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PRESENTATION

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GEOLOGICAL HAZARDS AND CULTURAL HERITAGE: THE 2014 SAN LEO LANDSLIDE (NORTHERN APENNINES, ITALY) AND ITS IMPLICATIONS

Ten years ago, on 27 February 2014, the town of San Leo, in the Emilia-Romagna region of Italy, experienced a tragic landslide event that captured both national and international attention. Perched atop a towering limestone cliff, San Leo is renowned not only for its impressive medieval fortress and rich cultural heritage, but also for its geologically unstable location. The landslide, which saw a significant portion of the north-eastern rocky cliff face collapse, emphasised the inherent vulnerability of communities living in spectacular yet hazardous environments.

This Special Issue aims to explore the 2014 San Leo landslide event from a broad perspective, drawing on insights from geology and engineering geology. The event was favoured by the underlying lithological and stratigraphical properties of the rock masses, which have driven the long-term evolution and instability of the local plateaus. In particular, the cumulative effects of weathering, groundwater infiltration, and flow, along with seismicity, have contributed to progressive slope weakening and failure. Understanding these processes is crucial to ensuring the future stability not only of San Leo cliffs, but also of other heritage sites exposed to similar landslide risks.

The 2014 event is not an isolated occurrence in the long history of the town. San Leo has a well-documented record of landslide activity dating back to medieval times. Its complex geological setting, as described in detail by Landuzzi et alii, featured by steep cliffs and continuous erosional processes, has predisposed the site to periodic, large-scale, rapid slope failures as part of slow-moving lateral spreading processes. Historical records reveal that landslides have affected the town and its surroundings for centuries, with earlier events significantly altering the landscape, threatening the historical monuments, and influencing the evolution of the town itself. The Marecchia Valley has also been shaped by tectonic and gravitational processes, with frequent earthquakes historically hitting the region, as reported by Zei *et alii*. These recurring episodes underscore the long-standing relationship between human settlements and the evolving natural landscape in our country as a whole. The analysis of risk mitigation measures carried out by Lucente and Doglioni in the aftermath of the 2014 event offers valuable insights into how these challenges have been addressed through engineering solutions and monitoring efforts.

The introduction of modern geotechnical modelling and monitoring technologies has significantly improved our understanding of landslide mechanisms in view of putting in place risk mitigation measures. Advanced numerical modelling techniques have also been employed to reconstruct past landslide events and predict future failures under different environmental and geological conditions. These models, coupled with historical data, can elucidate the long-term behaviour of slopes and the potential impacts of climate change on landslide frequency and intensity. Donati *et alii* offer key lessons and challenges in reconstructing the mechanics of such complex events.

The Special Issue features two innovative studies, such as Martino's work on unstable rock cliffs through vibrational behaviour analysis, demonstrating the growing importance of integrating engineering–geological and geophysical approaches to assess slope instability. These methods provide critical insights into the structural integrity of rock masses and help to identify areas prone to future failure. Similarly, Elmo's research on rock bridges and their influence on rock mechanics challenges traditional perspectives on rock stability. These studies stress the need for more nuanced approaches to evaluating rock mass stability, particularly in complex geological settings like San Leo.

In this collection of studies, we document the event and its aftermath, present detailed analyses of landslide mechanisms, risk assessment methodologies, and emergency response strategies, as well as the impact of the event on both the local community and the

cultural heritage of San Leo. The 2014 event serves as a case study showing how state-of-the-art modelling techniques and innovative monitoring technologies can be integrated into comprehensive landslide hazard mitigation strategies. Additionally, this issue delves into the broader implications of the event in terms of regional landslide monitoring, hazard mitigation, and sustainable management of at-risk historical landmarks. The findings presented here contribute to a deeper understanding of the evolving challenges faced by communities that populate geologically sensitive areas, particularly in light of climate change, which is increasing the frequency and intensity of extreme weather events in the Romagna region, as well as in other areas in Italy and beyond.

By examining the San Leo landslide through a comprehensive and interdisciplinary lens, this Special Issue highlights how historical records, cutting-edge technology, and modelling can be combined to protect cultural heritage, enhance community resilience, and inform sustainable land-use planning. The lessons learned from San Leo experience provide a roadmap for other heritage sites facing similar geological hazards, ensuring that their irreplaceable cultural assets are safeguarded for future generations.