Rockfall hazard mapping methodology applied to the Geological Hazard Prevention Map in Catalonia 1:25000

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1. What is the Geological Hazard Prevention Map of Catalonia 1:25000 (MPRG25M)?

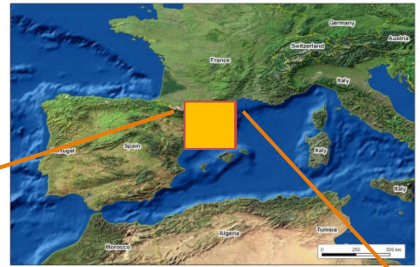
2. The methodology used for assessing the rockfall hazard in the MPRG25M.

Geological Hazard Prevention Map 1:25000

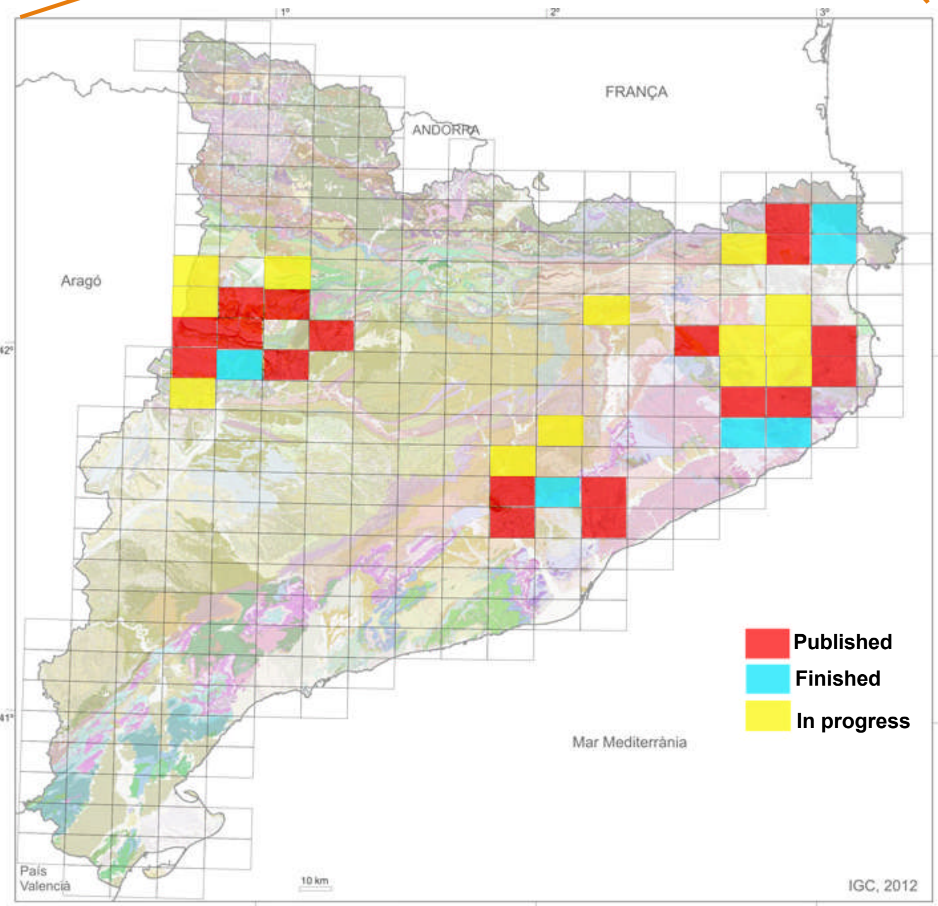
- The MPRGC is a 1:25000 scale map where terrain is zoned according to geological hazard.
- It's a multihazard map.
- The purpose of this tool is to support urban, road and infrastructure planning.
- The map identify areas where it is advisable to perform detailed studies in case of action planning.
- At the same time these information is incorporated on a database, that in the future, it will become the Geological Hazard Information System of Catalonia (SIRGC).

Geological Hazard Prevention Map 1:25000 (MPRG25M)

Area Catalonia: 31.895 km²
Nº maps = 304 (~140 km²)



- It started in 2007
- 304 sheets (18 published, 6 finished and 14 in progress)



http://www.igc.cat/

Phenomena represented on the map

- **Landslides**
  - Slope movements
    - Slides
      - Translational
      - Flows
      - Lateral spreading
      - Complex movements
    - Rockfall
      - falls
      - topples
    - Torrent flows
      - Debris flow (basin-fan relationship)
  - Sinkholes
    - Collapses
    - Subsidence
- **Snow avalanches**
- **Flooding**
- **Seismicity**

Based on Varnes (1984)

Phenomena represented on the map

Hazard matrix

- **Landslides**
  - Slope movements
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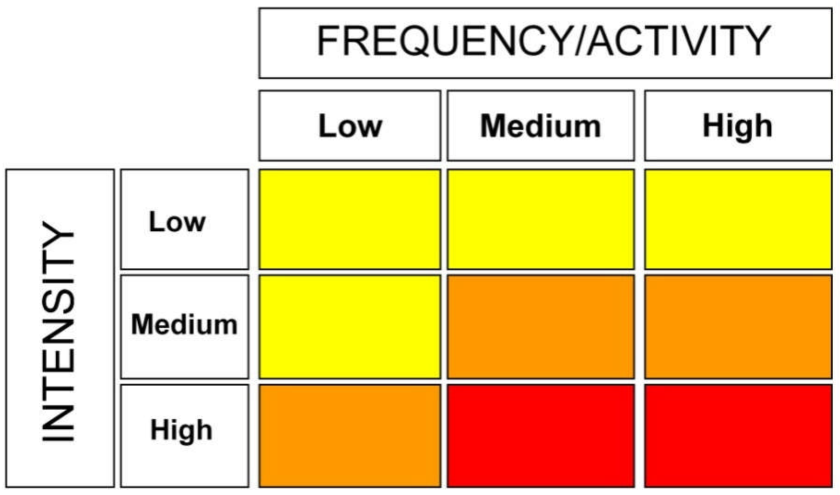
Based on Varnes (1984)

Hazard matrix

- To obtain an equivalent hazard value for each phenomena, an effort was made to match the parameters that define them.

- The same frequency/activity values were used for all phenomena, but magnitude values were adapted for each of them.

Hazard is classified in three levels using the hazard matrix



- The upper frequency boundary is 50 years, justified by the return period of the rainfalls responsible for major flooding and widespread landsliding in Catalonia, which is between 40 and 70 years (Corominas et al., 2010).

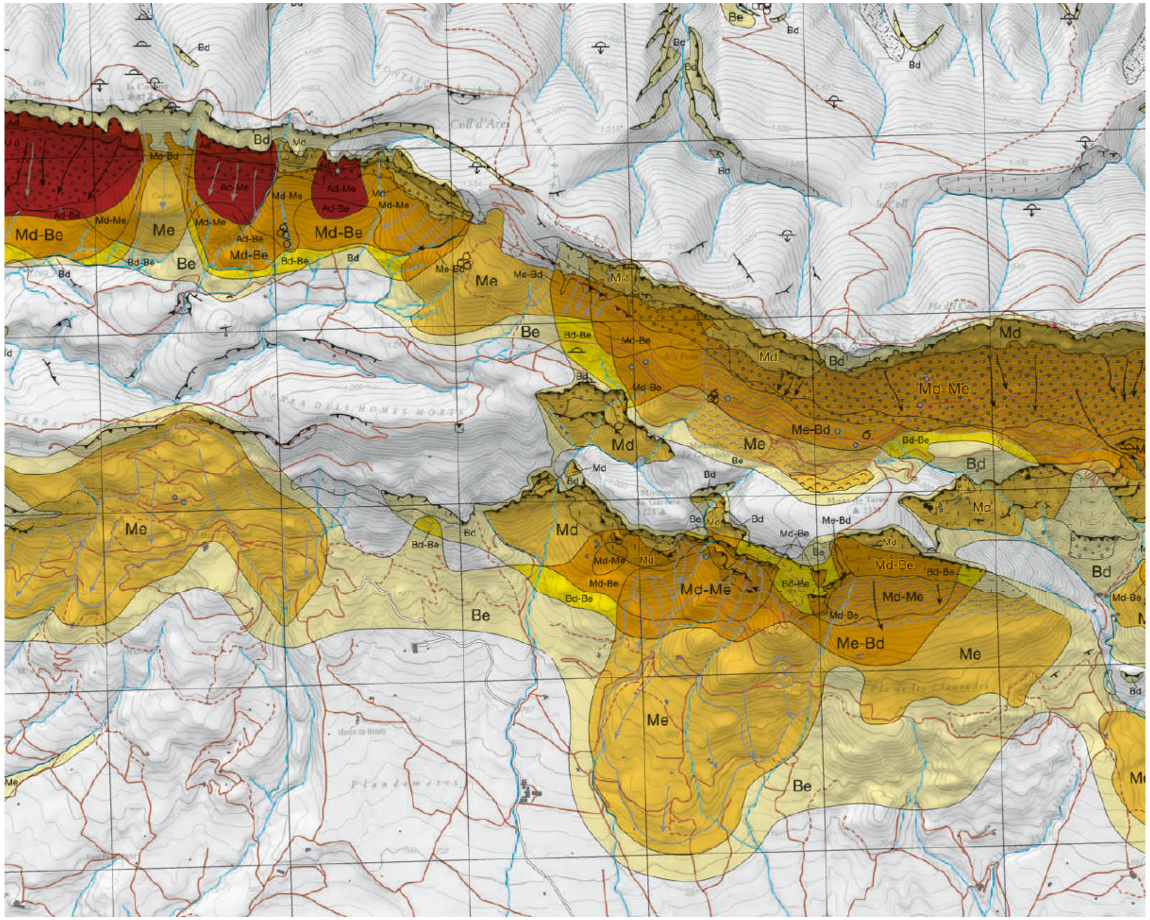
- We used a logarithmic scale to set the boundary for low frequency (return period of 500 years) because it minimizes the uncertainty in its assessment.

Geological Hazard Prevention Map 1:25000 (MPRG25M)

Hazard identification implies the recommendation of doing further detailed studies if any action is planned.

INTENSITY	FREQUENCY/ACTIVITY: Low	FREQUENCY/ACTIVITY: Medium	FREQUENCY/ACTIVITY: High
Low			
Medium			
High			

HAZARD	**PREVENTION**: **DETAILED STUDIES**	**PREVENTION**: **HAZARD MANAGEMENT**
Not observed	-----	-----
Low	**Recomendable**	**Necessary in certain cases**
Medium	**Indispensable**	**Necessary in many cases**
High	**Indispensable**	**Necessary in most of the cases**



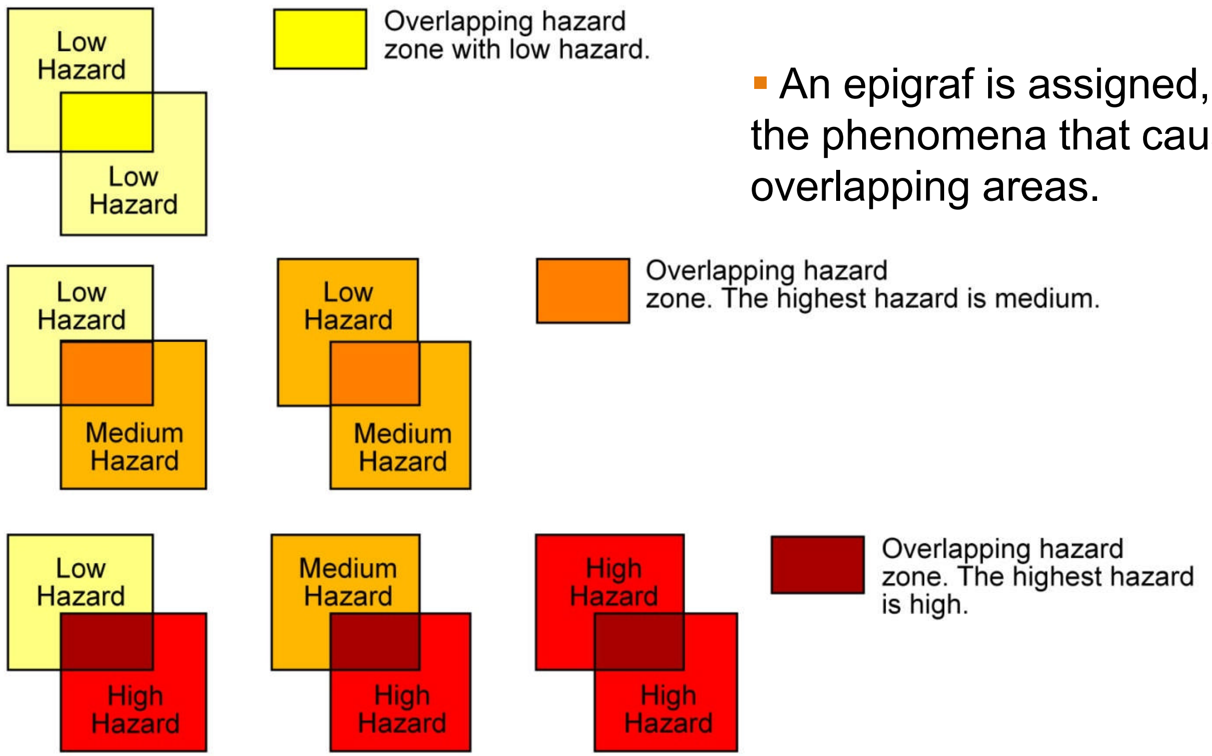
Multihazard representation

- Hazard from each phenomena is analyzed individually.

- The main challenge of the map is to easily represent the overlapping hazard of different phenomena.

The methodology allows to identify when several overlaps exist and it indicates the maximum hazard exists.

- An epigraf is assigned, to identify the hazard level and the phenomena that causes it, especially in the overlapping areas.



Multihazard representation. Hazard epigraf

This epigraf consists of two characters, the first in capital letters, indicates the **value of hazard**

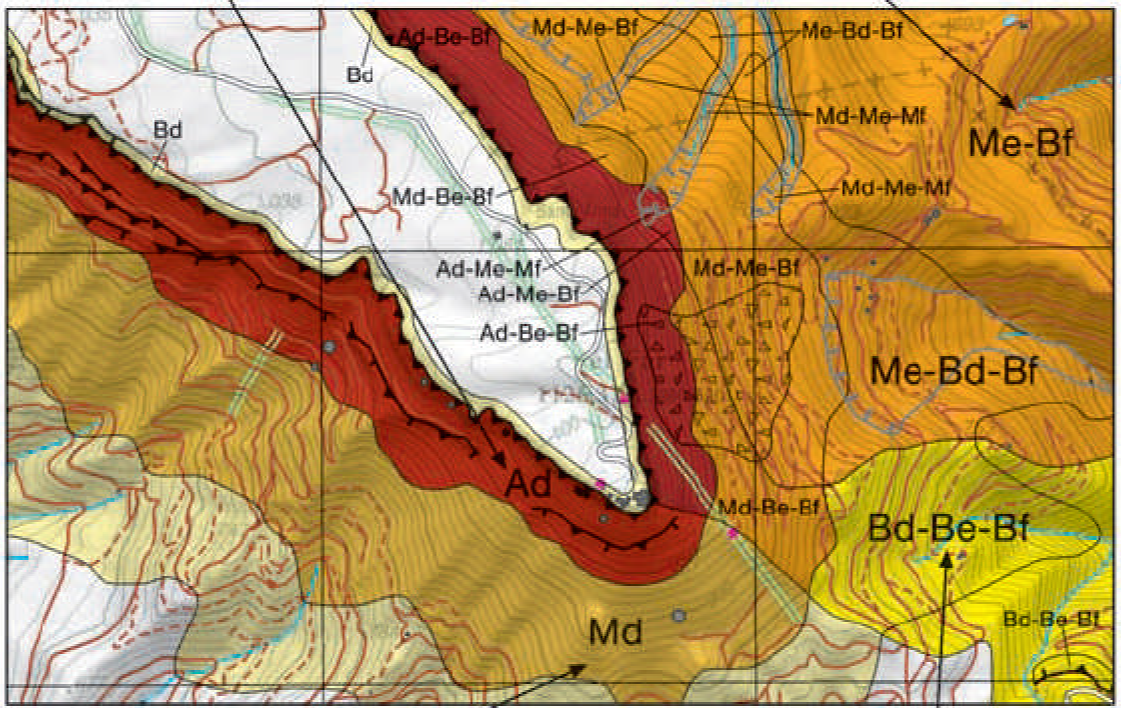
A - High hazard
M - Medium hazard
B - Low hazard

And the second, in lower-case, indicates the **type of phenomena**

e - Landslides
d - Rockfalls
f - Torrent flows
s - Sinkholes
a - Snow avalanches

High rockfall hazard (Ad)

Medium landslide hazard and low torrent flows hazard (Me - Bf)



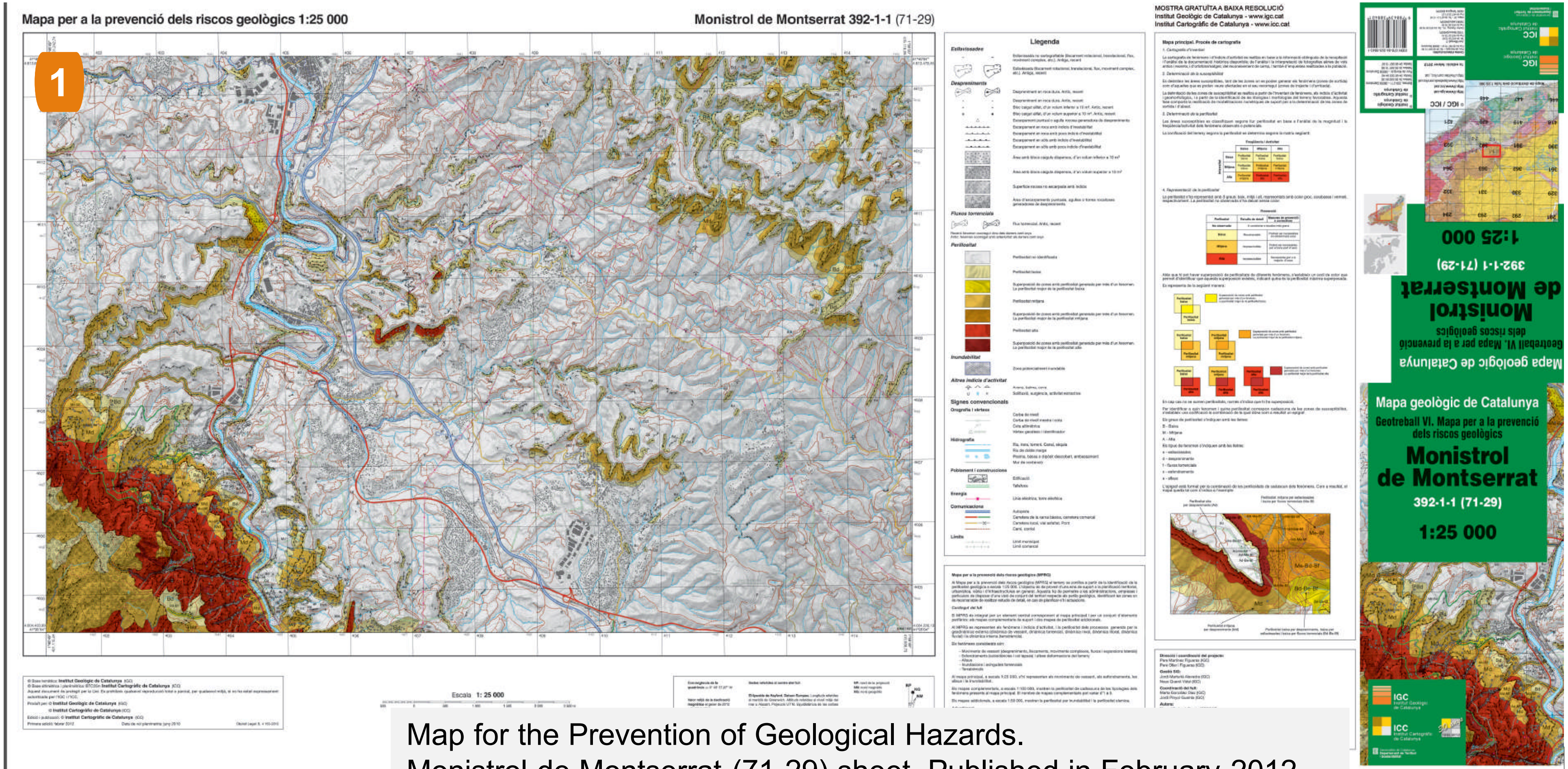
Medium rockfall hazard (Md)

Low hazard for rockfall, landslide hazard and torrent flows (Bd - Be - Bf)

Geological Hazard Prevention Map 1:25000 (MPRG25M)

1. Main map

The main map is a multihazard map, and includes landslides, snow avalanche and the geomorphological flood hazard.



Map for the Prevention of Geological Hazards.
Monistrol de Montserrat (71-29) sheet. Published in February 2012.

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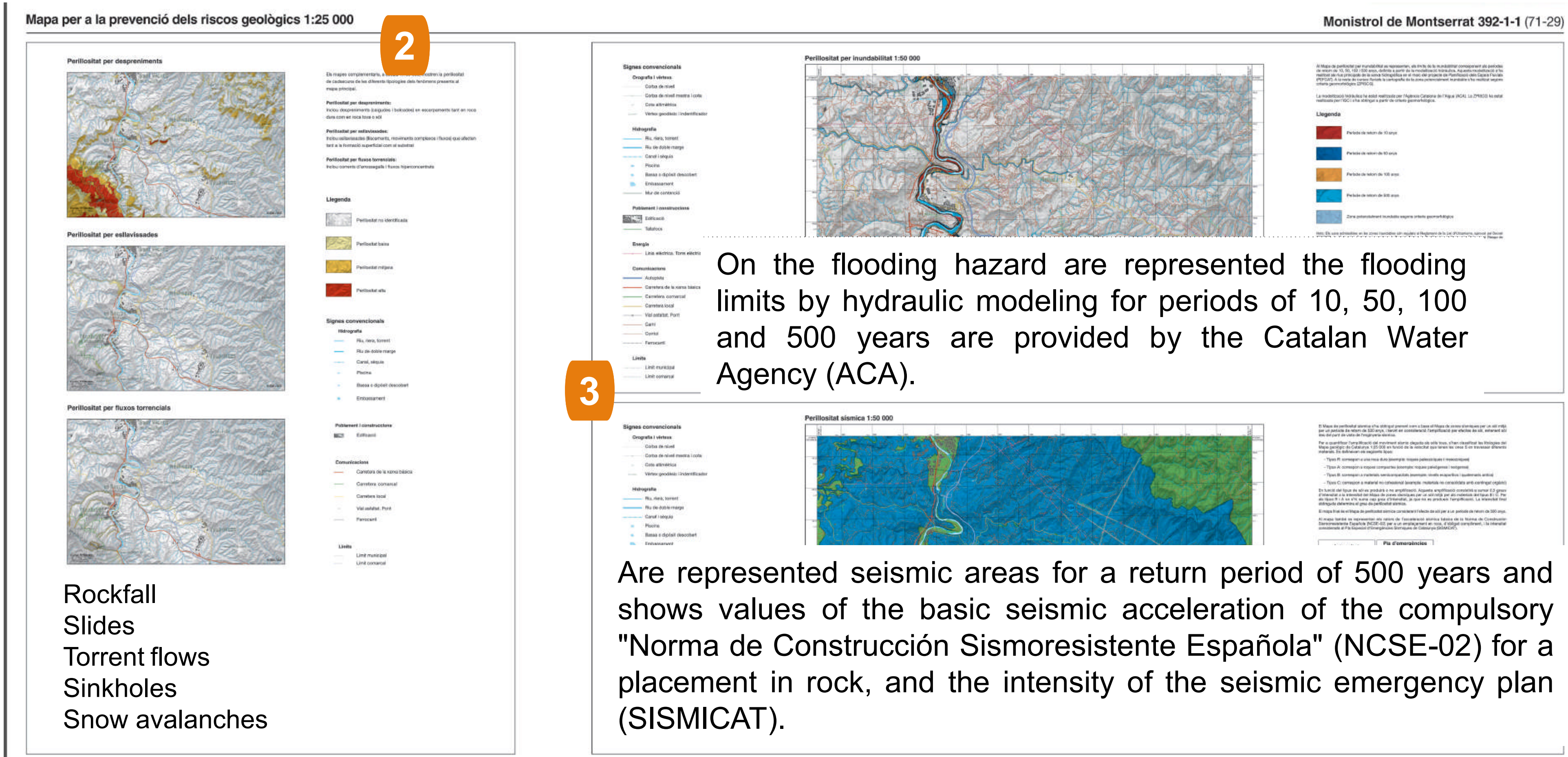
Geological Hazard Prevention Map 1:25000 (MPRG25M)

2. Complementary maps (1:100000)
Represent the hazard determined for each individual phenomena. The purpose of these maps is to facilitate the interpretation of the main map. The number of these can vary from 1 to 5.

3. Additional maps (1:50000)
The additional are maps for flooding and seismic hazards.



Rockfall
Slides
Torrent flows
Sinkholes
Snow avalanches

On the flooding hazard are represented the flooding limits by hydraulic modeling for periods of 10, 50, 100 and 500 years are provided by the Catalan Water Agency (ACA).

Are represented seismic areas for a return period of 500 years and shows values of the basic seismic acceleration of the compulsory "Norma de Construcción Sismoresistente Española" (NCSE-02) for a placement in rock, and the intensity of the seismic emergency plan (SISMICAT).

Remarks about methodology

- The methodology is adapted to the scale of work, time and economic resources assigned to this mapping plan.

- The goal is to make a systematic and uniform hazard assessment for the whole territory with the purpose of obtaining comparable results.

Rockfall hazard mapping methodology

Landslides are a very important phenomena according to their socioeconomic impact in Catalonia. We focus on rockfall because the methodology for hazard assessment has been recently improved.

- **Landslides**
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Based on Varnes (1984)

Rockfall hazard mapping methodology

The rockfall hazard methology consists in three steps:

1. **Inventory of phenomena and activity evidences**

2. **Susceptibility determination**

   - To slope failure (starting zone) and the areas that may be affected (run-out zone).

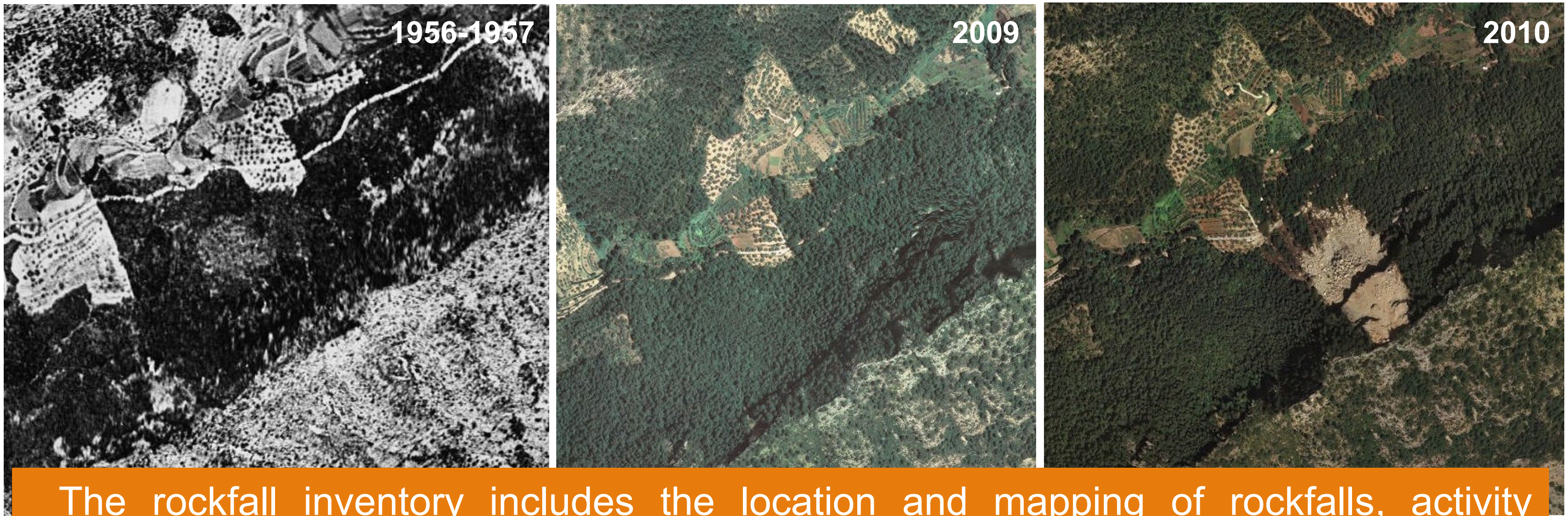
3. **Hazard Assessment**

Rockfall hazard mapping methodology. Inventory of phenomena and evidences (1:10000)

1. **The inventory of phenomena and activity evidences** is the base of the further susceptibility and hazard analysis.

The information is obtained from:

- Bibliographic and cartographic search,
- Analysis of available historical documentation,
- Photointerpretation of old and recent aerial photographs,
- Field survey, and
- Population inquiries.



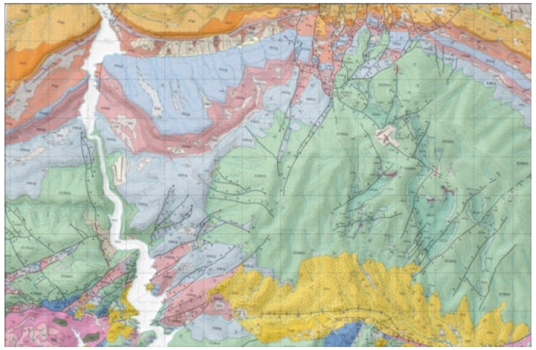
The rockfall inventory includes the location and mapping of rockfalls, activity indicators, detached volume, height of the cliff, volume of fallen blocks, favorable terrain morphologies, etc.

Rockfall hazard mapping methodology. Preliminary susceptibility (GIS Automatic /Slope& Lithology)

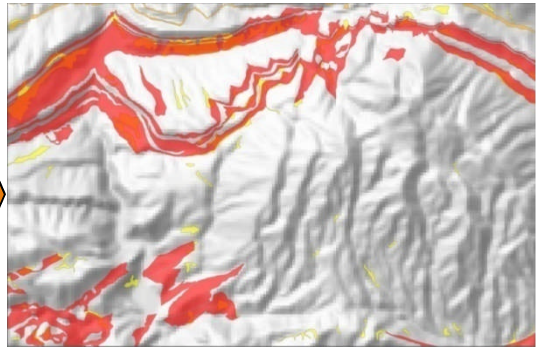
This procedure identifies the terrain susceptible to develop the phenomena.

Lithology	Terrain Slope		
	> 70º Cliff	**70-45º Rocky slope**	**45-35º**
Hard rock and unfavorable structural setting	High	High	Medium
Hard rock and favorable structural setting	Medium	Medium	Low
Alternating hard and soft rocks and favorable structural setting	High	High	Low
Soft rocks	High	High	Medium

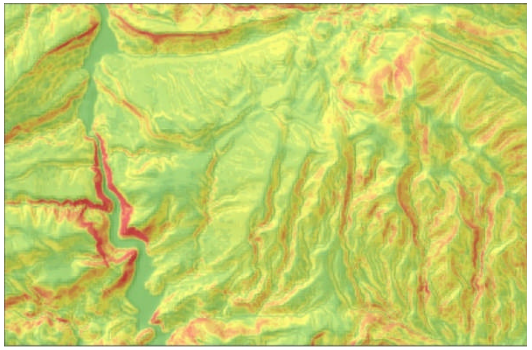
Geological map 1:25.000



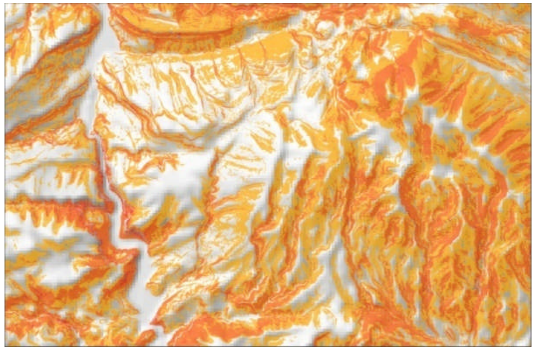
Susceptible lithologies map



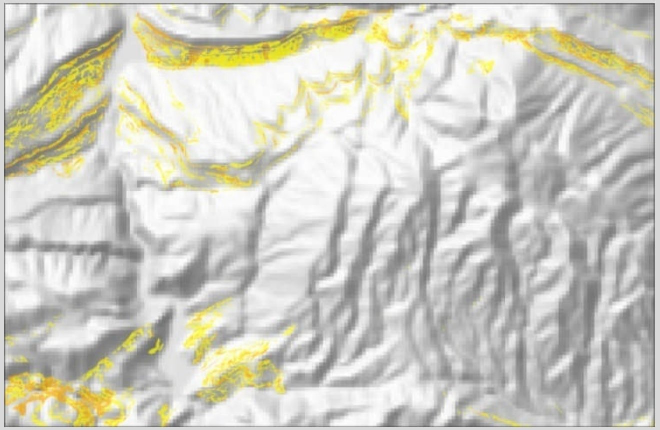
Slope inclination map (DEM 5x5 m)



Slope inclination classes map



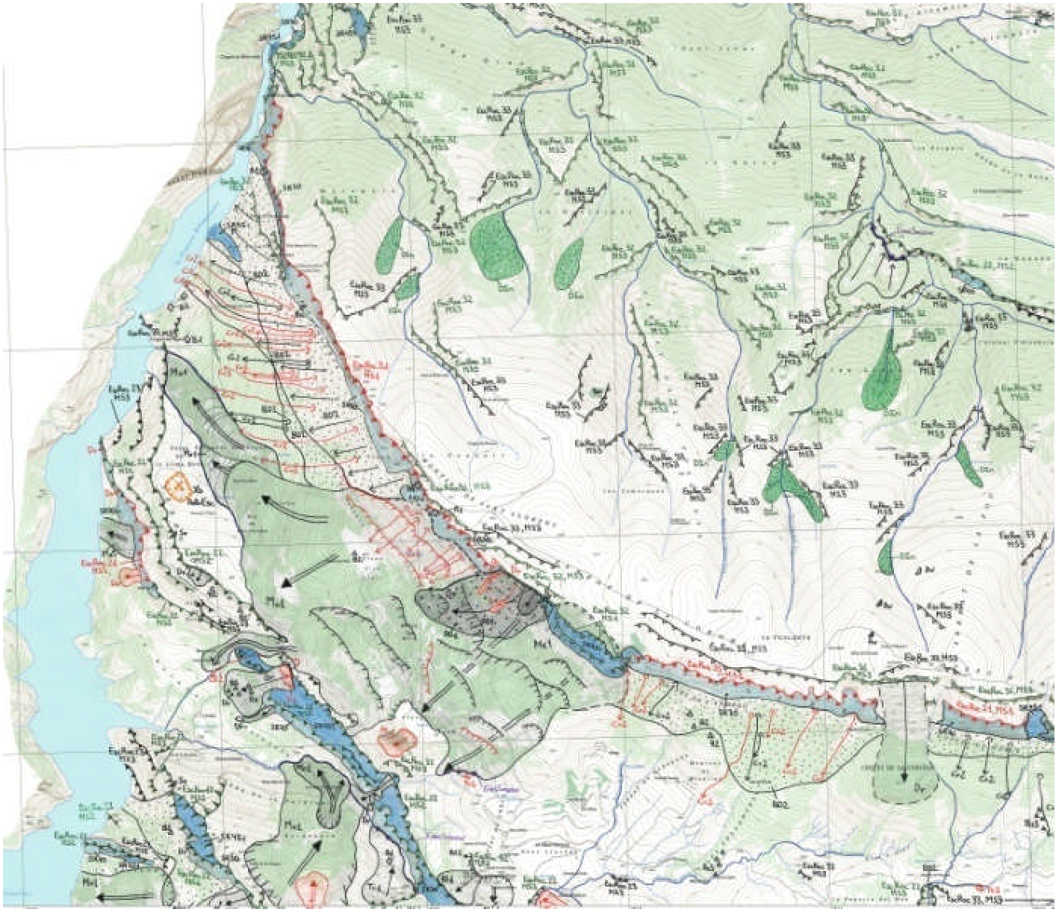
Rockfall Susceptibility Map 1:25000



Rockfall hazard mapping methodology. Final Susceptibility

To validate the susceptibility, the inventory map is compared with the preliminary susceptibility map.

- If the activity indicators evidence corroborates automatic susceptibility, it is confirmed.
- If no evidence is found, the expert validates or rejects it.
- The potentially area affected by the trajectories is defined by the reach angle .



Rockfall hazard mapping methodology. Hazard Assessment

To perform the hazard assessment is needed to determine frequency and magnitude of the starting zone, and the areas that may be affected

But for rockfalls…

The most appropriate procedure to determine the frequency and magnitude of them would be from the analysis of the recorded events.

However in most cases it is not possible to have enough data to determine return periods or representative data of output volumes.

In these cases a systematic method of field data collection has been established.

Hazard Assessment: The probability of occurrence of this characteristic rockfall (frequency)

Frequency is determined by:

(i) Recent observed rockfalls;
(ii) Density and size distribution of rockfall scars;

\- → +

Frequency	Number of rockfall recent events by length of rock face (500 meters lineal scars)	Density distribution of rockfall old scars (500 meters lineal scars)
Low	0 events/1000 m	3% old scars
Medium	0/ 500 m or (1-2)/1000 m	3-30% old scars
High	≥ (1-2)/500 m or ≥ 3/1000m	> 30% old scars

Example of frequency classes based on activity indicators for a 50 meters vertical drop rock face

Hazard Assessment: Define the volume of the largest characteristic rock block (magnitude)

Magnitude is determined by:

(i) Potential characteristic rockfall volume;
(ii) Volume of individual rock blocks observed on the slope

Rockfall volume (m^3)	Volume of individual rock blocks observed on the slope (m^3)
< 10	< 2
10-100	< 5 (2-5)
100-1000	< 50 (5-50)
> 1000	> 50

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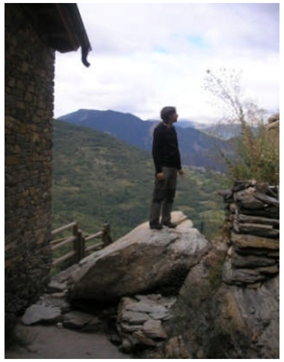
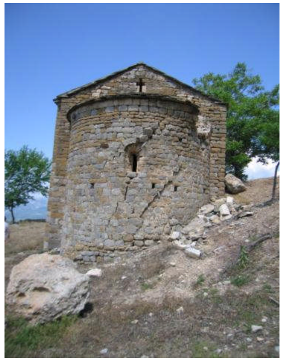
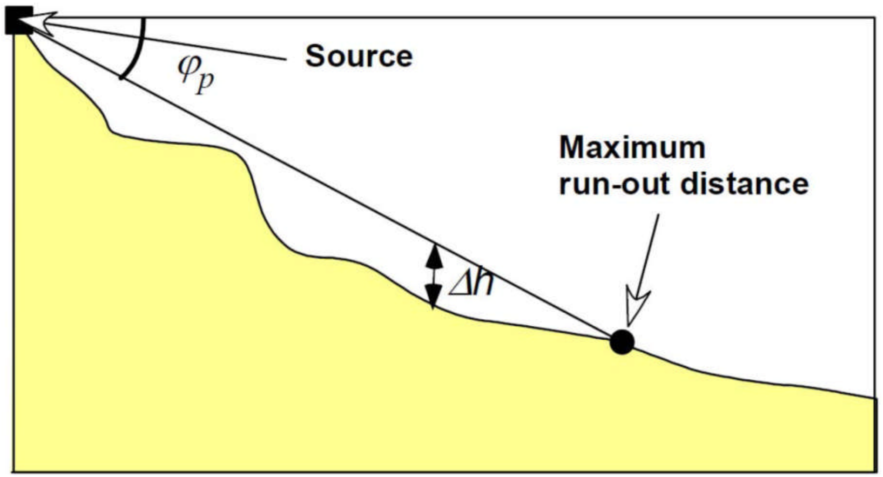



Hazard Assessment: Areas affected (run-out zone) by rockfall. Reach angle

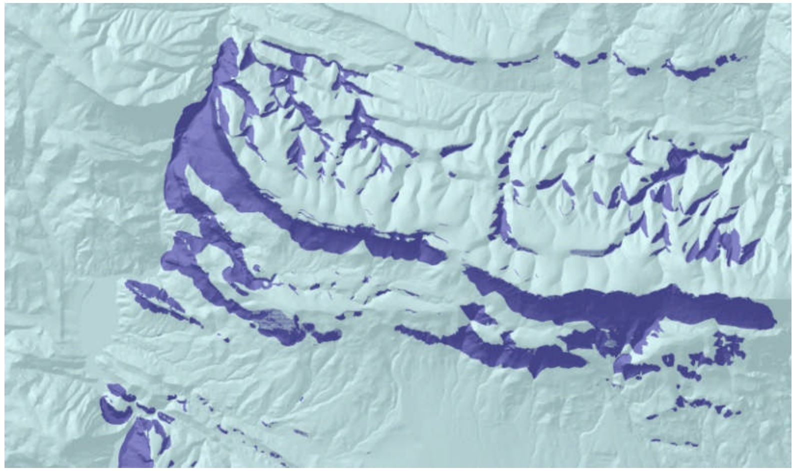
The area potentially affected by the rockfall trajectories is determined by the reach angle of the potential characteristic rockfall volume, according the criteria of the table:

Rockfall volume (m^3)	Volume of individual rock blocks observed on the slope (m^3)	Reach Angle
< 10	< 2	48 – 40º
10-100	< 5 (2-5)	40 – 33º
100-1000	< 50 (5-50)	33 – 26º
> 1000	> 50	< 26º

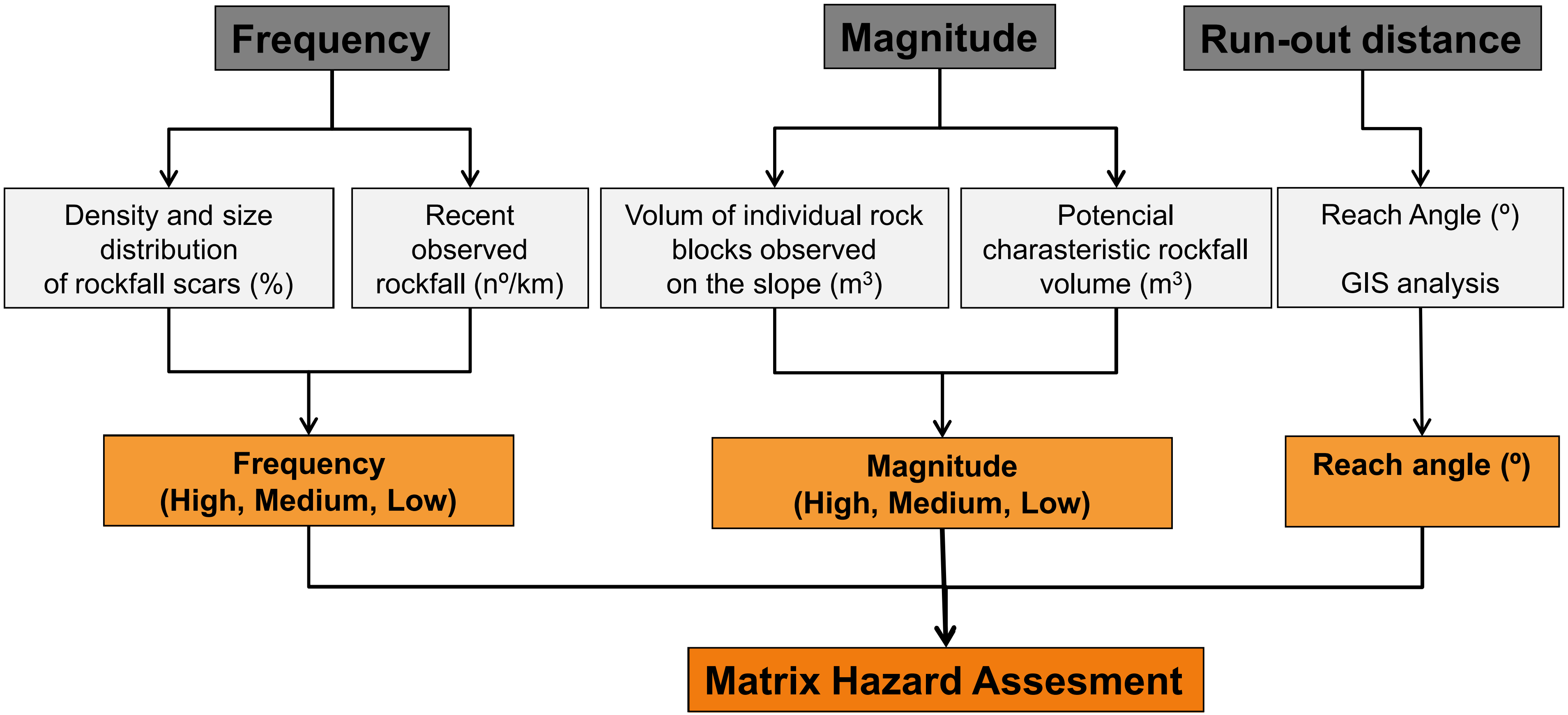
- The reach angle values proposed were obtained from a database of rockfall that occurred in Catalonia , based on direct observations (Corominas et al. 2010).



Example of the 33º reach angle



Hazard Assesment

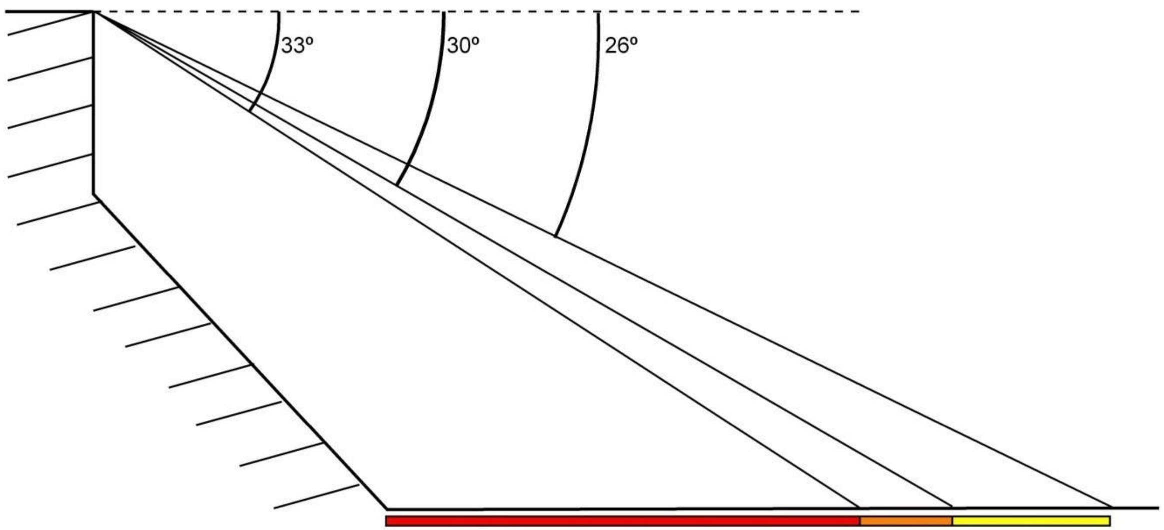


Hazard Assesment

- Example of hazard boundaries based on the **reach angle** for a 10-100 m cliff, with instability evidences and potential rockfall volumes between 100-1.000 m^3.

	90%			10%
Magnitud	High			
Angle of reach	≥33º	≥30º	≥26º	≥23º

Source areas Frequency		Frequency run-out			
	High	High	High	Medium	Low
	Medium	High	Medium	Low	Low
	Low	Medium	Medium	Low	Very Low



Despreniments < 10 m³ (blocs individuals < 2 m³)

	90%		10%
Magnitud	Baixa		
Angle d'abast	≥48°	≥40°	≥33°

Freqüència de sortida	Freqüència d'arribada		
Alta	Mitjana	Mitjana	Baixa
Mitjana	Mitjana	Baixa	Molt Baixa
Baixa	Baixa	Molt Baixa	Molt Baixa

Taula 11. Matriu de perillositat per despreniments de < 10 m³.

Despreniments 10 - 100 m³ (blocs individuals < 5 m³)

	90%		10%
Magnitud	Baixa		
Angle d'abast	≥40°	≥33°	≥30°

Freqüència de sortida	Freqüència d'arribada		
Alta	Alta	Mitjana	Baixa
Mitjana	Mitjana	Mitjana	Baixa
Baixa	Mitjana	Baixa	Molt Baixa

Taula 12. Matriu de perillositat per despreniments de 10-100 m³.

Despreniments 100- 1000 m³ (blocs individuals < 50 m³)

	90%			10%
Magnitud	Baixa			
Angle d'abast	≥33°	≥30°	≥26°	≥23°

Freqüència de sortida	Freqüència d'arribada			
Alta	Alta	Alta	Mitjana	Baixa
Mitjana	Alta	Mitjana	Baixa	Baixa
Baixa	Mitjana	Mitjana	Baixa	Molt Baixa

Taula 13. Matriu de perillositat per despreniments de 100-1000 m³.

Despreniments en massa >1000 m³ (blocs individuals > 50 m³)

	90%			10%
Magnitud	Baixa			
Angle d'abast	≥30°	≥26°	≥23°	≥21°

Freqüència de sortida	Freqüència d'arribada			
Alta	Alta	Alta	Mitjana	Baixa
Mitjana	Alta	Mitjana	Baixa	Baixa
Baixa	Mitjana	Mitjana	Baixa	Molt Baixa

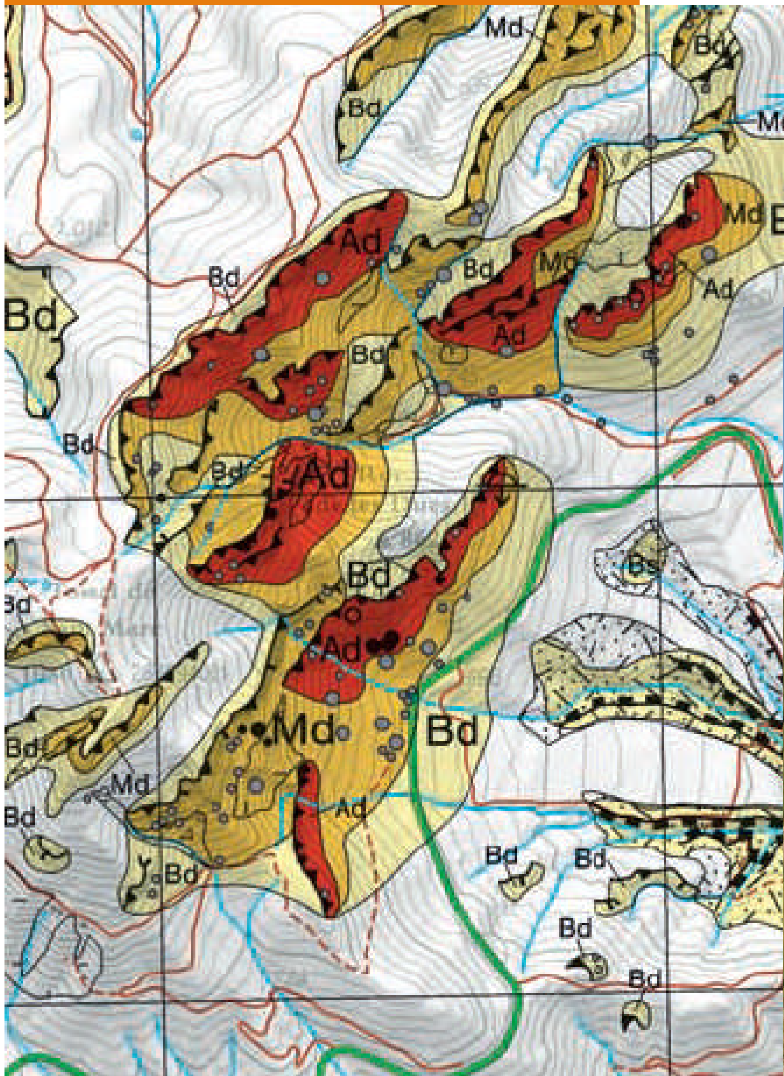
Taula 14. Matriu de perillositat per despreniments de > 1000 m³.

A la Taula 15 es mostres alguns exemples extrets de les diferents matrius en funció de l'alçada del escarpament, dels indicis d'activitat i del volum potencial de sortida.

EscRoc12 / MS1 (Vps > 100m³) Alçada: 10-100 m Molts indicis d'inestabilitat Freqüència → Alta Magnitud → Alta Perillositat → Alta Angles abast : A 30°/M 26°/B 23°	**EscRoc13 / MS3** (Vps < 10m³) Alçada: < 10 m Molts indicis d'inestabilitat Freqüència → Mitjana Magnitud → Baixa Perillositat → Mitjana Angles abast : M 48°/B 40°	**EscRoc21 / MS1** (Vps > 100m³) Alçada: > 100 m Indicis d'inestabilitat Freqüència → Alta Magnitud → Alta Perillositat → Alta Angles abast : A 30°/M 26°/B 23°
EscRoc21 / MS2 (Vps 10- 100m³) Alçada: > 100 m Indicis d'inestabilitat Freqüència → Alta Magnitud → Mitjana Perillositat → Alta Angles abast : A 40°/M 33°/B 30°	**EscRoc22 / MS1** (Vps > 100m³) Alçada: 10-100 m Indicis d'inestabilitat Freqüència → Mitjana Magnitud → Alta Perillositat → Alta Angles abast : A 33°/M 30°/B 26°	**EscRoc22 / MS2** (Vps 10- 100m³) Alçada: 10-100 m Indicis d'inestabilitat Freqüència → Mitjana Magnitud → Mitjana Perillositat → Mitjana Angles abast : M 33°/B 30°
EscRoc22 / MS3 (Vps < 10m³) Alçada: 10-100 m Indicis d'inestabilitat Freqüència → Mitjana Magnitud → Baixa Perillositat → Mitjana Angles abast : M 48°/B 40°	**EscRoc23 / MS3** (Vps < 10m³) Alçada: < 10 m Indicis d'inestabilitat Freqüència → Baixa Magnitud → Baixa Perillositat → Baixa Angles abast : B 30°	**EscRoc31 / MS1** (Vps > 100m³) Alçada: > 100 m Pocs indicis d'inestabilitat Freqüència → Mitjana Magnitud → Alta Perillositat → Mitjana Angles abast : A 33°/M 30°/B 26°
EscRoc31 / MS2 (Vps 10-100m³) Alçada: > 100 m Pocs indicis d'inestabilitat Freqüència → Mitjana Magnitud → Mitjana Perillositat → Mitjana Angles abast : M 33°/B 30°	**EscRoc32 / MS1** (Vps > 100m³) Alçada: 10-100 m Pocs indicis d'inestabilitat Freqüència → Baixa Magnitud → Alta Perillositat → Mitjana Angles abast : M 30°/B 26°	**EscRoc32 / MS3** (Vps < 10m³) Alçada: 10-100 m Pocs indicis d'inestabilitat Freqüència → Baixa Magnitud → Baixa Perillositat → Baixa Angles abast : B 48°

Taula 15. Exemples de angles d'abast per diferents escarpaments.

Peramola (67-24) Sheet. Example: Tossal de Sant Marc



Final remarks

- The target of this mapping plan is to give an overview of the territory at 1:25000 scale, with respect to geological hazards (landslides and snow avalanches) identifying areas where it is advisable to carry out detailed studies in case of urban or infrastructure planning.

- The methodology developed for determining all hazard (including rockfalls) represented on the MPRG25M, allow to obtain a homogeneous and comparable results for the whole territory.


Thank you very much
for your attention !