Holocene slope instability in the Italian Dolomites: paleoclimatic significance of landslides in a European perspective

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Temporal occurrence of landslides

Several papers report landslide dates obtained through different methods and showing different chronological distributions.

In literature: chronological schemes of the Holocene showing climate changes

Correlation between landslides and climate change

Chronological schemes for different European regions

The influence of Holocene climatic changes on landslide occurrence in Europe

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Abstract: The paper deals with the role played by the occurrence of extremes in the regional rainfall on the occurrence of landslides in the Dolomites during the Holocene. Several published works dealing with the Holocene climatic changes in Europe were selected and the regional rainfall changes were identified from the available data. The study was then focused on the Dolomites, where landslides have been intensively studied and where a large amount of historical and geological data is available. The results show that the occurrence of landslides has a direct relationship with the occurrence of extremes in the regional rainfall, which was mainly influenced by the regional climate. This finding is further supported by the fact that the frequency and magnitude of landslides are higher during the Holocene than during the Pleistocene, which is in agreement with the results of other studies. The study also highlights the importance of the regional rainfall in controlling the occurrence of landslides in the Dolomites. The results of the study are relevant for the understanding of the relationship between landslides and climatic changes in Europe during the Holocene, particularly in the Italian Dolomites, where landslides are a major hazard.
Climate changes occurred since the Late-glacial have certainly influenced landslide occurrence.

**Glaciers retreat**

- **Climate**
  - **Temperature**
  - **Rainfall**

**GEOLOGICAL CONDITIONS**
- Stratigraphy (brittle dolomite rocks overlay plastic pelitic rocks)
- Tectonics (intense faulting and jointing favour seepage in depth and the formation of detachment zones and sliding surfaces)
- Neotectonics (few cases of earthquake-triggered landslides, e.g., Cinque Torri earthflow, 15 sept. 1976 – Friuli earthquake)

**MAIN LANDSLIDE CAUSES in the Dolomites**

- **Glaciations**
  - Glacio-pressure (related to Würm pleniglacial - LGM ice cap, particularly intense at the confluences of different tongues, caused rocks to deform in correspondence of structural discontinuities favouring the formation of sliding surfaces at deglaciation)
  - Permafrost melting (made rocks weaker and more water available at greater depth)

**CLIMATIC VARIATIONS**
- Temperatures (and related changes in vegetation cover and altitude)
- Rainfall (changes in annual total precipitation and precipitation pattern)

**HUMAN ACTIVITIES**
- (Early settlements = deforestation?)

**CASE STUDIES in the Dolomites**

- Reconstruction of ice cap at ca. 2300 m a.s.l.
Case Study 1: ALTA BADIA

San Leonardo (ALTA BADIA)
- Earth flow event dated to ca. 5600 cal yr BP
- Reactivated in 1997

San Cassiano (ALTA BADIA)
- Mudflow event dated to ca. 2800 cal yr BP

Passo Gardena (ALTA BADIA)
- Rockslide event dated to ca. 10,000 cal yr BP

R90-1358 surface exposure dating by cosmogenic 36Cl AMS measurement in dolomite rock from the main scarp
Age: from about 11,800 to 8,500 yr BP with erosion rates from 20 to 10 mm/ka respectively

Passo Gardena (ALTA BADIA)
- Earth flow event dated to ca. 7200 cal yr BP

24 Landslides dated in ALTA BADIA

San Cassiano (ALTA BADIA)
- Mudflow event dated to ca. 2800 cal yr BP

B-128366
Organic soil in excavation
3610 - 5475 Cal yr BP

B-128366
Trunk in excavation
2960 - 2496 Cal yr BP

B-128366
Organic soil in excavation
2960 - 2496 Cal yr BP

B-128366
Trunk in excavation
2960 - 2496 Cal yr BP
Colfosco (ALTA BADIA)
Rockfall / rock avalanche event dated to ca. 5000 cal yr BP

- B-112024
  4420 ± 70 14C yr B.P
  5030 - 4870 Cal. yr BP

Col Maladat (ALTA BADIA)
Series of rotational slide events dated to ca. 10,000 cal yr BP by way of dam-lake deposits

- B-112022 (tree trunk, -1.44 m)
  3210 ± 60 14C yr B.P
  3626 - 3272 Cal. yr BP

- B-112027 (wood, -5.4 m)
  6460 ± 90 14C yr B.P
  7563 - 7213 Cal. yr BP

Corvara (ALTA BADIA)
Series of earth flow events dated from ca. 10,000 to 2000 cal yr BP

- B-105976 (tree trunk, -6 m)
  3830 ± 60 14C yr B.P
  4417 - 3999 Cal. yr BP

- B-112032 (wood, -25.37 m)
  8820 ± 50 14C yr B.P
  10,152 - 9632 Cal. yr BP
Case Study 2: CORINA D’AMPEZZO

Col Druscié (CORINA D’AMPEZZO)

Rock slide event dated to ca. 10,000 cal yr BP

Pietrosà (CORINA D’AMPEZZO)

Rock slide event dated to ca. 12,000 cal yr BP

Lacedel (CORINA D’AMPEZZO)

Earth flow events dated from ca. 12,000 to 10,000 cal yr BP

Cortina-begontina (CORINA D’AMPEZZO)

Series of earth flow events dated from ca. 10,000 to 3000 cal yr BP
A total of 62 dates have been collected in Alta Badia and Cortina.

Are they all "climatically significant"???

The degree of "CLIMATIC SIGNIFICANCE" of each dated event has been assessed on the basis of the following aspects:

- Geomorphological context in which the dated landslide took place
- Type of dated landslide
- Size/magnitude of the dated landslides
- Material involved in the dated landslide (rock, earth, debris, ...)
- Type of dated material (wood, peat, soil, ...)
- Depth at which the dated material has been found
- Borehole stratigraphy (if dated material is from cores)

Temporal distribution of "climatically significant" landslide events in the Dolomites In Europe

From:
Can a concentration in time of landslide events indicate a climatic variation?

Yes, but not necessarily

Non-climatic causes
- Lithology
- Tectonics
- Morphology
- Hydrogeology
- Vegetation
- Land use
- Human activities
- etc.

Other uncertainty factors

WORK IN PROGRESS

A national research project has recently been founded by the Italian Ministry of Instruction, University and Research (MIUR):

COFIN 2002
Geomorphological evolution of slopes and climate changes: landslide analysis and paleoclimatic reconstructions in Northern Italy

Scientific Coordinator: Mauro Soldati

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Data collecting

Database and GIS

Archive of dated landslides in the Alps and in the Northern Apennines (in construction)
Published on the internet (http://geoserver.disat.unimib.it)

Dendrochronological Analysis

Paleobotanical Analysis

Paleoenvironmental evolution during middle Holocene: information on climate, vegetation, slope instability, snow avalanches and human activity
Future developments in the framework of “global” climate reconstructions: comparison with other environmental proxies

- Landslide event dated at 5600 cal BP nearby a Bronze Age fortified Village
- Future developments in the framework of “global” climate reconstructions: comparison with other environmental proxies
- Holocene records of the lake-level fluctuations in the Jura mountains (Magny, 1999);
- Dated Cortina and Corvara landslides events;
- Periods of enhanced landsliding in the Western Alps (Debrenne, 2002);
- Phases of glacier retreat in the Central Swiss Alps (Hormes et al., 2001);
- Holocene variations of glaciers in the Alps (Gamper and Suter, 1982);
- The PCI at GISP2 (Mayewski et al., 1997);
- The IRD events marked by Icelandic glass and hematite-stained grains (core VM 29-191, North Atlantic, Bond et al., 1997)
- Chronozones (Orombelli and Ravazzi, 1996)