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The giant landslide in Niscemi (Italy): history and geomatics reveal its 17th- century anthropogenic roots

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Abstract

The recent reactivation of the Niscemi (Sicily) giant deep-seated landslide in January 2026, following a similar event in 1997, highlights a complex geomorphological setting with an evolution dating back centuries. Historical sources document a massive 1790 event that severely damaged the town's outskirts. However, due to a recognized structural gap in bridging pre-industrial historical evidence with modern spatial analysis, the exact spatial extent and the long-term anthropogenic preconditioning of this 18th-century failure remained largely unexplored. By combining critical analysis of historical archives with modern geomatics, we achieve two primary outcomes. First, we backdate the initial slope instability to a critical precursor event in 1776 and accurately geolocate the spatial extension of the subsequent 1790 landslide crown. Second, through detailed analysis of multi-century cadastral records (1600–1800), we correlate a marked demographic increase with radical deforestation and hydrographic modifications, suggesting that pre-industrial land-use changes critically preconditioned the hydrogeological hazard. In doing so, we also refute a two-century-old historiographical error that erroneously attributed the 1790 collapse to a tectonic earthquake. Ultimately, this study provides a generalizable methodology to spatially resolve the anthropogenic impact on deep-seated landslides, yielding crucial baselines to design geomorphologically and ecologically sound mitigation strategies.

Introduction

Giant deep-seated landslides represent a major global hazard, yet quantifying the long-term contribution of pre-industrial human activities remains a critical scientific challenge. While susceptibility models successfully evaluate the anthropogenic impact on shallow slope failures, the multi-century human preconditioning of deep-seated landslides remains largely unquantified[1,2]. Although the role of anthropogenic drivers is widely recognized, historical research and modern spatial analysis are traditionally conducted in isolation. Historical documents can recover event timing and causation but often lack spatial precision[3,4]. Conversely, modern photogrammetric reconstructions are typically limited to the advent of widespread aerial coverage in the 1940s, precluding the direct observation of much older source-area geometries[5]. As highlighted by hazard literature, this gap persists because bridging heterogeneous sources across disciplines involves structural and epistemological difficulties in scale, uncertainty, and georeferencing[6,7]. The lack of an integrated framework combining pre-industrial historical evidence with modern sensor integration often prevents researchers from physically identifying the spatial limits of past events, such as historical landslide crowns, and from evaluating how centuries-old land-use changes precondition modern landslide dynamics[8,9].

To bridge this recognized methodological gap, we present a novel, transferable framework, utilizing the Niscemi giant landslide (Sicily) as an exceptional natural laboratory.

Between January 15 and 26, 2026, a massive landslide struck the urban area of Niscemi, a town of over 24,000 inhabitants in southeastern Sicily[10]. This event followed two similar historical and recent episodes in 1776–1790 and 1997, with a significant increase in both the landslide's extent and the

volumes of material involved. The current landslide front (Fig. 1) spans 4.7 km, and the detached sectors exhibit average heights of 25 to 30 m. The total volume of soil affected by the 2026 landslide movements has been estimated at approximately 80 million m^3[11]. This gravitational instability stems from various converging factors that have created a scenario characterized, over the last thirty years, by a worrying escalation in both the volume of soil involved and the geographical extent of the area affected by the landslide. The primary factor identified is lithological and structural: the area where Niscemi is situated is characterized by a succession of permeable sandy-arenaceous levels and clayey-marly units[11] and the city itself is situated on a sequence of Early Pliocene to Middle Pleistocene terrains[12]. From a strictly lithological perspective, the succession transitions from recent and active alluvial deposits formed by sediments from the area's main watercourses to Pleistocene sandy deposits, which consist of medium and fine-grained material alternating with arenaceous levels. These sands have an overall thickness varying between 30 and 60 meters. The sequence is underlain by Middle Pliocene grey-blue marly clays, which reach a considerable thickness of at least 100 m and constitute the impermeable substratum. This impermeability, coupled with poor geomechanical properties, gives rise to conditions favorable to the formation of sliding surfaces. Other factors include the complex tectonic setting of southern Sicily, which is tied to the Gela Nappe and the foreland–foredeep–chain system of the Sicilian Maghrebian belt[13,14,15]. From a geodynamic perspective, the Niscemi area is located within a complex tectonic transition zone: it lies southeast of the Caltanissetta Trough, a Neogene basin undergoing rapid subsidence[16]; at the front of the Gela Nappe, a large allochthonous unit advancing toward the SE[13,15]; and in direct contact with the Hyblean Foreland, the African foreland block adjacent to the frontal thrust structures and affected by a prevailing strike-slip regime[13,17,18]. The southern margin of the plateau, where the inhabited center is located, is bounded by a sub-vertical escarpment ten meters high trending in a N–S direction on the western side of the town and in an E–W direction south of the town. At the base of the escarpment, gentle slopes (≈ 10°) extending for several hundred meters descend toward the Benefizio Torrent and minor watercourses. The Benefizio Torrent deeply dissects the slope, separating two orthogonal landslide sectors: one oriented N–S (downstream of the town) and the other E–W. The overall morphological setting is characterized by steps and scarps along the slopes, resulting from both ancient and recent landslides, badlands, and deep gullies caused by concentrated erosion from unregulated surface waters, urban runoff, springs, and drainage collectors. Furthermore, hydrogeological conditions play a significant role, given the hypothesis that surface water flow and infiltration networks contribute to the mechanisms driving this gravitational evolution. While these natural lithological, tectonic, and morphological conditions establish the baseline susceptibility of the slope, they do not fully explain why the system has evolved with such dramatic acceleration over recent decades. The aim of this paper is twofold. First, we backdate the initial slope instability to a critical precursor event in 1776 and physically map the exact spatial extension of the subsequent 1790 landslide crown. Second, we investigate the multi-century anthropogenic preconditioning of the slope, analyzing the relationships between the increasing demographic pressure in the Niscemi area (between the 17th and 19th centuries) and the accelerated erosive processes that lowered the failure threshold for the 1776–1790, 1997, and 2026 episodes. Crucially, this historical approach allows us to decouple human-induced

destabilization from alleged natural triggers, correcting long-standing historiographical errors that attributed past landslide to tectonic seismicity.

By reconstructing the precise failure of geometry and identifying the eradicated original geo-botanical cover (e.g., deep-rooted oak and wild olive forests), we provide crucial baseline data for modern hazard management. Knowing the spatial limits of the historical crown guides targeted urban restrictions against regressive dynamics, while identifying the native vegetation offers a blueprint for nature-based mitigation solutions.

Beyond the immediate implications for local hazard assessment, this work demonstrates that bridging historical cadastral archives with modern geomatics provides a transferable framework to uncover the long-term anthropogenic roots of giant landslides, offering a new baseline for investigating complex slope instabilities worldwide.

Results

Spatial geometry and kinematics of the 1790 event

Primary historical accounts[19,20] establish a precise chronology for the 18th-century paroxysm. Historical chronologies indicate that the 1790 event was preceded by a highly localized small landslide in 1776, which manifested as a ground fissure approximately 2.5 m wide, causing local subsidence at the northwestern edge of the system (Poggio di Sante Croci, see all the toponyms here reported in Fig. 1). The main landslide subsequently began on the evening of March 18, 1790 (at approximately 8:30 PM), marked by a prolonged subterranean rumbling. This was followed the next morning, March 19 (at approximately 11:30 AM), by localized tremors and progressive ground subsidence.

We developed a precise spatial reconstruction of the 1790 landslide using a geomatics-based analysis of old photogrammetric campaigns spanning the entire 20th century, before and after the 1997 episode. During the main event of March 1790, this 1776 structural weakness was absorbed into broader failure systems encompassing an estimated area of nearly 3.4 km², with longitudinal and transversal extents both exceeding 1 km. Tracing the reconstructed perimeter, the detachment originated at Coste dello Sbanco (near Contrada Banco) and extended northward along the eastern escarpment facing the Benefizio Torrent as far as Terre del Perillo and the easternmost apex at Punta del Pizzo del Banchitello (Fig. 1). From this point, the fracture line propagated sharply westward along Poggio del Trappeto, skirting the southern periphery of the Niscemi urban area for over 1 km, before terminating at the westernmost limit of Sante Croci and Canalicchio neighborhoods.

The main crown along the northern and western margins exhibited progressive failure dynamics, marked by the formation of 1 m scarps on March 19, and culminating in sub-vertical scarps reaching over 20 m in the following days. Crucially, severe morphodynamic alterations occurred at the depositional toe: in Contrada Benefizio, located on the valley floor below the advancing eastern mass, observers reported a

massive ground upheaval. Described historically as a "volcano," this phenomenon began as a 4.12 m bulge and eventually reached a height of 12.9 m, accompanied by the opening of a 0.51-m-wide vent.

Re-evaluation of natural triggers

A systematic review of regional historical seismicity and local weather conditions was conducted to contextualize the role of natural forcings on the 1790 landslide. According to CPTI15 (Rovida et al. 2022) and DBMI15 (Locati et al. 2022), historical macroseismic intensities at Niscemi, excluding the 1693 earthquake, generally did not exceed VI MCS. The critical review of January 11, 1693, Val di Noto mainshock (Mw 7.3) found that, despite the high macroseismic intensity experienced at Niscemi (VIII-IX MCS), no landslides, severe ground fissures, or hydrological anomalies are documented within the urban area. Furthermore, post-1693 reconstruction information shows that major buildings were rebuilt on their exact original sites[21] without evidence of structural measures related to ground instability mitigation. While documentary silence cannot preclude all contemporary geomorphological effects, it prevents the definitive attribution of the slope preconditioning solely to co-seismic shaking.

Regarding the 1790 event, cross-referencing of historical accounts reveals the genesis of a historiographical error: primary local sources explicitly mention ground subsidence but report no tectonic seismic shocks. The "slight tremor" felt on March 18 and 19 was a localized acoustic and mechanical consequence of rock mass fracturing. The erroneous seismic attribution was traced back to a journalistic conflation published in the Gazzetta Universale (Florence, May 1, 1790)[22]. This journalistic conflation strongly influenced the 19th-century geological tradition: Huot (1837)[23] associated the Niscemi landslide with an earthquake, while Le Coq (1839)[24] introduced the claims of successive seven shocks, subsequently taken up by Lyell (1839)[25]. Consequently, while early seismological catalogues, as Perrey (1848)[26] and Mercalli (1883)[27] maintained a chronological distinction, Baratta (1901)[28] merged the journalistic accounts with Le Coq's narrative, consolidating the false tectonic trigger in the historical record.

Similarly, Landolina[19] explicitly records a “particularly rainy winter” preceding the March event and notes that “continuous rains” during the subsequent spring delayed his post-event survey. While these accounts attest to abundant seasonal precipitation, there is insufficient historical data to define the exact rainfall intensity and temporal distribution immediately prior to the March 18–19 paroxysm. Furthermore, local chronicles state that, on the day the fractures began to form, the local population was actively engaged in routine agricultural labor in the fields. This suggests that while seasonal precipitation plausibly contributed to the hydrological loading of the system, it cannot be definitively classified as the ultimate, immediate trigger. Rather, the catastrophic failure mechanism acted upon an already severely preconditioned slope.

Anthropogenic land-use evolution and hydrographic alterations

Archival sources, notably the baronial assessment conducted in April 1601 by surveyor I. De Mainolfo[29], attest that at the dawn of the 17th century, prior to the town's official foundation, the Niscemi plateau and its slopes were dominated by extensive, deep-rooted woodlands (e.g., Quercus suber, Quercus ilex), ensuring highly effective natural armoring of the sandy-clayey slopes[30]. Following the formal establishment of the town in 1626, a marked demographic increase was recorded, with the population growing from 568 inhabitants in 1656 to 6678 in 1798[31].

This demographic pressure drove unsustainable resource exploitation, leading to the radical eradication of the native vegetative cover. Historical records from the *Fondo Lanza di Trabia, Serie I - Carte Branciforte* in Archivio di Stato di Palermo (ASP) document extensive illegal logging and intentional forest fires, specifically aimed at producing charcoal and clearing land for agriculture (Fig. 2). Notably, widespread and uncontrolled deforestation was already underway in 1601, well before the formal foundation of the town, across the feudal domains of Niscemi (the exact site of the 1790 landslide), Santa Barbara, and Costafredda. Archival sources reveal that Prospero de Blasquis, the delegate for the Niscemi fiefdom, was formally instructed to investigate these abuses and severely punish the perpetrators[29]. The persistence of this environmental degradation is further corroborated by a 1620 penal trial against two individuals held responsible for intentionally igniting a forest fire to illegally expand agricultural land[32]. Following the formal establishment of the town, in 1626, the 1634 lease contracts legally authorized citizens to collect wood, further accelerating the deforestation process[32]. In 1718, a strict ban issued by Stefania Branciforti officially documented the complete depletion of the woodlands, noting the consequent disappearance of local wildlife[33].

The eradication of the protective forest cover was followed by aggressive agricultural cycles that progressively degraded soil cohesion. Data from the historical fiscal censuses (Riveli di beni e di anime) of the State Archive of Palermo indicate that by 1656, the slope had been subjected to deep soil trenching to accommodate a massive monoculture of 285,300 grapevines[34]. Less than a century later, an agronomic report dated May 12, 1747 (by surveyors Campolino and Damasi)[34] certified the economic failure of these vineyards. Consequently, landowners systematically uprooted the vines to convert the slopes into arable land for barley and wheat.

Concurrently, the slope underwent continuous artificial hydrographic regimentation. Prior to the landslide, the Benefizio Torrent and surrounding districts were systematically exploited for intensive irrigation. Landolina[19] describes a heavily anthropized slope rather than a natural hydrological system. Prior to the landslide, the Benefizio Torrent (described as a canyon over 25 m deep) and the surrounding Gebbiazza and Congeria districts were systematically exploited for intensive irrigation. Crucially, on the day of the landslide, construction was underway by local master builders to erect a "large wall for the conservation of waters" in the Benefizio area. The widespread presence of watering troughs (*abbeveratoi*), masonry cisterns, and the forced deviation of multiple springs (Spasimo, Cresiazza) indicate a continuous artificial loading of the slope's hydrological system. The sudden disappearance and erratic reappearance of these springs during the days of the collapse confirm that the subsurface

groundwater circulation was highly pressurized and directly interconnected with these artificial superficial structures (Fig. 3).

Discussion

The 1790 Niscemi landslide should be interpreted as the result of a synergistic interaction: the inherent litho-stratigraphic fragility was the pre-existing condition, while the pre-industrial demographic and agricultural pressure acted as the fundamental, long-term anthropogenic preconditioning. The stratigraphic sequence, characterized by highly erodible Pleistocene sandy-arenaceous deposits overlying impermeable Middle Pliocene marly clays, renders the area naturally susceptible to sliding. However, historical evidence suggests that following the town's foundation, rapid population growth forced an aggressive expansion of the agricultural frontier. The clearing of oak forests and the massive planting of vineyards (over 285,000 vines by 1656), subsequently violently uprooted in 1747 to make way for cereal crops, modified the slope's boundary conditions, bringing the unstable system closer to its failure threshold. The degradation of the vegetative cover reduced the shear strength reinforcement of the superficial layers, while hydraulic interventions required for this urban expansion introduced concentrated infiltration patterns. By successfully quantifying this multi-century land-use legacy, our analysis addresses the typical shallow-landslide bias prevalent in current susceptibility models. Therefore, the heavy rainfall documented during the winter and spring of 1790 may have contributed to triggering the catastrophic landslide because the socio-economic necessities of an expanding population had already critically compromised the resilience of the deep-seated geological system. Bridging the epistemological gap between qualitative historical archives and quantitative spatial data allows for a robust interpretation of the 1790 landslide kinematics, framing it as a deep-seated, complex rotational-translational failure.

The geomorphological evolution was progressive, as evidenced by a 2.5 m wide ground fissure at Sante Croci in 1776, serving as a critical precursor of localized internal deformation. The timeline of the main event in March 1790 corroborates this progressive dynamic, with the rotational sliding component indicated by the oblique tilting of masonry structures. The most compelling geomorphological evidence regarding the depth and volume of the mobilized mass is the phenomenon observed at the depositional toe. The historical description of a "new volcano", characterized by rapid ground upheaval, is a clear manifestation of passive toe bulging under undrained loading conditions. As the intact eastern block of the Niscemi plateau translated downwards, its weight compressed the saturated sediments of the Benefizio valley floor, resulting in localized liquefaction and the upward extrusion of pressurized fluids and mud. The spatial reconstruction of the 1790 landslide crown provides a crucial interpretive key for understanding contemporary disaster risk in the Niscemi area. The 1790 eventcarved a massive "scar" along the flanks of the plateau, drastically altering the regional stress field by removing lateral support and leaving oversteepened scarps in the sandy deposits. By extending our spatial analysis beyond the traditional 1940s photogrammetric barrier, we demonstrate a clear pattern of structural inheritance. The spatial geometry confirms that the catastrophic 1997 reactivation initiated precisely along the margins of the 1790 crown, exploiting pre-existing planes of weakness. This structural continuity culminated in

the disastrous reactivation of January 2026, forcing mass evacuations and proving that the geological discontinuity created by the 18th-century collapse remains active. Consequently, the recent events in Niscemi cannot be analyzed as isolated phenomena triggered solely by modern extreme weather events or recent urban mismanagement. They represent the direct, evolutionary phases of a single, massive gravitational system. Locally, the precise spatialization of the 1790 landslide crown, combined with the knowledge of the pre-industrial anthropogenic cofactor, provides essential insights for stakeholders involved in hazard reduction in Niscemi town. Furthermore, identifying the eradicated native vegetation offers a concrete blueprint for implementing nature-based mitigation solutions to stabilize the plateau's margins. On a broader scale, this study demonstrates that integrating multi-century archival research with modern geomatics provides a transferable framework to physically reconstruct historical landslide geometries, overcome persistent observational gaps, and investigate the long-term anthropogenic roots of complex slope instabilities worldwide.

Methods

To guarantee rigorous spatial reconstruction and to quantify both the natural and anthropogenic factors influencing the 1790 Niscemi landslide, this study adopted an integrated multidisciplinary workflow. The methodology was structured around three primary objectives: 1) mapping the spatial geometry of the historical landslide; 2) assessing the alleged seismic trigger; and 3) reconstructing the pre-1790 anthropogenic land-use dynamics.

Spatial reconstruction of the 1790 landslide

The methodological workflow starts from a systematic extraction of spatial and morphometric data to accurately constrain the geometry of the 1790 Niscemi landslide. This phase relied on an interdisciplinary approach integrating primary textual accounts, historical cartographic representations, and a robust sequence of aerial photogrammetry.

To define the exact geometry and structural damage of the 1790 event, we first analyzed near-contemporary local accounts, notably the detailed report written by Saverio Landolina Nava[19] and the contemporary reports by Niscemi's parish-priest from the Antologia Romana[20]. These sources were critically assessed in terms of their chronology, provenance, directness of observation, and relationship of dependence. Landolina's account, although published in 1792, derives from a field investigation conducted in Niscemi in 1790: commissioned by the Viceroy on May 11, Landolina reached Niscemi on June 30, where he directly examined the effects still visible on the ground and reconstructed the March landslides through interviews with eyewitnesses, cross-checking the accounts of his local informants. He provided a remarkably detailed description of the affected area, recording toponyms, distances, measurements, chronology, and evidence useful for reconstructing the kinematics of the ground movements. These primary sources were integrated with Maugeri's (1869) later account[35], combining earlier sources, surviving local memories, and direct observations useful for historical toponym identification and localization, and with modern local historiography and geographical works by Angelo

Marsiano (1982[36]; 1984[30]; 1987[31]; 1995[21]). This textual dataset was then validated through recent field surveys, which included interviews with local experts to recover surviving historical toponymy (Table 1).

Table 1
Location of the historical toponyms identified in the study area.

HISTORICAL NAME	DESCRIPTION FROM SOURCES	PRESUMED LOCATION
Coste dello Sbanco	Southernmost point, origin of the landslide.	Contrada Banco, Strada vicinale Banco
Beveratojo della Cresiaccia, Contrada Cresiaccia (or Cresiazza or Chiesazza)	Point of Coste dello Sbanco where the landslide began	Contrada Banco, Strada vicinale Banco (37.126838, 14.391369)
Punta del Pizzo del Banchitello	Easternmost point of the landslide according to Landolina, near the beginning of the road leading to Acate	South of present-day Via Gorizia, between the strada vicinale Benefizio and the SP10.
Contrada Gebiazza	Mentioned by Landolina after Pizzo del Banchitello without providing descriptions.	Along the SP10, between Contrada Beneficio and Contrada Banco.
Le Valanche di Gibillio	Landolina states this was the name given to two small mounds (hillocks, land elevations) rising alongside Contrada Gebiazza	Along the SP10, between Contrada Beneficio and Contrada Banco.
Terre del Perillo	Point where, over a kilometer, the landslide changes direction towards the West.	Between the town and the *strada vicinale* Benefizio.
Poggio del Trappeto	Area along which the landslide continues westward for over a kilometer	South of Niscemi, between Via Gorizia and Poggio di Sante Croci.
Poggio delle Sante Croci	Westernmost point, where the landslide stops.	Area of the former Church of Sante Croci.
Canalicchio	Point of Sante Croci where the landslide stops, on the road descending from the municipality towards Gela.	South of the current Largo Canalicchio
Fiumicello	A public wash-house near Canalicchio fed by a spring suppressed by the landslide and reopened around 1867, from which time it fed a watering trough built in place of the wash-house ("with two sources").	South of Sante Croci (37.141149, 14.384596)
Lands of Congeria in Contrada Beneficio	Place where Landolina records land subsidence recounted by men working there, and where the "volcano" rose, described as also being inside the perimeter of the subsidence, thus perhaps right	Between Contrada Benefizio and Contrada Banco

HISTORICAL NAME	DESCRIPTION FROM SOURCES	PRESUMED LOCATION
	next to the landslide. Here, a concurrent uplifting of the earth was also recorded, creating a sort of small hill.	(37.133656, 14.388159)

A critical methodological step for the subsequent GIS (Geographic Information System) mapping was the quantitative standardization of ancient measurements. Textual descriptions providing distances, widths, and structural damage metrics were translated into the International System of Units (SI) (Table 2). The conversion was performed using 19th-century official metrological tables (Codice Metrico Siculo, 1812[37]; Afan de Rivera, 1840[38]; Tavole di Ragguaglio, 1877[39]). A careful philological distinction was applied based on the author's origin: for local sources (Maugeri, Antologia Romana), we applied the Palermitan/Sicilian metric system. Conversely, for Landolina, we accounted for his use of Neapolitan and Italian standard units, as the author himself explicitly specifies his adopted measurement system, notably referencing the "Italian square mile".

Table 2
Standardisation of historical morphometric data of the 1790 Niscemi landslide extracted from contemporary and retrospective primary sources. Values are converted to the International System of Units (SI).

SUBJECT OF MEASUREMENT	ANTOLOGIA ROMANA	LANDOLINA	MAUGERI
Total extent of the affected area		One square mile = approx. 3.4 square km	2/3 miles = 2.97/4.46 kilometers
Distance of Cresiaccia (or Cresiazza or Chiesazza) from the town			Two km South-East
Height of the 1776 landslide at Sante Croci		10 palms = 2.58 meters.	
Distance of the landslide from the town along Trappeto/Sante Croci	No more than 10 canes (on the left side of the road descending from the plain towards Gela) = just over approx. 20m	Approx. 100 paces from the town = approx. 185m	10 Canes (according to citizens alive in 1790 spoken to by Maugeri) = just over approx. 20m
Distance from South (Sbanco) to North (Pirillo/Pizzo del Banchitello)			Over one km
Distance from East (Pizzo del Banchitello) to West (Sante Croci/Canalicchio)			Over one km
Height of the landslide along Sante Croci/ Trappeto/ Pirillo/Pizzo del Banchitello	Up to over 60 Palms = 15.48 meters	Up to 80 Palms = 20.64 meters (developed gradually, until 19/03 only 4 palms, on 20/03 it was 8 and reached 80 over the following days)	Up to 80 Palms = 20.64 meters
Distance of Cresiaccia (or Cresiazza or Chiesazza) from the extreme north of Benefizio (Lands of Rosario Vallone)		Approx. 400 paces = approx. 738m	
Height of the small hill in Contrada Beneficio		Approx. 16 palms initially (4.128 meters), then approx. 50 palms (12.9 meters)	Approx. 50 palms (12.9 meters)
Diameter of the "volcano"		Approx. 2 palms (just over 50cm)	Approx. 2 palms (just over 50cm)
Height of the landslide in the east from Sbanco to		Approx. 70 palms (18.06 meters)	

SUBJECT OF MEASUREMENT	ANTOLOGIA ROMANA	LANDOLINA	MAUGERI
Pizzo del Bianchitello			
Height of the landslide at the contrada known as la Gebbiazza		Approx. 72 palms (approx. 18.51 meters)	
Width of the fissures that opened		From half a palm (Gebbiazza) = approx. 12.5cm to over 10 palms = over 2 meters	
Height of the Valanche di Gibillio		100 palms = approx. 25.8 meters	

The spatialization of the textual metrics was anchored using an unprecedented dataset of historical cartographic representations spanning from the 17th to the 20th century. To assess the pre-event topographic baseline and verify the structural stability of key urban landmarks prior to the 1693 Val di Noto earthquake, we utilized the view “Niscemi Terra nel Regno di Sicilia” dell’Eccellen.mo Sig. D. Carlo Carafa, drawn by architect Simone Felice Delino (1680–1693, Österreichische National bibliothek, Wien)[40]. The identification of persistent urban structures, rebuilt on their original sites after the 1693 earthquake. (the Chiesa Madre, S. Maria del Bosco, and S. Antonino di Padova)[21] provided stable landmarks for long-term spatial orientation.

To reconstruct the post-landslide landscape, we analyzed three cartographic drawings on paper from the Archivio di Stato di Palermo: one from 1830[41] and two from approximately 1847 [42,43].

This historical cartographic dataset was aligned with early modern geodetic frameworks using the 1867 Topographic Map of the Gela Territory (IGM, scale 1:50,000)[44], the 1943 Topographic Map by the US Army Map Service (Sheet 272-II NE Niscemi, scale 1:25,000)[45] and the 1955 Geological Map of Gela (Sheet 272 Geological Map of Italy, scale 1:100,000)[46].

Geomatic Reconstruction and Photogrammetric Processing of the Historical Baseline

While historical archives provided a qualitative spatial hypothesis for the 1790 event, we employed historical aerial photogrammetry using Istituto Geografico Militare (IGM; Italian Military Geographic Institute) datasets to achieve precise spatial georeferencing. This geomatic workflow allowed us to precisely delineate the exact location of the original 1790 headscarp and digitally reconstruct the baseline slope morphology prior to modern landslide reactivations. The primary analytical dataset comprised 12 analog stereo-pair frames acquired on August 19, 1938, representing the earliest and closest available airborne photographic survey to the 1790 event. According to the archival metadata, the flight was executed at an altitude of 3800 m using 13 X 18 cm monochromatic glass plates. The use

of glass plates, as opposed to traditional cellulose film, is highly advantageous for historical photogrammetry, as it guarantees superior dimensional stability and minimizes non-linear physical deformations of the support medium over time.

Multitemporal Spatial Anchoring and Cascading Co-Registration Protocol

Multitemporal Spatial Anchoring and Cascading Co-Registration Protocol
To define an absolute geodetic reference system capable of accurately reconstructing the spatial position of the 1790 landslide crown, the archival imagery from 1938 required rigorous anchoring to a contemporary, ultra-high-resolution spatial baseline. This baseline was acquired on April 21, 2026, following the major landslide reactivation of January 2026. The contemporary survey utilized an Unmanned Aerial Vehicle (UAV) platform – specifically a DJI Mavic 3 Enterprise (Mavic 3E) equipped with an RTK positioning module – generating a dense 3D point cloud, a digital orthomosaic with a Ground Sample Distance (GSD) of 0.04 m/pixel, and a corresponding high-resolution Digital Elevation Model (DEM). Real-time differential corrections were streamed via the NTRIP protocol using Sicili@net (https://www.ct.ingv.it/index.php/risorse-e-servizi/sicil-net), the regional GNSS CORS network operated by the Istituto Nazionale di Geofisica e Vulcanologia (INGV – Osservatorio Etneo, Catania). This configuration guarantees centimetric absolute positioning accuracy in the WGS 84 / UTM Zone 33N projected coordinate reference system (EPSG:32633) (Fig. 4a, d).

Direct co-registration of the 1938 frames with the 2026 datum presented methodological challenges due to the restricted spatial footprint of the UAV survey (resulting from low-altitude flight requirements necessary to achieve high spatial resolution, which inherently limited regional coverage due to UAV battery endurance and flight time constraints), alongside radiometric disparities, vegetation cover evolution, and non-linear optical distortions inherent to legacy flights. Indeed, while Structure from Motion (SfM) is a proven asset for reconstructing long-term terrain evolution[47,48,49,50], producing reliable 3D models from such legacy flights requires advanced co-registration strategies and rigorous Ground Control Point (GCP) networks to mitigate these inherent limitations[51,52]. To bridge this spatial gap and eliminate systemic deformational bias, a Cascading Master-Slave Co-Registration Protocol was implemented (Fig. 4a). An intermediate historical dataset – the 1992 IGM flight (comprising 7 panchromatic frames captured on 23 X 23 cm cellulose film at ≈ 6000 m altitude with a calibrated 153.22 mm WILD camera lens) – was utilized as a spatial Master model to propagate the geodetic datum.

To optimally constrain the photogrammetric blocks, a master network of 12 sub-metric, physically invariant features were established across the epochs. Target selection was constrained by strict stationarity filters:

1. Deformational Exclusion: Points were strictly isolated outside the cumulative deformational envelopes of the 1790, 1997, and 2026 failures, localized exclusively within the stable tectonic core

of the Niscemi plateau or un-deformed bedrock outcrops.
2. Morphological Invariance: Features were restricted to cross-epoch physical invariants, encompassing structural corners and foundation basements of historical masonry edifices, and street intersections and stone boundary walls preserved in situ.

The cascading protocol was executed in two sequential hierarchical steps:

- Step 1: Master Dataset Establishment (1992): The 1992 IGM photogrammetric reconstruction was anchored directly to the 2026 UAV-RTK baseline. Georeferencing and scaling were achieved using 4 unambiguous Ground Control Points (GCPs) extracted directly from the overlapping 2026 domain (blue circle in Fig. 4a).
- Step 2: Slave Dataset Alignment (1938): Leveraging the geometrically validated 1992 Master model as a robust geodetic bridge, 9 homologous invariant features were successfully identified across the 1938 Slave block (Fig. 4a).

To ensure rigorous processing and independent statistical validation, the 9 identified points on the 1938 dataset were partitioned into two mutually exclusive subsets:

- Ground Control Points (GCPs, N_{GCP} = 6): Integrated into the Structure-from-Motion (SfM) Bundle Block Adjustment (BBA) in Agisoft Metashape Professional™ (version 2.3.0 build 21954)[53]. Because specific internal orientation (IO) metadata were omitted in the original 1938 flight records, an on-the-job camera self-calibration was executed simultaneously to solve for focal length (f), principal point offset (cx, cy), radial distortion (K1, K2, K3), and tangential distortion (P1, P2).
- Check Points (CPs, N_{CP} = 3): Deliberately excluded from the BBA optimization matrix and sequestered strictly as an unconstrained independent vali2dation set. The planimetric absolute accuracy of the final 1938 photogrammetric model was quantified by computing the Root Mean Square Error ($RMSE_{XY}$) of these CPs (red triangles in Fig. 4a):

$$RMSE_{XY(CP)} = \sqrt{\frac{1}{N_{CP}} \sum_{i=1}^{N_{CP}} \left[\left(X_{i,obs} - X_{i,ref} \right)^2 + \left(Y_{i,obs} - Y_{i,ref} \right)^2 \right]}$$

Historical Scarp Vectorization and Asymmetric Spatial Uncertainty Modeling

The optimized SfM reconstruction generated a historical Digital Elevation Model (DEM1938) characterized by a specific spatial resolution (σ_{DEM}) (Fig. 5a). To objectively extract the 1938 landslide crown and mathematically retro-project its 1790 probabilistic origin, a rigorous GIS-based morphometric protocol was implemented. To suppress high frequency altimetric noise originating from urban structures, a spatial smoothing filter utilizing a circular kernel of 15 pixels (corresponding to a ground footprint of approximately 12 m) was applied to the DEM_{1938} in QGIS (Fig. 5b). Following surface

smoothing, topographic slope gradient arrays were generated. While the theoretical critical failure angle for the local sandy-calcarenite facies is identified between 30° and 35°[54,55,56], the spatial smoothing operation redistributed peak gradients across a broader slope band. Consequently, the operational failure threshold was recalibrated to 28°, effectively isolating the continuous scarp corridor (Fig. 5c). Vectorization was executed along the upper contour segments corresponding to the primary break-of-slope; localized gaps were manually bridged following the macro-morphological rim trajectory and explicitly codified as "uncertain" (rendered as dashed vectors) within the geodatabase (Fig. 5d).

Building upon this vectorized 1938 scarp, a GIS-based spatial uncertainty model was formalized to reconstruct the probabilistic location of the original 1790 landslide crown. The model integrates two independent components: the morphodynamics of retrogressive scarp retreat over time (D_{retro}) and the intrinsic spatial uncertainty of the photogrammetric historical dataset ($\sigma_{spatial}$). The total buffer distance (D_{total}) applied to the 1938 crown line is governed by the general formulation:

$$D_{total} = D_{retro} + \sigma_{\text{spatial}}$$

Expanding both components yields an asymmetric formulation where the secular retrogressive retreat is combined with the root-sum-square (RSS) photogrammetric error:

$$D_{total} = (v \cdot \Delta t) + \sqrt{\sigma^{2}_{DEM} + RMSE^{2}_{1992\ XY(CP)} + RMSE^{2}_{1938\ XY(CP)}}$$

Within this formulation, Δt represents the elapsed temporal interval of 148 years between the initial historical failure event (1790) and the photogrammetric aerial survey (1938). The parameter defines the mean annual retrogressive retreat rate, established at 0.10 m/year. This secular benchmark is strictly grounded in empirical measurements for structurally equivalent environments characterized by a brittle caprock (calcarenite/sandstone) overlying ductile soft sediments (Plio-Pleistocene clays and marls). While active clay earthflows can exhibit short-term peak velocities of several meters per year[57,58], secular escarpment retreat in inland sedimentary plateaus operate at significantly lower rates[59]. Specifically, retreat rates for calcarenite layers over soft clay in Southern Italy systematically range between 0.08 and 0.12 m/year[60], aligning with peak long-term escarpment retreat rates of 100 mm/year (0.10 m/year) documented in comparable sandstone-capped tablelands[61]. Geomechanically, this retrogressive failure does not occur as a continuous catastrophic runout, but propagates through episodic, sequential block collapses controlled by the strain-softening behavior and 3D spatial variability of the underlying sensitive clay[62].

The term Dretro thus represents the theoretical cumulative backward displacement over this period (v ·Δt). The spatial uncertainty component (σspatial) is calculated via Root Sum Square (RSS) to rigorously propagate the cascading geometric errors, accounting for both the spatial resolution of the DEM1938 (σDEM) and the indipendent planimetric absolute errors accumulated through the Master-Slave coregistration protocol (RMSE1992XY(CP) and RMSE1938XY(CP)). These RMSE values, derived strictly from the unconstrained Check Points in Agisoft Metashape, accurately quantifies the model's exterior

orientation accuracy without statistical overfitting. Ultimately, a continuous, scientifically valid probability band for the historical position of the crown in 1790 was produced by applying the computed distance D_{total} as an asymmetric vector buffer in QGIS software (semi-transparent red envelope in Fig. 5d).

Assessing the alleged natural triggers

The effects of the January 11, 1693 Val di Noto earthquake at Niscemi were also investigated through a critical review of historical documentation, including contemporary vice-regal reports preserved at the Archivo General de Simancas (published in Guidoboni et al. 2018[63]), post-earthquake reconstruction records (published in Vullo 1997[64]), and the accounts by Boccone[65] (1697) and Mongitore[66] (1743). Particular attention was paid to documentary evidence of coseismic ground failures and other environmental effects. The primary objective of this study was to conduct a systematic critical review of the alleged seismic trigger for the 1790 landslide; a hypothesis long entrenched in the seismological tradition prior to modern macroseismic and parametric reference catalogs. To investigate the origin and propagation of this hypothesis, we cross-referenced European newspaper accounts, such as the *Gazette Nationale*[67] (Paris, June 1790) and the *Gazzetta Universale*[22] (Florence, May 1790), with the 19th-century geological treatises (Ferrara, 1810[68]; Huot, 1837[23]; Le Coq, 1839[24]; Lyell, 1839[25]; Bianconi, 1840[69]; Von Hoff, 1840[70]) and early seismological catalogs (Perrey, 1848[26]; Mercalli, 1883[27]; Baratta, 1901[28]) that subsequently formalized the interpretative error.

The historical attribution of a spurious seismic event to the 1790 Niscemi landslide was then cross-checked against current Italian macroseismic and parametric catalogs and databases. Specifically, we queried CPTI15-DBMI[71,72], CFTI5Med (Guidoboni et al 2018), and CFTIlandslides[73,]

to assess whether it was supported by the available macroseismic and earthquake-induced environmental-effect data for the Niscemi area. This validation definitively distinguished historical misunderstandings from actual physical or coseismic evidence in the Niscemi area.

Reconstructing the pre-1790 anthropogenic land-use dynamics

Finally, to quantify the long-term anthropogenic impact, a dedicated archival investigation was conducted at the State Archive of Palermo (ASP). Crucially, primary data concerning the feudal administration, land use, and territorial disputes before and after the town's foundation were extracted from Fondo Lanza di Trabia (Serie I - Carte Branciforte). The specific volumes (nn. 463–466) consulted include: n.463: “Storia scritturale dello stato e signoria della terra di Niscemi” 1535–1727. n.464: “Scrittura diversa dell’affitto dello stato di Niscemi” 1544–1723, containing primary lease contracts for individual agricultural lots; n.465: “Atti di Prospero de’ Blaschis delegato della Deputazione degli stati di Butera” 1600–1601; n.466: A composite volume containing: 1) Patronato sulla chiesa parrocchiale di Niscemi 1633–1724; 2) Atti giudiziari 1696–1824; 3) “Rollo dei censi dello stato di Niscemi” 1791 (essential for cross-referencing late 18th-century crop distributions with Landolina's post-landslide

accounts); 4) “Scritture e cautele diverse dell’università di S. Maria di Niscemi” 1628–1761. These extensive administrative, demographic, and legal documents, combined with the demographic and agricultural censuses (Riveli di beni e anime) and their attached agronomic reports, were systematically analyzed to reconstruct the timeline of deforestation, hydrographic alterations, and the massive agricultural transition preceding the landslide.

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Data Availability

All historical and archival sources analyzed in this study are cited in detail within the manuscript and are preserved in the respective public archives mentioned in the text. All processed geological and geomatic data supporting the findings of this study are included in the article.

Declarations

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Author Contribution

All authors contributed to the conceptualization of the study and data analysis. S.B., M.M., and D.M. collected and analyzed the geological and geomatic data. C.M. and P.M. conducted the archival and secondary source research and analyzed the historical data. C.C. collected and analyzed the historical seismology data and the archival sources related to the 1790 event. All authors contributed to the writing and revision of the manuscript and approved the final submitted version.

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Data Availability

All data supporting the findings of this study are available within the paper. Specifically, all processed geological and geomatic data are included in the article. Historical and archival sources analyzed in this study are cited in detail within the manuscript and are publicly preserved and available for consultation in the respective public archives mentioned in the text

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Figures

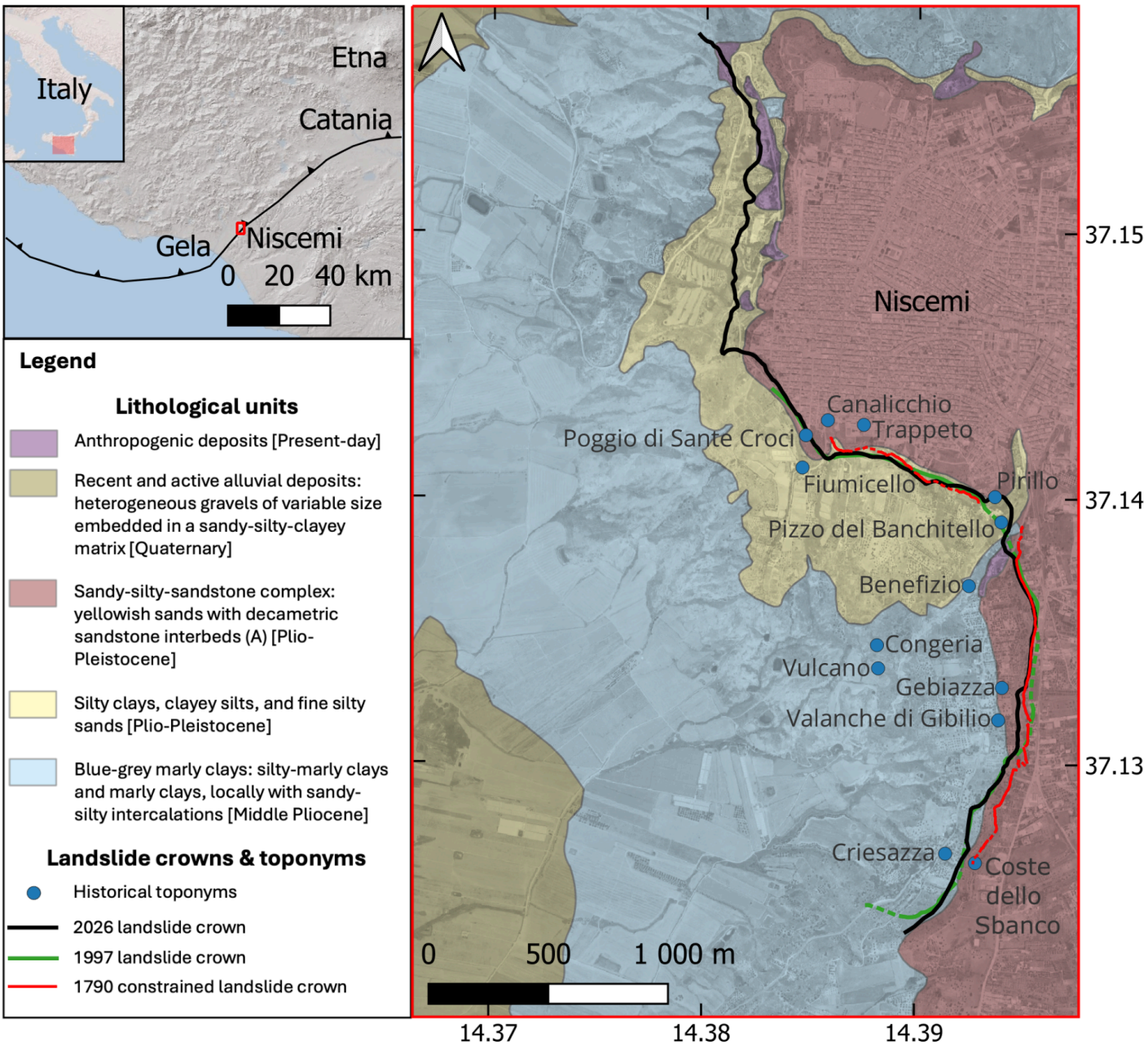

Figure 1

Regional geodynamic framework, lithology, and multi-temporal landslide evolution of the Niscemi plateau. Top-left inset: Regional tectonic setting of southeastern Sicily, highlighting the frontal thrust of the Gela Nappe and the location of Niscemi in relation to the Hyblean Foreland, the Catania plain, and Mt. Etna. Main map: Simplified lithological map of the Niscemi plateau (modified after Casagli N. et al., 2026). Superimposed vectors trace the multi-century evolutionary of the landslide system across three major paroxysms: the 1790 historical crown constrained through archival-geomatic cross-referencing (red line), the 1997 reactivation crown, and the catastrophic January 2026 failure front spanning 4.7 km (black line, derived from Casagli N. et al., 2026). Blue circles mark primary historical toponyms

documented by archival chronicles[19,20]. Geographic coordinates refer to WGS 84 (EPSG:4326 / UTM 33N).

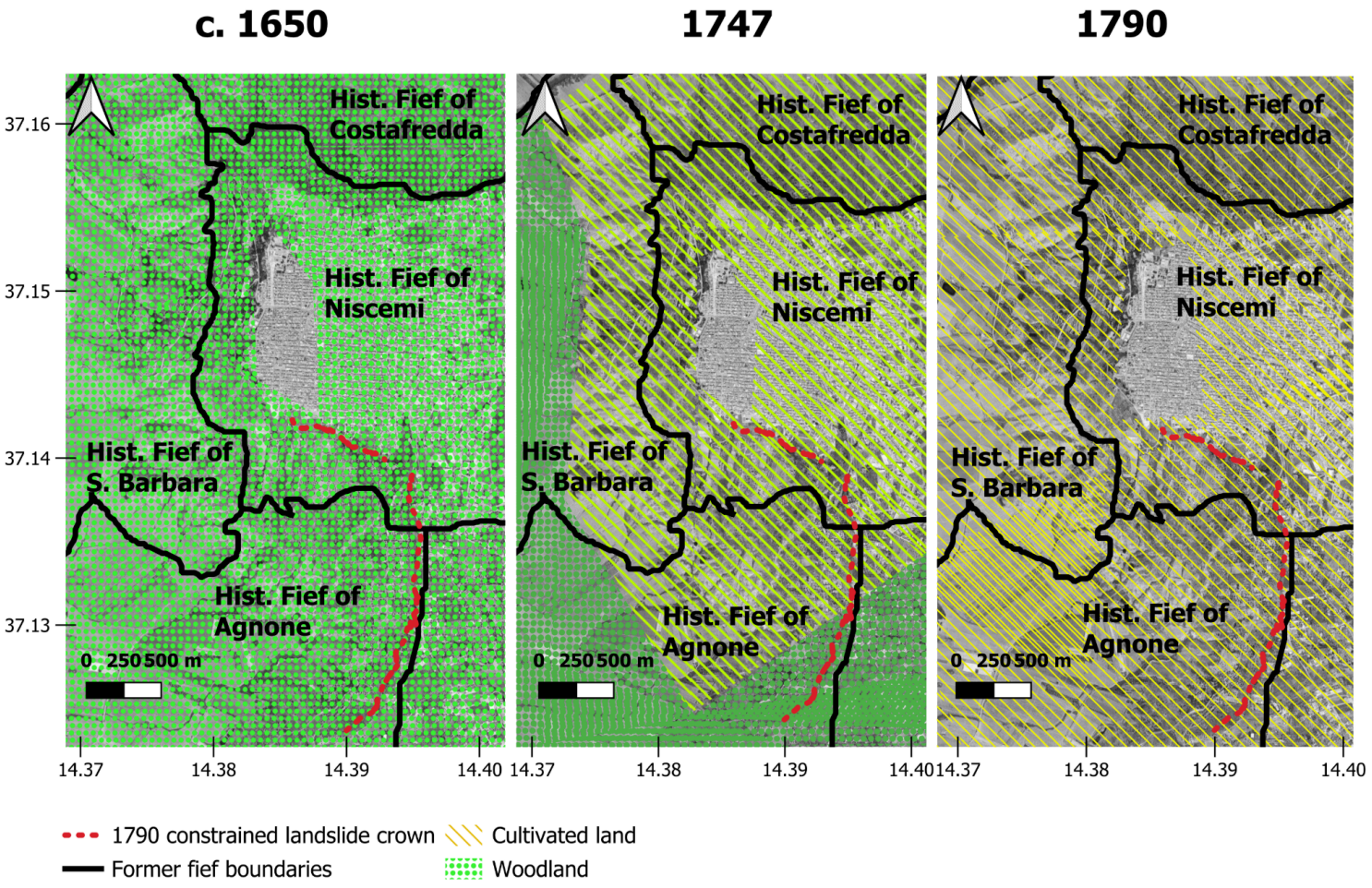

Figure 2

Deforestation and land cultivation processes in the landslide-affected area between c. 1650 and 1790

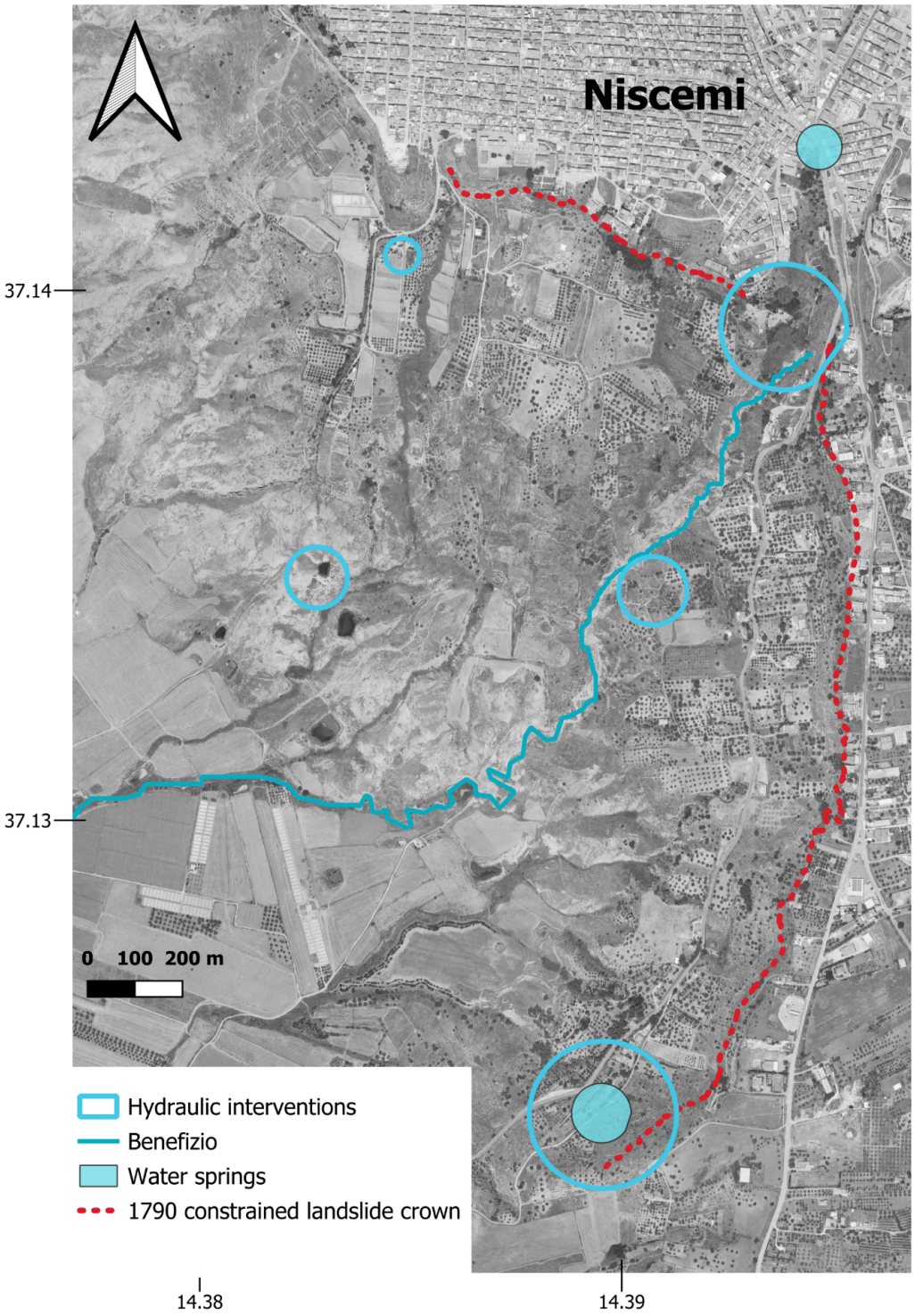

Figure 3

Distribution of water springs and pre-1790 hydraulic interventions along the Benefizio torrent, within the Niscemi landslide area

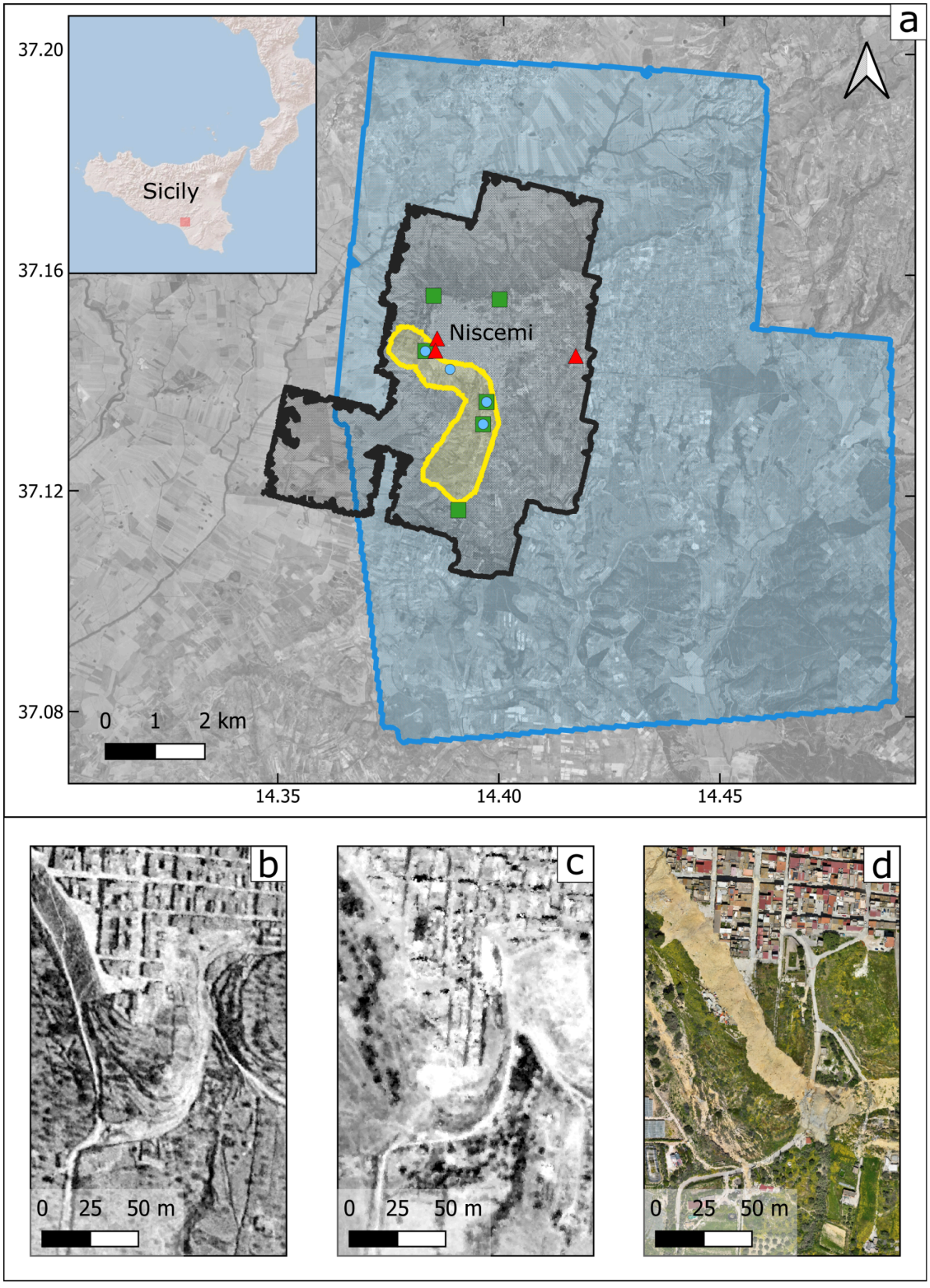

Figure 4

Cascading Master-Slave co-registration protocol and multitemporal photogrammetric baselines. a Spatial footprint of the multitemporal airborne surveys over the Niscemi plateau, showing the low-altitude 2026 UAV-RTK survey baseline (yellow footprint), the intermediate 1992 IGM Master block (blue footprint), and the 1938 IGM Slave block (black footprint). Spatial distribution of the time-invariant geodetic network illustrates the two-step hierarchical cascading alignment: unambiguous GCPs used to

anchor the 1992 Master model to the 2026 RTK datum (blue circles), homologous GCPs integrated into the 1938 Bundle Block Adjustment (green squares), and unconstrained independent Check Points used for absolute exterior accuracy validation (red triangles). b–d High-resolution detail comparison across the three epochs over a sector encompassing a portion of the urban area and the landslide body: b 1938 historical orthomosaic reconstructed from 13 X 18 glass plates; c 1992 intermediate Master orthomosaic (23 X 23 cm film); d 2026 ultra-high-resolution UAV digital orthomosaic (GSD = 0.04m/pixel).

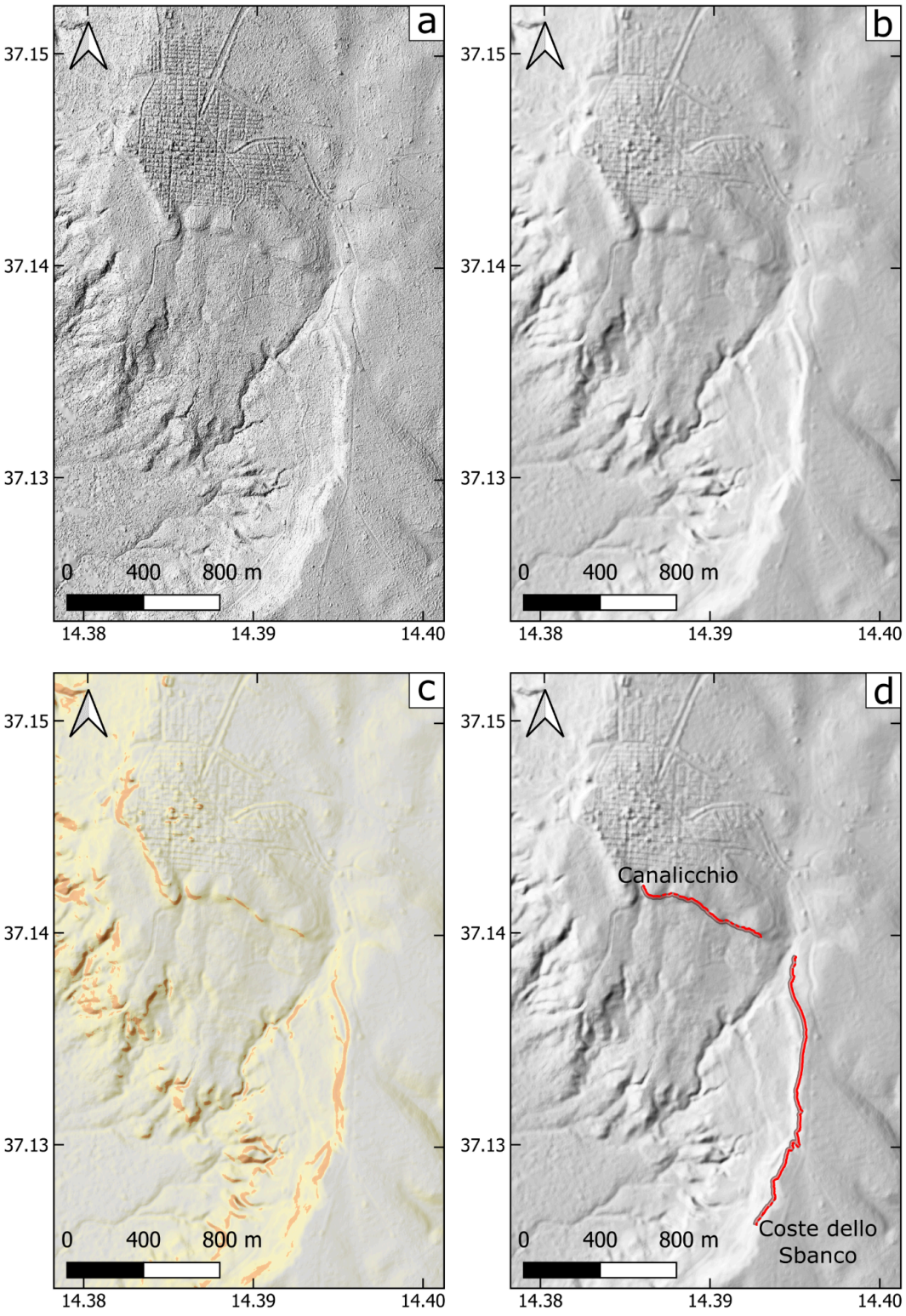

Figure 5

Morphometric scarp extraction and archival-geomatic calibration of the 1790 landslide crown. a, Shaded relief of the raw 1938 Digital Elevation Model (DEM1938) showing archival and urban altimetric noise. b, Filtered hillshade after spatial smoothing with a 15-pixel circular kernel (≈12 m ground footprint). c, Topographic slope map classified along a three-step ramp (<27.9° light gray, 27.9° yellow, ≥28° orange) isolating the operational scarp failure corridor. d, Scarp vectorization and historical anchoring. Black lines denote escarpments extracted from the morphometric threshold (solid: confident breaks-of-slope; dashed: bridged sectors). The red line marks the active 1790 crown, constrained between its historical lateral limits (Coste dello Sbanco and Canalicchio). The semi-transparent red envelope illustrates the probabilistic 1790 crown position modeled via the total uncertainty buffer (Dtotal). Scale bars are uniform across all panels.