the discrete to the continuous representation was carried out by means of an exponential function that interpolates the histogram with a correlation coefficient equal to 0.92, thus obtaining a first level instrument for the evaluation of the zones of influence of the translated masses.

Figure 11.
Rock-block slide near Feisoglio town: The mass movement slid about 50–60 m from their original position, destroying a road. The estimated area was about 4.63 ha, while the volume was about 385,000 m^3*. The gray layer surface is evident. The small white house moved together with the rock block nearly undamaged.*

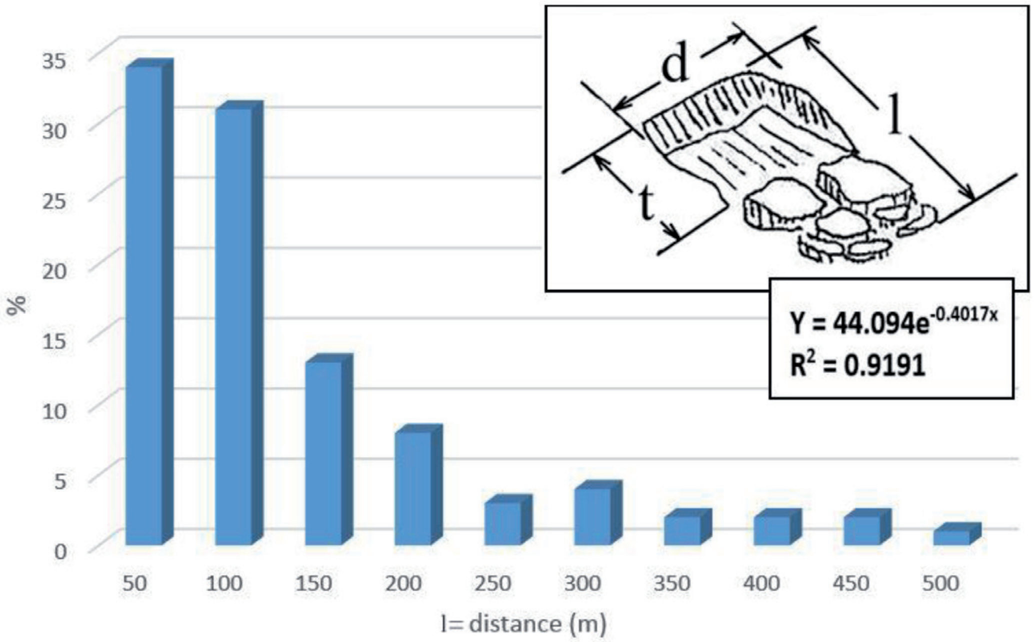

Figure 12.
Distance between main scarp and lower edge of displaced mass. Over 65% of the distances are <100 m according to an analysis of 108 TRBSs in the Langhe hills in the last 25 years ([7], modified).

5. Phases of rock-block sliding movements

In relation to conditions of progressive slope destabilization, studies of past rock-block slides [7, 8, 27] identified four phases of development.

In the first phase, which can continue also for some decades, sub-rectilinear cracks and tension gashes in the ground surface open and they develop to considerable depths. They are generally discontinuous or isolated events and occur primarily in the upper part of the slope. Concurrently, a swelling usually occurs in the middle and lower parts of the slope. In some cases, this phase is characterized by very limited premonitory signs that occur only a few hours or minutes before the sliding.

In cases in which the dynamics of sliding has been recognized, researchers have noted that the time interval between the appearance of the first premonitory signs and the sliding have not exceed 4 h in nearly three quarters of cases ([5], modified).

The second phase (**Figure 13**) differs from the previous one not for the typology of the processes but for the persistence in time of the described disasters that are repeated for the most part in the same places even when they are subject to readjustments for anthropic intervention.

The general conditions remain on average apparently stationary for many years, and the only indication of a growing instability is sometimes provided by the appearance of new small fissures in the ground, arranged in groups, soon, however, partially remodeled by the agro-cultural activities.

In the third phase, a portion of the slope collapses, usually without warning, resulting in the sliding of huge, disjointed rock blocks. The movements can take place over periods that vary between a few minutes for small landslides and some hours for large ones, and it may develop as a result of the erosion of the main scarp. At a later stage, the crown of the landslide may retreat, and the accumulated deposit may become partially fluidified. The mobilized masses slide along stratigraphic surfaces and often preserve the characteristics of the bedrock, even with respect to bedding, particularly over relatively short distances. In some cases, buildings have been propelled forward together with the rock block without being appreciably damaged and showing only cracks in their walls.

The last phase of the movement leads to new conditions of equilibrium, which are achieved by a slow succession of adapting movements that develop with

Figure 13.
Spectacular example of rock-block slide in a second stage characterized by a period of quiescence that can last for several years. During this time, the density of fracture systems increases greatly, leading to vertical displacements and the formation of morphological steps. Cracks can be some hundreds of meters long, often coinciding with the perimetrical fractures of older translational block slides.

progressive demolition of the blocks as a result of natural or human activity. Within a relatively short period of time, slopes are remodeled by the formation of a continuous colluvial cover that tends to hide the characteristic elements of the original landslides.

6. The role of rainfall

The majority of rock-block slides occur in concomitance with long periods of rainfall, even when these are of only moderate intensity. Govi et al. [9] studied the planar landslides that occurred before 1975 and identified a relationship between hourly rainfall intensity and critical rainfall, in which the effective rainfall of a single event is expressed as a percentage of the mean annual rainfall (**Figure 14**). The November 1994 event confirmed the results obtained by these authors. They analyzed the total rainfall delivered by the triggering event, antecedent precipitation (up to 60 days before the event), and the monthly distribution of rock-block slides.

Slope instability usually occurred after periods of heavy rainfall. The prior minimum rainfall needed to reach critical soil conditions varied according to the month: they were the highest in the period preceding the November event. Conditions for instability involved a combination of 60 rainy days and high-intensity precipitation. The rain that fell during the whole 2-month period fed the permeable horizons in the stratigraphic sequence to a critical level. The precipitation mainly influenced the volumes of stored water along fractures and rock discontinuities. The actions of the two variables may not cause instability separately, but together, they can trigger a rock-block slide.

Hourly intensities play an important role in the identification of the different phases. **Figure 15** shows the times of onset and collapse of the planar landslides plotted against hourly precipitation values. However, these data were collected for less than 25% of all movements that occurred in November 1994, and hence,

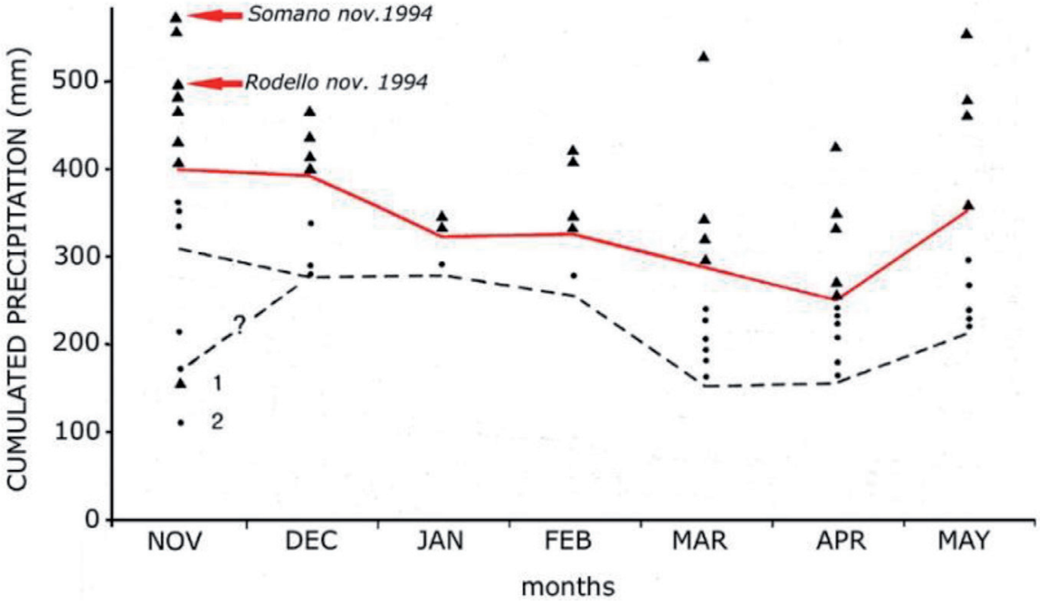

Figure 14.
Diagram showing precipitation amounts triggering rock-block slides in the Langhe hills. The dashed line defines the area of minimum rainfall values in the 60 days before the collapse. The red line denotes the threshold total values (previous rainfall + event rainfall) that cause landslides (1 – cumulated precipitations triggering landslides; 2 – cumulated rainfalls that do not trigger landslides). The rainfall values triggering the Somano and Rodello TRBS occurred on November 1994 are indicated with a red arrow ([9], modified).

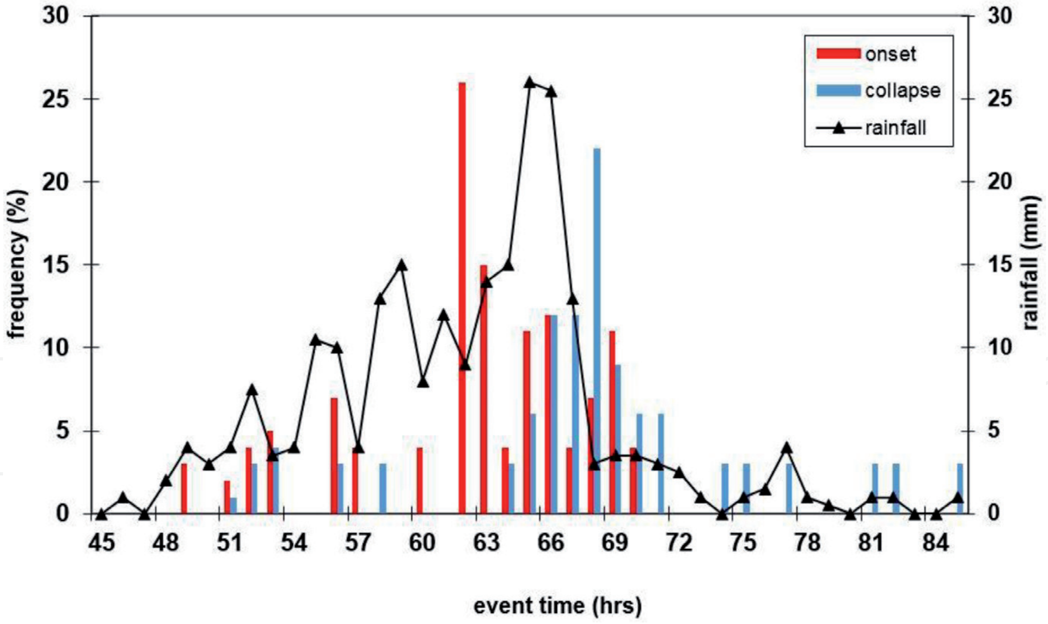

Figure 15.
Relationship between precipitation and time of onset and collapse of translational block slides in the Langhe hills during the severe November 1994 event.

the plotted values may not be representative of failure times as a whole, as it can be argued that the times of onset and collapse are more likely to be noticed during daylight hours than at night. The peak level of the storm was shown to have occurred at 65 h. The threshold total value was reached after 53 h. The climax of the failures occurred at 62 h, while the peak level of collapses occurred after 68 h of rainfall [33]. These observations indicate that there was a time lag of about 6 h between maximum rainfall intensity and failure.

The history of the major events highlights how TRBS always occurs for periods of intense rainfall that exceed a certain cumulative value.

For this reason, although we often hear about the role of climate change in progress, it seems difficult to find a good correlation between the frequency of the processes and the annual cumulated rainfall. In this regard, the graph in **Figure 16**

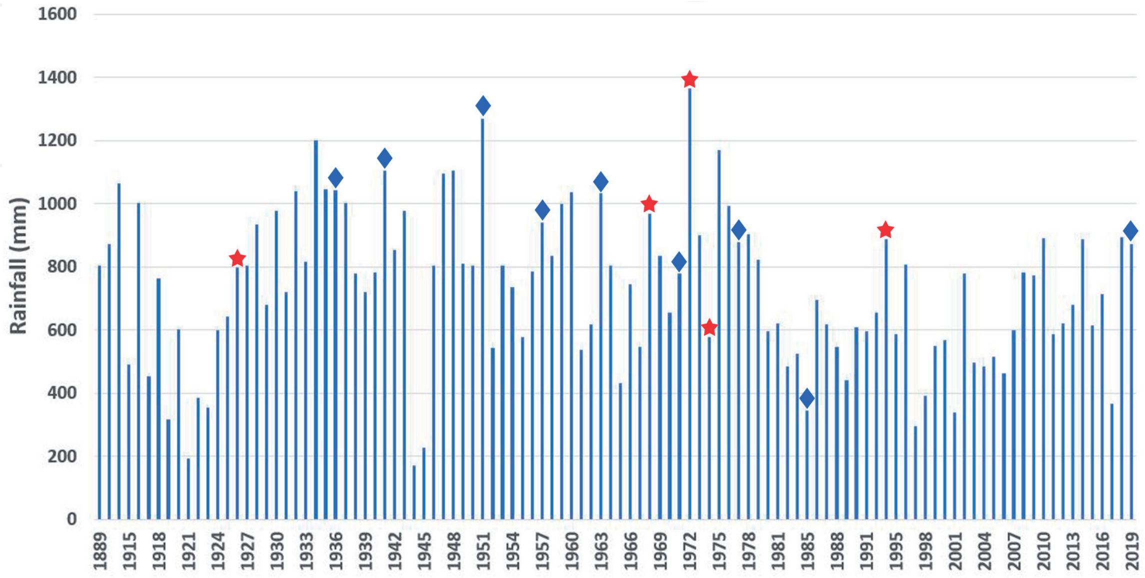

Figure 16.
Cumulative annual rainfall recorded in Alba (1889–2019 with some missing years), the most significant measurement station for the Langhe hills. The blue rhombuses indicate the years in which the minor TRBS occurred. The red stars indicate the years in which the major landslides took place.

shows the cumulative precipitation for each year since 1889 (with some gaps) for the Alba station. The symbols indicate the years in which the TRBS occurred (see **Table 1**).

Considering the seasons from a meteorological point of view, that is, winter from December 1 to the end of February, spring from March 1 to May 31, and so on, we can examine the 27 planar landslide events for which we know the month of occurrence (**Table 1**): it can be noted that as many as 18 of 27 cases (66%) occurred in the spring linked to the concomitance of the rainfall and the melting of the snowpack.

7. Damage

As previously described, in their movement, these landslides often involve structures and infrastructure. The percentage of buildings threatened is higher than that of destroyed or damaged buildings. In 1994, for example, if we take into account that many settlements were not directly affected by the landslides that took place, we can believe that there is a direct knowledge of the problem that led to a physiological selection over time of the safest areas to be used as residence. The same statement loses meaning for the road network where the relationship is reversed: that is, there are fewer cases in which the road network is threatened than those in which the road network is directly affected. Probably, this is due to the fact that the development of communications, as a need to maintain activities in this area, has undergone a significant increase compared to residential urban development which has been rather oriented toward the recovery of the existing one. Following the November 1994 event, more than 1300 TRBSs were recorded, of which almost half caused damage. Over a hundred landslides affected the road system, causing injuries for a total length of over 23 km, equal to about 230 m for each individual gravitational process [56]. The analysis of the damage caused to the inhabited centers by the action of the planar sliding landslides triggered during the November 1994 event highlighted how the highest percentage of damage was recorded for the houses located along the supper and middle sectors of the slopes. On the contrary, buildings built at the foot or near the crest have been less prone to damage in percentage terms. Examining the location of the historical urbanized areas, it is noted that, in the area most frequently affected by planar slides, 64.5% is located in a crest position and only 9.7% in the central sections of the slope [56]. The choice of the most suitable sites for the construction of the settlement centers therefore derives from the knowledge of the phenomenon of stability and the awareness of the effects by the population. The finding that the numerous planar landslides of November 1994 did not cause victims, as, moreover, observed almost generally also in other episodes of the past, suggests that in the population, there is a good historical memory of the process, which depends on the high frequency with which this type of landslide is proposed again and from the daily relationship with the territory, with a predominantly agricultural vocation.

8. Relationships between human activities and translational block slides

For the most of the landslides examined, the anthropic role has been very important: it occurred through actions that have modified the natural distribution of both surface and underground outflows. In this context, a predominant role is attributable to the significant development assumed by the road network, through new tracks and the restoration of old rural cart roads. Immediately following, in order of importance, the effects due to agricultural processes follow.

The analysis of the TRBSs of the Langhe hills mainly for the 1972, 1974, and 1994 events indicates that there is an evident correlation between the activation of movements and the human activities. While in many cases human-induced causes of landslides can be identified, the immediate triggering factor in this case is always an intense and prolonged rainfall. Human activity and land use both increase the potential for landslide activation, primarily where they modify the natural balance of surface runoff and subsurface infiltration.

It has been repeatedly observed that the slope cuts for the opening of service roads, exposing the cracked substrate and thus facilitating the infiltration of water into the subsoil are preferential places for the development of the first movement of land, with extensive opening of the cracks and subsequent propagation of the instability in the closest zones (**Figure 17**).

Similar considerations can be made with regard to the terracing and excavation works that interrupt the continuity of the layers, carried out to reduce the slope of the land for agricultural purposes or around residential settlements. The plows with deep furrows and the heavily engraved drainage network, almost always without protective channels, presumably constitute other important reasons, predisposing to the reactivation of the slipping.

But perhaps the most important aspect is the type of cultivation called "rittochino" or "franapoggio." The first is a hydraulic-agrarian arrangement of the sloping lands. The purpose of this arrangement is to regulate the flow of water while simultaneously reducing the risks of erosion and landslides. The lines on which the cultivation units and the hydraulic-agricultural products are developed follow the lines of maximum slope: the processes, the rows of arboreal plants, and the drainages develop orthogonally to the isohypses in order to favor rapid runoff of rainwater preventing excessive infiltration into the ground. It is probably the

Figure 17.
Murazzano rock-block slide, one of the most showy TRBSs triggered in November 1994, here shot a week later when a temporary road had already been restored. The clods moved along a surface with a gradient of 9.8° for a distance of about 80–100 m. The crown was located about 20–25 m upstream of the provincial road.

oldest settlement adopted in many hilly regions of Italy. The second, "franapoggio," instead, derives from the fact that the workings follow the isohypses: the cultivation is made by furrows arranged in a normal direction to the lines of maximum slope. The advent of agricultural mechanization has determined the almost total abandonment of the "reggipoggio" because tractors work in better conditions on the lines of maximum slope. This cultivation is still present in viticulture.

The most evident aspects of human activities that cause landslides in the Langhe hills are the following ones: (1) surface runoff is concentrated where roads are built in line with the fracture planes of past landslides; (2) water stagnates upstream of road embankments that lack drains; (3) the secondary hydrographical network is occluded due to agricultural work; and (4) water leaks from artificial reservoirs excavated on the slope in order to store rainwater [8].

9. Discussion

The fact is that the numerous rock-block slides did not cause many casualties, on November 1994 and also in other episodes of the past, as previously mentioned, it suggests that there is a certain historical memory of the problem, which depends on the high frequency with which this type of landslide is repeated and from the daily relationship with the territory, with a predominantly agricultural vocation. This entailed an accurate selection of areas to be used for permanent settlement purposes (the damage analysis shows that the percentage of buildings that are threatened is significantly higher than the destroyed ones), and the surprising sensitivity to perceive comes from the same reasons and distinguishes the warning signs of instability.

Thanks to this awareness of the problem and also bearing in mind that the preparatory phase of landslides due to gliding can last for several years and that the interval between the appearance of warning signs and the collapse is generally more than 2 h, it can be assumed that in the Langhe hills, an increase in the socially acceptable risk threshold has been reached, which must not, however, exempt us from deepening our knowledge of the problem. Indeed, the progress of knowledge confirms what has already been reported at the conclusion of the study cited on landslides in the Langhe of the Cuneo province in the years 1972–1974, and that is, the slopes in question need to be considered areas with high risk of landslide, even if there are not always perceptible signs of instability.

The knowledge gained on rock-block slides was further enriched with the alluvial event of November 2–6, 1994, which proposed a great variability of situations of great importance for the understanding of these phenomena: an extraordinary, and perhaps unrepeatable, "didactic gym," as well as a field of intervention for the competences of the Public Administration, which has provided several points for reflection, some of which are briefly outlined here. The significant morphological effects on the slopes and the spread of damage to the roads and the residential fabric led, a few days after the event, to the creation of a Regional Advisory Commission with tasks of methodological orientation and support to the operating bodies. Among the first products, as early as January 1995, a summary map was made available on a scale of 1:25,000 of the landslide phenomena recognized by photo-interpretative study, accompanied by an appropriate "data base" containing considerations on the evolutionary stage and damage caused by each of the 470 census landslides. The creation of a suitable survey card allowed us to collect data from 200 sample landslides on the ground. The detailed mapping on a scale of 1:10,000 and the subsequent digitalization also represented the justification for a complete review of the entire area and its evolutionary history.

The extensive amount of data acquired allowed a comparison between the events of the 2-year period of 1972–1974 (on a window of 200 km^2): as many as 130 landslides of 200 recognized, even as more ancient phenomena, were reactivated in that period [8]. Not different was the 1994 event, as 46% of the census landslides were considered as reactivations of previous phenomena.

For large sectors (e.g., area of Somano, Serravalle Langhe, and Bossolasco), it was possible to speak of "persistent intermediate stage" with episodic aggravations, which are also important, distinguishable over time.

A systematic photo-interpretative analysis of planar slips activated in spring 1972 compared with those of the autumn 1994 event allowed further significant considerations on the dynamic and evolutionary characteristics of these phenomena, namely:

- widespread reactivation of sectors or portions already place of movement in the 2-year period of 1972–1974;
- clear conditioning of the most significant morphostructural elements already manifested in that period;
- complete evolution of sectors in which signs of incipient instability were present; and
- reappearance on artificially reshaped slopes of fractures and traction joints that had affected the movements in 1972–1974.

The same considerations can be valid, in general terms, also for sectors of slopes that have been affected by landslides prior to 1972. It can therefore be argued that many of the areas affected by movements in 1972 were reactivated, especially for the larger phenomena, in 1994 with various spatial modalities but mainly using the same structural guidelines.

Based on testimonies collected from the affected population, an interesting information was provided regarding the perception of the warning signs and the times of landslide development. In general, it was found that for about 60% of the 70 cases analyzed, the interval between the appearance of the warning signs (cracks on the artifacts and in the ground) and the collapse phase is about 2–4 h.

10. Conclusions

The purpose of this paper is to make TRBSs known to the international scientific community, showing a synthesis of the studies and history of about these phenomena in the Langhe region, in north-western Italy. The Langhe delineates themselves, in the articulated panorama of the Piedmontese relief geological instability, due to the high presence and repetitiveness over time of the planar landslide process. Alongside important episodes of activations widespread in 1972, 1974, and 1994, still recognizable on the slopes, especially with the help of aerial photographs, there are signs of ancient movements, also large sizes.

These particular landslides clearly reveal the area's intrinsic morphological instability and the principal morphogenetic factors on slopes. Moreover, slope instability creates huge problems for the people of this hilly zone, not so much for the number of victims (<15 in the 340 years analyzed in **Table 1**), but for the extent of the land involved: just think that in some municipal areas such as Serravalle Langhe and Bossolasco, the area involved in landslides represents 40–42% of the total area [5].

During major hydrological events, main highways, secondary road networks, farmland, and rural buildings are often damaged. Field surveys can provide direct knowledge of the contemporary problem and its long history. Fortunately, unlike some earlier landslides, the more than 450 translational landslides that occurred in November 1994 claimed no casualties, but these are always possible, as the rock-block slides are potentially highly dangerous. Given the short-time lapse between maximum rainfall intensity and rock-block slide failure, an adequate meteorological network is needed with the capacity to detect thresholds of alarm during precipitation and snow-melt events, so that public authorities can be prewarned of emergency situations.

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