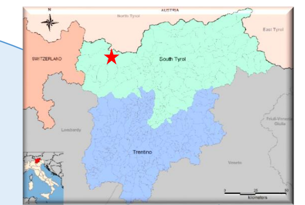
Geomorphological Survey and Remote Sensing analysis: a multidisciplinary approach to reconstruct triggering factors of a DSGSD in Maso Corto (South Tyrol, Italy)

*Gabriele Amato * (1), Giandomenico Fubelli (1), Gianluca Piccin (2), Giulia Chinellato (3), Christian Iasio (4), David Mosna (5) and Corrado Morelli (5)*

(1) Roma Tre University, Department of Sciences, Rome, Italy; (2) Dolomiti Project srl, Feltre (Belluno), Italy; (3) EURAC Research, Remote Sensing Department, Bozen, Italy; (4) Henesis srl- Camlin Group, Parma, Italy; (5) Autonomous Province of Bozen, Geological Service, Kardaun (BZ), Italy

* *gabriele.amato@uniroma3.it*

Fig.1. Red stars indicate geographic location of the study area.



I. INTRODUCTION

The **SloMove Project** aims to consolidate know-how of the ordinary monitoring applications of surface movements, evaluate their pros and cons and optimize the expected technical procedures of investigation in order to contribute to safeguard installations and to ensure inhabitants and tourists safety, in the Alpine regions. Within this project, an experimental composite monitoring has been carried out in the touristic site of Maso Corto (South Tyrol, Italy) (Fig. 1). The purposes of this experiment are:

1. to reconstruct the geomorphological dynamics and their state of activity;
2. to provide considerations on the role of permafrost as an influential factor for landslide activity.

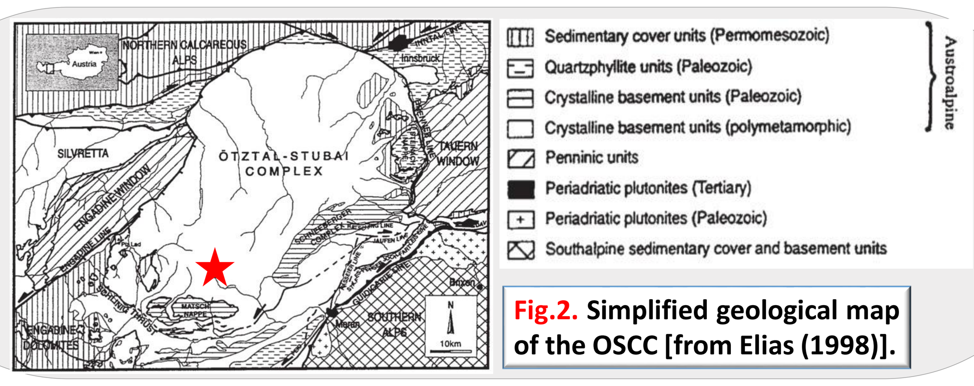


Fig.2. Simplified geological map of the OSCC [from Elias (1998)].

II. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The investigated area, approx. 3km^2 wide, extends just north of Maso Corto, between 2000 and 2900 m asl. It is located north of the Periadriatic tectonic lineament that separates the Austroalpine Units from the Southalpine ones (Azzaroli & Cita, 1963). In detail, it is within the **Oetztal-Stubai Crystalline Complex (OSCC)**, part of Austroalpine *nappe* that overlaid on Penninic Units during the Alpine Orogeny (Konzett et al., 2003) (Fig. 2).

The OSCC consists of medium-to-high metamorphic grade gneissic rocks, deriving from pelitic-to-psammitic protolytes, interbedded with mica schists, quartzites, orthogneiss, amphibolites, eclogites and rare marbles.

Geomorphological assessment of the area shows the most important alpine and periglacial features: landscape is characterized by several U-shaped valleys that, since the LGM, have been engraved by glaciers which different regression phases are documented by till deposits and lateral and frontal moraines.

Moreover, several rock glaciers are present and blocky slope deposits, rock avalanche deposits and rocky debris flow deposits are widespread.

III. MATERIAL AND METHODS

Structural-Geomorphological survey has been carried out complying a **geomorphic object-based approach** that allowed to highlight the relationship between structural assessment of the outcropping lithologies and some specific geomorphological markers (i.e. trenches, counterscarps, outcropping sliding surfaces) (Figs. 3, 4). Homogeneous lithological, geomorphological and structural features characterize each geomorphic object identified through the field survey.

The whole area is characterized by N350-to-N30 foliated OSCC metamorphic rocks (Fig. 8). Moreover, joints due to frost thaw activity are common in the shallow layer (Fig. 5) and two sets of tectonics fractures (N45, 45°-60° and N360, sub-vertical) have been recognized (Fig. 6). Rock glaciers in the area (Fig. 8) are located at elevations ranking between 2200 and 2700 m asl, above local timberline, and are characterized by well-preserved diagnostic geomorphic features.

SAR interferometry data have been processed by TRE® through the SqueeSAR™ analysis using Radarsat and Envisat images acquired between 2003 and 2009. To better handle the amount of SAR data, time series graphs of groups of Point Scatterer corresponding to different geomorphic objects have been represented separately. Diagrams that highlight the displacements of all the PS contained within a same group (**Standardized Cumulative Curve**) have been built (Fig. 7) .

GPS surveys were carried out through the technique of Rapid-Static Relative Positioning during the summers of 2012 and 2013; data acquired allowed to detect direction of movements and amplified the spectrum of activity rate detectable by SAR technique (Tab. 1).

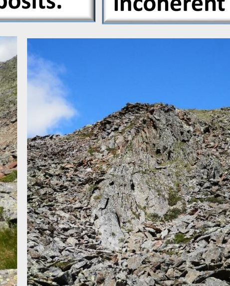
Fig.3. (above) View from SSE of the investigated slope. From the peak and downward you can see two main scarps and several trench zones and counterslopes.

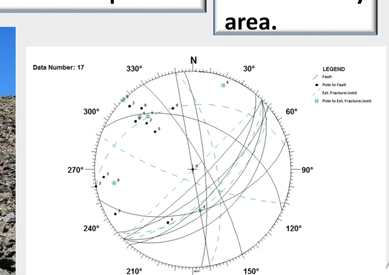
Fig.7. (on the right) SCCs and time series of some geomorphic objects identified during the field survey. SCCs have been extrapolated by calculating for each day the standardized value of the sum of the displacement of all the PSs, belonging to a same geomorphic object, and plotting the resulting serie.

Fig.4. (below) View from NW of the most evident counterslope affecting the whole investigated slope and locally covered by incoherent blocks deposits.

Fig.5. (below) Outcrop of bedrock in the investigated slope, surrounded by incoherent blocks deposits.

Fig.6. (below) Tectonic discontinuitie s in the study area.





IVa. DISCUSSION

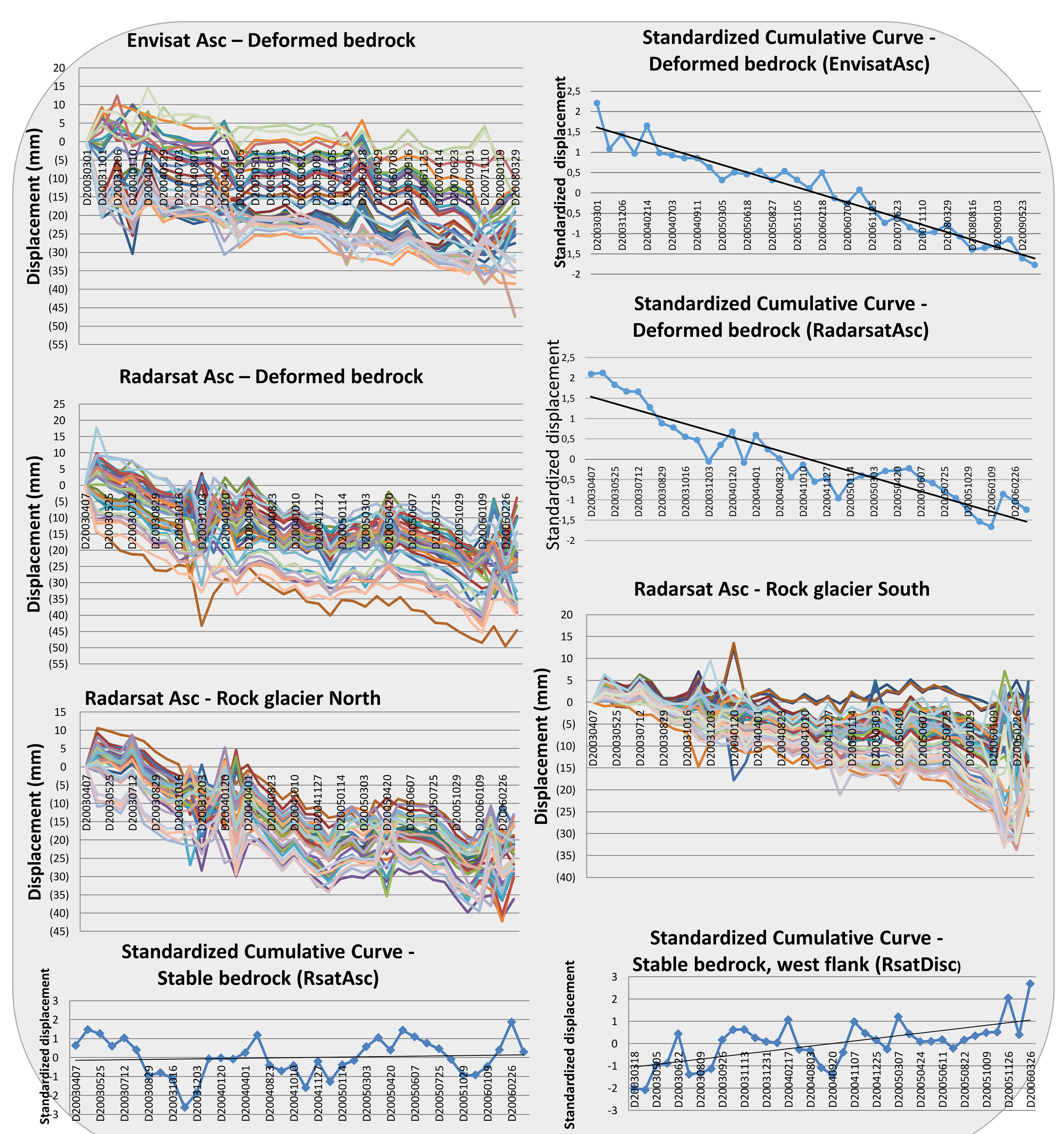
Data shows that the east flank of the relief north of Maso Corto, where the adjacent re-incised N-S glacial valley rises the maximum deep, is affected by a **Deep Seated Gravitational Slide Deformation (DSGSD)** that affects the outcropping OSCC rocks throughout most part of the slope. A clearly visible sliding surface, rising further upstream, separates stable bedrock by the deformed layer. ***On the base of the geomorphic objects identified through the field survey, we discriminated different type of gravity phenomena, from deep-seated to shallower, locally overlapped*** and we understood boundaries of the DSGSD. Instrumental data show different velocity for different objects so, for each of them, subtracting value due to shallower movements, the velocity component related to the DSGSD activity has been calculated. Velocity of this phenomenon results extremely slow and toward southeast but is not laterally homogenous: it varies from a minimum average speed of 3-5 mm/y in the southern part of the slope to a maximum average speed of 10-15 mm/y in the central part (Fig. 9).

IVb. PERMAFROST

GPS measured 34 mm/y as the maximum horizontal velocity value of the rock glaciers in the study area. From the orientation of the displacement vectors, their movements should not be associated to that of the DSGSD (Fig. 9). This displacement rate can be considered generally low for the Alpine rock glaciers (Haeberli, 1985; Barsch, 1996; Roer et al., 2008). This velocity value, correlated with elevation ranges of rock glaciers occurrence and their geomorphological features, allowed us to assume that discontinuous, shallow, hot and thin **permafrost** may be present in the area.

Tab. 1. Comparison between October 2012 and July 2013 measurements

Point	ΔE (m)	ΔN (m)	ΔQ (m)	Vector 2D (m)	Vector 3D (m)	ΔTime (months)	Vel (cm/mese)	Vel 2D (cm/mese)	Vel 2D (mm/y)
1	0,5349	0,0453	1,3046	0,5368	1,4107	9,6	14,6951	5,5918	671,02
13	0,5273	0,0689	1,3039	0,5318	1,4082	9,6	14,6685	5,5394	664,73
3	0,0188	0,0115	-0,0117	0,0220	0,0250	9,6	0,2599	0,2296	27,55
4	0,0178	0,0194	-0,0320	0,0263	0,0414	9,6	0,4317	0,2743	32,91
5	0,0235	0,0148	-0,0109	0,0278	0,0298	9,6	0,3108	0,2893	34,72
7	0,0171	0,0102	-0,0133	0,0199	0,0239	9,6	0,2494	0,2074	24,89
8	0,0083	0,0079	-0,0144	0,0115	0,0184	9,6	0,1917	0,1194	14,32
10	0,5006	-0,0217	1,0390	0,5011	1,1535	9,6	12,0158	5,2195	626,34
14	0,0076	0,0041	-0,0185	0,0086	0,0204	9,6	0,2127	0,0900	10,79
15	0,0091	0,0022	-0,0292	0,0094	0,0307	9,6	0,3194	0,0975	11,70
16	0,0025	0,0075	-0,0191	0,0079	0,0207	9,6	0,2153	0,0824	9,88
17	0,0101	-0,0052	-0,0076	0,0114	0,0137	9,6	0,1424	0,1183	14,20
18	0,0111	0,0007	-0,0090	0,0111	0,0143	9,6	0,1490	0,1159	13,90
19	0,3633	-0,3865	-0,3369	0,5304	0,6284	9,6	6,5457	5,5254	663,05
20	0,0086	0,0031	-0,0132	0,0091	0,0161	9,6	0,1673	0,0952	11,43
21	0,5676	-0,0185	0,9849	0,5679	1,1369	9,6	11,8427	5,9156	709,88



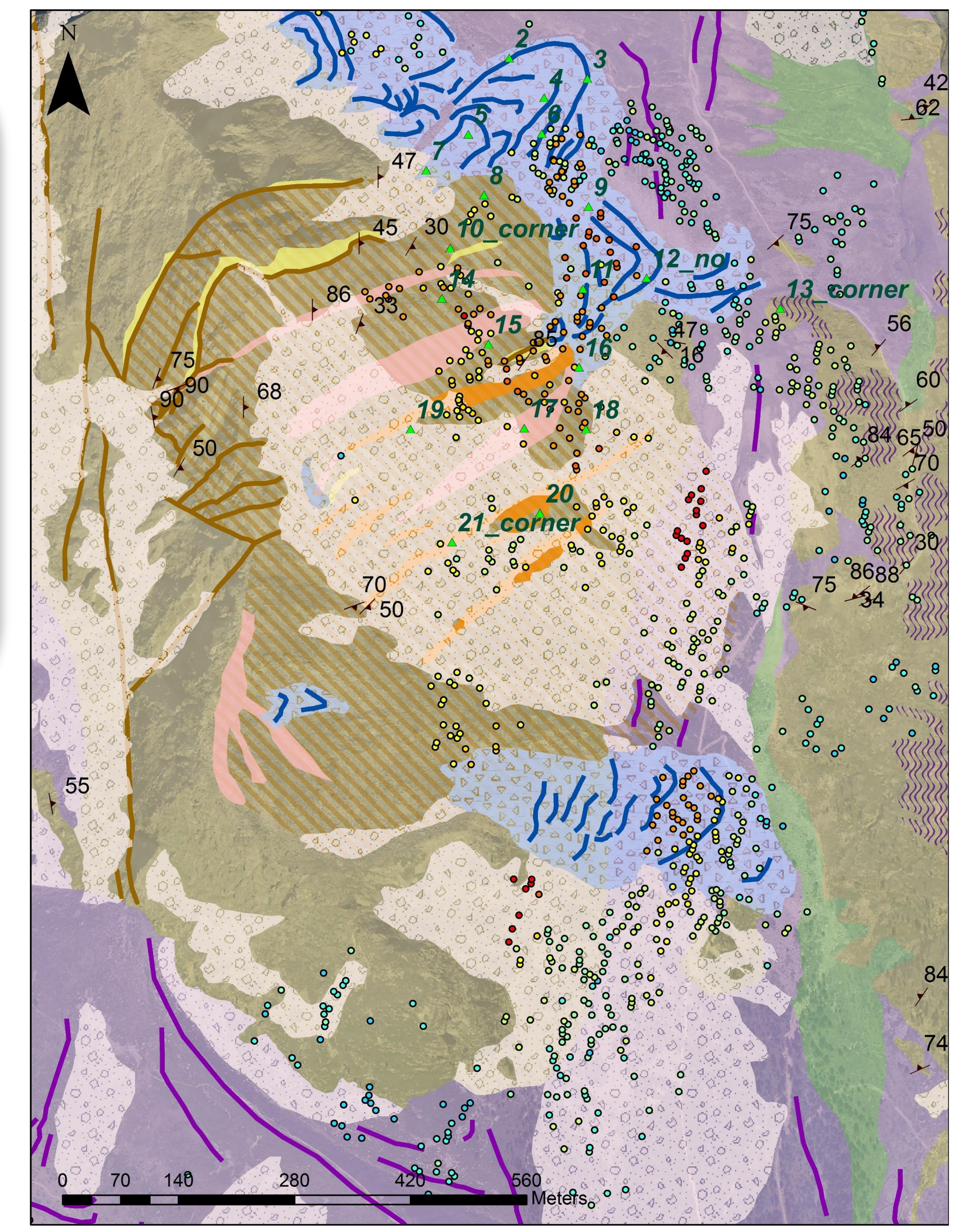


Fig.8. Geomorphological map of the investigated area with SAR data exposed. Legend below.

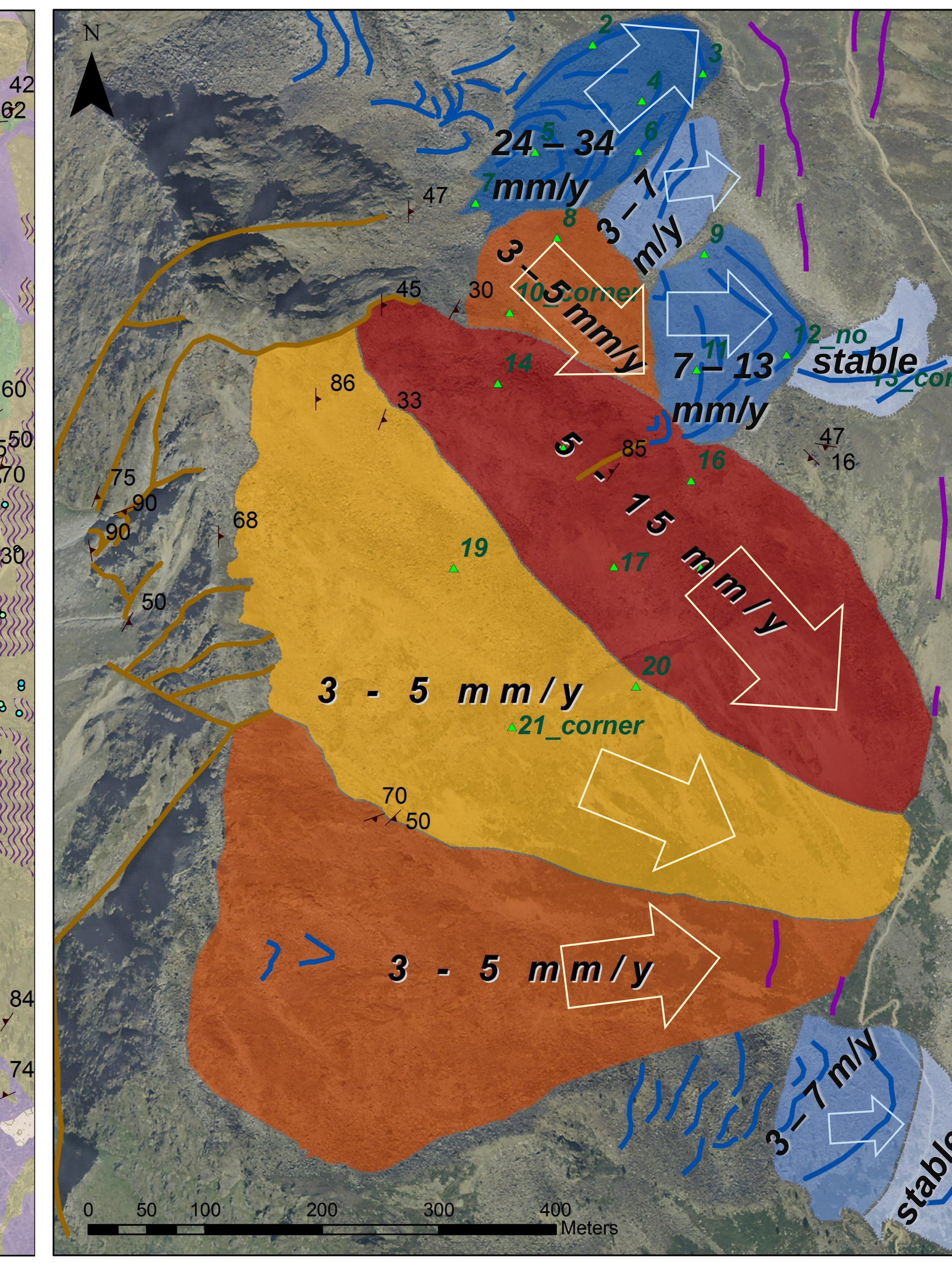


Fig.9. Map of the deformation zones subdivided in base of their state of activity. Mean annual velocity and direction of movements are reported. Areas involved in DSGSD are represented in red-to-yellow while those involved in permafrost creep are represented in blue scale. Legend below.

LEGEND

GPS points
foliation

PS velocity (mm/y)
- -15,77 - -13,00
- -12,99 - -10,00
- -9,99 - -7,00
- -6,99 - -5,00
- -4,99 - -3,00
- -2,99 - -1,00
- -0,99 - 0,00
- 0,01 - 1,00
- 1,01 - 5,00
- 5,01 - 10,00
- 10,01 - 20,00
- 20,01 - 100,00

Morpholines
- moraine
- rock glacier lobe
- tectonic discontinuities

Litologies
- Otzal bedrock
- alluvial deposits
- glacial deposits

Geomorphic objects
- blocky deposits coverture
- counterslope
- rock glacier
- scarp
- trench zone
- area involved in DSGSD
- sheepback Otzal bedrock

Geom. objects activity rate
- active with highest vel
- active with medium vel
- active with lowest vel
- stable
- fully active
- incipient activity
- in exhaustion phase

V. CONCLUSIONS

The DSGSD may have been predisposed by deglaciation, subsequent river incision and presence of tectonic discontinuity surfaces, favorably oriented with respect to the maximum slope, whereas the recent degradation of permafrost, due to post-LGM global warming, might have triggered or accelerated the movement. Moreover, a correlation between the occurrence of rock glaciers and DSGSD can be hypothesized: outside of the boundaries of the DSGSD, detrital blocks are relatively more stable favoring creeping related with permafrost active layer seasonal variations; vice versa, above the DSGSD body, blocks can be considered more constantly destabilized by the slow deep movement and they react with faster and paroxysmal processes to restore their equilibrium slope angle. Thus, this phenomenon can be considered as a predisposing factor for those shallow and rapid gravity processes as like rock avalanches, rockfalls and debris flows in glacial deposits.

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