7th International Conference on Debris-Flow Hazards Mitigation

Characteristics of debris flows just downstream the initiation area on Punta Nera cliffs, Venetian Dolomites

Martino Bernard[a], Matteo Berti[b], Giacomo Crucil[c], Alessandro Simoni[b], Carlo Gregoretti[a,]*

[a]*Department Land Environment Agricolture Forestry - University of Padova, Viale dell'Università 16, Legnaro 35134, Italy*
[b]*Department of Biological, Geological and Environmental Sciences - University of Bologna, Piazza di S. Donato 1, Bologna 40126, Italy*
[c]*Georges Lemaitre Centre for Earth and Climate Research – Universitè Catholiquè de Louvain, Louvain-la-Nevue 40126, Belgium*

Abstract

The Piees de ra Mognes fan at the base of the Punta Nera cliffs, in the Venetian Dolomites (Italy), has been subject to debris flow activity for decades. Until recently, these debris flows never reached the National Road 51 on the valley bottom. Debris flows usually initiated at the base of an incised rocky channel in the Punta Nera cliffs where runoff is delivered to loose scree deposits of the fan. The main debris flow channel is strongly incised at the apex of the fan and splits into several minor channels at lower elevations. During the autumn 2014 and May 2016, two cliff collapses produced large debris deposits. Since then, the frequency of debris flows increased considerably because of the availability of debris deposits at very steep slope that lowered the runoff discharge needed for the debris flow initiation. In a few cases, debris flows that initiated in the rocky channel reached and interrupted the National Road 51, about 2 km downstream the well-known touristic village of Cortina d'Ampezzo. On July 2016, a monitoring station was placed at the beginning of the debris flow channel just downstream the base of the rocky channel. In the period between July and -September, the monitoring station recorded six debris flow events. Analysis of these data is used to describe the characteristics of debris flow initial routing. Moreover, we use video image analysis to investigate the velocity and depth of the surge from the 5 August 2016 event.

Keywords: runoff-genenerated debris flows; initiation area; front velocity; flow depth.

1. Introduction

Several adjacent debris-flow catchments parallel the south side of the Boite Valley, in the Venetian Dolomites, Northeast Italy. The debris-flow channels incise the dolomitic bedrock in their upper part and transition to run over the scree deposits at lower elevations (Gregoretti et al., 2016). High intensity rainfalls of short duration (tipically < 1 h) produce abundant runoff which entrain loose debris along the channel forming solid-liquid surges that route downstream as debris flows (Berti and Simoni, 2005; Gregoretti and Dalla Fontana, 2008; D'Agostino et al., 2010, Gregoretti et al., 2019). The debris flows initiated by the entrainment of solid material into runoff, are named runoff-generated debris flows (Kean et al., 2013). These debris flows are widespread in Alps (Theule et al., 2012; Navratil et al., 2013; Tiranti and Deangeli, 2015) and other contexts (Coe et al., 2008; Hurlimann et al., 2014; Imazumi et al., 2006; Kean et al., 2011; Okano et al.; 2012; Ma et al., 2018). Nevertheless, due to poor accessibility monitoring systems in the initiation area of debris-flow catchments are rare. Instrumented sites include those described by Berti et al. (1999), McCoy et al. (2012), Kean et al., (2013), Navratil et al., (2013) and Hurlimann et al. (2014). Field observations of the debris-flow initiation are very important to understand its dynamic and models testing.

In the Autumn of 2014 and May 2016, two rockfall events deposited approximately 100.000 cubic meters of debris in the headwater basin of the Punta Nera debris-flow catchment. The rockfalls were possibly favoured by climate

* Corresponding author e-mail address*: carlo.gregoretti@unipd.it*

change that, at higher altitudes, can cause permafrost melting in this area (Boeckli et al., 2012). They caused a dramatic increase in the frequency and magnitude of debris flows because their deposits, positioned on slopes averaging 40 degrees can be easily entrained by runoff caused by unexceptional rainfall events. We installed a monitoring system downstream the rocky cliffs where the debris-flow channel is stable, with the purpose of observing the debris flow characteristics during the initial stages.

2. Materials and methods

2.1. The study site

In dolomitic areas, abundant coarse hillslope sediment is commonly found at the toe of rocky cliffs. Debris-flow channels origin where the bedrock surfaces deliver surface runoff, at the outlet of chutes incised into the cliffs. Debris flows initiate along such talus-incised channels following intense rainfall and determine the progressive erosion and deepening of the channels. Sediment recharge mechanisms include rock fall, dry ravel processes, channel-bank failures

The Punta Nera basin includes the cliffs of Punta Nera peak (2847 m a.s.l.) and the Piées de ra Mognes fan (Fig. 1a and Fig. 2) and is dominated in its upper part by the dolomitic cliffs belonging to the “Dolomia Principale” Formation of Triassic age (Fig. 2). It is located on the left side of the Boite Valley in the Venetian Dolomites (northeast Italy, see the inset of Fig. 2). The upper rocky headwater basin is incised by a very steep channel (about 40°) ending with a chute delivering runoff discharge to the apex of the Piées de ra Mognes fan (Fig. 1a and Fig. 2). The debris flow-channel begins at the chute and 400 m further downstream, splits into multiple channels (Fig. 2). In this area, channel avulsion is common due to debris-flow deposits often clogging the channel.

Before 2014, debris flows used to initiate downstream the rocky chute along the talus-incised channel and exhibited poor mobility with most of the sediment depositing at elevations ranging between 1500 and 1300 m a.s.l.. Cliff collapses occurred between 2014 and 2016 (Fig. 1a), deposited a large amount of loose unconsolidated debris along the rocky channel in the headwater basin. Such deposits resting on slopes at or in excess of 40° were easily entrained by runoff, triggering debris-flow mass transport phenomena that propagated downstream along the debris-flow channel located on the fan (Fig. 1b).

This explains the notable increase of debris-flow events since June 2015. For the first time, in the last few decades, debris flows repeatedly reached and blocked the National Road 51. Local authorities consequently built road defense structures in the form of a series of retaining basins (Fig. 2). We installed a monitoring system at short distance from the fan apex where the debris-flow channel is deeply incised and avulsion is unlikely (Fig. 1b and Fig. 2), at the purpose of observing the debris flow characteristics shortly after its initiation.

In the last decade, the occurrence of cliff collapses and large rockfalls notably increased in the Alpine region, likely due to thermoclastism and permafrost melting whose action is intensifying due to the increase of average temperatures caused by global climate change. These phenomena commonly affect reliefs higher than 2500 m a.s.l. (Cremonese et al., 2011) as in the case of the Punta Nera Peak. Similar evidences include the rockfall occurred on November 2014 on the dolomitic massif Mount Antelao, located just few kilometers south of Punta Nera. It deposited a large amount of debris on a rocky sloping plateau that was mobilized on August 2015 by abundant runoff descending from the overhanging cliffs, producing a debris flow whose magnitude (about 100000 m^3) has never been reported in the historical records for the specific catchment (Gregoretti et al., 2018).

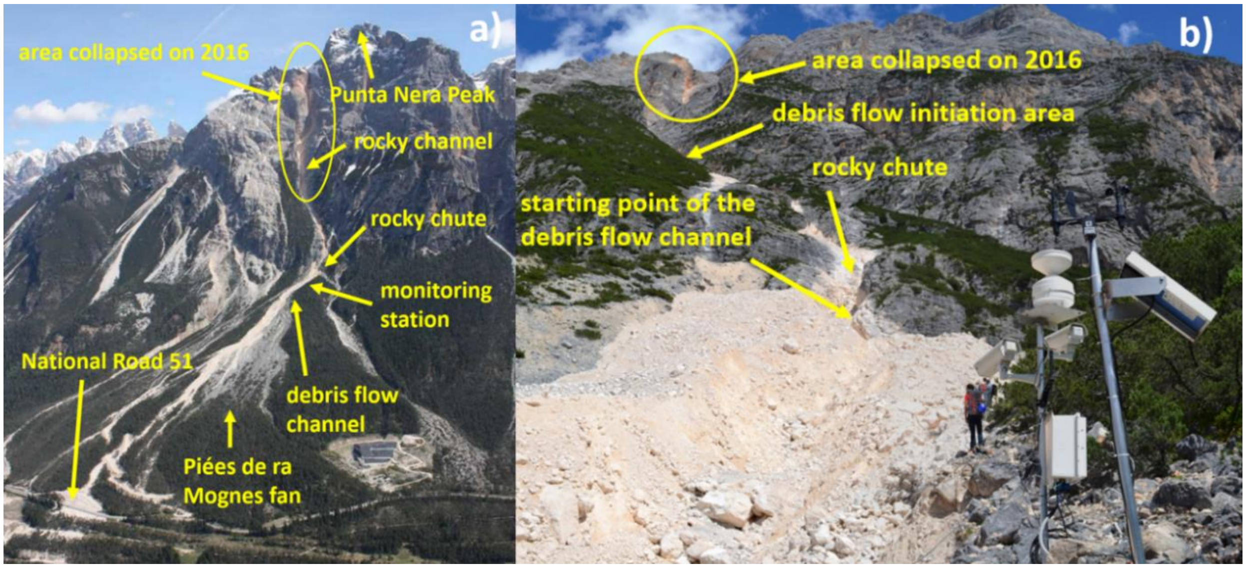

Fig. 1. Frontal view of the Punta Nera rocky cliffs and Piées de ra Mognes fan (a) and the initial reach of the debris-flow channel downstream of the rocky chute with the monitoring station installed at 1515 m a.s.l. (b).

2.2. The monitoring station

Debris-flow initiation is expected to happen upstream or downstream the bedrock – scree transition, so we installed the monitoring station, in this area on the left bank of the debris-flow channel (Fig. 1b). The monitoring station is a programmable data-logger that acquires data from a rain gauge, anemometer, two pressure transducers buried in the channel 7 m apart and two time-lapse cameras that record images to a memory card (frequency: 0.5 s-1). The monitoring station is powered by a battery and a solar panel. Data are acquired every 5 min (normal mode). When the rainfall intensity exceeds 6 mm/h, the system switches to "event" mode and acquires data every five seconds; the time-lapse cameras are also triggered and capture images for two hours. The time-lapse cameras frame different scenes: one frames upstream to record the routing of the debris flow along the chute and the upper reach of the channel; the other frames the channel downstream with the intent to calculate flow depths and velocity. Several targets were placed on the opposite bank of the cameras to provide scale and framing.

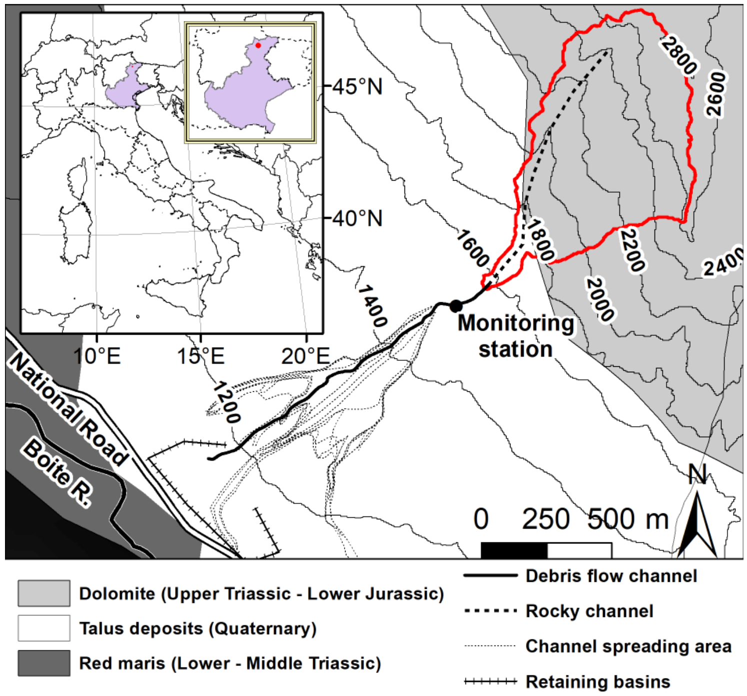

Fig. 2. Schematic geological map of the studied area showing instrumentation and main morphological features. Red line denotes the boundaries of the basin where runoff is simulated.

3. General characteristics of the occurred debris-flow events

During the period from 17 July to 29 September 2016, six debris flows and six runoff events occurred, four debris flows occurred during daylight, one at dusk and one during the night (no time-lapse video). In two cases, the debris-flow events were preceded by water runoff.

3.1. Observed behavior of the debris flows during their initial stages

The debris flows that occurred during daylight consisted of a series of solid-liquid surges. The majority of surges flowed down the channel in unsteady flow conditions. In some cases, incoming surges overtook those preceding. In other cases, surges or their rear part stopped in the channel and their deposits were totally or partially re-mobilized by incoming surges and/or by runoff that infiltrated the deposit. We distinguish two re-mobilization mechanisms to the in-channel deposits. The first mechanism is due to entrainment and is observed when a sediment-laden water flow overtops a deposit and progressively erodes the material owing to the exerted shear stress. The second mechanism is a sliding failure and is observed when seepage of incoming runoff infiltrates the deposit increasing pore pressures and exerting a drag force within it (i.e. the seepage force). A similar mechanism was proposed for the mobilization of sediments accumulated to form a dam at Chalk Cliff (Colorado) by Kean et al. (2013). The two mechanisms can act together, due to the action of runoff, when loose deposits are present along bottom of the channel. The surges arriving from the rocky channel are typically composed of cobbles, gravel and sand. In the initiation area, the debris-flow surges can erode the channel banks inducing local failures that supply additional debris for entrainment. Samples of surge deposits upstream of the monitoring station indicate scarce or no fine fraction (silt and clay); however, fines are present in the channel bank samples and in surge deposits sampled further downstream.

3.2. The debris flows occurred on 5 August 2016

On 5 August 2016 two debris-flow events occurred, separated by runoff. The first from 9:14 to 9:58, the second from 18:00 to 18:05. The first event was composed of fourteen surges, while the latter event, initially a unique surge, switched to two surges because the surge tail stopped in-channel and after two minutes was subsequently re-mobilized by the action of runoff that infiltrated the deposit.

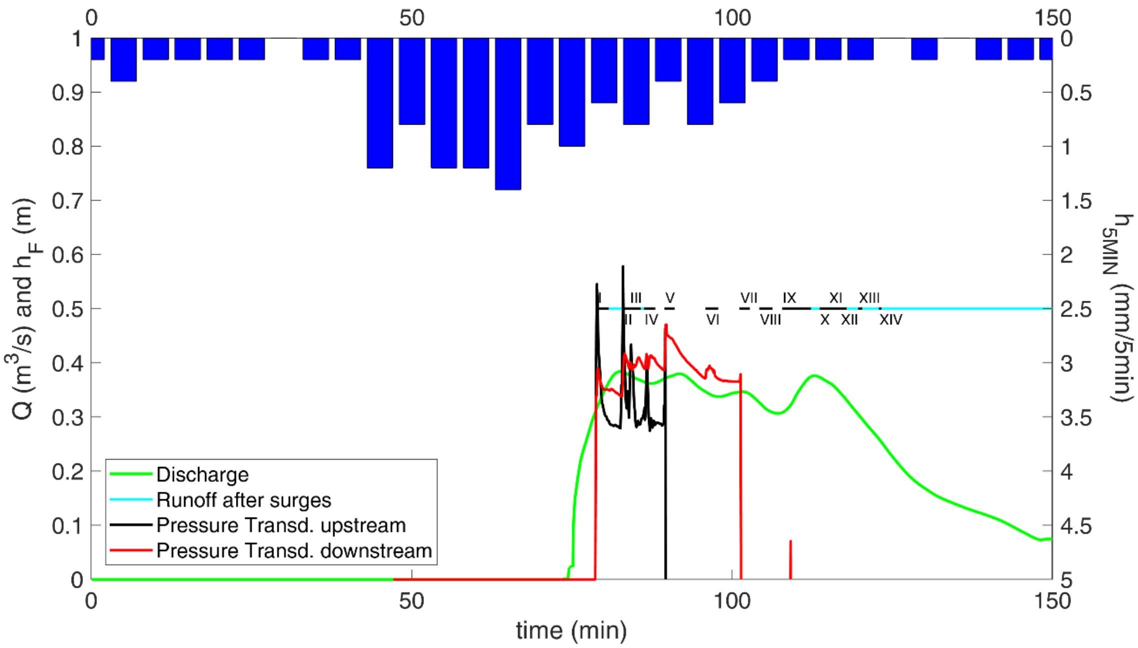

Fig. 3. Measured and simulated data of the debris-flow event occurred in the morning of August 5. The timing of observed debris-flow surges (roman numbers) is compared to pore pressures (h_F) measured in the channel bed and simulated runoff discharge (Q). Blue bars represent the 5 min rainfall (h_{5MIN}).

The surges are described in Table 1 (time of occurrence, duration and some of the characteristics) and Figure 3 graphs the sampled rainfalls, the simulated runoff, and the pressure head measured by the two transducers. Runoff was simulated at the transition between the rocky channel and the debris-flow channel (see Fig. 2) using the model proposed by Gregoretti et al. (2016) for headwater rocky basins, and tested against discharge measurements taken in a basin 8 km north with similar geologic and morphologic characteristics. The simulated discharge exhibits a rapid raise to peak (~ 0.4 m^3/s) followed by a nearly constant plateau, and after 40 minutes, it slowly decreases. Surge I is close to the peak of runoff (i.e. it coincides with the end of the sudden hydrograph growth) confirming the results of Rengers et al. (2016) who demonstrated that the runoff model can provide the timing of debris-flow surge close to the initiation area. Gregoretti et al. (2016) also obtained similar results in the two basins of Acquabona and Rovina di Cancia that share similar geologic and geomorphologic features with the Punta Nera basin. In the present case (Figure 3), the simulated runoff hydrograph nicely fit the timing of occurrence of the debris-flow surges. The last minor surges (XIII and XIV) are observed to travel down the channel at the beginning of the progressive hydrograph decrease when, probably, the discharge is no longer sufficient to mobilize sediment. This result confirms the model capabilities and indicates that the continue action of runoff higher than a certain critical threshold is required to maintain the mobility of debris-flow surges, as also observed by Capra et al., (2018) for lahars.

In between each of the 14 surges (Table 1), water runoff is observed in the channel except between surges IV-IX when the debris-flow surge IV stopped blocking the channel. The deposit remained stable despite incoming surges and infiltrating water until surges VIII and IX progressively entrained the material. Conversely, during the second event, the debris material deposited during the first surge was re-mobilized by runoff, generating the second surge. In this case, the simulated runoff intensity was larger (not shown here for brevity).

Pore water pressures measured in the channel bed during the first event correlates very well with the arrival of the debris-flow surges: they quickly raise up to the peak during the passage of the front and then gradually decrease. The two transducers were swept away during the passage of surges V and VIII, both transporting boulders of size larger than 2 m. Front velocity and flow depth were estimated by image analysis of the time-lapse videos. Cross sections of the channel together with the position targets were surveyed by Real–Time Kinematic GPS (RTK-GPS). The surveys allow for the computation of the distances (along and normal to the flow direction) needed in the image analysis to fix the position of the surge front at different time steps and the quote of the surface of the surge with respect to the bottom. The flow depth is estimated in a fixed position located 2 m downstream of the upstream pressure transducer. The average velocity of the front is estimated during its advancement from the position where flow depth is estimated, so that the first estimate coincides with the fixed position. Both flow depth and front velocity can be estimated until the front is in view of the camera, for a time interval of about ten seconds.

Figure 4 shows the estimates of the front velocity and debris-flow surge depth together with the pore pressures measured by the transducers. Front velocity ranges between 1 and 2 m/s. Flow depth is increasing during the passage of surges II and V because these fronts have an elongated shape. The short time interval of measure prevents any other consideration about flow depth. Conversely, flow depth is rather constant for surge IV, suggesting that in this case conditions close to the uniform flow are attained. Pressure heads tend to increase rapidly only after the front arrival (see Figures 3 and 4) except for surge IV, when they remain nearly constant. This could mean that, in general, the front is not saturated and it is dominated by collisional and frictional stresses. Berti et al., (2000) and McArdell et al., (2007) observed similar effects, also explained as incomplete saturation of the front. In the case of the surge IV, maybe the interstitial fluid could be negligibile.

Table 1. The surges of the two debris-flow events occurred on 5 August 2016 with their description (R = runoff after the surge; F = surge followed by another one; * bed returned to the topographical condition preceding the first surge routing).

n. surge	Time of occurrence (h:m:s)	Duration (sec)	Characteristics of the surge
I	9:13:50 R	116	Front composed by gravel without boulders
II	9:17:50 F	68	Front with boulders of size > 2 m
III	9:18:58 R	108	Front composed by gravel without boulders
IV	9:21:16	106	Front with boulders of size > 2 m; deposit on the bed
V	9:24:26	96	Front and body rich of boulders with size > 2 m; deposit on the bed
VI	9:30:50	120	Front and body rich of boulders with size > 2 m; deposit on the bed
VII	9:36:14	94	Front and body rich of boulders with size > 2 m; deposit on the bed
VIII	9:39.14	124	Front and body rich of boulders with size > 2 m; small erosion of the bed
IX	9:42:48 R	272	Front and body rich of boulders with size > 2 m; large erosion of the bed*
X	9:48:40 F	70	Front with boulders of size > 2 m
XI	9:50:04 R	84	Front composed by gravel without boulders
XII	9:51:54 R	60	Front composed by gravel without boulders
XIII	9:54:42 R	38	Front composed by gravel and cobbles
XIV	9:57:54 R	26	Front with boulders of size > 2 m
I	17:00:25 R	78	Front with boulders of size > 2 m
II	17:04:11R	58	Solid-liquid surge restarted by runoff as in Kean et al., (2013)

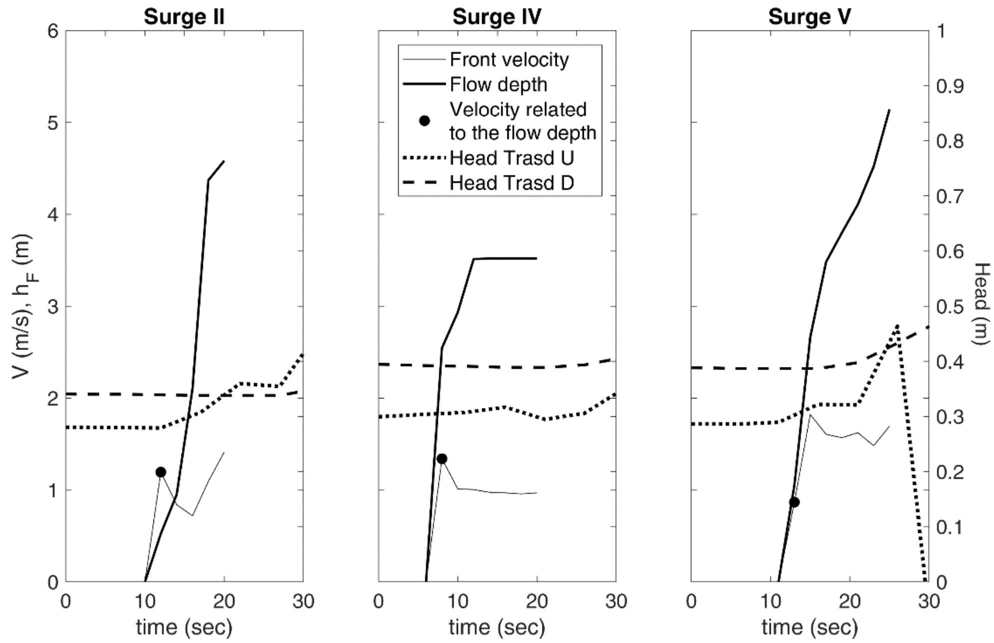

Fig. 4. Estimates of front propagation velocity (V) and flow depth (h_F) compared to measures of pore water pressures (Head) debris flow surges II, IV and V.

4. Discussion and Conclusions

Two cliff collapses, occurred between November 2014 and 2016, deposited a large amount of debris in the rocky headwater basin of Punta Nera. In particular, the material deposited along the main bedrock-incised steep (> 40°) channel was subject to frequent rainfall-induced mobilization. Since June 2015, debris-flow activity increased in frequency and magnitude. Multiple events reached the National Road along the valley bottom causing repeated interruptions whereas the Punta Nera debris flow has no record of such events.

Monitoring activities began in 2016 and focused on the debris-flow channel at short distance from the fan apex. Our data document that the debris-flow initiation occurs in the headwater rocky basin and involves the recent rockfall deposits. Debris-flow events arrive at the outlet of the rocky basin with a substantial solid concentration and surging behaviour. It is our belief that prior to the rockfall episodes, debris-flow activity was much less intense because debris was scarce in the steep headwater basin and events used to initiate at the fan apex where the slope is lower (~ 25°) and the channel is incised in talus deposits. Aerial photographs confirm that before 2015, debris-flow events at Punta Nera were rare and much less mobile depositing debris at 1300 m or higher.

The rockfalls triggered an abrupt change in the regime of the Punta Nera debris-flow catchment. Such modification that can be interpreted as accidental or related to the general temperature increase due to the global climate change. In fact, unusually high temperatures favour thermoclastism and permafrost melting which promote instability at high elevation in the Alpine region (Boeckly et al, 2011; Cremonese et al., 2011). Such effect may influence the behaviour of an increasing number of first-order alpine catchments in the near future.

Monitoring activities provided also other more specific information. During the summer of 2016, we documented six debris flows. All of them were composed of solid-liquid surges that in some cases merged, in some cases stopped along the channel to be re-mobilized by incoming surges or by the action of water runoff.

The comparison between the water discharge simulated by an hydrologic model, specifically developed for headwater rocky basin (Gregoretti et al., 2016), measured pore water pressures in the channel bed and image-derived flow properties yields good results in terms of timing. Observed arrival and propagation of the solid-liquid surges correspond to the simulated peak water discharge. Whenever the simulated water discharge drops significantly, the flow becomes turbulent and sediment transport is greatly reduced. Measures of pore fluid pressure on the channel bottom show that the surge front is less saturated than the body and that collisional-frictional forces dominate the flow.

Acknowledgements

We would like to thank the Regole d'Ampezzo Association for the permission to install the monitoring station and the help provided during field work. The authors also thank the reviewers for the useful comments and suggestions that helped to improve the work.

References

Berti, M., Genevois, R., Simoni, A., and Tecca, P.R., 1999, Field observations of a debris flow event in the Dolomites: Geomorphology, v. 29, p. 265–274, doi:10.1016/S0169-555X(99)00018-5.

Berti, M., Genevois, R., LaHusen, R.G., Simoni, A., and Tecca, P.R., 2000, Debris flow monitoring in the Acquabona watershed on the Dolomites (Italian alps): Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, v. 25, p. 707–715, doi:10.1016/S1464-1909(00)00090-3.

Berti, M., and Simoni, A., 2005, Experimental evidences and numerical modelling of debris flow initiated by channel runoff: Landslides, v. 2, p. 171–182, doi:10.1007/s10346-005-0062-4.

Boeckli, L., Brenning, A., Gruber, S., and Noetzli, J., 2012, A statistical approach to modelling permafrost distribution in the European Alps or similar mountain ranges: The Cryosphere, v. 6, p. 125–140, doi:10.5194/tc-6-125-2012.

Capra, L., Coviello, V., Borselli, L., Márquez-Ramírez, V.-H., and Arámbula-Mendoza, R., 2018, Hydrological control of large hurricane-induced lahars: evidence from rainfall-runoff modeling, seismic and video monitoring: Natural Hazards and Earth System Sciences, v. 18, p. 781–794, doi:10.5194/nhess-18-781-2018.

Coe, J.A., Kinner, D.A., and Godt, J.W., 2008, Initiation conditions for debris flows generated by runoff at Chalk Cliffs, central Colorado: Geomorphology, v. 96, p. 270–297, doi:10.1016/j.geomorph.2007.03.017.

Cremonese, E. et al., 2011, Brief Communication: "An inventory of permafrost evidence for the European Alps": The Cryosphere, v. 5, p. 651–657, doi:10.5194/tc-5-651-2011.

D'Agostino, V., Cesca, M., and Marchi, L., 2010, Field and laboratory investigations of runout distances of debris flows in the Dolomites (Eastern Italian Alps): Geomorphology, v. 115, p. 294–304, doi:10.1016/j.geomorph.2009.06.032.

Gregoretti, C., and Dalla Fontana, G., 2008, The triggering of debris flow due to channel-bed failure in some alpine headwater basins of the Dolomites: analyses of critical runoff: Hydrological Processes, v. 22, p. 2248–2263, doi:10.1002/hyp.6821.

Gregoretti, C., Degetto, M., Bernard, M., Crucil, G., Pimazzoni, A., De Vido, G., Berti, M., Simoni, A., and Lanzoni, S., 2016, Runoff of small rocky headwater catchments: Field observations and hydrological modeling: Water Resources Research, v. 52, p. 8138–8158, doi:10.1002/2016WR018675.

Gregoretti, C., Degetto, M., Bernard, M., and Boreggio, M., 2018, The Debris Flow Occurred at Ru Secco Creek, Venetian Dolomites, on 4 August 2015: Analysis of the Phenomenon, Its Characteristics and Reproduction by Models: Frontiers in Earth Science, v. 6, p. 80, doi:10.3389/feart.2018.00080.

Gregoretti, C., Stancanelli, L.M., Bernard, M., Boreggio, M., Degetto, M., and Lanzoni, S., 2019, Relevance of erosion processes when modelling in-channel gravel debris flows for efficient hazard assessment: Journal of Hydrology, v. 568, p. 575–591, doi:10.1016/j.jhydrol.2018.10.001.

Hürlimann, M., Abancó, C., Moya, J., and Vilajosana, I., 2014, Results and experiences gathered at the Rebaixader debris-flow monitoring site, Central Pyrenees, Spain: Landslides, v. 11, p. 939–953, doi:10.1007/s10346-013-0452-y.

Imaizumi, F., Sidle, R.C., Tsuchiya, S., and Ohsaka, O., 2006, Hydrogeomorphic processes in a steep debris flow initiation zone: Geophysical Research Letters, v. 33, p. n/a-n/a, doi:10.1029/2006GL026250.

Kean, J.W., Staley, D.M., and Cannon, S.H., 2011, In situ measurements of post-fire debris flows in southern California: Comparisons of the timing and magnitude of 24 debris-flow events with rainfall and soil moisture conditions: Journal of Geophysical Research, v. 116, p. F04019, doi:10.1029/2011JF002005.

Kean, J.W., McCoy, S.W., Tucker, G.E., Staley, D.M., and Coe, J.A., 2013, Runoff-generated debris flows: Observations and modeling of surge initiation, magnitude, and frequency: Journal of Geophysical Research: Earth Surface, v. 118, p. 2190–2207, doi:10.1002/jgrf.20148.

Ma, C., Deng, J., and Wang, R., 2018, Analysis of the triggering conditions and erosion of a runoff-triggered debris flow in Miyun County, Beijing, China: Landslides, v. 15, p. 2475–2485, doi:10.1007/s10346-018-1080-3.

McArdell, B.W., Bartelt, P., and Kowalski, J., 2007, Field observations of basal forces and fluid pore pressure in a debris flow: Geophysical Research Letters, v. 34, p. L07406, doi:10.1029/2006GL029183.

McCoy, S.W., Kean, J.W., Coe, J.A., Tucker, G.E., Staley, D.M., and Wasklewicz, T.A., 2012, Sediment entrainment by debris flows: In situ measurements from the headwaters of a steep catchment: Journal of Geophysical Research: Earth Surface, v. 117, p. n/a-n/a, doi:10.1029/2011JF002278.

Navratil, O., Liébault, F., Bellot, H., Travaglini, E., Theule, J., Chambon, G., and Laigle, D., 2013, High-frequency monitoring of debris-flow propagation along the Réal Torrent, Southern French Prealps: Geomorphology, v. 201, p. 157–171, doi:10.1016/j.geomorph.2013.06.017.

Okano, K., Suwa, H., and Kanno, T., 2012, Characterization of debris flows by rainstorm condition at a torrent on the Mount Yakedake volcano, Japan: Geomorphology, v. 136, p. 88–94, doi:10.1016/j.geomorph.2011.04.006.

Rengers, F.K., McGuire, L.A., Kean, J.W., Staley, D.M., and Hobley, D.E.J., 2016, Model simulations of flood and debris flow timing in steep catchments after wildfire: Water Resources Research, v. 52, p. 6041–6061, doi:10.1002/2015WR018176.

Theule, J.I., Liébault, F., Loye, A., Laigle, D., and Jaboyedoff, M., 2012, Sediment budget monitoring of debris-flow and bedload transport in the Manival Torrent, SE France: Natural Hazards and Earth System Sciences, v. 12, p. 731–749, doi:10.5194/nhess-12-731-2012.

Tiranti, D., and Deangeli, C., 2015, Modeling of debris flow depositional patterns according to the catchment and sediment source area characteristics: Frontiers in Earth Science, v. 3, p. 1–14, doi:10.3389/feart.2015.00008.