GEOITALIA 2009 – VII Forum Italiano di Scienze della Terra Rimini, 9 - 11 Settembre 2009
*Session B7 "Landslide forecasting"*

# Rock-fall hazard assessment in a sample area of the Sorrento Peninsula (Campania, southern Italy)

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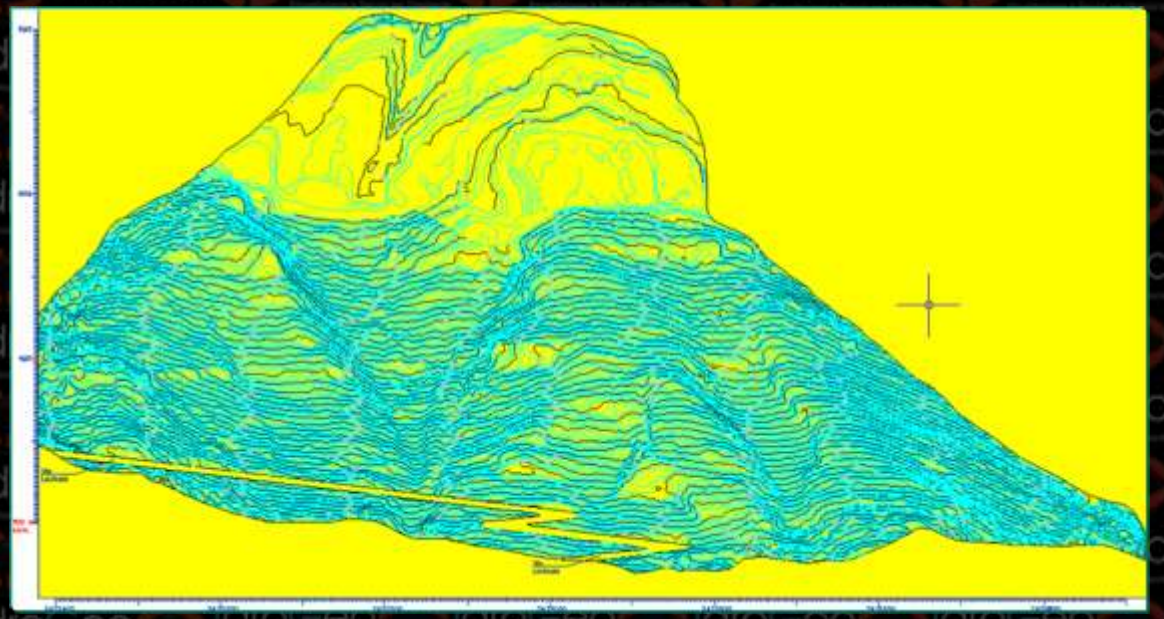
# OUTLINE

- ***Description of the study area***
- ***Structural and geomechanical analysis***
  - ✓ In situ surveys;
  - ✓ Elaboration of structural data;
  - ✓ Tests: Goodman, Markland and Matheson;
- ***Analysis of blocks trajectories***
- ***STONE***
- ***Risk mitigation***

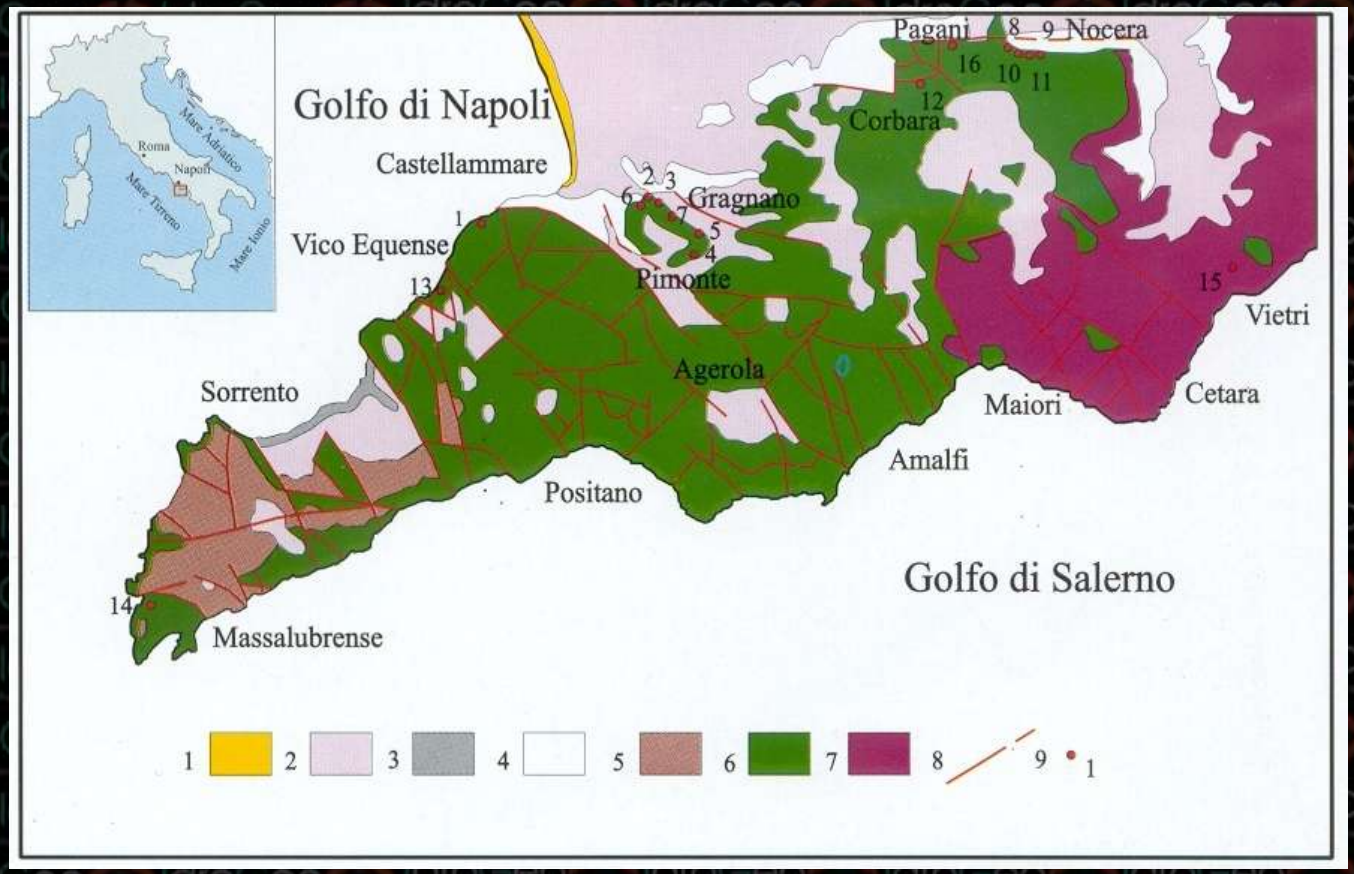
# Study area

**Sorrento Peninsula, municipality of Piano di Sorrento**

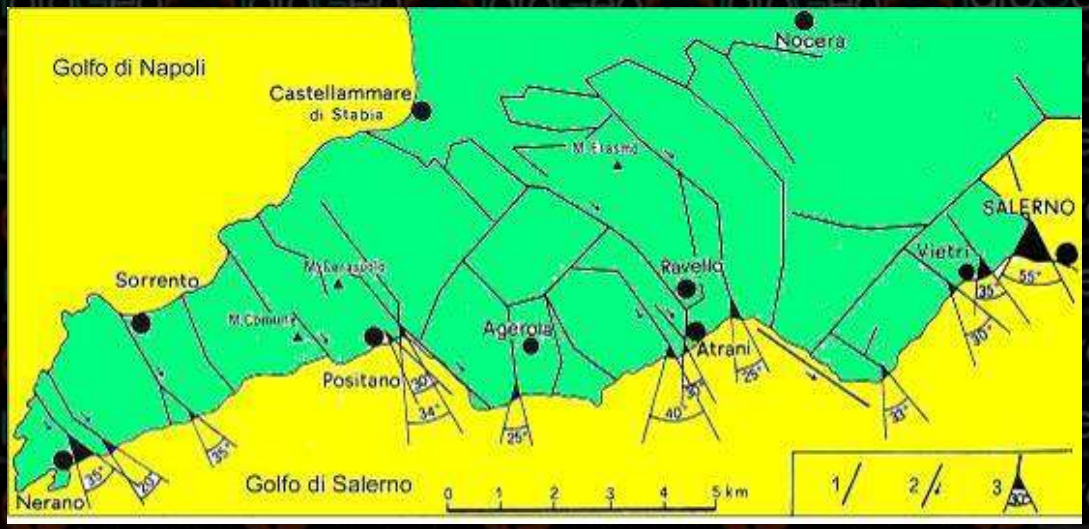




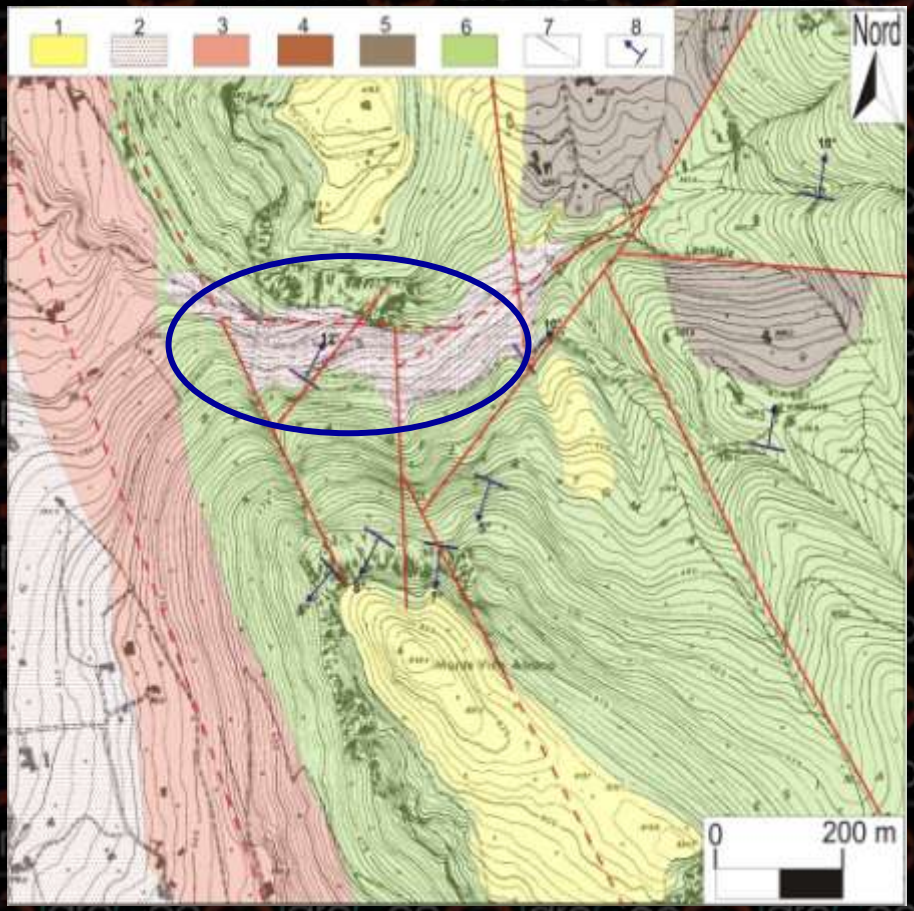
**Laser scanner survey**



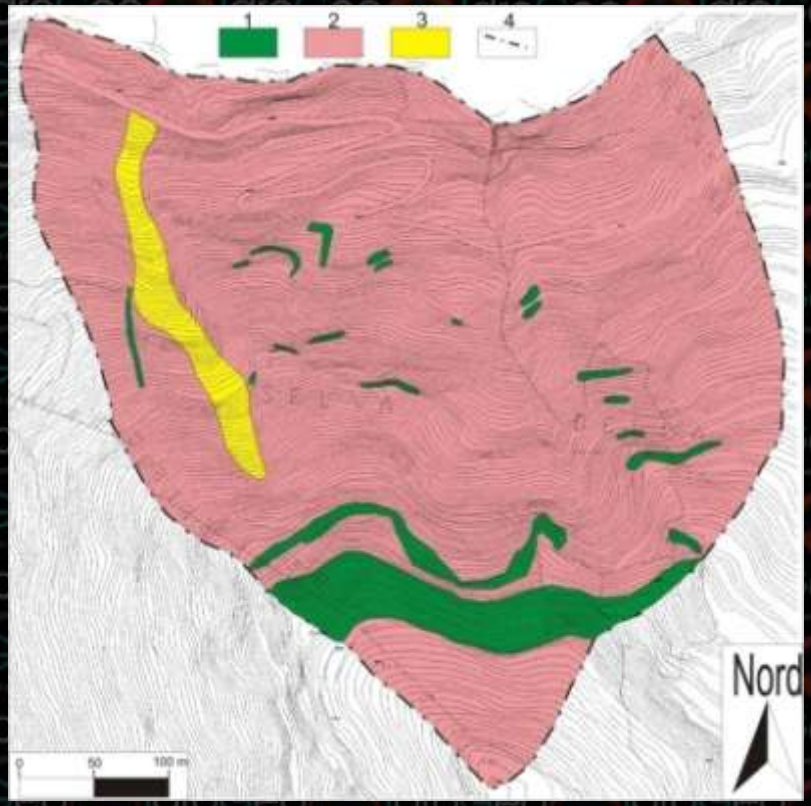

**Geologic sketch of Lattari Mountains**
(Di Crescenzo & Santo, 1999)



# Geology

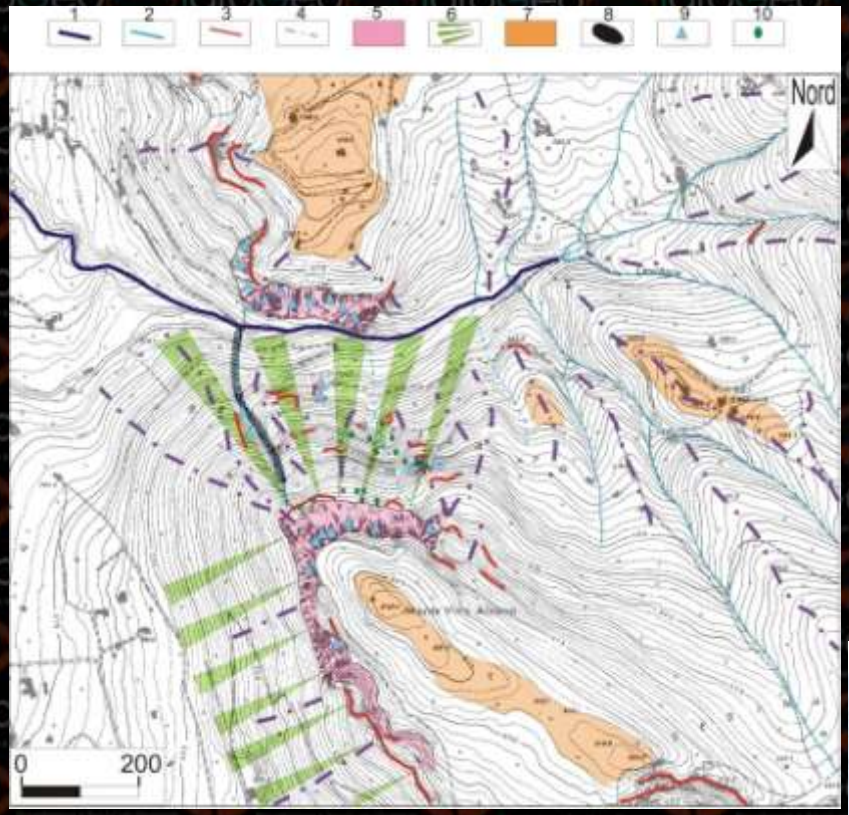



1) Fall pyroclastic deposits (Holocene-Upper Pleistocene).
2) Slope debris (Holocene-Pleistocene).
3) Conglomerates (Upper Pleistocene).
4) Marly limestones (Miocene-Oligocene).
5) Sandstones (Lower Tortonian).
6) Limestones (Upper Cretaceous).
7) Tectonic discontinuities.
8) Strata bedding.




1) CLASS A: outcrops of carbonate bedrock.
2) CLASS B: cover deposits with thickness mostly lower than 0.5 m.
3) CLASS C: cover deposits with thickness mostly in the range 0.5-2.0 m.
4) Boundary of the study area.

# Geomorphology




1) Canyon.
2) Water line, dashed when slightly incised and characterized by poor morphological evidence.
3) Edge of structural or morphological scarp.
4) Ridge.
5) *Free Face*.
6) Structural slope.
7) Paleosurface.
8) Rockfall-flow.
9) Rockfall affecting limestone rock mass.
10) Carbonate block fallen from the vertical or sub-vertical rock walls.

**Frontal view**

# Rock face investigation and surveys

# Location of measurement stations for geomechanics

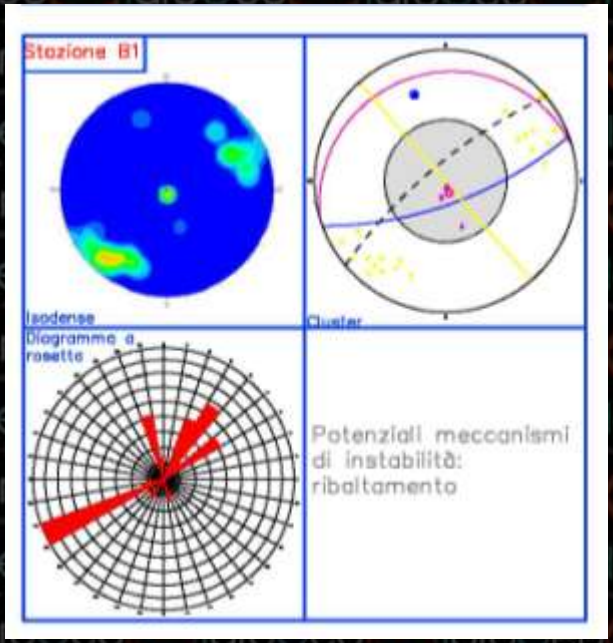
# Example of survey data sheet

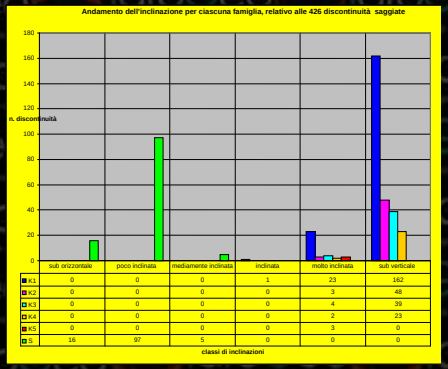
PIANO DI SORRENTO - Via Lavinola - STAZIONE ST9 orizzontale

fronte 60/80

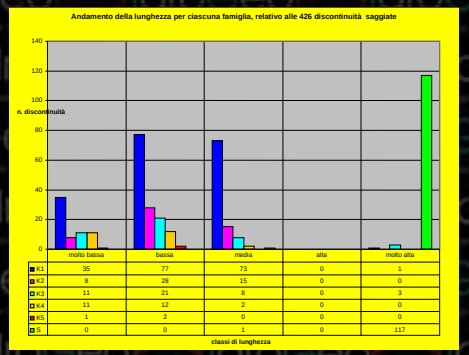
| TIPO | NUMERO | IMMERSIONE | INCLINAZIONE | LUNGHEZZA (m) | SPAZIATURA (m) | PERSISTENZA | SCABREZZA | APERTURA (mm) | FORMA | RIEMPIMENTO | H2O |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J | 1 | 155 | 85 | 0,4 | 0 | J/R | 4 | 50 | P | S | W1 |
| J | 2 | 120 | 85 | 1,8 | 1,1 | X/X | 4 | 50 | S | S | W1 |
| J | 3 | 120 | 80 | 0,7 | 2 | R/J | 4 | 3 | SLU | A | W1 |
| J | 4 | 150 | 85 | 0,5 | 2,1 | X/X | 4 | 100 | S | S | W1 |
| J | 5 | 50 | 84 | 0,5 | 2,55 | J/X | 3 | 5 | P | S | W1 |
| J | 6 | 305 | 80 | 0,1 | 2,95 | R/X | 3 | 30 | P | A | W1 |
| J | 7 | 320 | 80 | 0,1 | 3 | R/R | 3 | 1 | P | A | W1 |
| J | 8 | 315 | 80 | 0,1 | 3,18 | J/R | 5 | 1 | STU | S | W1 |
| J | 9 | 310 | 80 | 1,5 | 3,75 | X/X | 3 | 200 | SLU | S | W1 |
| J | 10 | 40 | 75 | 1,5 | 4,05 | X/X | 5 | 5 | SLU | S | W1 |
| J | 11 | 130 | 85 | 0,05 | 5,21 | R/R | 3 | 2 | P | A | W1 |
| J | 12 | 320 | 65 | 1,8 | 5,7 | X/X | 5 | 200 | S | S | W2 |

# Geomechanical data processing

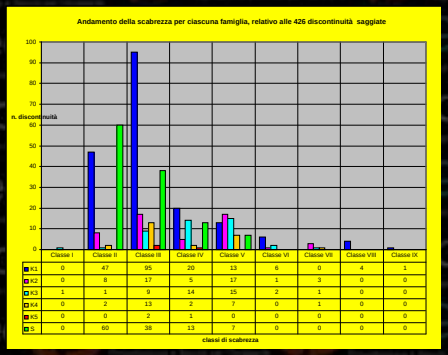


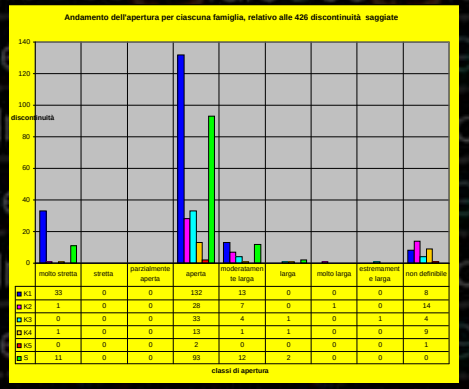

| | sub orizzontale | poco inclinata | mediamente inclinata | inclinata | molto inclinata | sub verticale |
|---|---|---|---|---|---|---|
| K1 | 0 | 0 | 0 | 1 | 23 | 162 |
| K2 | 0 | 0 | 0 | 0 | 3 | 48 |
| K3 | 0 | 0 | 0 | 0 | 4 | 39 |
| K4 | 0 | 0 | 0 | 0 | 2 | 23 |
| K5 | 0 | 0 | 0 | 0 | 3 | 0 |
| S | 16 | 97 | 5 | 0 | 0 | 0 |




| | molto bassa | bassa | media | alta | molto alta |
|---|---|---|---|---|---|
| K1 | 35 | 77 | 73 | 0 | 1 |
| K2 | 8 | 28 | 15 | 0 | 0 |
| K3 | 11 | 21 | 8 | 0 | 3 |
| K4 | 11 | 12 | 2 | 0 | 0 |
| K5 | 1 | 2 | 0 | 0 | 0 |
| S | 0 | 0 | 1 | 0 | 117 |



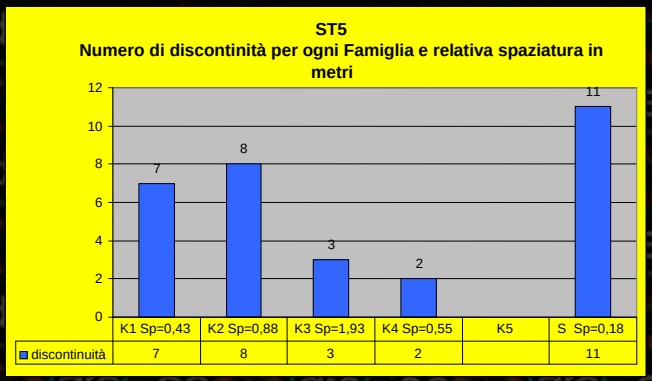

| | Classe I | Classe II | Classe III | Classe IV | Classe V | Classe VI | Classe VII | Classe VIII | Classe IX |
|---|---|---|---|---|---|---|---|---|---|
| K1 | 0 | 47 | 95 | 20 | 13 | 6 | 0 | 4 | 1 |
| K2 | 0 | 8 | 17 | 5 | 17 | 1 | 3 | 0 | 0 |
| K3 | 1 | 1 | 9 | 14 | 15 | 2 | 1 | 0 | 0 |
| K4 | 0 | 2 | 13 | 2 | 7 | 0 | 1 | 0 | 0 |
| K5 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| S | 0 | 60 | 38 | 13 | 7 | 0 | 0 | 0 | 0 |




| | molto stretta | stretta | parzialmente aperta | aperta | moderatamente larga | larga | molto larga | estremamente larga | non definibile |
|---|---|---|---|---|---|---|---|---|---|
| K1 | 33 | 0 | 0 | 132 | 13 | 0 | 0 | 0 | 8 |
| K2 | 1 | 0 | 0 | 28 | 7 | 0 | 1 | 0 | 14 |
| K3 | 0 | 0 | 0 | 33 | 4 | 1 | 0 | 1 | 4 |
| K4 | 1 | 0 | 0 | 13 | 1 | 1 | 0 | 0 | 9 |
| K5 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 |
| S | 11 | 0 | 0 | 93 | 12 | 2 | 0 | 0 | 0 |

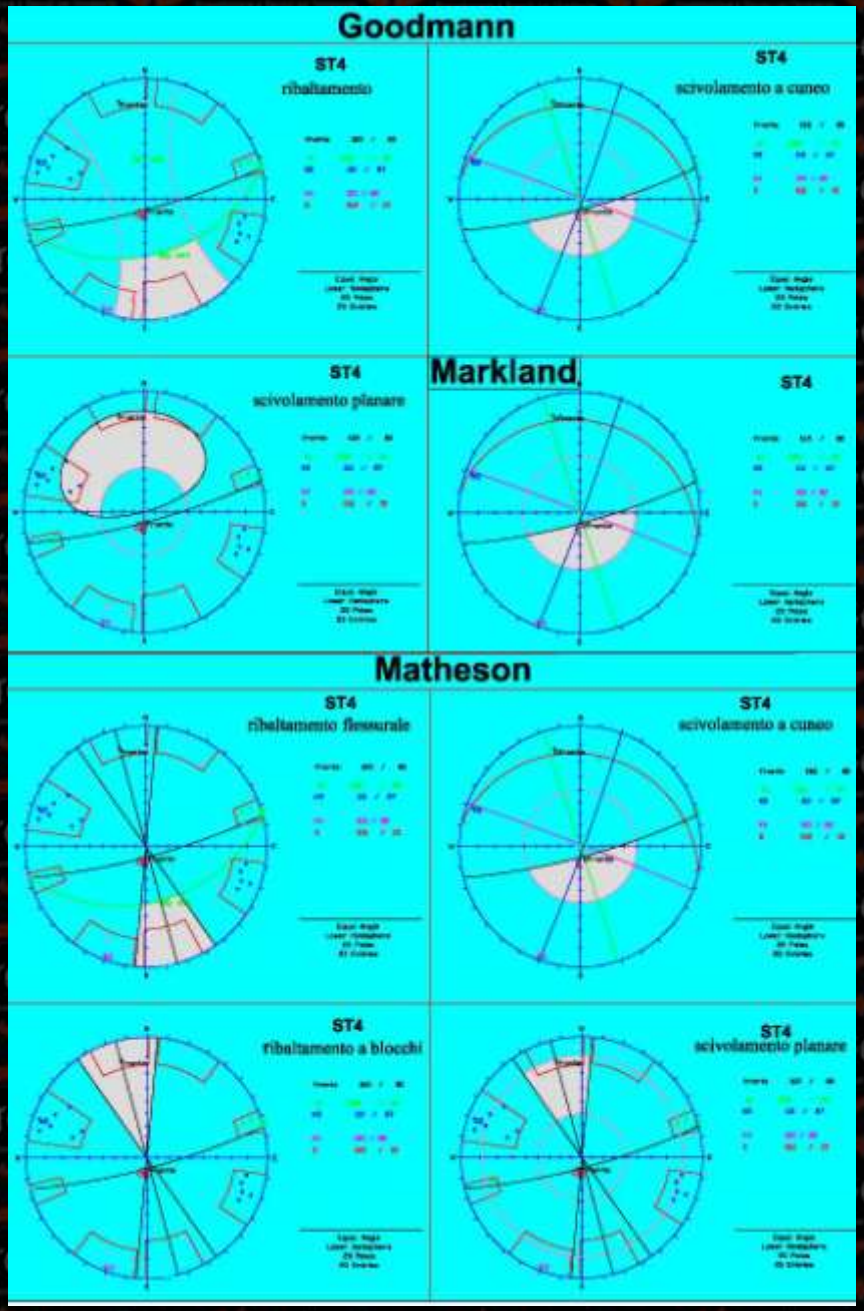
| ORIENTAZIONE MEDIA | | |
|---|---|---|
| FAMIGLIA | IMMERSIONE | INCLINAZIONE |
| STRATI S | N 195° | 5° |
| K1 | N 209° | 81° |
| K2 | N322° | 87° |
| K3 | N 65° | 82° |
| K4 | N 161° | 76° |
| K5 | N 39° | 74° |
| K6 | N 287° | 89° |

The field surveys pointed out to the presence of 6 *families* of discontinuities (in addition to strata bedding).



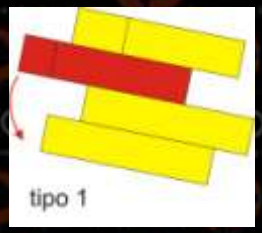
Orientation of the many rock faces, combined with the discontinuities in the rock mass, control the detachment of rock blocks and slabs, up to some cubic metres in volume. Maximum value calculated "volume of the project" 4.6 mc (ST 5)



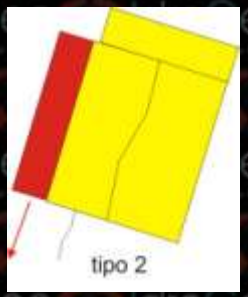



Kinematics evaluation according to the tests of Goodman, Markland and Matheson

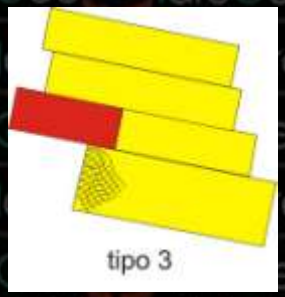
# Mechanisms of failure




Flexural instability (*type 1*)



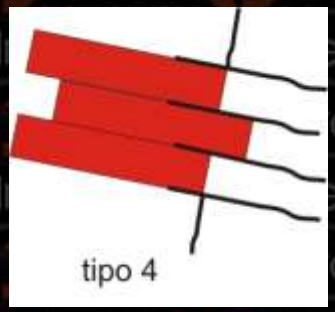

Failure due to shear of unsupported rock (*type 2*)

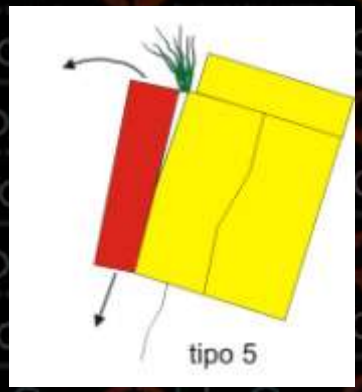



Flexural instability combined to presence of sub-vertical joints (*type 3*)

# Mechanisms of failure

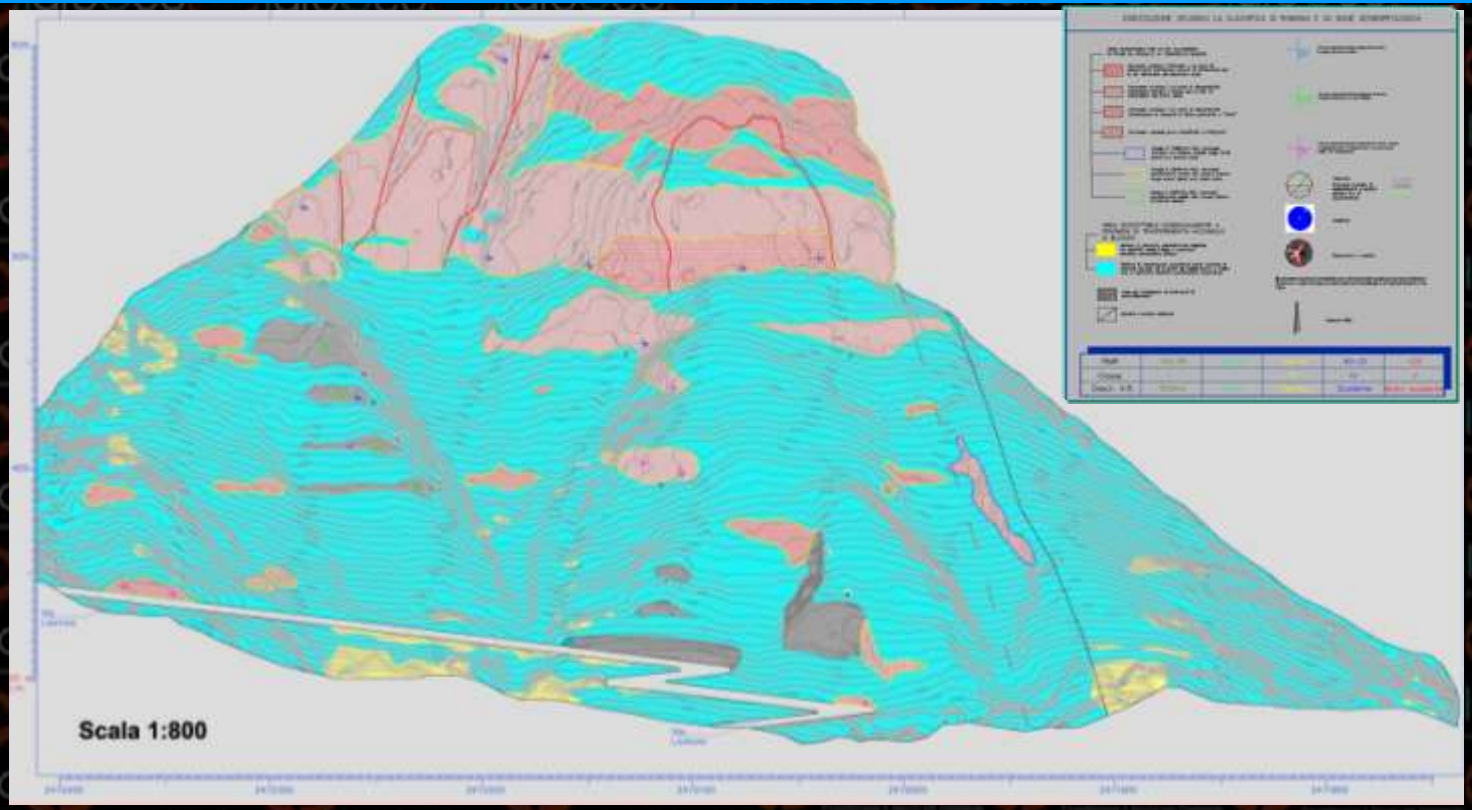
Interaction among rock slabs
(*type 4*)

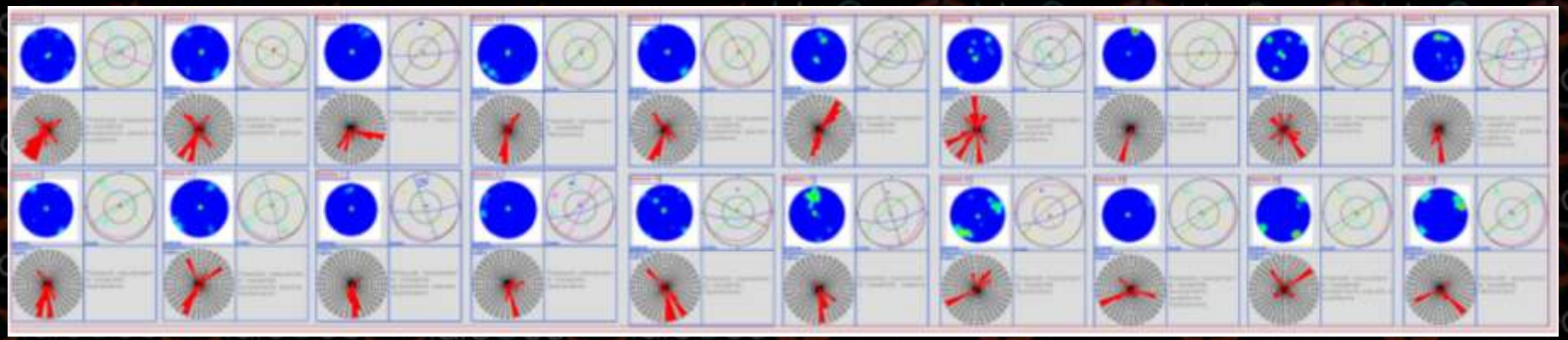


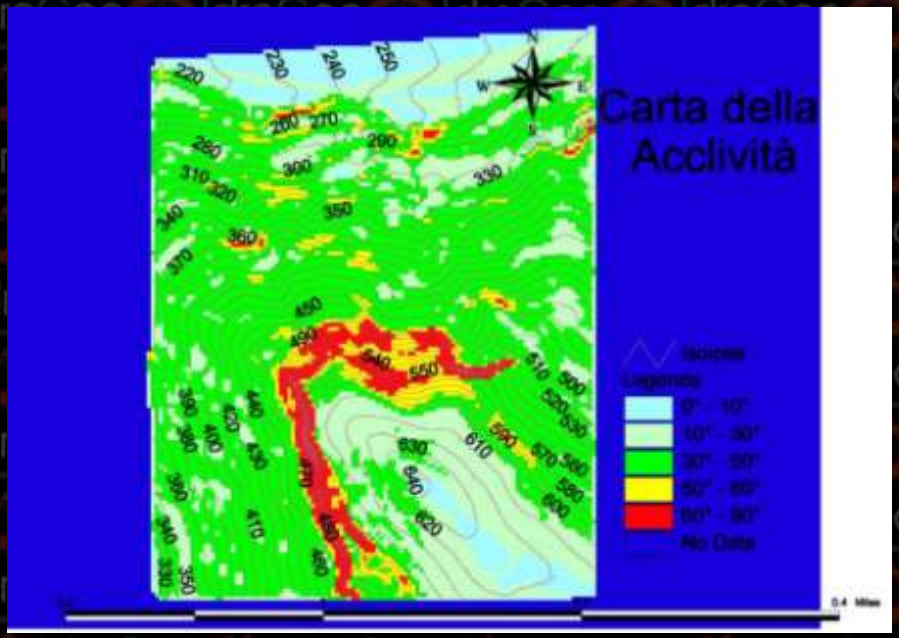



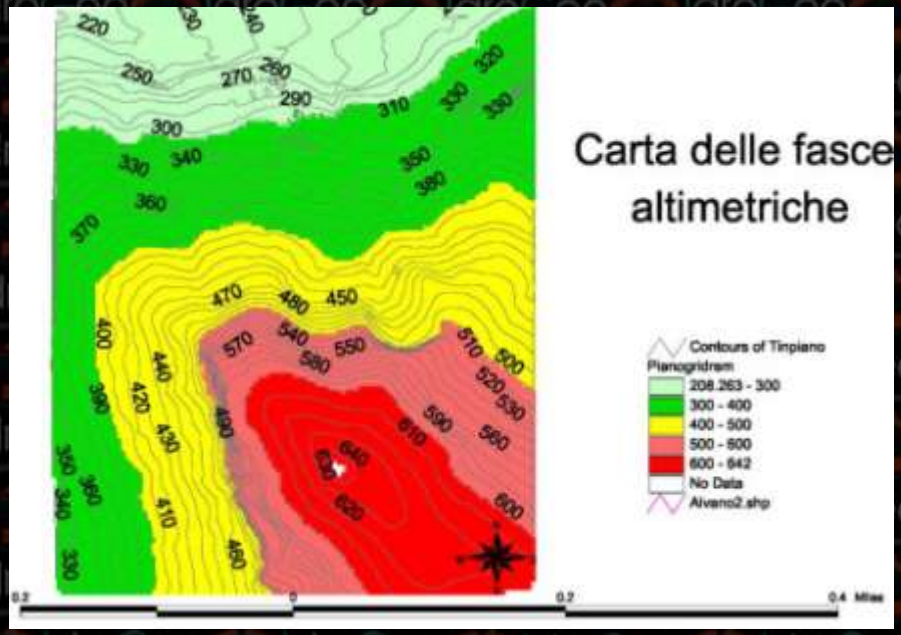

Toppling
(*type 5*)

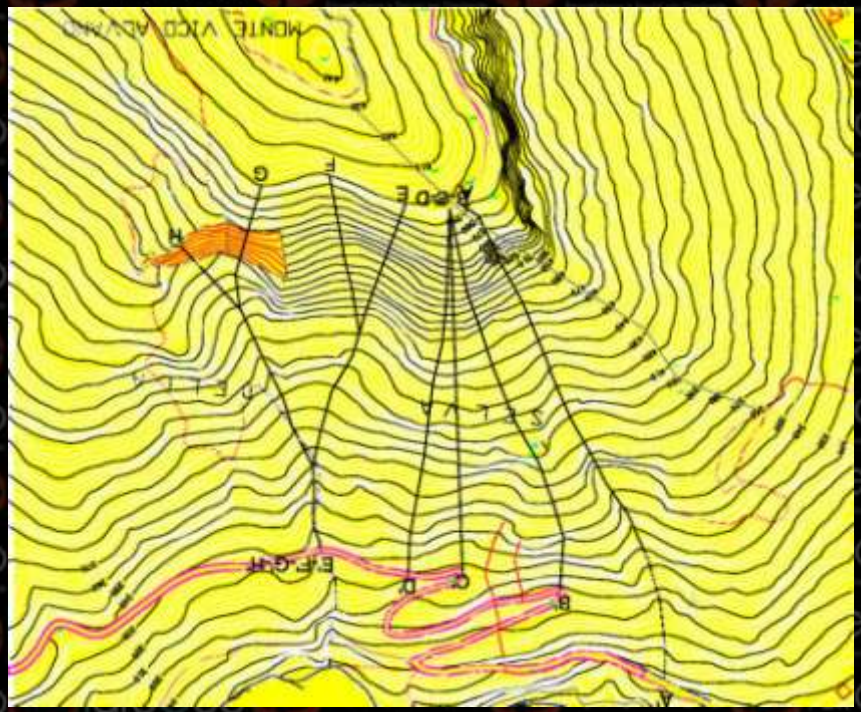
# Geomechanical measurement stations and slope zonation





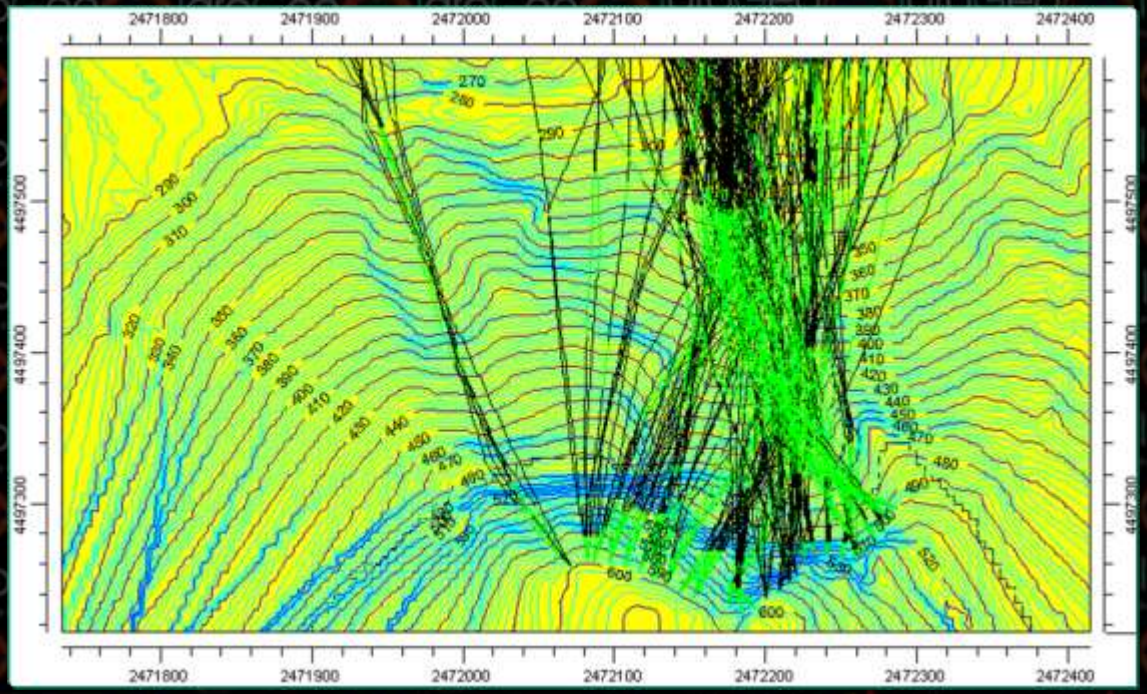



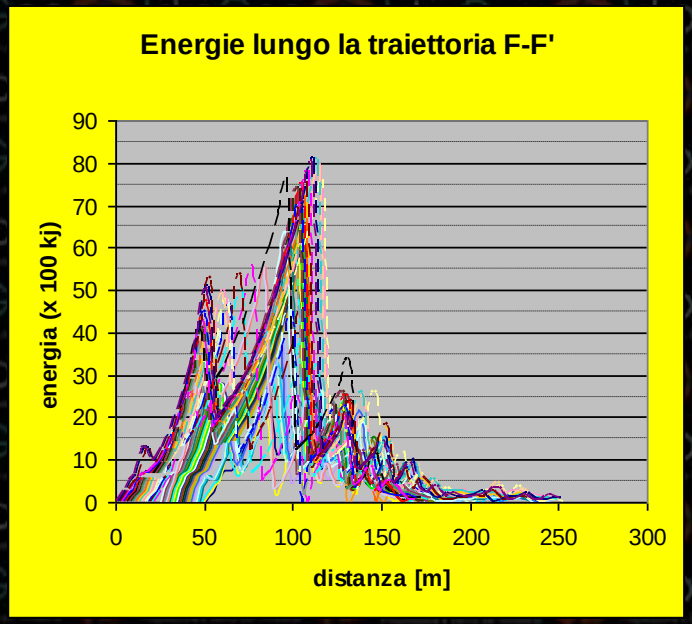
**Trajectories of blocks**



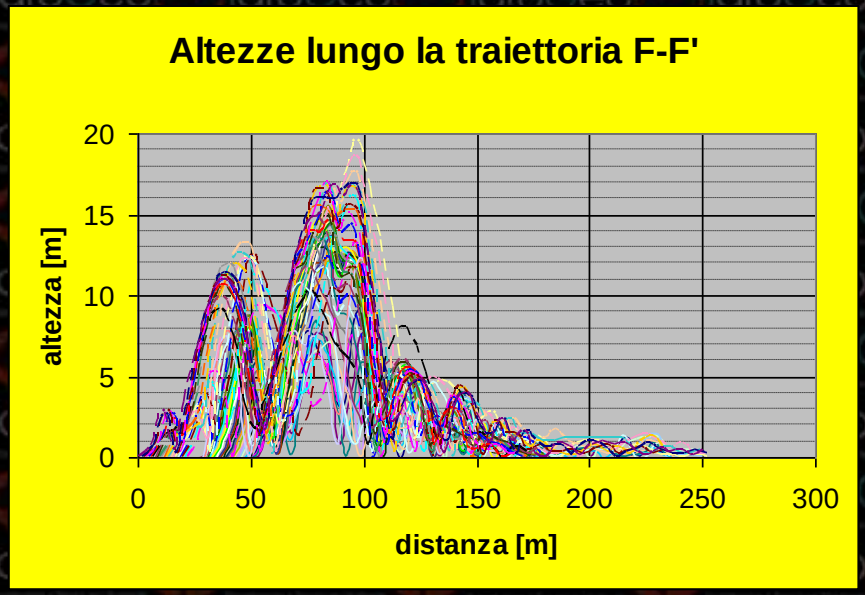

| LITHOLOGY - HOEK (1967) | $r_n$ | $r_t$ | s |
|---|---|---|---|
| Rock (limestone) | 0,53 | 0,9 | 0,4 |
| Debris mixed with soil and pyroclastic cover | 0,32 | 0,8 | 0,5 |




ROTOMAP



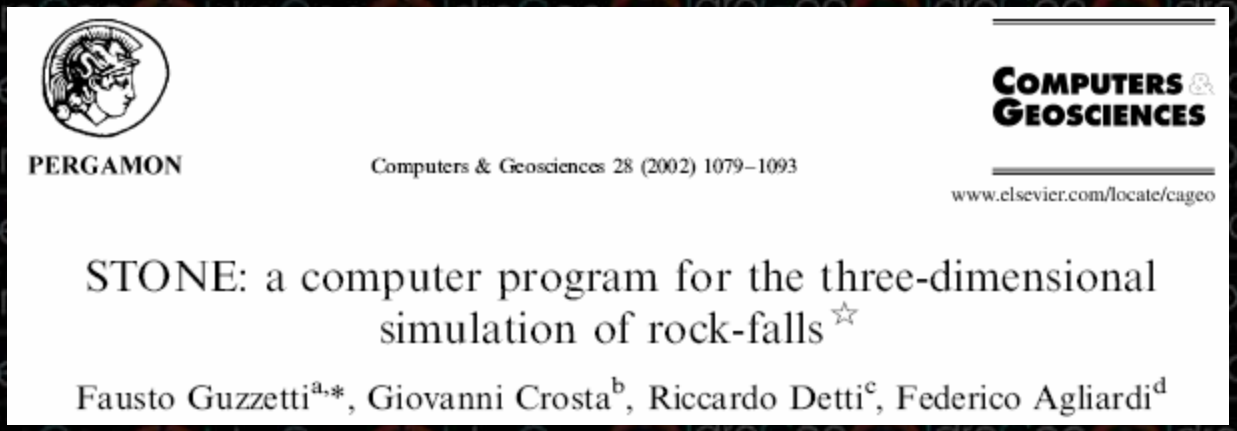

CRSP. Energy chart.




CRSP. Height of rebounds chart

# STONE specifications

- Use existing thematic data, or information that can be acquired easily and at low cost.
- **Work in 3-dimensions, using a lumped-mass approach.**
- Allow for the natural variability of rock falls and the uncertainty of the input data.
- **Output in raster and vector format.**
- Output compatible with GIS software.



PERGAMON

Computers & Geosciences 28 (2002) 1079–1093

COMPUTERS & GEOSCIENCES

www.elsevier.com/locate/cageo

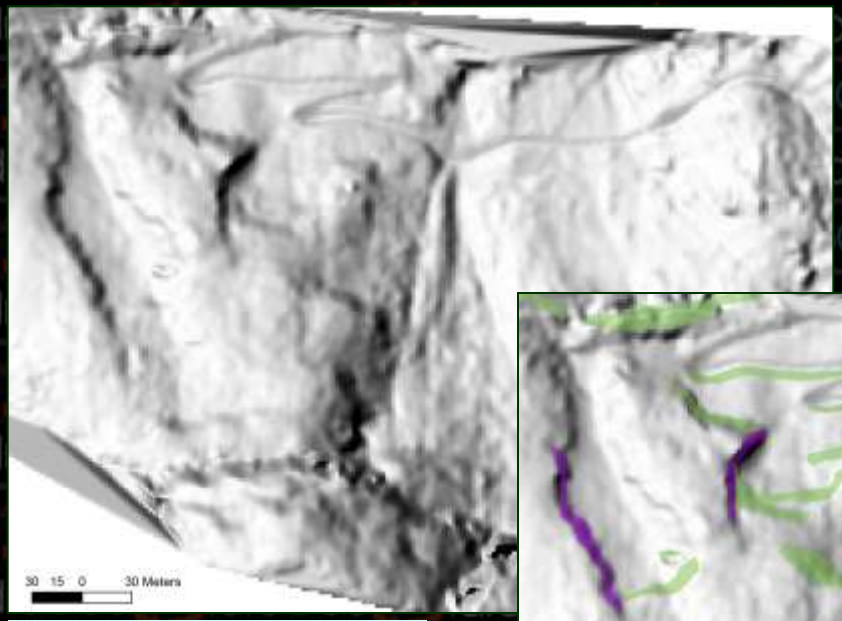
STONE: a computer program for the three-dimensional simulation of rock-falls ☆

Fausto Guzzetti[a,*], Giovanni Crosta[b], Riccardo Detti[c], Federico Agliardi[d]

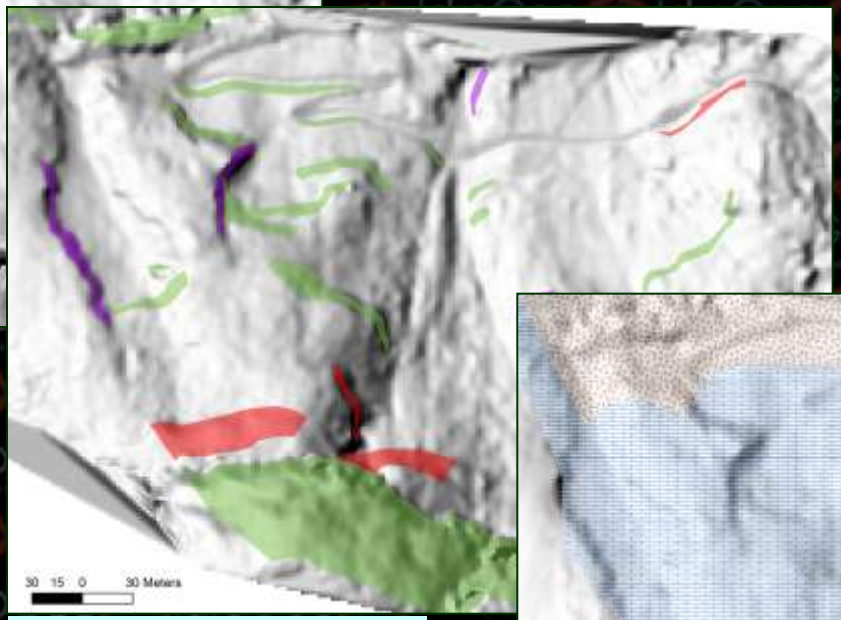
# Input data needed by STONE

- Digital Elevation Model (DEM)
- Location of Rock Fall source areas
- Dynamic friction coefficients (for dynamic rolling)
- Normal & tangential restitution coefficients (at impact points)

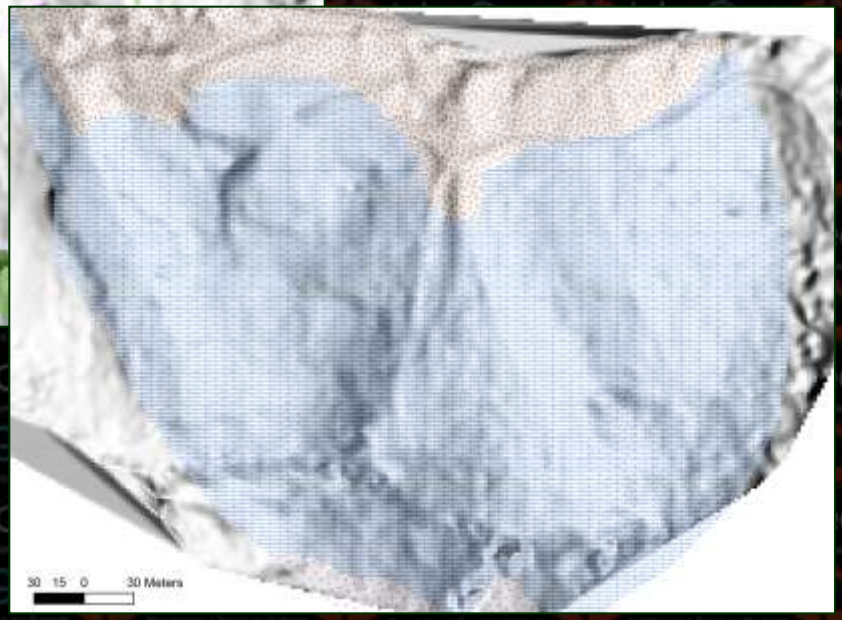
# Initial modelling conditions



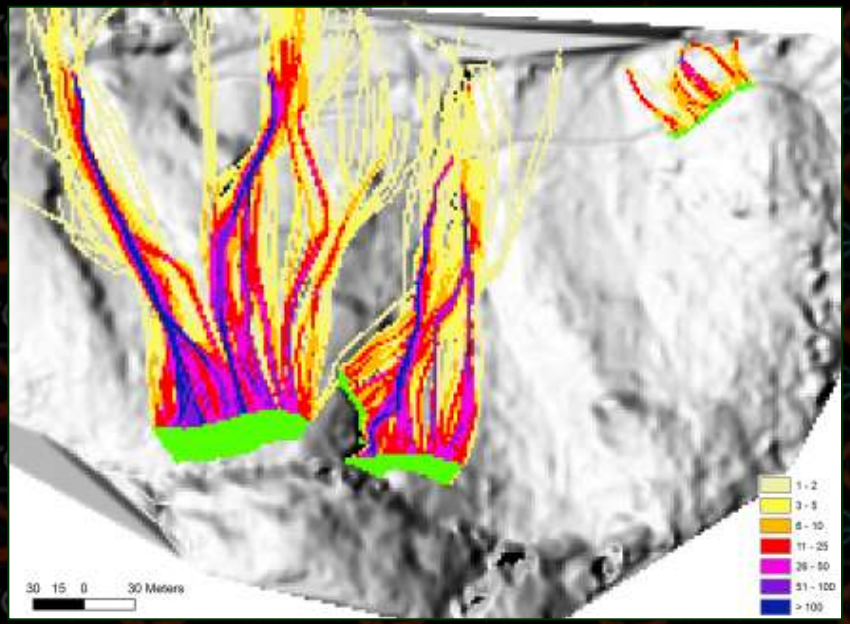

DTM (2m × 2m)



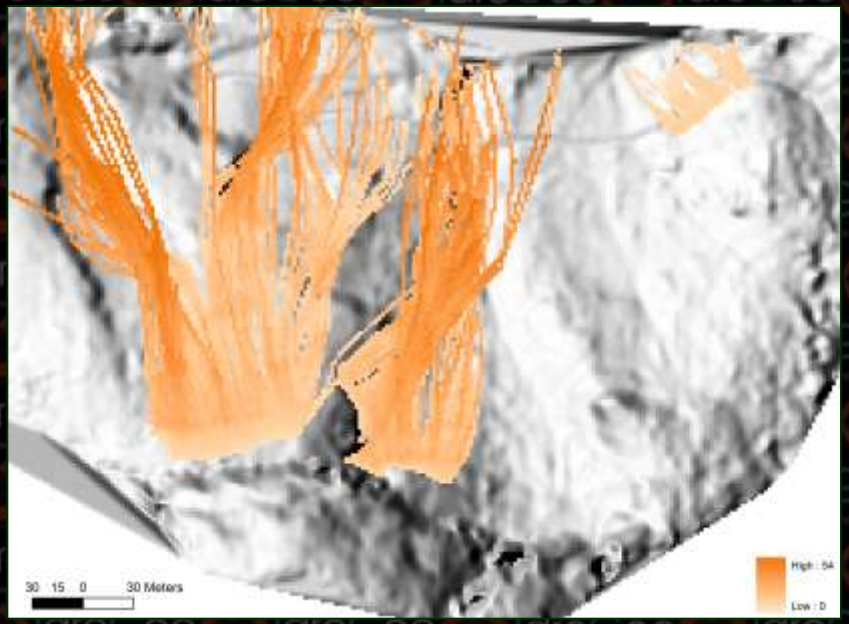

Source areas



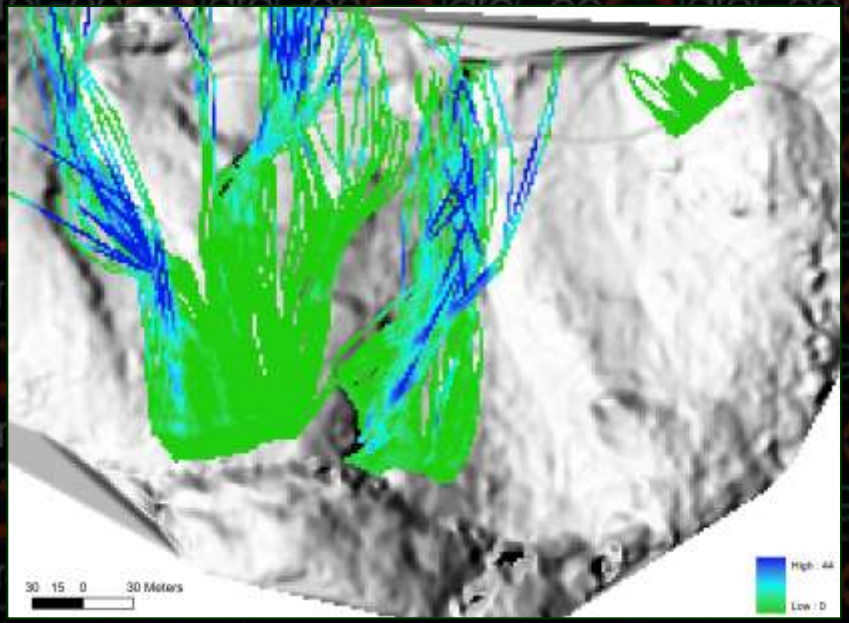

Lithological map



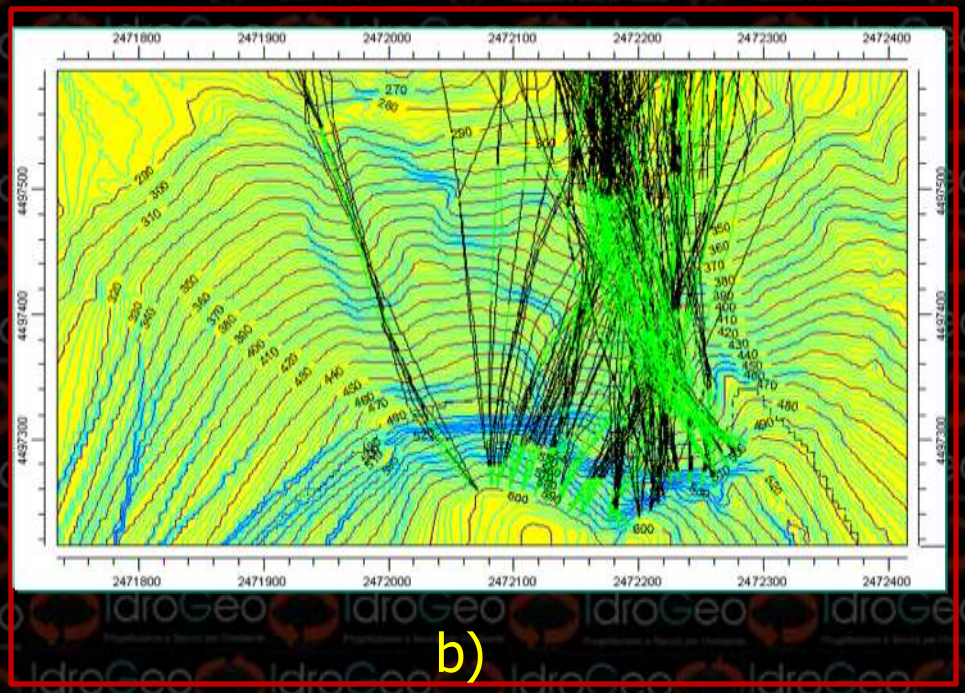

*COUNT OF ROCK FALL TRAJECTORIES*

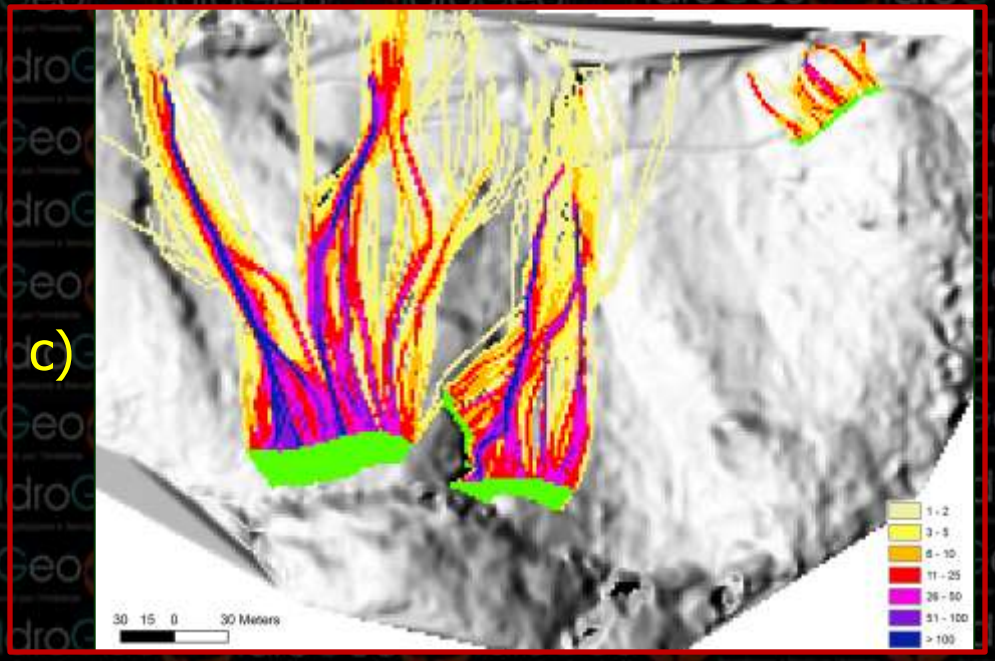



*MAXIMUM ROCK FALL VELOCITY*



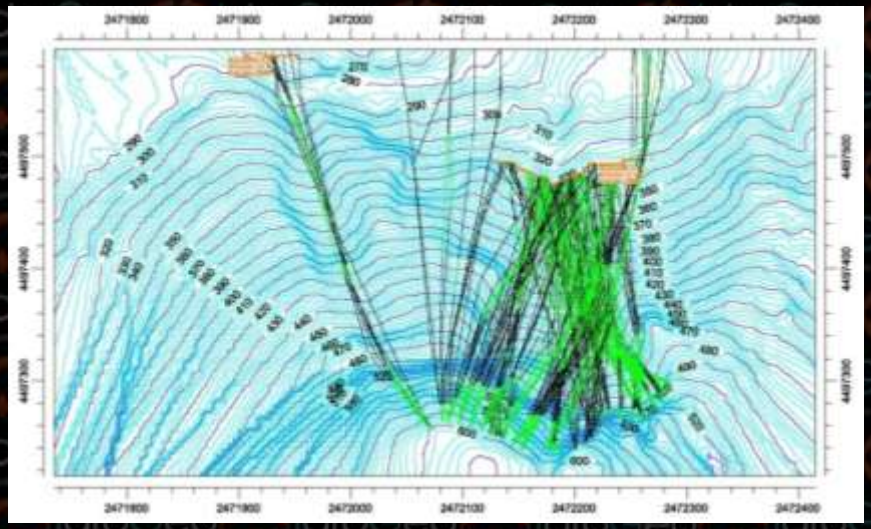

*ROCK FALL FLYING HEIGHT*


Comparison between observed trajectories of blocks (a) and those computed by ROTOMAP (b) and STONE (c)

# Protective measures



**Active (anchorages) and passive (rockfall barriers) measures**

# Concluding remarks

- STONE is a computer program capable of simulating rock fall trajectories along a slope, in 3-dimension.
- From existing thematic information, STONE generates maps useful to define rock fall magnitude and to evaluate rock fall hazard (and eventually risk).
- STONE allows for the uncertainty in the input data.
- High resolution DEM are required to model small areas in detail
- STONE outputs may be combined with data from detailed field surveys and direct observations from rock falls to gain useful information for protective measures