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Geomorphologic map of the Adige Valley; North of Trento, Italy. Scale 1:25,000

continuous	occasional	inactive	activity
			Structural forms
■			Rockwall
■			Slope > 45°, with frequent outcrops
■			Slope < 45°, with few outcrops and accumulation of detritus
■			Slope > 20°, with cover of detritus
■			Isolated rock outcrop
			Glacial forms and deposits
		■	Rock-drumlin
		■	Area with signs of glacial modification
		■	Area with (fluvio-) glacial deposits
			Slope forms and deposits
	■		Debris slope
	■		Debris cone
	■		Debris flow
	■		Landslide
		■	Paleo-landslide
			Karst
■			Area affected by karst processes
■			Cave

continuous	occasional	inactive	activity
			Fluvial forms and deposits
■			River
■			Torrent (perennial)
	■		Torrent (non-perennial)
		■	Paleo river
■			Floodplain (frequently inundated)
	■		Floodplain (not frequently inundated)
	■		Alluvial plain
	■		Alluvial fan
	■		Debris fan
		■	Lacustrine plain
■			Fluvial erosion scarp (active)
		■	Fluvial erosion scarp (not active)
			Anthropic forms
■			Build up area
■			Dike / protective embankment
■			Embanked infrastructure
■			Non-build up area anthropically modified
■			Waste disposal site
■			Ski run
		■	Quarry (abandoned)
■			Irrigation lake
■			Irrigation canal

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Geomorphologic Map of the Adige valley, north of Trento, Italy.

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Abstract
This contribution is a short and concise explanation to the geomorphologic map of the Adige valley, Italy between Trento and Mezzocorona / Piana Rotaliana. The geomorphologic map was part of the GETS research objectives and forms the basis for the additional analyses that were done during the GETS project.

Keywords
Geomorphology, Trento, Italy

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1. INTRODUCTION

The geomorphologic map, scale 1:25000 is the result of a series of field surveys, carried out in the 1998 and 1999 during the European Union funded project GETS – Geomorphology and Environmental Impact Assessment for Transportation Systems, EU contract number ER13FMRX-CM-0162. The map served the following objectives:

- Identify and map the main geomorphologic features of the study area.
- To allow a qualitative geomorphologic hazard assessment.
- Form the basis for a map of the geomorphologic assets.
- As a source map for statistical geomorphologic hazard assessment techniques.
- As a data-layer in spatial multi criteria decision support systems.

To meet all these objectives, the geomorphologic map consists only of area-elements (polygons) and does not contain any linear or point elements (zero-area elements). On traditional geomorphologic maps, large parts of the maps remain unclassified because they show no particular features. However, also unclassified areas, without particular forms, represent geomorphologic landforms. For comparison in a GIS with other data-layers (land-use, geology…) also these areas need to be classified. Such a geomorphologic map requires new legend units that not always have only a geomorphologic origin. In this survey morphometric criteria coming from geometry (slope-angle) and lithology (loose material or bedrock) were used to define geomorphologic units.
The whole area was surveyed at a mapping scale of 1:10.000. In addition to the field observations, stereo-photos were interpreted at various scales ranging from 1:33.000 (1973

flight) to 1:70.000 (1988 and 1994 flights). These aerial photos were available at the Geological Survey of the Autonomous Province of Trento.

2. STRUCTURAL FORMS

The general morphology of the area is defined by the lithological characteristics of the substratum and by the main tectonic elements. The main tectonic structures consist of a system of SE-vergent NNE-SSW trending thrust faults with a ramp and flat geometry. This system has been successively cut by almost N-S striking left-lateral strike-slip faults some of which may have been active during recent times (Zambana area, etc.). The location of the thrust system is enhanced by the huge structural terrace of Monte di Mezzocorona - Fai della Paganella.

The area is characterised by a complex and thick sedimentary succession deposited on the Trento plateau from the Permian to the Cretaceous. On the East side of the Adige valley, near Lavis the oldest units are found; they consist of thick ryolitic volcanics and volcaniclastics Late Permian in age. In the Pressano area, these volcanics are directly covered by the Werfen Formation, gypsum layers, dolostones and by the Formazione a Gracilis and by the Voltago Conglomerate (MARONI, 2001)**.** The succession passes upward to the Moena Formations and to the thick and monotonous, shallow water, carbonatic succession of the Contrin Formation. On the western side of the valley, thick carbonatic units form the high cliffs that pass upward directly to the Norian Dolomia Principale Fm. These units are about 500-600 m thick and form the high cliffs from Zambana to Mezzolombardo and Mezzocorona. An important thrust faults doubles the carbontaic succession, forming a well marked ledge in the middle of the rockwall. At the topo of the scarp the dolomitic succession is covered by the Jurassic Calcari di Noriglio Fm. and successively by the Jurassic to Cretaceous units. In the area of La Rocchetta this succession is tectonically covered by the Paganella thrust unit, which includes slightly different sedimentary units.

Recent seismic and gravitational investigations revealed that the Adige valley is much deeper than previously assumed. ROSELLI *et alii* (19??) show that the first evidence of bedrock is found of a depth of 600 - 650 meters below the present surface (i.e. +/- 400 meters below present sea level).

The structural forms are primarily classified according to the slope angle:

2.1 Rock wall

Near vertical cliffs with (slope > 60°) with no sedimentary cover or soils. The whole area between the top and bottom of the rock wall is delineated. Typical for the rock walls on the western side of the Adige is the abundance of small circular forms sculpted in the rock, indicating source areas of rock-fall.

2.2 Slope >45°, with frequent outcrops

Steep slopes in bedrock, usually with irregular forms, with sometimes a shallow cover of debris (mostly due to rock-fall). On some parts soils may form. Related to rock-fall phenomena these slopes can function as source, transit zones as well as deposit areas.

2.3 Slope <45° with few outcrops and with accumulation of detritus

Less steep, irregular shaped slopes with in general a thick accumulation of deposits but with occasional outcrops of the bedrock material. Typically these zones are well vegetated and have well-defined soils.

2.4 Slope <20° with cover of detritus
Slopes of low inclination without particular features. Well vegetated or used for anthropic activities.

2.5 Isolated rock outcrop
Bedrock outcrops isolated from neighboring bedrock evidence. Some may show clear outcrops, others manifest themselves as small hills without clear evidence of rock material.

3. GLACIAL FORMS AND DEPOSITS

Even though the structural origin of the Adige valley is much older, the main landscape-forming events occurred during the Quaternary period when the Adige Valley was completely glaciated several times. At the maxima, the ice covered the whole area with perhaps the exception of the highest peaks. This is evident in the well-rounded forms of the slopes that can be observed today on both sides of the valley. Near the village of Pressano long elongated, smoothly rounded hills are found that can be interpreted as rock-drumlins (drumlins with a rock-core) or whalebacks that are typically formed under ice-sheets or broad valley glaciers. Glacial deposits are present on the higher structural terraces of Monte di Mezzocorona and of Fai della Paganella (about 600 – 800 meters above the present valley floor) and near the narrow gorge La Rocchetta, but are not found in the lower parts of the study area, like the Adige valley floor. However, it is assumed that the deepest deposits in the filled in Adige valley are of glacial and glacio-fluvial origin, mixed with detritus and rock slides coming from the steep side-slopes.
The following glacial forms and deposits are identified:

3.1 Rock drumlins
Also called whalebacks. Glacially smoothed, elongated hills. They usually occur in clusters with varying spacing between individuals. Sizes vary greatly but are commonly a few tens of meters high and can be hundreds of meters long. Contrary to drumlins, rock-drumlins have a rock core but can be covered by a relatively thin layer of till making it difficult to distinguish the two forms.

3.2 Area with signs of glacial modification
General description of those areas that are clearly affected by glacial presence, but that cannot be classified as specific landforms. It is used to classify the area “in-between” specific features.

3.3 Area with fluvio-glacial deposits
General description of those areas with clear evidence of fluvial deposits related to glacial presence. These deposits can be either transported by the glacier itself (glacial deposits) or due to fluvial processes related to glacial melt-water. There are no particular landforms distinguished.

4. SLOPE FORMS AND DEPOSITS

In the stretch of the Adige valley that is studied in this research – San Michele to Trento – there is a distinct difference between the east slopes and the western slopes.

The western slopes are near vertical cliffs, formed in the succession of limestones, reaching its top in the Monte Paganella (2125 m). Most processes here are gravity-related like rock-fall and rock avalanches. Fluvio-gravitation phenomena are also found on this side, like debris-flow and debris cones. At the base of these cliffs, small accumulations of detritus are found in the form of debris cones, but large landscape dominating debris slopes are absent which suggests that rock-fall related processes are of a limited activity. However, the 1955 Zambana rock-avalanche / debris-flow, shows that such events can still occur and must not be underestimated. Also individual rocks and boulders are still coming down the steep slopes. More information on the Zambana rock-avalanche can be found in NARDIN *et alii* (1991)**.**
The slopes of the Monte Corona between San Michele and Lavis show little evidence of large-scale slope instability. Only where the torrents have incised deep valleys into the mountain flank, soil slips can occur. Signs of soil erosion on the intensively used fields have been observed.
Large accumulations of detritus are found between Mezzolombardo and La Rocchetta on the northern slope of Dosso della Tia and in the area of San Michele - Faedo on the eastern slope of the Adige valley. The first is though to be the result of landslide or rock-fall event, or a series of events. This is suggested by the presence of a scarp-like structure in the Dolomia Principale. Large blocks of Dolomia Pricipale are found, set within a matrix of finer material. Near the scarp, smaller scale processes are still active, like debris flows and active debris slopes. The accumulation near Faedo is less steep and looks more like a debris-fan, which suggests that water played a large role in its formation. Its shape suggests that this landform is the result of more continuous fluvial processes or series of events (mudflows), rather than one single, large event. Both accumulations are thought to be post-Würm.
The following slope forms and deposits were identified:

4.1 Debris slope
Accumulation slope of debris deposits. Also known as talus or scree slopes, debris slopes have typical slope angles between 30° – 45°. An important characteristic is their straight profile, differentiating them from irregular shaped slopes of the same inclination. Debris slopes form along relatively straight cliffs by rocks falling down due to gravitational force.

4.2 Debris cone
The same as debris slope, only they tend to be more cone-shaped because the debris falling down is first funnelled and concentrated by gullies or stream channels that notch the cliff face.

4.3 Debris flow
Debris flows are characterized by a transport mechanism that is driven by a mix of gravity and water. In those areas (or situations) where the gravity component is dominant one could also speak of debris avalanches. As the water component increases, the more fluid the behavior of the debris flow / debris avalanche and it can travel considerable distances. In this study, no distinction is made between debris avalanches and debris flows.

4.4 Landslide
Slope failure that results in the displacement of loose material in a singular event, or succession of singular events. Usually driven by extreme climatic events that result in rapid rise of the groundwater table or increased undercutting by swollen torrents. No distinction is made between various types of landslides as slumps and slides. Typically a landslide is characterized by a scarp on the top side and – if not eroded – on the down side a bulging form where the wasted material has come to a rest.

4.5 Paleo-landslide
Large landslide (or series of landslides) that occurred under different climatic circumstances. These include the large accumulation of detritus found near Mezzolombardo and San Michele / Faedo. The first one is considered as the result of (a series of) large rock avalanches, attributed to the deglaciation period of the area after the Wurm ice age. The second one is also associated with the deglaciation period of the study area when large amount of water were available to transport material. In comparison to the Mezzolombardo site, the water component was of far greater importance.

5. KARST FORMS

5.1 Area affected by karst processes
General description of those parts (on the border) of the study area that are clearly influenced by karstic processes, many of which are too small to be mapped on a scale of 1:25.000. Hence these zones are classified as karst area. These micro karst features include among others: karren, rainpits, limestone pavements, dolines and water sinks.

5.2 Cave
Limestone caves are evidence of subsurface water action and are sculpted mainly by solution of the limestone in water, but also mechanical abrasion can be of importance. On the map, only the entrance area of the caves is indicated; no information is given about the size and extent of the cave systems.

6. FLUVIAL FORMS AND DEPOSITS

Of the presently active geomorphologic actors, fluvial processes are the most visible. The Adige River is the key-feature of the valley and it has created a large alluvial plain. Before the area became inhabited, the river was free to choose its course and it often changed its streambed. Old riverbeds and meander-curves are still visible in the terrain, sometimes accentuated by land-use patterns.
Two tributaries join the Adige in the study area, the Noce and the Avisio and have created large alluvial fans. The Alluvial fan of the Noce – also know as the Piana Rotaliana – has its apex near the snout of the gorge of La Rocchetta at an altitude of 238 metres above sea level (a.s.l.) and an elevation of 205 m. (a.s.l.) at its former confluence with the Adige, giving it an average gradient of 5 m/km. The second tributary, the Avisio River, enters the Adige valley near Lavis. The elevation of its fan at that point is 237 m. (a.s.l.) 3 kilometres downstream, at the confluence the altitude is 195 m. (a.s.l.), giving the Avisio an average gradient of 14 m/km.
The contributing basin of the Adige when it enters the study area at San Michele is 7200 km^2 and has an average discharge of 200 to 250 m^3/s, but during floods this value can rise to over 1000 m^3/s. In 1965 a maximum discharge of 1885 m^3/s was measured at Trento. The basin of the Noce has a surface area of 1390 km^2 and the average discharge at Mezzolombardo is 30 to 40 m^3/s. The surface area of the Avisio is 930 km^2 and the average discharge is around 10 m^3/s.

The Noce and the Adige rivers are largely modified by human action. Dams (near Giustino-Cles, near Mollaro and near La Rocchetta) regulate the discharge of the Noce and on the Piana Rotaliana the river is diverted towards the south to its present confluence with the

Adige near Zambana. The Adige is canalised and confined to its allocated space on the valley floor by dikes on both sides of its bed. The Avisio is relatively unregulated, only where it enters the Adige plain, are dikes constructed to keep the rivers to its allocated course.

The following fluvial forms and deposits were identified:

6.1 River (perennial)
Major watercourse carrying water through all the seasons.

6.2 Torrent (perennial)
Minor watercourse carrying water through all the seasons. In exceptional situations the riverbed may become dry for a limited period.

6.3 Torrent (non-perennial)
Minor watercourse that does not carry water through all the seasons. There is a wide range in the dynamics of these streams: some may occasionally carry water, e.g. after a rain storm but are dry most of the time, while others may be normally carrying water, but are occasionally dry due to a long (seasonal) period without rain.

6.4 Paleo riverbed
At one time did the river have its riverbed at this position, which it abandoned at a certain moment for a new bed, either through the natural process of avulsion or due to anthropic canalization activities.

6.5 Floodplain (frequent inundated)
That part of the river adjacent to the river channel that is flooded periodically when discharge increase due to seasonal variation in the river basin area. The frequently inundated floodplain is characterized by little or no vegetation. It also includes the territory between the dikes and the river channel where artificial levees (dikes) are constructed close to the channel.

6.6 Floodplain (less frequent inundated)
The part of the river, adjacent to the river channel that is flooded only during exceptional events with return periods at least several times longer than seasonal periodicity. It is characterized by abundant vegetation that is well adapted to the humid conditions and the occasional flood event.

6.7 Alluvial plain
Planar area consisting of loose gravel, sand and finer materials deposited by the action of rivers with an inclination of less than a few degrees. As river gradients diminish, less energy can be devoted to transport sediments, which are deposited primarily in the riverbed, but during floods also on the adjacent territory. Lateral migration of the streambed e.g. by avulsion, and a long history of flood events result in a planar plain.

6.8 Alluvial fan
Planar, usually fan or cone shaped area with an inclination no more than a few degrees, consisting of unconsolidated gravel, sand and finer materials deposited by the action of rivers. Alluvial fans are usually found where side valleys enter a planar area e.g. an alluvial plain. The apex of the fan points upstream and it marks the thickest part of fan's mass. The fan deposits become thinner as they are traced outwards and downwards and as the stream breaks up into a number of distributaries. Because the stream velocity is checked by the change of

the gradient at the mountain front and because the stream splits up into distributaries, more of its energy is used top overcome friction, leaving less energy for sediment transport. Thus deposition occurs in the form of a fan.

6.9 Debris fan
Intermediate form between debris cone and alluvial fan. Where debris cones are formed by mainly gravity driven processes and alluvial fans are typical deposits of sediments carried by water, debris fans are hybrid forms, formed by the action of both agents. They are formed there where steep mountain torrents and debris flows enter an area of decreased gradient. The apex points upstream and, similar to alluvial fans and debris cones, here the deposits are thickest, while radiating outward and downstream, the thickness of the deposits decreases. Gradients are in between those of alluvial fans and those of debris cones, i.e. they range from 10^o to 30^o, where an increase of gradient signifies an increase in importance of the gravity component as forming agent.

6.10 Lacustrine plain
Horizontal planar area consisting of unconsolidated sand and finer materials deposited in a lake – now completely filled-in or drained.

6.11 Fluvial erosion scarp (active)
Steep slope terminating a plateau, plain or any level upland area created by the erosive activity of rivers. Wherever the sediment load of a river is below the carrying capacity at that river stretch, the river tends to pick up material either from the riverbed itself (down-cutting) or from the adjacent territory (lateral erosion). Either way, material from aside the river is taken away by the river, resulting in fluvial erosion scarps. These scarps can be of a wide range of dimension, from several decimetres as much as hundred meters and also in a wide range of materials, from loose sediments to bedrock. “Active” indicates that there are clear signs that the activity of erosion is still ongoing, like exposed material, little vegetation, slope instability ….

6.12 Fluvial erosion scarp (not active)
Same as fluvial erosion scarp (active) only that there are clear signs that the activity of erosion has stopped. No indication is given to how or when this activity has ceased.

7. ANTHROPIC FORMS

7.1 Build-up areas
Any continuous or semi-continuous group of buildings, e.g. villages, localities and industrial zones.

7.2 Dike, protective embankment
Dikes are man made structures along a watercourse that should prevent that the stream waters leave its allocated space. They are especially designed to confine the river within its designated area during events of large discharge. Protective embankments are similar structures, but are not solely restricted to offer protection against water, they can also act as defense work against e.g. rock-fall.

7.3 Infrastructure (embanked)

Large infrastructure like highways and railroads that are build on a dike-like structure called embankment so they are elevated several meters above the surrounding terrain.

7.4 Non build-up area, anthropically modified
General term used for those areas where no continuous or semi-continuous group of buildings are present but where clear evidence exists that the terrain is significantly altered by human activities.

7.5 Waste disposal
Area used – or still in use – to deposit waste material.

7.6 Ski-Run
Part of the slope that has been significantly adapted to become suitable for alpine skiing.

7.7 Quarry
Open air extraction site of raw material, like gravel, sand, gypsum, dolomite, etc.

7.8 Irrigation lake
Man made lake used for surface water storage.

7.9 Irrigation Canal
Man made watercourse for irrigation purposes. Note:
The canalization works on the Adige and the Noce are not considered as canals.

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