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THE 1963 VAJONT LANDSLIDE (NORTHEAST ALPS, ITALY) POST-CONFERENCE FIELD TRIP (OCTOBER 10TH, 2013)

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ABSTRACT

The post-conference field trip focuses on the Vajont reservoir landslide, one of the best known examples of disasters induced by human activity; it offers the possibility to appreciate the complexity both of the surrounding area and of the particular geological, structural and geotechnical features of the landslide. The Vajont reservoir is located in the SE part of the Dolomite Region of the Italian Alps, about 100 km north of Venice. The doubly curved arch dam stands 265.5 metres above the valley floor and was the world's highest thin arch dam when it was built. On October 9th, 1963, during the third filling of the reservoir, a mass of approximately 270 million m^3 detached from the left side of the valley and slid into the water at velocities up to 30 m/sec. A wave subsequently overtopped the dam by 250 m and swept into the Piave Valley below, resulting in approximately 2000 deaths. The sliding lasted less than one minute and produced seismic shocks, which were recorded throughout Europe. Remarkably the dam remained intact. The landslide moved mainly along a chair-shaped failure surface, which corresponded to a pre-existing slip surface as recognized before 1963 by E. Semenza. The 1963 slip surface was confined within 0.5–18 cm thick clay-rich layers, which were almost continuous over large areas of the failure surface. The landslide was characterized by a long-term phase of accelerating creep lasting 2–3 years followed by the catastrophic failure.

Key words: Vajont Slide, stratigraphy, tectonics, geomorphology

INTRODUCTION

GEOLOGY OF THE BELLUNO BASIN AND THE SOUTHERN ALPS

The Southern Alps are a large structural unit of the Alpine chain located in Northern Italy (Fig. 1a). To the North, the Southern Alps are separated from the main body of the Alps by the major tectonic Periadriatic Line. To the South, the crystalline and sedimentary rocks of the Southern Alps are buried by the alluvial sediments of the Po Plain. Along the Southern Alps, which extend for about 700 km in an E-W direction, a tilted, nearly

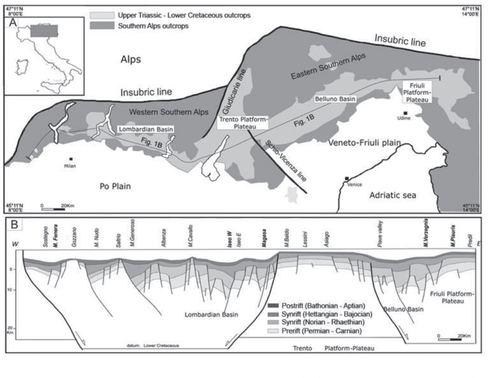


Fig. 1 - *a) The Mesozoic structural domains in the Southern Alps; b) the extensional Mesozoic architecture of the Southern Alps at the end of the Early Cretaceous (redrawn and modified after Bertotti et alii, 1993; in Fantoni & Scotti, 2003 for the western and eastern sectors)*

complete, crustal section is exposed (Fig. 1b). At the westernmost end, deep continental crust rocks of the Ivrea-Verbano Zone outcrop, while Mesozoic-Cenozoic sedimentary covers characterize the eastern sector. The sedimentary cover of the Southern Alps is considered a well-preserved section of the southern (Apulian) continental margin of the Mesozoic Tethys, characterized by a horst and graben structure inherited from the rifting associated with the opening of the basin in the central North Atlantic. The rifting phase took place in the late Triassic (Rhetic) and the Early Jurassic and created high-standing blocks separated by troughs. The western sector of the margin (Piedmont and Lombardy) was rapidly flooded in the Early Liassic. In the eastern Southern Alps three paleogeographical-structural units are recognizable. These are, from west to east (Winterer & Bosellini, 1981): a carbonate platform, which was flooded in the Early Jurassic, evolving into a pelagic plateau with condensed sedimentation during the Late Jurassic (Trento Platform/Plateau) and bordered to the west by the Lombardy Basin; a basin that developed in the Early Jurassic (Belluno Basin); and a carbonate platform that persisted from the Jurassic till the Cretaceous (Friuli Platform).

THE BELLUNO BASIN

The birth of the Belluno Basin is linked to Early Jurassic rifting that generated a fault system roughly oriented N–S (Masetti & Bianchin, 1987). The faults cut the wide peritidal platform where the Dolomia Principale was deposited, and separated areas with different subsidence rates. To the west, shallow-marine calcarenites, corresponding to a marginal facies of the Calcari Grigi Group accumulating in the Trento Platform, were deposited; in the east, dark cherty, basinal micrites (Soverzene Formation) accumulated during Hettangian–Pliensbachian time (Fig. 2). The pervasive dolomitization at the Triassic–Jurassic boundary, which affected the oldest stratigraphic units of the Belluno Basin, prevents accurate dating of this particular paleogeographic unit of the Southern Alps. Nevertheless, based on data in the Carnian Prealps, which represent the north-eastern extension of the Belluno Basin and where sediments are free from heavy dolomitization, the birth of the Belluno Basin can be ascribed to the Triassic–Jurassic boundary interval or even to the late Triassic.

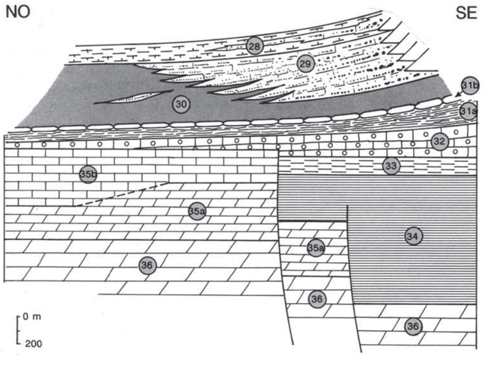


Fig. 2 - Stratigraphic relationships of Mesozoic units outcropping in the Belluno Basin. 36-Dolomia Principale; 35-Calcari Grigi, a) dolomitized, b) not dolomitized; 34-Soverzene Formation; 33-Igne Formation; 32-Vajont Limestone; 31a-Fonzaso Formation; 31b-Rosso Ammonitico; 30- Biancone; 29- Soccher Limestone; 28-Scaglia Rossa (from Costa et alii, 1996)

SOVERZENE FORMATION (HETTANGIAN-PLIENSBACHIAN; 600 METRES THICK)

This unit is about 600 m thick and is made of grey and brown micrites that are commonly dolomitized, are well stratified with beds 20-40 centimetres thick, and alternate with thin levels of grey and yellow marls. The carbonate mud is a mixture of pelagic sediment and fine-grained material derived from the surrounding carbonate platforms (peri-platform oozes). Black chert nodules are present, as are fossils of the *Zoophycos and Chondrites ichnogenera*. The lower half of the unit is completely dolomitized and virtually devoid of cherts; its uppermost portion constitutes a characteristic horizon of white nodular calcarenites containing a rich fauna of Ammonites and Aulacoceras (Masetti & Bianchin, 1987). Many unconformable bodies of breccia, consisting of cherty clasts embedded in dolomicrite, cut the Soverzene Formation and the overlying Vajont Limestone. According to Zempolich & Hardie (1997) the emplacement of these bodies could be related to in situ fracturing of the rock by means of late hydrothermal dolomitizing fluids.

IGNE FORMATION (TOARCIAN-BAJOCIAN; 0 TO 150 METRES THICK)

The formation is characterized by considerable lithological heterogeneity. The succession, from bottom to top, is as follows: a basal unit of alternating marls and grey limestones with individual layers of 50 cm thickness; a middle unit of laminated black shales and Manganoan carbonates, recording the Early Toarcian oceanic anoxic event in the Belluno Basin (Jenkyns & Clayton, 1986); and an upper unit of nodular limestones in the Rosso Ammonitico facies corresponding to the Hildoceras bifrons Zone, H. sublevisoni Subzone (Lower Toarcian) (Jenkyns *et alii,* 1985). The upper boundary of the Igne Formation is an erosional surface carved by oolitic turbidites of the Vajont Limestone. In some areas these erosive events obliterated the formation.

VAJONT LIMESTONE (LATE BAJOCIAN- BATHONIAN; 450 METRES THICK)

One of the peculiar features of the Belluno Basin is represented by the Vajont Limestone, composed of oolitic sands and biogenic skeletal debris deposited by means of gravity-flow processes that transferred material from the western edge of the Friuli Platform into slope and basin environments (Bosellini & Masetti, 1972). This resedimented material consists of thick beds of oolitic calcarenites intercalated with brown basinal micrites and breccia formed by clasts ripped-up from basinal micrites. Nodules of brown chert can be locally present. The age of the Vajont Limestone has been revised by Cobianchi (2002) using nannofossil biostratigraphy performed on several sections spanning the whole Toarcian–Tithonian interval. On the basis of this study, the age of the Vajont Limestone falls into the late Bajocian–Bathonian interval, since the topmost part of the underlying Igne Formation belongs to the late Bajocian and the base of the overlying Fonzaso Formation is Callovian. During the Middle Jurassic, deposition of the Vajont Limestone progressively levelled the tectonically controlled submarine relief of the Belluno Basin.

FONZASO FORMATION (CALLOVIAN-OXFORDIAN; 10 TO 40 METRES THICK)

Gnaccolini (1968) named the succession between the Vajont Limestone and the Scaglia Rossa the Soccher Limestone. However, the classic units called the Fonzaso Formation, Rosso Ammonitico and Biancone in the Veneto area can be identified within this unit. For this reason we preferred to adhere to the old formational terms, using 'Soccher Limestone' only for the Cretaceous succession, well-known everywhere as Biancone. The Fonzaso Formation is formed by an intercalation of thin beds of fine-graded biocalcarenites with parallel and oblique laminations and dark micrites very rich in chert. The micrite microfacies is characterized by radiolaria, often siliceous, and thin-shelled pelagic pelecypods; the calcarenites come from the Friuli Platform and contain neritic grains and fossils. The cherty carbonate beds are intercalated with green clay layers 0.5-18 cm thick, which acted as planes of weakness in the movement of the Vajont landslide (Fig. 3). These clay layers have been interpreted by Bernoulli & Peters (1970) as volcanic ash deposits widespread in the Eastern Southern Alps. The formation does not record important changes in depositional environment

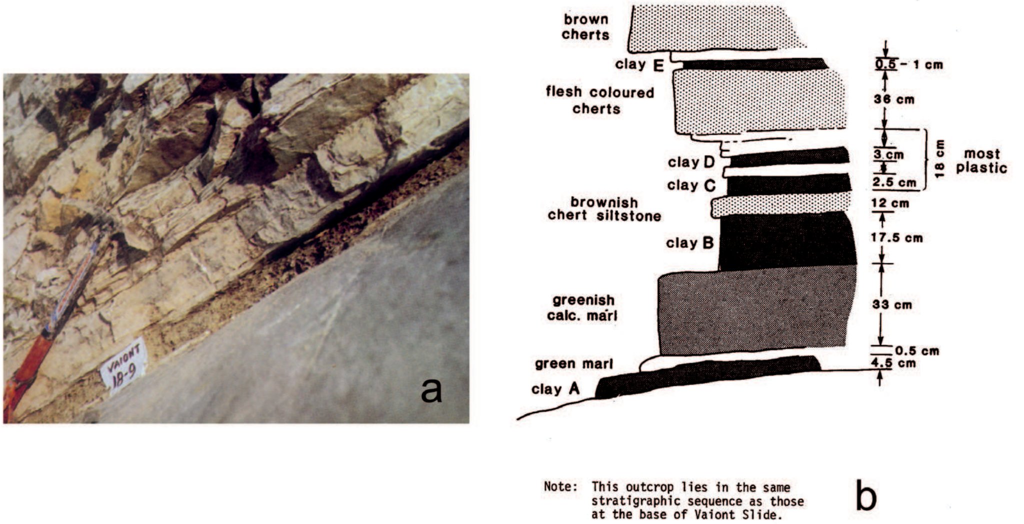


Fig. 3 - a) Clay interbeds outcropping on the sliding surface; b) sketch of the Fonzaso Fm. outcropping southwest of Casso (from Hendron & Patton, 1985)

compared to the Vajont Limestone: the most important variations are related to the quantity (smaller) and to the quality (bioclastic grains instead of oolites) of the turbidites coming from the Friuli Platform.

ROSSO AMMONITICO (OXFORDIAN-TITONIAN; 5 -15 METRES THICK)

The Fonzaso Formation grades upwards into nodular, micritic red limestones similar to the Rosso Ammonitico Veronese (Upper Member, Upper Kimmeridgian to Lower Tithonian). This unit consists of reddish and grey, thick-bedded, nodular micritic limestones, different only in colour from the classic facies outcropping westward, in the Veneto area. This formation is virtually devoid of resedimented deposits and the microfacies is characterized by peloidal pelagic micrites bearing Saccocoma.

SOCCHER LIMESTONE (CRETACEOUS P.P.; 150 METRES THICK)

The Early Cretaceous palaeogeographic scenario is characterized by an eastern, shallow-water domain of the Friuli Platform facing the western, deep-sea area including the Lombardy Basin, the Trento Plateau, and the Belluno Slope (Fig. 2). At the end of the Jurassic and during the Early Cretaceous, while shallow-water sedimentation persisted on the Friuli Platform, the deep-sea region of the Southern Alps was blanketed by calcareous pelagic oozes, mostly consisting of nannofossils. These white mudstones have been called Maiolica in Lombardy and Biancone in the Venetian region. The present-day Vajont Valley represents the base of the slope connecting the top of the Friuli Platform to the basin floor. As clearly depicted in Fig. 2, along the slope and at its base the pelagic, micritic sediment (Biancone) was interlayered with resedimented calcarenites and calcirudites coming from the Friuli Platform. This close intercalation of pelagic micrites and resedimented calcarenites, not present in the Biancone formation, represents the Soccher Limestone. As mentioned above, this formational term has been used here only for the Cretaceous succession. The fine-grained deposits are made of thin-bedded cherty limestones and grey, red, or greenish marls. These limestones are locally nodular, exhibiting facies of Rosso Ammonitico (Castellavazzo Marble). The presence of many slump scars in the Soccher Limestone is further evidence that the deposition of this unit took place along the slope of the Friuli Platform.

SCAGLIA ROSSA (UPPER CRETACEOS P.P. – LOWER PALEOCENE P.P.; ABOUT 300 METERS THICK)

Red marls and red marly limestones, completely devoid of resedimented deposits in the typical facies of Scaglia. This formation records the levelling-up of the pre-existing articulated topography.

FLYSCH (EOCENE; ABOUT 200 METRES THICK)

A thick succession of turbiditic arenites interlayered with grey marls. The coarse fraction is represented by calcarenites passing to grey or yellow litharenites.

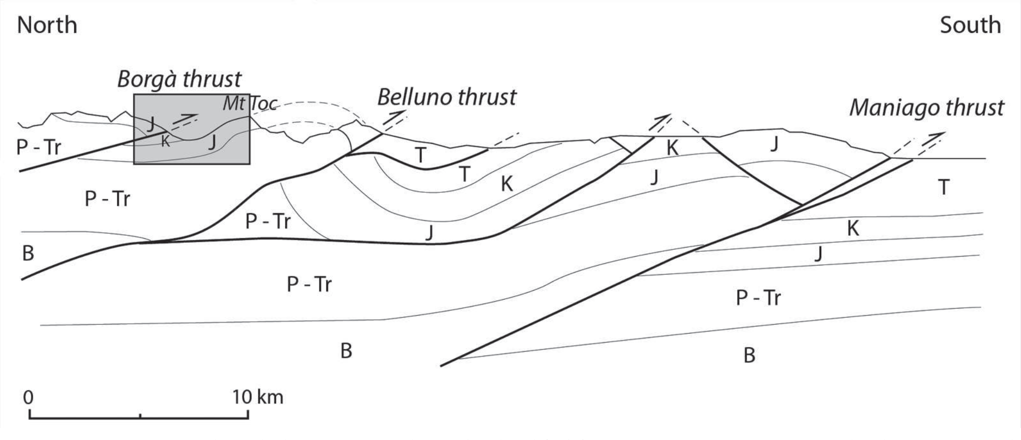


Fig. 4 - Cross-section through the eastern Southern Alps (modified from Doglioni & Carminati, 2008). The grey rectangle shows the Erto Syncline. Legend: B = crystalline basement; P – Tr = Permian-Triassic; J = Jurassic; K = Cretaceous, T = Tertiary

TECTONICS OF THE VAJONT VALLEY

The Vajont Valley follows the core of an Alpine syncline (Erto Syncline) with an E-W to WNW-ESE trending axis (Ferasin, 1965; Riva *et alii,* 1990) gently plunging towards the E (Broili, 1967). The Erto Syncline lies on the hanging wall of the Belluno Thrust, a main structure of the Venetian south-vergent Alps (Doglioni & Carminati, 2008) and it is paired with the frontal asymmetric anticline (Belluno Anticline) (Fig. 4). The northern limb of the Erto Syncline (north side of the valley) is reversed and stretched by the Mt. Borgà Thrust, an older thrust passively transported on the back of the Belluno Thrust.

The Vajont landslide reworked a paleo-landslide covering the northern slope of the Mt. Toc (Giudici & Semenza, 1960; Semenza, 2010). Mt. Toc is structurally located on the southern flank of the Erto Syncline and is enclosed between two N-S to NNW-SSE striking and downward converging reverse fault systems (Croda Bianca-Col Tramontin system and Col delle Tosatte Fault). This peculiar structural setting has led to the newly recognized N-S trending Massalezza Syncline (Massironi *et alii*, this volume), which accounts for an overall concave shape of the sliding surface and the two distinct lobes of the Vajont landslide. The sliding mass was furthermore laterally constrained by a system of subvertical faults (Croda Bianca and Col Tramontin Lines to the east and west branch of the Col delle Erghene Line to the west), while the rockslide crown was constrained by E-W structures (Col delle Erghene Line; Riva *et alii,* 1990).

FIELD TRIP STOPS

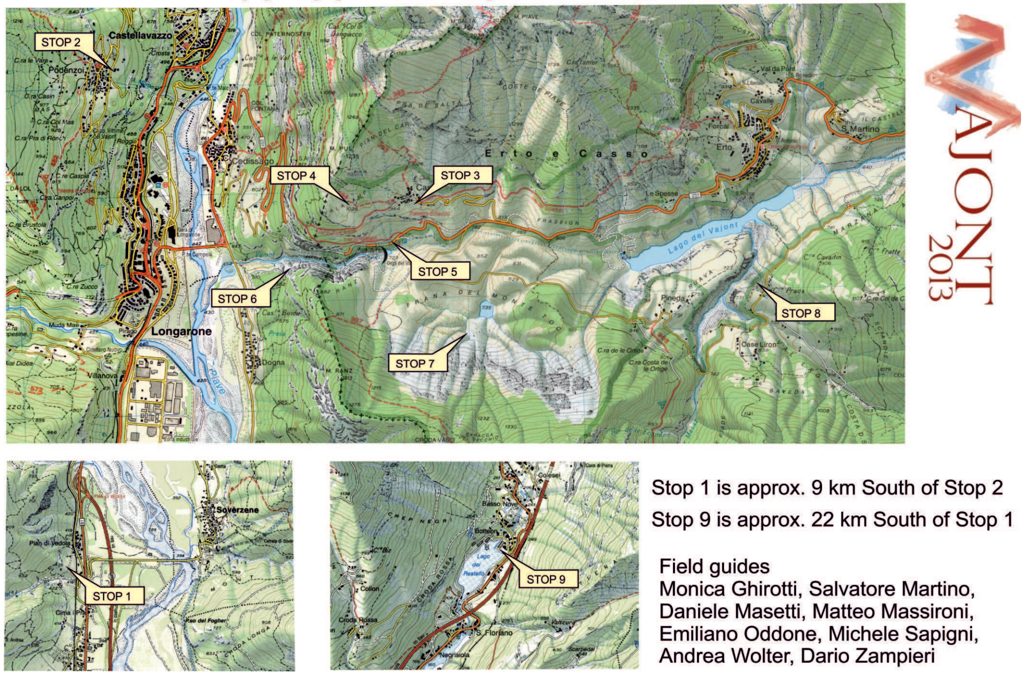
The stops on the field trip (Fig. 5) cover the geology, stratigraphy, tectonics and geomorphology of the Vajont Valley and their controlling effects on the 1963 landslide. Part of the field trip is dedicated to the main structures that led to the development of and interference between the Erto and Massalezza synclines, as well as to their possible controlling effects on the 1963 sliding event, and part to geomorphological features of large prehistoric landslides that dammed the valley.

STOP 1

PIAN DI VEDOIA: PANORAMIC VIEW OF THE BELLUNO THRUST HANGING WALL.

Fig. 6 shows a view of the mouth of the Piave Valley taken from Pian di Vedoia, on the right side, about

POST-CONFERENCE FIELD TRIP MAP



Stop 1 is approx. 9 km South of Stop 2
Stop 9 is approx. 22 km South of Stop 1

Field guides
Monica Ghirotti, Salvatore Martino,
Daniele Masetti, Matteo Massironi,
Emiliano Oddone, Michele Sapigni,
Andrea Wolter, Dario Zampieri

Fig. 5 - Field trip map

3 km north of Ponte nelle Alpi. To the right, Mt. Dolada corresponds to the forelimb of the Belluno anticline, associated with the south-verging Belluno thrust. In the background (to the left), the Mt Borgà Thrust outcrops on the right side of the Vajont Valley.

STOP 2

PODENZOI: THE LEFT SIDE OF THE PIAVE VALLEY

Panoramic view of the left side of the Piave Valley (Fig. 7). In the upper part of the slope the southern limb of the Erto Syncline and the Vajont sliding surface are prominent. In the lower part of the slope the Col delle Tosatte Fault is seen. It is a west-verging reverse fault cutting the base of the Erto Syncline (see Stop 6).

STOP 3

CASSO: SIGHT OF THE LANDSLIDE

From the village of Casso, just in front of the slide, we can appreciate the entire landslide. The landslide involved Jurassic and Cretaceous rocks (limestones and marls) with varying degrees of fracturing. Movement occurred along a chair-shaped failure surface in part corresponding to a pre-existing slip surface at or close to residual strength as indicated by the geological evidence recognized before 1963 (Semenza & Ghirotti, 2000). The failure zone was largely confined to 0.5-18 cm thick clay-rich layers (Hendron & Patton, 1985) that were observed to be continuous over large areas of the failure surface. Geological and tectonic evidence suggests that both the 1963 landslide and the prehistoric one are limited by one or more faults (Hendron & Patton, 1985).

During the third reservoir emptying operation, the northern slope of Mt. Toc failed suddenly over a length of 2 km and a surface area of 2 km^2. The slide moved a 250 m thick mass of rock some 300 to 400 m horizontally (Fig. 8a) with an estimated velocity of 20 to 30 m/s, before running up and stopping against the opposite side of the Vajont Valley. The majority of the slide moved as a whole and reached the opposite side of the valley without any change in shape apart from a general rotation evident from both the surface morphology and the stratigraphical sequence that remained essentially unchanged after the movement (Fig. 8b). Giudici & Semenza (1960) discussed the geology in detail and put forward the hypothesis of the existence of a very old landslide on the left bank of the Vajont reservoir area. During their surveys they discovered a highly fractured zone ("mylonite") extending about 1.5 km along the left side of the valley corresponding to the sliding plane of the prehistoric landslide (Ghirotti, 2012). Nevertheless, the dam designers concluded that a deep-seated landslide was very unlikely to occur, mainly because of both the asymmetric form of the syncline, which was expected to act as a natural obstacle for possible slope movements, and the good quality of in situ rock masses, as derived from seismic surveys (Müller, 1964, 1968, 1987).

STOP 4

CASSO: THE CLAY INTERBEDS OF THE FONZASO FM

Today, it is generally agreed that 1963 failure occurred mostly along planes of weakness represented by clay-rich interbeds (Fig. 3) within the Fonzaso Formation (Hendron & Patton, 1985; Tika & Hutchinson, 1999; Ferri *et alii*, 2011). However, the continuity and the existence itself of clay interbeds in the calcareous sequence repre-

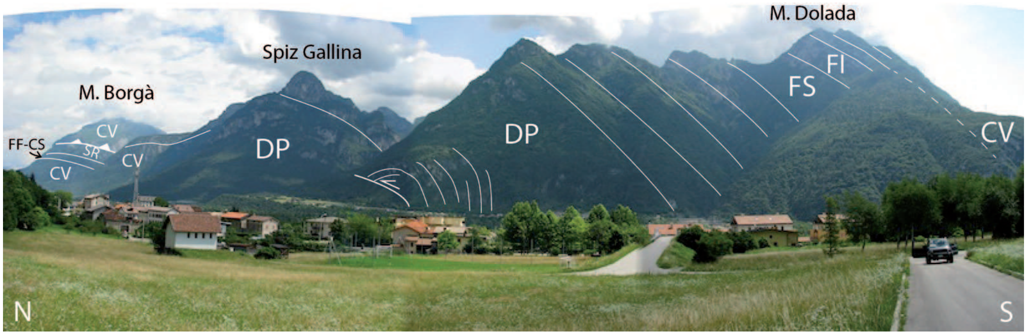


Fig. 6 - *View of the mouth of the Piave Valley taken from Pian di Vedoia. Legend: DP = Dolomia Principale (Upper Triassic); CV = Vajont Limestone (Middle Jurassic); FF = Fonzaso Fm + Rosso Ammonitico (Middle-Upper Jurassic); CS = Soccher Limestone (Cretaceous); SR = Scaglia Rossa (Upper Cretaceous-Lower Tertiary) (Photo by D. Zampieri)*

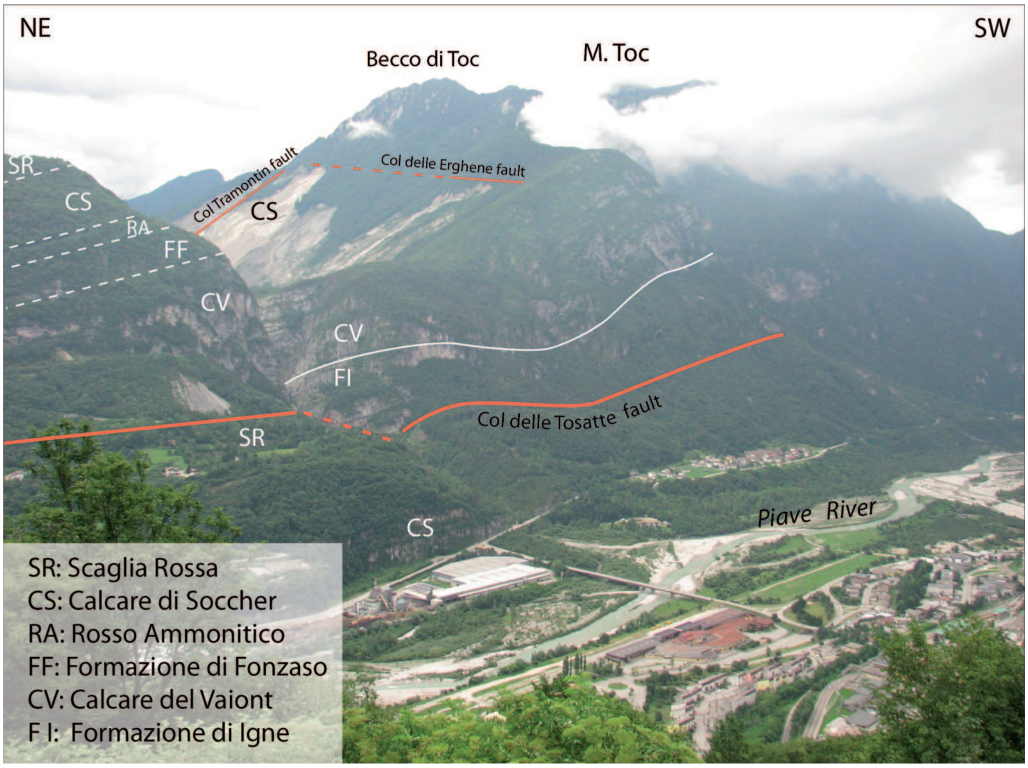


Fig. 7 - Panoramic view of the left side of the Piave Valley, overlooking Longarone (Photo by D. Zampieri)

sented a controversial aspect for many decades. The statement that "*...the succession does not include any clay beds or intercalations which some authors consider may have been responsible for some aspects of the phenomenon*" (Müller, 1968) was definitively dismissed only after 1985 with the work of Hendron & Patton (1985). For these authors, the increase in pore water pressure due to the raising of the water level in the reservoir caused a decrease in effective normal stress, favouring the sliding on these clay layers characterised by a residual friction angle φ_r between 8° and 10°. Clay interbeds are well exposed in an outcrop southwest of Casso.

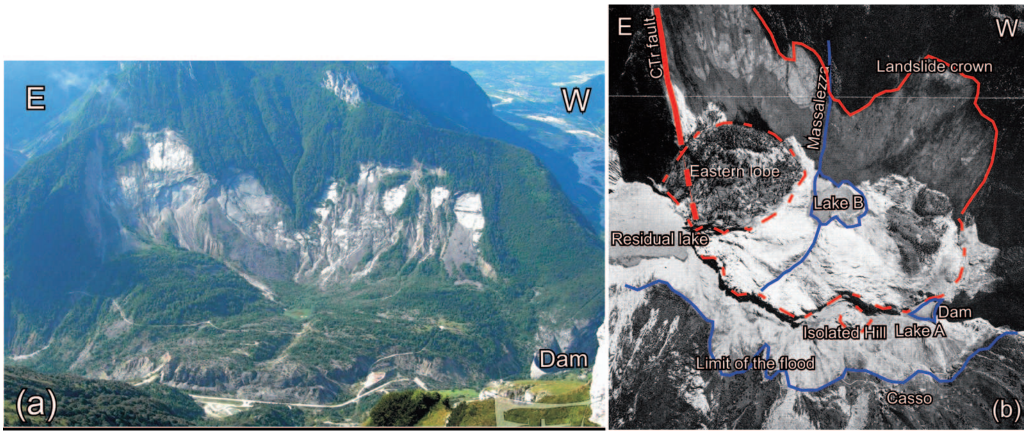


Fig. 8 - a) The failure scar and the deposit of the 1963 slide (Mount Toc behind) (from Ghirotti, 2012); b) aerial photo few days after the slide: toponyms are highlighted (modified after Selli et alii, 1964)

STOP 5

WALK ON THE CROWN OF THE DAM

The walk on the crown of the Vajont Dam (constructed between 1957 and 1960) gives the possibility to observe the dam itself, which was at that time the highest thin arch dam in the world. The doubly curved, 265.5 m-high arch dam (Fig. 9) has abutments anchored in the steep flanks of the deep canyon that cuts limestones of Malm and Dogger age. The planned full reservoir capacity was a volume of 169 million m^3. Remarkably, the thin arch dam resisted the forces imposed by the 1963 landslide and suffered only minor damages. The Vajont Dam withstood a load eight times greater than it was designed to withstand. Engineers who built the Vajont Dam were working toward a masterpiece in engineering history, which they achieved.

Fig. 9 - The Vajont Dam

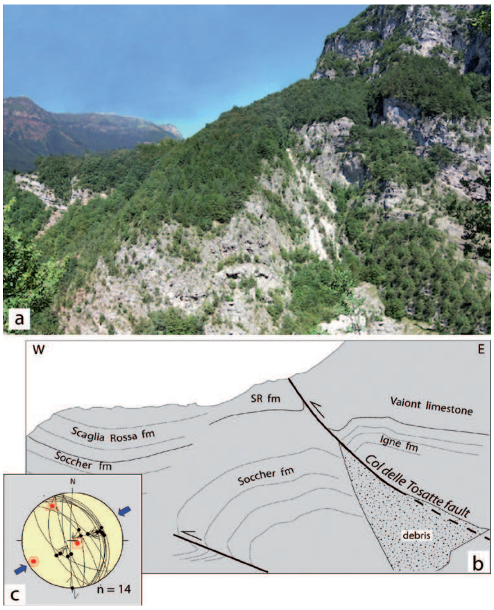


Fig. 10 - a) Panoramic view of the right side of the Vajont gorge, downstream of the dam; b) sketch of the Col delle Tosatte Fault cropping out on the right side of the Vajont gorge; c) plot (lower hemisphere) of mesoscale reverse faults collected close to the main fault (after Massironi *et alii, in this volume)*

STOP 6

VAJONT GORGE AND THE COL DELLE TOSATTE FAULT

Within the Vajont gorge, downstream of the dam, the Col delle Tosatte Fault outcrops (Fig. 10a). It is clear from the field as well as from historical photographs (A-11 and A-25 in Masé *et alii*, 2004) that this fault unambiguously dips towards the east and is a westward-directed reverse fault. The fault is associated with a ramp anticline deforming the Liassic

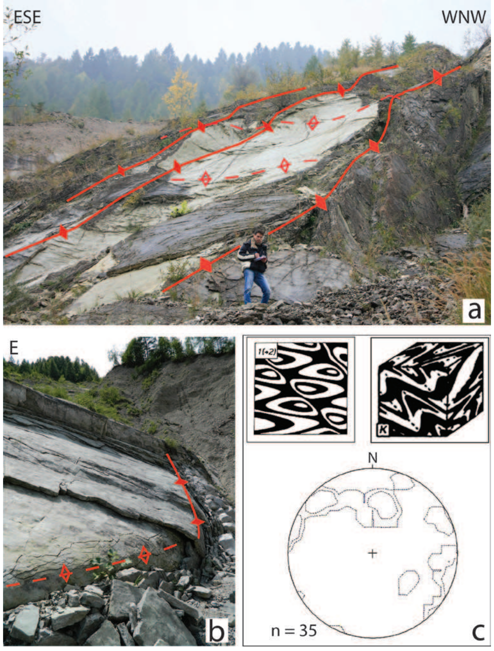


Fig. 11 - The interference between folds related to the Erto (E-W to WNW-ESE) and Massalezza (N-S to NNW) synclines: a) Meso-scale refolded folds on the sliding surface at Massalezza; b) Meso-scale refolded folds on the sliding surface of the western lobe (continuous line = hinges of the Massalezza syncline fold set; dashed line = hinge of The Erto syncline fold set); c) Top: Interference pattern after Ramsey *(1967) (left) and* Thiessen *&* Means *(1980) obtained by considering the average axes trends and axial planes of the Massalezza Syncline and Erto Syncline sets. Bottom: Contour plot (equal-area lower-hemisphere) of the fold axes on the sliding surface (after* Massironi *et alii, this volume) (Photo by M. Massironi)*

Igne Formation, at present overlying the Cretaceous Soccher sequences (Figs. 10b, 10c). At the Col delle Tosatte Fault footwall a minor splay has been found; it is associated with a ramp anticline in the hanging wall and an asymmetric syncline in its footwall, both involving the Soccher sequence and Scaglia Rossa Formation (Figs. 10b, 10c).

The westward propagation of this fault is distinctive with respect to the south-vergent Belluno Thrust and related folds (Stop 1) and suggests a different origin for this structure: it could be an inherited Dinaric thrust or alternatively the result of a transpressional reactivation of a pre-existing Mesozoic fault during the Alpine convergence. This peculiar fault is structurally related to the N-S striking Massalezza Syncline, which strongly affected the failure surface (Stop 7).

STOP 7

SLIDING PLANE AT MASSALEZZA CREEK

The Vajont landslide occurred on the southern limb of the Erto Syncline, which dips 30° to 50° towards the NNE and N. The sliding plane has an overall concave shape with the eastern and western lobes converging toward Massalezza Creek, which coincides with the hinge of the Massalezza Syncline. The result is that the Vajont failure surface is everything but sharp and smooth. The E-W to WNW-ESE folds and related joints are responsible for several structural terraces (the most prominent one affecting the eastern lobe) and monoclines (see also Broili, 1967 and Hendron & Patton, 1985), whereas the N to NNW trending undulations (axes average trend/plunge: N010°/40°), often control gully incisions, particularly in the western lobe of the sliding surface (see also Hendron & Patton, 1985). Parasitic folds tend to increase towards the hinges of the main folds; hence, the most tectonized sector of the sliding plane is downstream of Massalezza Creek where the hinges of the Erto and Massalezza synclines interfere with each other (Fig. 11). The E-W to WNW-ESE folds affecting the Fonzaso Fm. beds frequently display flexural slip processes generating meso-scale flat-ramp thrusts verging towards the south (Fig. 12). These anti-gravitational kinematics suggest that the E-W to WNW-ESE folds are unrelated to gravitational events. Similarly, the orientation of the Massalezza-related poly-harmonic folds exclude any gravitational origin.

In summary, the orientation of the failure surface is the product of at least two episodes of folding, which originated the multiple steps that are observed on the failure surface. All of these elements, mainly pre-dating any gravitational event on the Mt.Toc northern slope, may have played a significant role in failure behaviour and may also be used to model the landslide with two- and three-dimensional codes.

STOP 8

MESAZZO SECTION

The stratigraphy mapped by Rossi & Semenza (1965) outcrops in the Mesazzo Valley. The original maps present the stratigraphy as a simple succession. In reality, it may be complicated by folding and faulting. All the tectonic lines of greater interest are oriented roughly E-W with a small angle and involve extensive movement producing the repetition of the stratigraphic sequence several times.

LA PINEDA LANDSLIDE

There are quaternary sections of extraordinary beauty at the confluence of the Mesazzo Stream and Vajont River. The Pineda deposit located east of the Vajont Slide is an example of prehistoric mass movements in the Vajont Valley. It has been hypothesized to originate from either the north or south slope of the valley, but the most widely accepted view is that its source area is the steep, bare slope on the north slope (Fig. 13).

The landslide would have dammed the Vajont River and Mesazzo Stream, with implications for river course, erosion of the landslide dam, and evolution of the valley geomorphology. The Pineda Landslide overlaps a delta sequence (topset, foreset, bottomset) of glaciofluvial origin, allowing its preservation. This delta entered a

Fig. 12 - Flexural slip processes generating meso-scale flat-ramp thrusts verging towards the south (Photo by D. Zampieri)

now-extinct glacial lake, as witnessed by laminite sequences with drop-stones (Fig. 14). There is a diamictite deposited on the Pineda landslide, hypothesized to be glacial till. This would point to a pre-Pleistocene age for the Pineda. However, recent field investigations were inconclusive. It was likely not the only large prehistoric landslide to dam the valley. Other movements include the prehistoric Vajont and Monte Borgà failures.

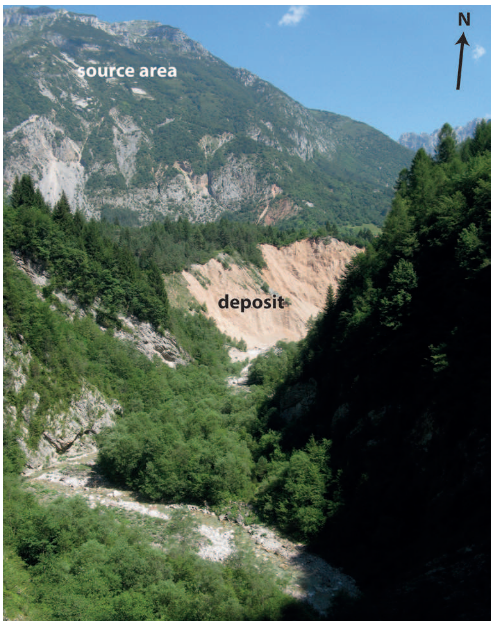


Fig. 13 - Most likely source area of the Pineda Landslide. The deposit is in the middle ground, whereas the source area is in the background (Photo by A. Wolter)

Fig. 14 - Photo of E. Semenza dated July 1959 (from MASÈ et alii, 2004). The original caption of the picture stated: the left bank of the lower Mesazzo Valley, seen from the right bank below Case Prada (el. 700 m a.s.l. approx.); on the right the village of Erto and the Zemola Valley. From top to bottom can be recognized: Dogger debris and cataclasite, conglomerate with local cross-bedding, alluvial uncemented deposits and steeply inclined Flysch. The conglomerate present on the right bank is also visible at the left edge of the photo; the alluvial deposits are present on the right bank, on the right side of the photo near the old house

STOP 9

THE NOVE HYDROELECTRIC POWER PLANT: THE PHYSICAL-HYDRAULIC MODEL

Soon after the discovery of the paleo-landslide by GIUDICI & SEMENZA (1960), the project engineers decided to build a physical model of the left slope of the Vajont Valley; it was not a landslide model but rather a model to simulate the hydraulic effects of mass movement into the reservoir. This was the first model of a landslide ever built in the world and it reproduced the dam, the valley and the landslide at a 1:200 scale (GHETTI, 1962).

In the first series of experiments, the model constituted a uniformly inclined (30°) wooden surface plank covered with sheet metal; the landslide mass was made up of gravel retained by flexible wire mesh and the fall was simulated by the sudden release of the containing mesh (Fig. 15). Semenza, who assisted in the first experiment on August 30 1961, suggested modifying the model so that the movement surface was similar to that of the actual landslide (Fig. 16). The requested

Fig. 15 - Original photo n.10, the landslide mass of gravel resting on the sliding surface, held in place by hemp nets and ropes, before a test of the second series (from GHETTI, 1962)

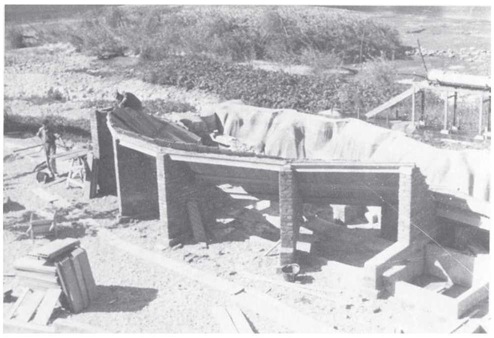


Fig. 16 - Original photo n.6, building of the concave shaped sliding surface (from GHETTI, 1962)

Fig. 17 - Original photo n.9, caterpillar tractor with the traction cables, is ready to cause the controlled movement of the slide (from Ghetti, 1962)

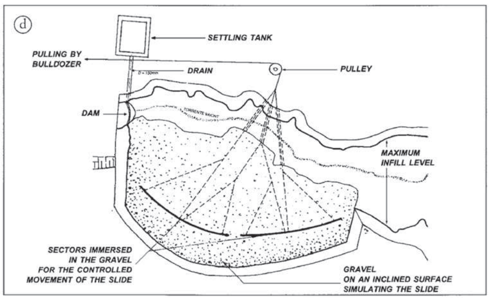


Fig. 18 - Part of the original plate N.2, drawing of the pulling system of the various sectors immersed in the gravel mass during the second series of tests (from Ghetti, 1962)

modifications were implemented based on a series of geological profiles provided by Semenza.

The gravel constituting the landslide mass was stiffened with rigid vertical sectors which were pulled by a tractor (Figs. 17, 18). This allowed, in spite of the chair-like form of the basal sliding surface, both the displacement of the entire landslide mass as a unique body and the movement of the mass with variable velocities at will.

The experiments were carried out with fall times ranging from several minutes (similar to the Pontesei landslide of 1959) down to one minute (equal to about 4.24 seconds in the model). Note that many technicians, in the years following the 1963 landslide, stated that if the model had simulated the actual velocity (two seconds in the model equal to 25 seconds in real time), the resulting wave would have corresponded to that of reality.

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