DOI: 10.4408/IJEGE.2013-06.B-59

AN ENGINEERING GEOMORPHOLOGICAL CHARACTERISATION OF THE 1963 VAJONT SLIDE

Andrea Wolter, Doug Stead, Brent C. Ward & John J. Clague

Simon Fraser University - Burnaby, Canada

ABSTRACT

The 1963 Vajont Slide is one of the most studied natural disasters in the world, with over 150 publications on its cause, mechanisms, behaviour, and effects. Most of these studies have considered the event from a descriptive, engineering geology, structural geology, or geophysical perspective, and the geomorphology of the Vajont Slide and the Vajont Valley has been neglected in all but a few papers. Nonetheless, geomorphological features and processes provide valuable insights into the preconditions and movement of the landslide. This paper presents the first engineering geomorphological maps of pre- and post-slide topography and their interpretation. The maps show changes in slope morphology, which indicate boundaries of landforms, and relationships between these landforms. Our interpretations support previous hypotheses, such as the existence of an ancient landslide in the same location as the 1963 event and the intact nature of the sliding mass. In addition, the landslide is proposed to have moved in two main blocks, with a possible third block on the west margin of the slide. A classification of failure scar morphology illustrates the implications of geomorphological features for failure behaviour, and the interaction between tectonic and geomorphic processes to precondition and degrade the slope to the point of failure is highlighted.

Key words: *Vajont Slide; engineering geomorphology; morphological maps; characterisation*

INTRODUCTION

Geomorphological factors contributing to slope instability are typically complex and interrelated. They include slope angle, weathering, freeze-thaw cycles, river incision, and glacial erosion. The study of these processes and their effects is critical in understanding not only regional landscape evolution but also the development of individual slopes, which may be the sites of engineering projects.

Engineering geomorphology developed as a discipline in recognition of the importance of surface processes and landforms to anthropogenic modifications of the Earth. It involves the application of geomorphological theory and methods to engineering activities and provides spatial context for engineering concerns, an assessment of the impact of engineering on the environment and landscape, and an evaluation of the risks and implications of landform change for society (Giardino & Marsten, 1999; Fookes *et alii*, 2005, 2007). In essence, the discipline endeavours to interpret geomorphological features, their interrelationships, and their evolution as applied to engineering works. An important aspect of this interpretation is the consideration of time on both engineering and geological scales, and an evaluation of dynamic processes and landform evolution as they affect engineering projects (Griffiths *et alii*, 2012).

The 1963 Vajont Slide, which is located just upstream of the Vajont Dam in northeastern Italy, has been studied extensively over the past 50 years. Research has highlighted the lithology, hydrogeology, kinematics and dynamics, and effects of the slide. The geomorphology of the area has been largely neglected, although some papers describe the geomorphological setting of the event (Giudici & Semenza, 1960; Carloni & Mazzanti, 1964a, 1964b; Selli & Trevisan, 1964; Rossi & Semenza, 1964, 1965; Broili, 1967; Semenza, 1967; Hendron & Patton, 1985; & Guerricchio & Melidoro, 1986). Most of these studies discuss the geomorphological features related to an ancient landslide at the same location as the 1963 event. Semenza (2001) provides a palinspastic reconstruction of the north slope of Monte Toc from before the paleo-slide to present, and Paronuzzi & Bolla (2012) update Semenza's slope reconstruction with a new geological model. Broili (1967) emphasises the slip surface geometry and properties of the 1963 landslide, in particular irregularities related to tectonic features and the role of clays. Hendron & Patton (1985) examined airphotos to determine whether or not an ancient slide could have been recognised prior to 1963; they conclude that, given the multiple scarps, depressions, and lineaments, the slide should have been identified. They produced the first geomorphological map of the slide area, illustrating scarps, depressions, streams, sinkholes, and gullies that are identifiable on the 1960 pre-slide airphotos. Only Guerricchio & Melidoro (1986) focus exclusively on geomorphology. They describe the southern and northern slopes of the Vajont Valley in the area of the 1963 slide, and provide sketches and maps of processes and landforms such as prehistoric and recent mass movements, as well as catchment and drainage maps. They also describe the geological history of the valley, including the development of a tectonic décollement on the northern slope of Monte Toc.

In this paper, we provide an engineering geomorphological perspective on the Vajont Slide based on preparation and interpretation of detailed pre- and post-1963 morphological and morphogenetic maps. The morphological maps show changes in slope that delineate boundaries between landforms, and morphogenetic maps enable interpretations of landform relationships and evolution. This perspective supports many previous findings on the slide and highlights some aspects of the event that have not previously been documented. Our objectives are to:

i. infer landslide behaviour from surficial expressions of geomorphological processes, and
ii. identify geomorphic controls and preconditions on the 1963 Vajont Slide.

REGIONAL GEOMORPHOLOGICAL AND STRUCTURAL SETTING

Vajont Valley has relief of approximately 1500 m, with the highest peak, Monte Borgá, reaching an elevation of over 2200 m asl. The rocks within the valley have been subjected to tectonic deformation, uplift, and glacial and fluvial erosion, but the evidence of these processes has been largely obscured by weathering, karstic processes, and mass wasting. Guerricchio & Melidoro (1986) summarise the history of landslides in the valley, including the Pineda, Monte Borgá, Colomber, and Vajont failures. They note that the Vajont River has been repeatedly dammed by these large events. An example is the Pineda deposit, which is adjacent to the Vajont Slide at the confluence of the Vajont and Mesazzo rivers. It has been incised by both rivers to form steep erosion scarps in intact rock strata and diamicton (Fig. 1). The deposit's location at the bottom of the valley and the flow of streams around it also indicate that it blocked the valley. Coppola & Bromhead (2008) discuss the stability of landslide dams in the Dolomites, as well as their significance to river morphology and application to hydroelectric power projects due to the increase in hydraulic head across the dams.

Another process that has importance for slope stability in the region is carbonate dissolution. Hendron & Patton (1985) and Guerricchio & Melidoro (1986) refer to a karstic plain with scattered dolines above the Vajont Slide, which they identified on airphotos. We could not verify this interpretation, but we did observe a relatively flat and hummocky area above the Massalezza catchment (Fig. 1). Rock pinnacles and caves in the area, however, are consistent with karstic topography. The Croda Vasei above the Vajont Slide (Fig. 1) may be a remnant karst tower, as it is undercut and contains fissures and caves. Several gullies in the Vajont Valley are also dry and terminate abruptly, consistent with the presence of karst.

Evidence of Pleistocene glaciation includes the broad floor of the Vajont Valley and scattered glacial deposits. A glacier in the Vajont Valley presumably would have been confluent with a larger glacier in nearby Piave Valley, which has been documented by Castiglioni (1940). Glaciation of the valley would serve to remove old landslide debris and oversteepen valley walls. An epigenetic gorge over 250 m deep and less than 30 m wide at its base marks the mouth to the Vajont Valley (Fig. 1). The origin of the gorge has not yet been adequately explained, although it could be a hanging valley or a bypass drainage route resulting from blockage of the mouth of the valley by a landslide. Given the geometry of the gorge and the numerous large instabilities that have dammed the valley, the latter explanation is more likely.

Most of the landforms mentioned above are controlled by tectonic structures. The Vajont Valley follows the Erto Syncline plunging 20° to the east, the southern limb of which defines the characteristic chair-shape of the north wall of Monte Toc (Massironi *et alii*, this volume; Fig. 1). The Erto Syncline transitions into the Belluno Anticline at the peak of Monte Toc, and the karstic plain referred to above follows this transition. The Massalezza Gully marks the axis of a north-plunging syncline (Wolter *et alii*, in review; Massironi *et alii*, this volume). These two fold generations interfere on the south side of the valley to create complex basin and dome structures. Several faults define the valley. The Monte Borgá overthrust dominates the north valley wall and is the initiation site of the Monte Borgá landslide. The steep north-dipping Col delle Erghene Fault delimits the west margin of the headscarp of the 1963 Vajont Slide, and the east side of the scarp is bounded by the west-dipping Col Tramontin Fault. This fault is a splay of the Croda Bianca Fault.

Although many valleys in the Dolomites have similar geomorphological and structural settings to the Vajont Valley, the combination of these factors at Vajont is responsible for the high number of catastrophic failures there.

METHODOLOGY

Fig. 2 illustrates the methodology we employ in this paper. Analysis began with the interpretation of aerial

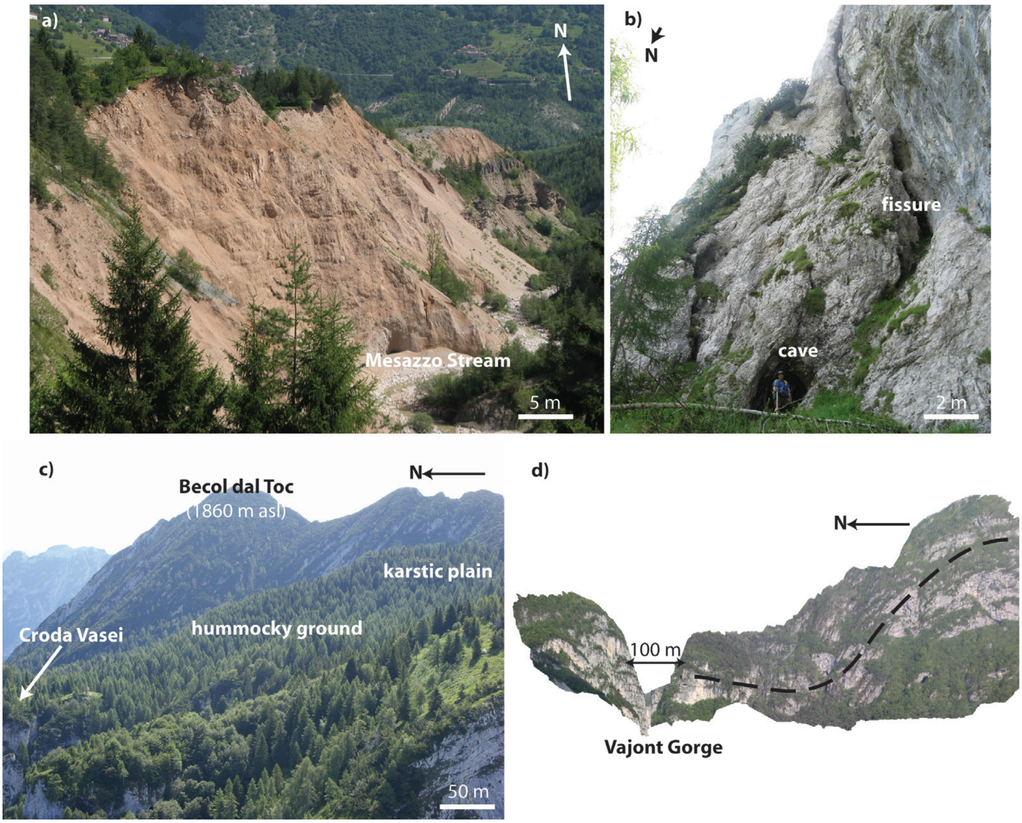

Fig. 1 - Geomorphological features of the Vajont Valley. a) The Pineda landslide deposit exposed along Mesazzo Stream; intact strata and diamicton are visible. b) Fissures and caves in the remnant karst tower Croda Vasei. c) Hummocky, less steep area behind the Vajont Slide that Hendron & Patton (1985) referred to as a karstic plain. d) Photogrammetry model profile of the north slope of Monte Toc as seen from Longarone. The profile shows the characteristic chair associated with the Erto Syncline and the narrow gorge at the mouth of the Vajont Valley

photographs from before (1960) and after (1963, 2004) the catastrophic failure. We completed detailed field mapping in 2010 and 2011 along roughly north-south transects at 50-m spacing (Fig. 3). Both the airphoto interpretation and field mapping focused on the slide area and were corroborated by interpretation of LiDAR DEMs. Abrupt concave and convex slope breaks and gradual changes in slope were extracted from the field traverses, airphotos, and DEMs. Slope angles were measured in the field with a clinometer and are point data rather than average values. Following recommendations by the Geological Society in London (1982), we estimated the relative ages and evolution of landforms visible on interpretative morphogenetic maps. The pre- and post-1963 maps were created at different scales: the pre-event map is at a smaller scale (of the order of 1:20 000), because it was created from small-scale airphotos; the post-event map has a larger scale (approximately 1:3000) as it incorporates field mapping, LiDAR, and observations derived from larger scale airphotos. We also briefly document the regional geomorphology using the airphotos and field observations.

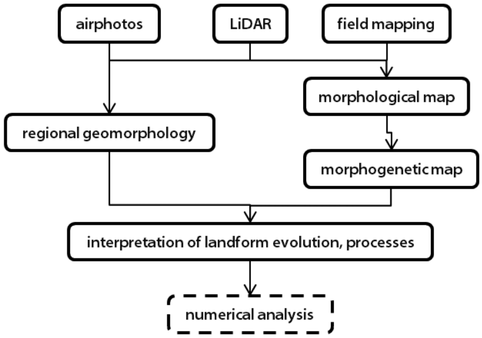

Fig. 2 - Flowchart of methods used to create the morphological and morphogenetic maps and to make engineering geomorphological interpretations of landform evolution and processes that informed numerical modelling. Numerical modelling is presented in another paper (Wolter et alii, in this volume), and hence this step in the flowchart is outlined with a dashed rectangle

RESULTS AND DISCUSSION

MORPHOLOGICAL MAPS

The pre- and post-event morphological maps are shown in Figs. 4 and 5 respectively. The difference in the observation scales mentioned above is evident from a comparison of the two maps. The post-event field map shows features at metre-scale and larger, whereas the pre-event map displays only features tens of metres or larger in size. The morphological maps are strictly descriptive; they provide the foundation for the interpretive morphogenetic maps.

MORPHOGENETIC MAPS

Examination of the pre-event morphological map indicates that active processes on the north slope of Mount Toc prior to the 1963 catastrophic failure include gullying, fluvial erosion, and surficial landsliding. Surficial landslides occurred on gully walls and at the toe of the slope where it is undercut by the Vajont

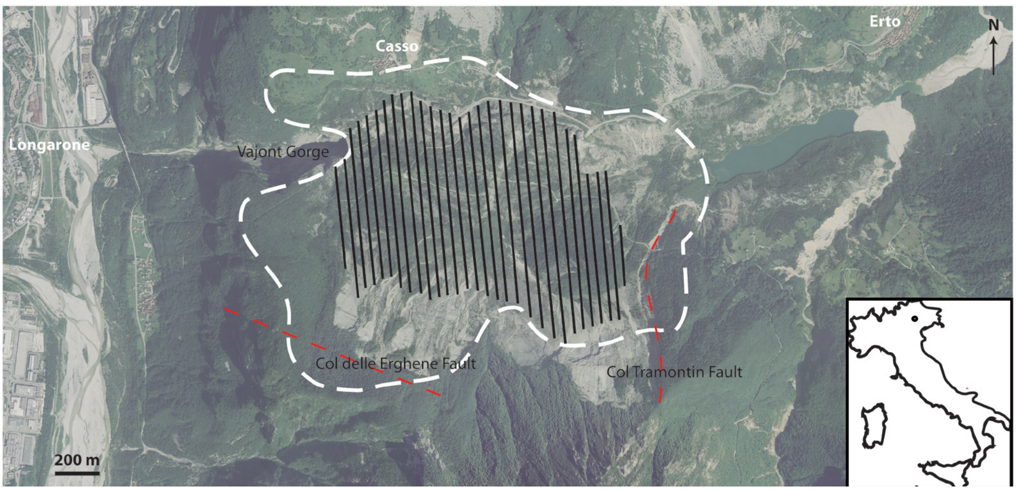

Fig. 3 - Map of field traverses spaced 50 m apart (black lines) within the mapping area (white dashed line). The two faults controlling the 1963 failure are indicated by red dashed lines. The inset shows the location of the Vajont Slide in northeastern Italy

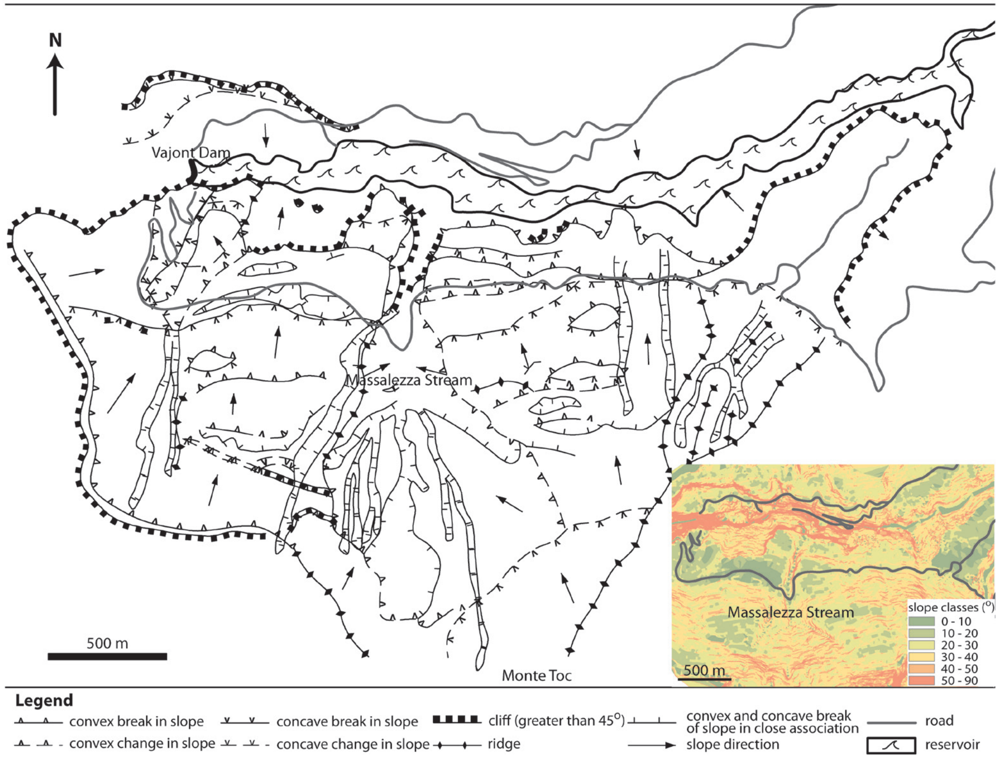

Fig. 4 - Pre-slide morphological map derived from the 1960 airphotos. Symbols represent changes in slope, as recommended by the Geological Society in London (1982). The inset is a slope map of the pre-1963 slide area. The sub-horizontal (green) areas are discussed in the text

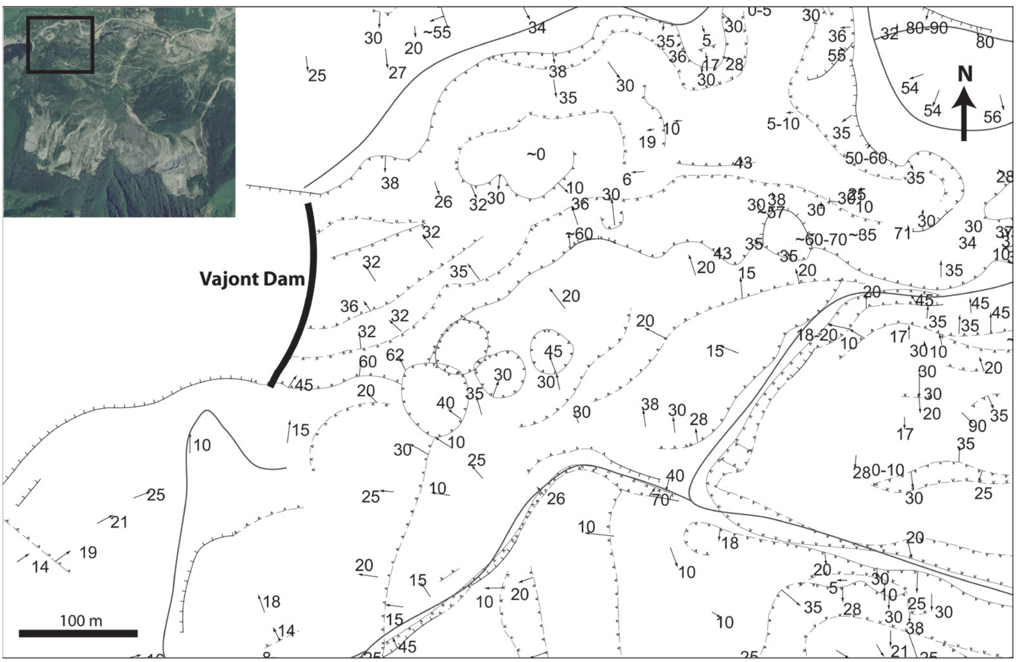

Fig. 5 - Part of the post-slide morphological map. The 2004 orthophotos are shown for reference. The inset shows the location of the mapped area. Symbols represent changes in slope (see Fig. 4)

River. Relict landforms such as eroded landslide deposits illustrate the palimpsestic history of the slope. The map also reveals several benches that we interpret to be products of the ancient landslide (Fig. 6). The largest bench, the Pian della Pozza, is about 500 m long and 300 m wide. The smallest bench, located at the east side of the headscarp of the 1963 failure, had an area of approximately 1300 m^2. The paleo-landslide appears hummocky on the airphotos, especially east of the Massalezza Gully. Our identification of the ancient landslide on the 1960 airphotos supports HENDRON & PATTON's (1985) statement that it could have been recognised before the catastrophic failure in 1963 had a thorough site assessment been conducted. The evidence is clear: hummocky ground, scarps, ridges, and active surficial landslides suggest previous as well as ongoing slope movement in 1960. Settlements, agriculture, horticulture, road construction, and dam construction have also modified the landscape, but it is unclear how extensively. For example, the pseudo-benches (with slopes between 10° and 20°) east of the Massalezza Gully system (indicated by 'p' on Fig. 6) have steeper slopes than the sub-horizontal benches west of the gully; they may be undulating topography or discrete blocks produced by the paleo-slide or flatter ground exploited for farming, homes, or cut-and-fill construction. Given the long history of settlement in the Vajont Valley, evidenced, for example, by remnants of Roman roads (HENDRON & PATTON'S, 1985; SEMENZA, 2001), any of these explanations is possible. The most likely explanation, however, is landsliding. The average elevations of some of the benches are similar, but it is unclear whether or not these benches were once connected, and have since been separated by the Massalezza Gully. Slope angles, however, suggest that most benches were not connected in the past. For example, the Pian della Pozza bench is sub-horizontal and tilts slightly into the slope, whereas the large pseudo-bench east of the Massalezza Gully dips down-slope. It is unlikely that these would have once been a single landform.

Several steep scarps attest to instability of the south Vajont Valley wall. Two of these scarps are WNW-ESE trending lineaments above the highest benches and coincide with the Col delle Erghene Fault. A third scarp

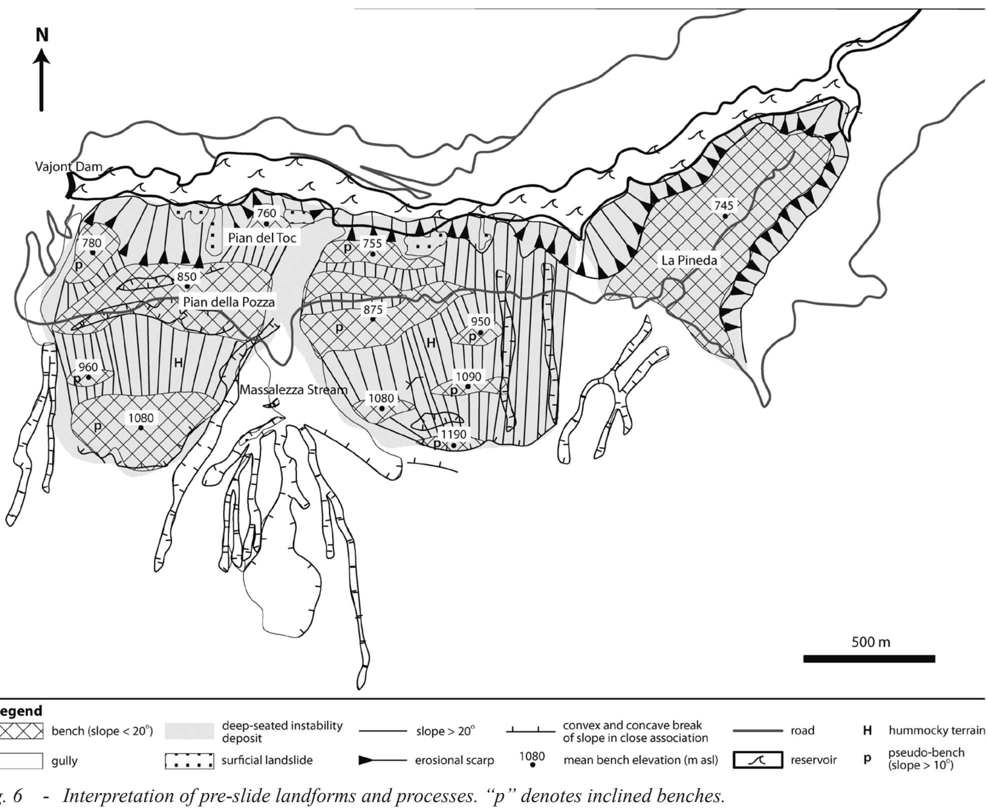

Fig. 6 - Interpretation of pre-slide landforms and processes. "p" denotes inclined benches.

is located just below the scarp east of the Massalezza Gully. Collectively, the three scarps approximately delineate the 1963 slide headscarp. Another, smaller scarp is located within the Pian della Pozza bench. It is likely a tension crack related to a slide in 1960.

A distinctive feature on the pre-1963 morphological map is the depressions in the palaeo-slide debris. The largest depression, located west of Massalezza Gully on the Pian del Pozza, comprises several semi-circular hollows. It is probably karstic in origin, and may have been exploited by the paleo-landslide and acted as a drainage sink. A similar cluster of semi-circular hollows is present near the western edge of the 1963 slide deposit (see below).

Relationships between the landforms identified on the pre-1963 morphogenetic map are complex. Several gullies appear to be relict, inactive features with mature vegetation. The Massalezza tributaries, however, remain active, with clear channel beds and evidence of gully wall erosion. The Massalezza Gully is either younger than the ancient slide, and has bisected an originally continuous deposit, or it could have acted as a lateral release to both the east and the west halves of the slide. The mouth of the gully may have failed, and the stream could subsequently have re-established its path. Another hypothesis is that the gully-slide relationship was the same as of the 1963 failure and gully: the gully could have failed with the slide, but remained intact (see below). The gully systems in the east are most likely associated with the Col Tramontin/Croda Bianca Fault zone. The surficial landslides at the toe of the slope appear fresh and are most likely related to fluvial undercutting and reservoir filling. The location of the November 1960 slide is apparent on the 1960 airphotos, which were flown before the failure.

The post-event morphogenetic map shows many of the same processes as the pre-event map. Gullying is common, but not in the same locations as before the catastrophic failure. The active gullies identified on the pre-event airphotos appear to be inactive on the 2004 orthophotos. Since 1963, gullies have formed in material that has moved down-slope. Talus cones located at the hinge of the Erto Syncline are associated with these gullies. The Vajont River no longer erodes the northern slope of Monte Toc behind the dam; it was redirected through the bypass tunnel constructed in 1961. Surficial landslides still occur along the deposit front and are especially common along the steep faces of the failure scar. In the field, we identified a relatively large new slide deposit that post-dates the 2004 imagery. Its source is the secondary scarp near the central lower portion of the failure scar east of the Massalezza Gully. The Col Tramontin Fault, which marks the east margin of the 1963 landslide, is another area of active erosion. A gully lies between the fault wall and the landslide debris and conveys sediment ranging in size from clay to boulders.

Other processes that have altered the 1963 landslide scar include piping, ponding, and road construction. Piping-related collapse is indicated by a cluster of circular depressions between 30 and 50 m in diameter and 10 to 20 m deep (Fig. 5) near the left side of the dam, which Semenza (1967) named “Costa dei Crateri”. These features appeared shortly after the 1963 slide and are still obvious today. Other smaller collapse features are scattered along the front of the deposit. Displacement wave water accumulated in a large depression behind the landslide front located at the hinge of the Erto Syncline between the failure scar and the deposit front. The so-called Massalezza Lake has since drained and partially infilled with sediment, leaving a wetland. Construction of the new road system has modified parts of the slide deposit.

IMPLICATIONS FOR THE 1963 FAILURE

The behaviour of the Vajont Slide can be inferred from its morphology. The intact nature of the displaced mass is evident from similarities in the pre- and post-event topography: benches and other features that can be seen on the 1960 photos are preserved, although displaced, on the post-event imagery. In particular, preservation of the Massalezza Gully within the 1963 slide deposit suggests a rigid displaced body that must have slid on a relatively thin, weak layer, rather than fragmenting. The hypotheses that the 1963 slide was a reactivation of an old slide and that clay interbeds in the rock slope were at residual strength at failure are supported by this geomorphic evidence.

As Hendron & Patton (1985) described, the east half of the landslide is morphologically and behaviourally different from the west. The slide block on the east is hummocky with curvilinear ridges and depressions that contain ponds (Fig. 7). The material forming this block was compressed, and its location above the rest of the displaced mass indicates that it moved after the

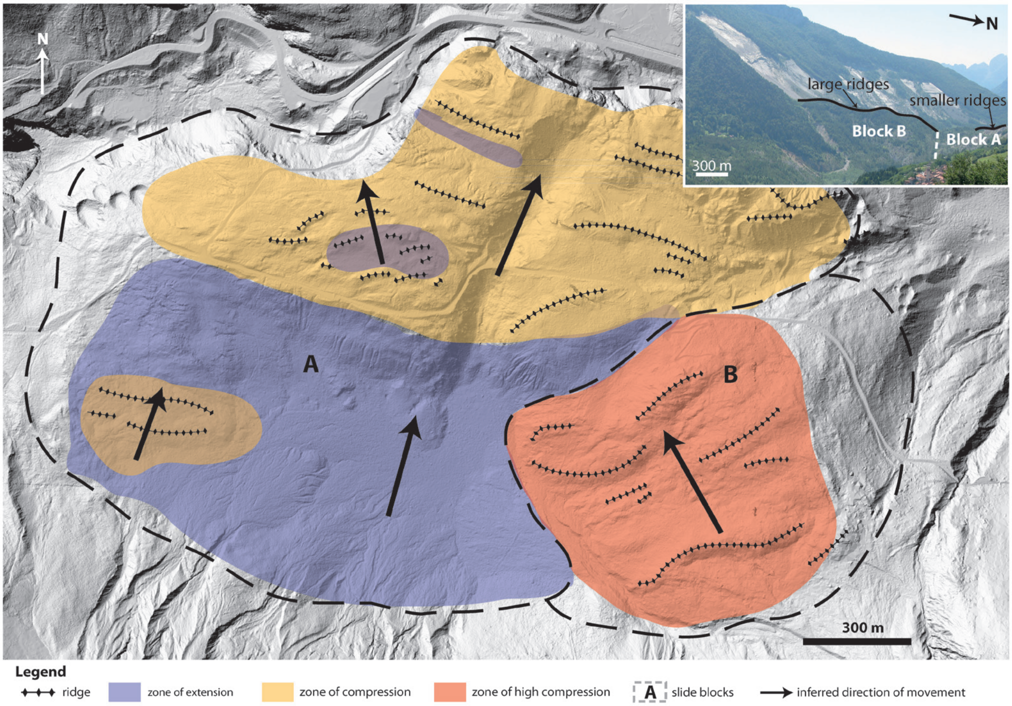

Fig. 7 - Compression and extension regions within the 1963 slide deposit, based on the distribution of ridges. Block B overrode Block A and is especially compressed. Slide directions are assumed to be perpendicular to ridge axes. The Massalezza Gully remained intact within Block A during sliding. Inset shows the difference in size of some of the ridges in Block B versus Block A, looking at the east margin of the slide from above Erto

main block to the west. The morphology of the failure scar supports this interpretation -- the eastern portion of the scar is rougher than the western area; the roughness may have inhibited motion in the east until the west block moved, providing kinematic freedom. SUPERCHI (2012) suggested that two main blocks were involved in the 1963 event, consistent with our interpretation. Field observations suggest a possible third block originating at the west corner of the failure surface. The failure scar here is bounded by a ridge at its west margin, suggesting a bulldozing motion to the northwest. Striations on the failure scar that plunge toward the northwest also indicate movement differing from the dominant direction of movement. Tentatively, this could be evidence of a block that separated from the main mass. Conversely, the northwest movement could be due to expansion of the material as it failed.

WOLTER *et alii* (in review) briefly discuss the 1963 slide deposit and the evolution of the failure scar. Our morphogenetic maps complement and supplement this work. The present failure scar consists of four elements: exposed bedrock, vegetated areas, coarse debris, and fine debris (Fig. 8). The failure zone consisted of coarse and fine debris and few areas of bedrock immediately after the event (Fig. 8). The coarser debris visible today appears to be older and more stable than the fine debris. The vegetated areas are also more stable than the fine debris and represent either blocks of material that remained intact during the 1963 slide or more cohesive blocks that were easily revegetated.

Finally, the surface morphology of the slide debris allowed us to identify zones of compression and extension (Fig. 7). The most obvious zone of extension is the depression behind the front of the deposit, roughly parallel to the axis of the Erto Syncline, where the Massalezza Lake formed. As already mentioned, the east block is hummocky with transverse ridges, suggesting compression. These ridges are up to several metres high and several tens of metres long. In contrast, ridges near the front of Block A are smaller, suggesting that the block was compressed, but not to the same extent as the eastern block. Two depressions within the front of Block A are illustrated, indicating zones of local extension within the larger compressed zone. Ridges also indicate

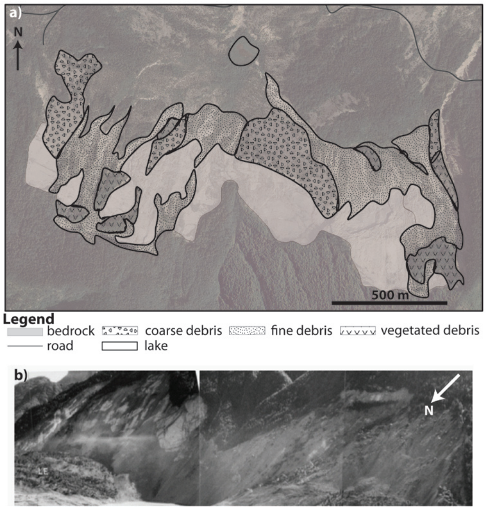

Fig. 8 - Evolution of the 1963 landslide scar. a) Map of surficial materials on the failure scar in 2010/2011. b) Photograph of the Vajont Slide area immediately after the 1963 failure. Note that most of the slide scar is covered by debris, especially on the west (photo: Semenza, 1964)

directions of movement of different parts of the debris mass. The east block likely moved to the NW. The ridges in the west block are less consistent, but generally suggest movement to the north. The west-central area seems to have moved to the NW, which may show a secondary failure rather than initial movements. Superchi (2012) hypothesises similar movements using vectors derived from pin points.

PRECONDITIONING FACTORS OF THE 1963 VAJONT SLIDE

The significance of the interaction between tectonic and geomorphic, or endogenic and exogenic, processes to slopes has only recently been recognised. Leith (2012) summarises this relationship within the context of geomorphology, rock engineering, and slope instability and applies it to two valleys in the southern Swiss Alps. The Vajont Slide also exemplifies the preconditioning of slopes related to their tectonic and geomorphic histories. Both tectonic deformation episodes and geomorphic processes have contributed to the cumulative damage, or degradation, of the rock mass on the north slope of Monte Toc. Faults have weakened the rock mass and acted as release surfaces for the slide. Two episodes of deformation produced folds that interfered with one other, producing a complex topography of basins and domes that had to be overcome, either by dilation or shearing through asperities, before catastrophic release was possible. The failure scar is a prime example of this complex interaction. Wolter *et alii* (in review) produce a preliminary classification of failure scar morphology based on a combination of photogrammetry, LiDAR, and field datasets, with classes ranging from very smooth and planar to very rough and crenulated. The rough areas of the failure scar, related mainly to the interference between the two dominant fold generations, likely inhibited movement, whereas the smooth regions likely facilitated movement. Geomorphological processes have preconditioned the slope for failure as well. Glaciers likely differentially eroded the hinge of Erto Syncline and oversteepened the valley walls. Rivers have incised the valley, locally creating steep slopes prone to failure. Surficial mass wasting has unloaded the slope, and several deep-seated failures have dramatically changed the topography and dammed the Vajont River. Karst processes have eroded carbonate bedrock and created pinnacles and dolines, and karst networks may have allowed groundwater transport to the failure surface from outside the surface drainage basin. Precipitation has infiltrated rock masses and locally elevated pore water pressures. Finally, anthropogenic activity has further destabilised valley walls, notably repeated filling and drawing down of the Vajont Reservoir between 1960 and 1963. Combined, the long- and short-term processes acting in the valley have influenced the geomorphic stress path of the slope, culminating in the catastrophic failure of 1963.

CONCLUSIONS

We interpreted the geomorphology of the 1963 Vajont Slide and the surrounding area using an engineering geomorphology approach. The morphological and morphogenetic maps revealed several aspects of the slide that support other research:

- a paleo-landslide is located in the same place as the 1963 failure,
- the 1963 slide consisted of two main blocks, with a possible third at the west corner of the slide area,
- the failed blocks remained largely intact during the slide, as shown by preservation of the Massalezza Gully and pre-existing benches, and
- tectonics, geomorphology, and anthropogenic activity interacted with one another, contributing to a time-dependent reduction in the stability of the south slope of Vajont Valley and ultimately to the 1963 failure.

ACKNOWLEDGEMENTS

We acknowledge contributions from our colleagues R. Genevois, M. Massironi, L. Superchi, and L. Zorzi at the University of Padova, M. Ghirotti and D. Donati at the University of Bologna and J. Griffiths at University of Plymouth. LiDAR data were provided by the Friuli-Venezia-Guilia Region. Research was funded through a Natural Sciences and Engineering Research Council of Canada (NSERC) Post-graduate Scholarship to A. Wolter and NSERC Discovery Grants to D. Stead and J.J. Clague.

REFERENCES

Broili L. (1967) - *New knowledges on the geomorphology of the Vaiont Slide slip surfaces.* Felsmechanik und Ingenieurgeologie, **5** (1): 38-88.

Carloni G.C. & Mazzanti R. (1964a) - *Rilevamento geologic della frana del Vaiont.* Giornale di Geologia, **32**: 105-138.

Carloni G.C. & Mazzanti R. (1964b) - *Aspetti geomorfologici della frana del Vaiont.* Rivista Geografica Italiana, **71**: 201-231.

Castiglioni B. (1940) - *L'Italia nell'età quaternaria. Carta delle Alpi nel Glaciale (1:200 000 scale).* In: Dainelli G. (Ed.). *Atlante Fisico-economico d'Italia.* C.T.I., Milano. Tav. 3.

Coppola L. & Bromhead E.N. (2008) - *Fossil landslide dams and their exploitation for hydropower in the Italian Dolomites.* Italian Journal of Geosciences, **127** (1): 163-171.

Fookes P.G., Lee E.M. & Griffiths J.S. (2007) - *Engineering geomorphology: theory and practice.* Whittles Publishing, Caithness, Scotland, 281 pp.

Fookes P.G., Lee E.M. & Milligan G. (2005, Eds.) - *Geomorphology for engineers.* Whittles Publishing, Caithness, Scotland, 851 p.

Geological Society in London (1982) - *Working Party Report on land surface evaluation for engineering purposes.* Quarterly Journal of Engineering Geology, **15** (4): 265-328.

Giardino J.R. & Marsten R.A. (1999) - *Engineering geomorphology: an overview of changing the face of earth.* Geomorphology, **31**: 1-11.

Giudici F. & Semenza E. (1960) - *Studio geologic del serbatoio del Vajont. Report for Societa Adriatica di Elettricita (SADE).* Venice, Italy. 63 pp.

Griffiths J.S., Stokes M., Stead D. & Giles D. (2012) - *Landscape evolution and engineering geology: results from IAEG Commission 22.* Bulletin of Engineering Geology and the Environment, **71**: 605-636.

Guerricchio A. & Melidoro G. (1986) - *Geomorphological analysis of Vaiont Valley prior to the huge 1963 landslide.* In: Semenza E. & Melidoro G. (Eds.). Proceedings of the Meeting on the 1963 Vajont Landslide, Universita di Ferrara, Italy: 157-173.

Hendron A.J. & Patton F.D. (1985) - *The Vaiont Slide: a geotechnical analysis based on new geologic observations of the failure surface.* US Army Corps of Engineers, Washington, DC, Technical Report GL-85-5, 324 pp.

Leith K.J. (2012) - *Stress development and geomechanical controls on the geomorphic evolution of alpine valleys.* PhD thesis, ETH Zürich, Switzerland, 167 pp.

Paronuzzi & Bolla A. (2012) - *The prehistoric Vajont rockslide: An updated geological model.* Geomorphology, **169-170** (1): 165-191.

Rossi D. & Semenza E. (1964) - *Relazione definitive sulle condizioni di stabilita della Costa delle Ortiche (Vaiont).* Unpublished report for Ente Nazionale per l'energia ELettrica (ENEL).

Rossi D. & Semenza E. (1965) - *Carte geologiche del versante settentrionale del M. Toc e zone limitrofe, prima e dopo il fenomeno di scivolamento del 9 ottobre 1963, Scale 1:5000.* Istituto di Geologia dell'Universita di Ferrara.

Selli R. & Trevisan L. (1964) - *Caratteri e interpretazione della frana del Vaiont. Giornale di Geologia,* **32**: 1-154.

Semenza E. (1967) - *Sintesi degli studi geologici sulla frana del Vaiont dal 1959 al 1964.* Museo Tridentino di Scienze Naturali, Trento, Italy, 50 pp.

Semenza E. (2001) - *La storia del Vajont, raccontata dal geologo che ha scoperto la frana.* Tecomproject Editore Multimediale, Ferrara, 280 pp.

Superchi L. (2012) - *The Vajont Rockslide: new techniques and traditional methods to re-evaluate the catastrophic event.* PhD thesis, Universita degli Studi di Padova, Italy, 187 pp.