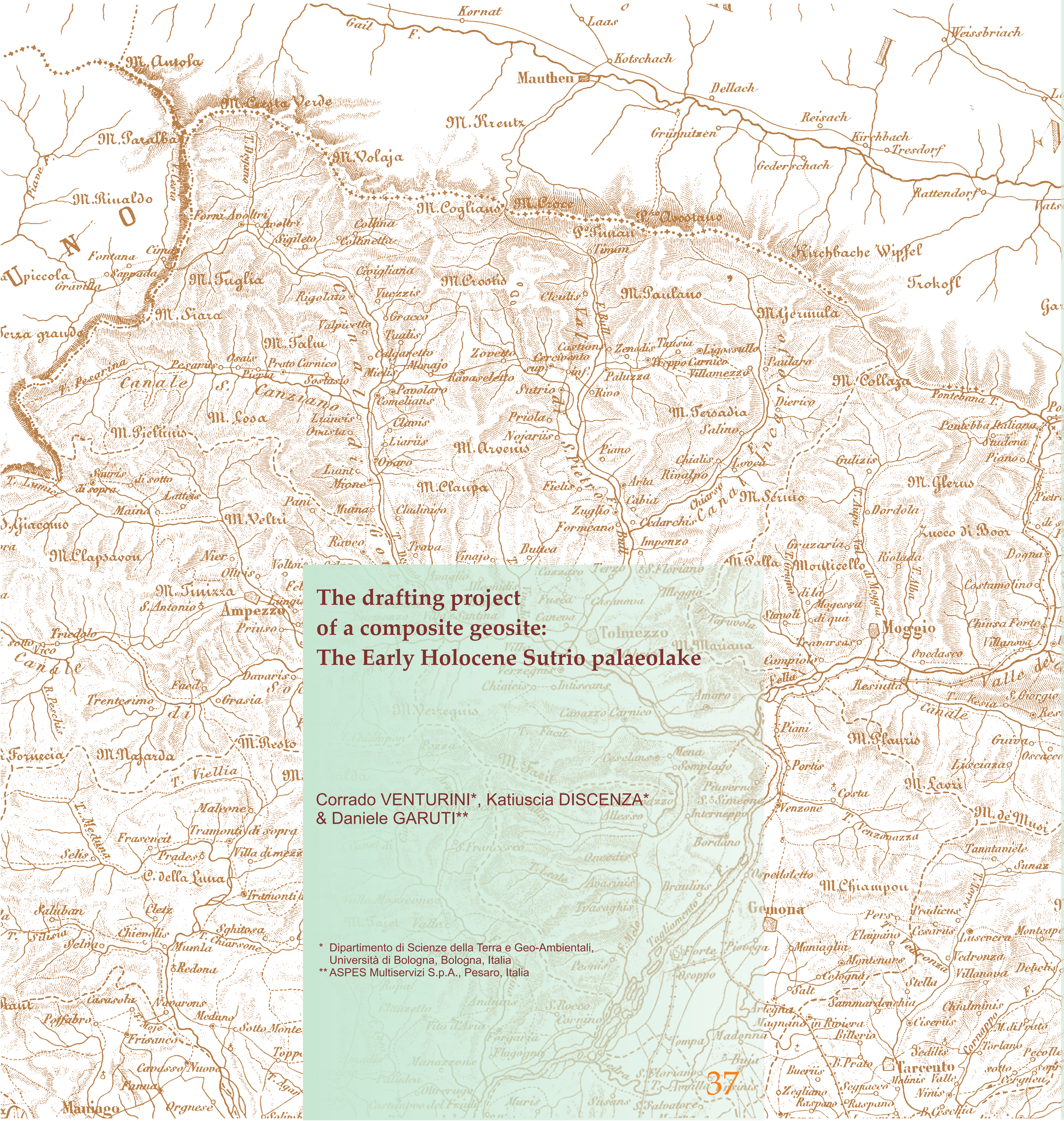
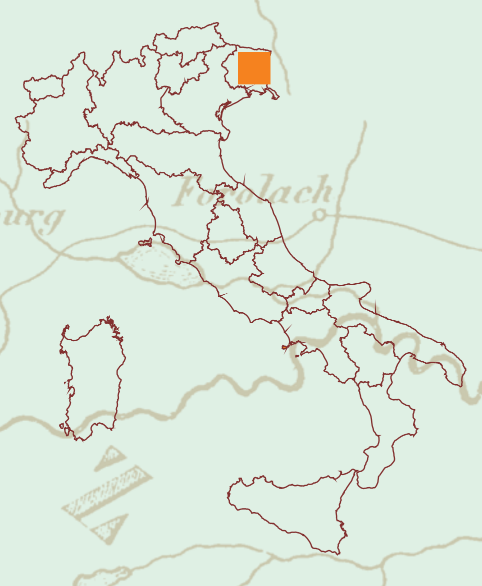
Mapping Geology in Geosites: Two case studies

Geosite:
A site with remarkable geological significance
to take care, highlight, and make known
to the lay public.





The drafting project of a composite geosite: The Early Holocene Sutrio palaeolake

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ABSTRACT

Aim of this work is to suggest a way to evaluate and to represent the several geo(mopho)logical data concerning a composite geosite.
A composite geosite is a geosite rich of several features and field evidences from various topics (e.g. stratigraphy, sedimentology, geomorphology, palaeontology, tectonics, and so on) which, all of main importance, put in evidence the significance of the site.
The work debates the strategy to organise a geosite draft, the hierarchy of the several groups of data (low and high rank data), and discusses the way to use them inside the draft project.

AIMS

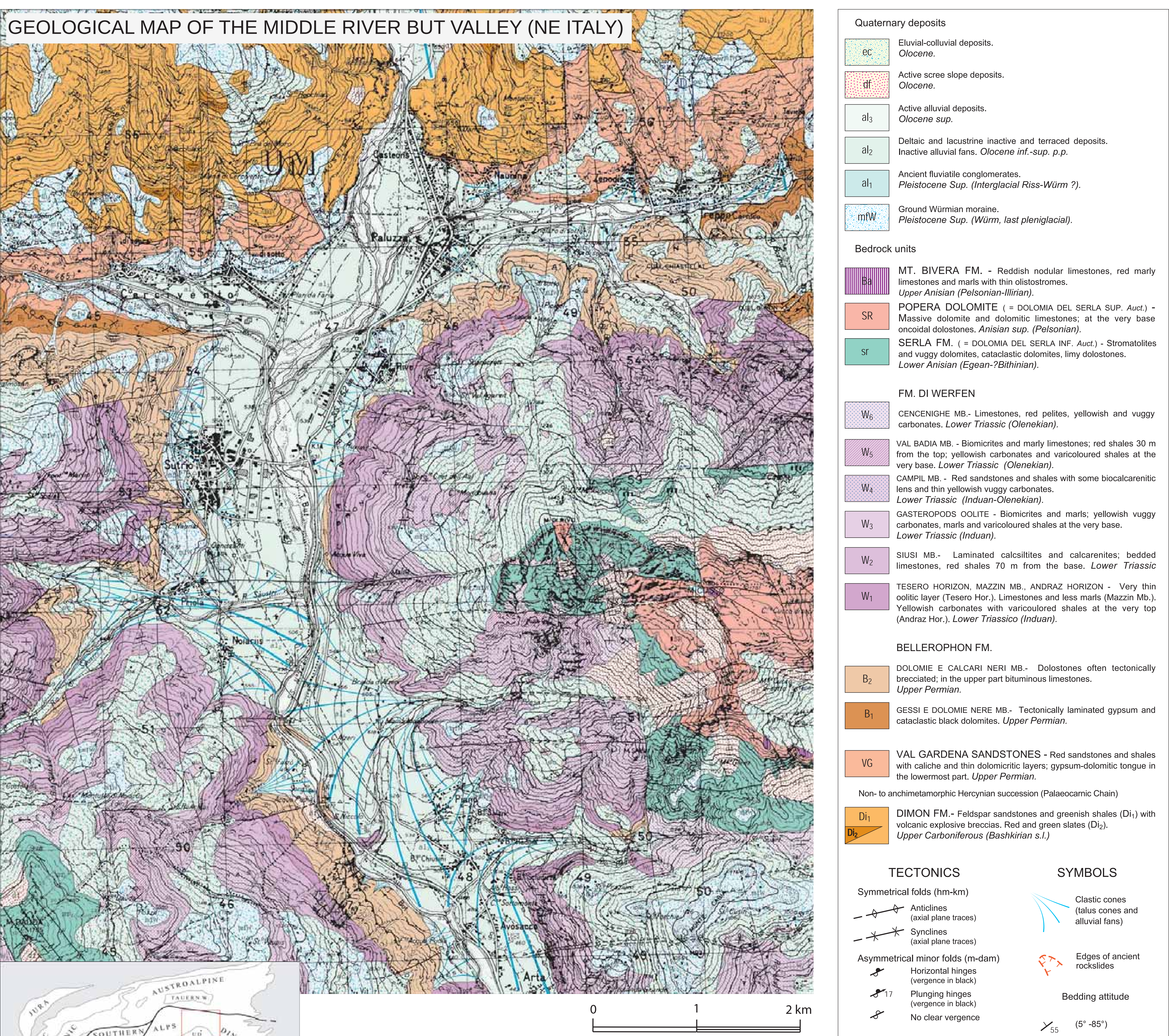
The work discuss a geosite case study in order
- to introduce the strategy suitable for the accomplishement of a drafting project illustrating the geosite peculiar features;
- to stress a metodology useful to highlight the several features (low rank and high rank data) of a composite geosite and their mutual relationships;
- to suggest how to represent the effects and relevant causes which the evolution history of the geosite is based on, by means of drawings, photos, DTM, virtual pictures and so on.

KEY WORDS

Geosite, metodology, Carnic Alps, River But, Quaternary, rockslide, lacustrine deposits, active tectonics, fluvial erosion.

RIASSUNTO

Questo contributo suggerisce un metodo per descrivere e rappresentare i numerosi dati geo(morfo)logici relativi ad un geosito complesso, ossia ricco di diverse evidenze relative a varie discipline (stratigrafia, sedimentologia, geomorfologia, paleontologia, tettonica), e tutte di fondamentale importanza per evidenziare il significato del sito.
Viene discussa la strategia di esposizione dei dati, considerati in modo gerarchico, illustrandone le proposte di rappresentazione.



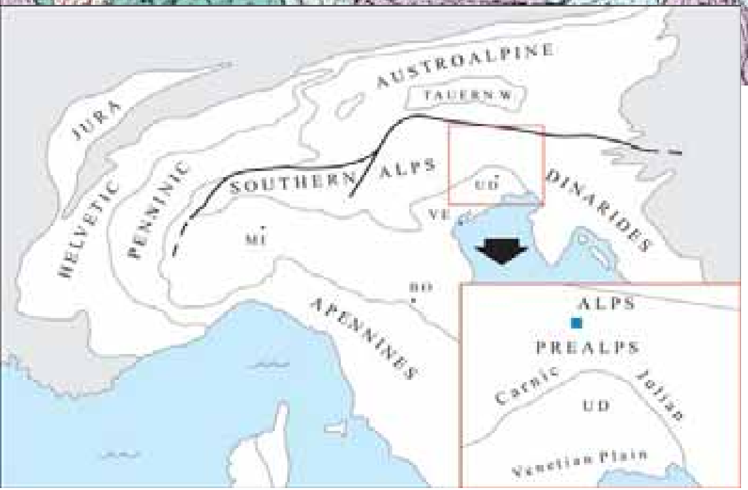


Fig. 1 - *The geological map of the middle But Valley (central Carnic Alps) located in the easternmost Southern Alps. The map is the starting point which the Quaternary investigations are based on. Only taking into account the complete geological data of the area the Quaternary evolution of the site can be more precisely defined (after* Venturini *et alii, 2001-2002, slightly modified). In the schetck map the bleu square shows the study area.*

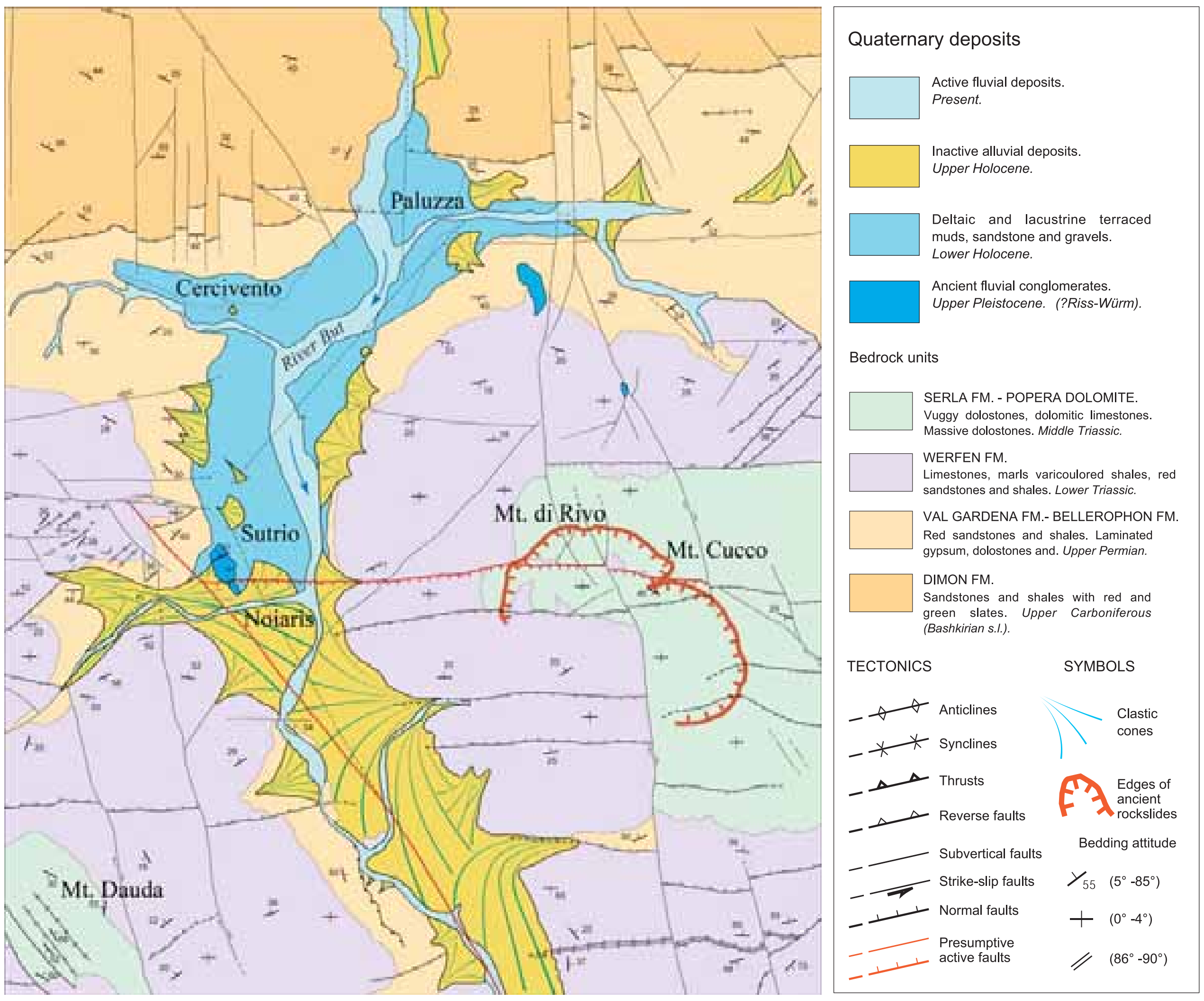


Fig. 2 - *The map highlights the type and distribution of Quaternary deposits. This has been derived from the geological map (Fig. 1) of the area (*VENTURINI *et alii, 2001-2002) with the addition of some Quaternary data.*

DRAFTING OF A GEOSITE PROJECT IN THREE EVOLUTIONARY STAGES

The geological importance of the middle But Valley geosite lies in its well-defined sequence of evolutionary stages (Fig. 3), in chronological order:

1) a massive rockslide from Mts. di Rivo and Cucco, which caused a large main scarp and gave origin to a thick chaotic deposit in the valley bottom (about 10,000 years ago).

2) a palaeolake more than 6 km^2-wide and about 100 m-deep, which formed due to blocking of the upstream water-flow of the River But; for almost 5,000 years, several tens of meters of muds, sands and gravels piled up on the palaeolake bottom.

3) the palaeolake emptying followed the collapse of the rockslide mass, about 5,000 years ago; this produced a terraced erosive surface in the lacustrine-deltaic sediments. At the same time, greater erosion of the main scarp of the rockslide and along the valley slopes resulted in the progradation of wide alluvial fans. In recent times, these alluvial fans have been cut off by fluvial erosion.

The same sequence (1-2-3) could be divided into many more events or ‘evolutionary stages’. These are, in order: a) massive rockslide; b) upstream water-flow stopping; c) lake formation; d) sedimentation onto the lake bottom; e) erosional collapse of the rockslide mass; f) emptying of the palaeolake; g) terraced erosion surfaces in the lacustrine deposits; h) erosion of the valley slopes; i) alluvial fans progradation; and j) recent fluvial cut-off of the alluvial fan deposits.

However, such a division is not advisable, as dealing with more than three evolutionary stages for one geosite would make it more difficult to understand and memorize. Therefore, two -or three at most- main evolutionary stages are sufficient to briefly describe the history of a composite geosite in order to make this evolution easily understandable.

On the other hand, those visiting the geosite should be informed of the main field evidences the interpretation is based on.

In the middle But Valley geosite, geomorphological and sedimentary processes occurred over an area of about 40 km^2 (Figs. 1 and 2) and over 10,000 years, from the early Holocene to the Present. It is of fundamental importance to look for field tracks and choose the best and most spectacular and outstanding of these in order to adequately document the discrete evolutionary stages of the area. The many features forming a composite geosite, such as those considered, can be highlighted in many and different ways.

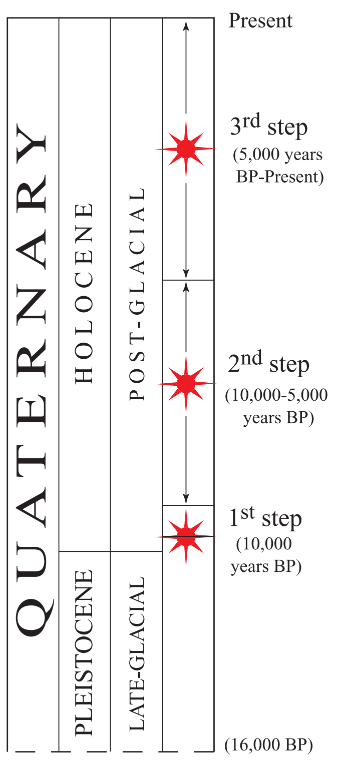


Fig. 3 - *Time-related events (stages) which characterised the middle But Valley evolution during the Holocene.*

The first of these methods are photographs with captions providing explanations. Nevertheless, photographs are often not sufficient to provide the layman with an understanding of the true meaning of the depicted object, and in many cases it will be necessary to include signs and graphic markers in the pictures (Figs. 5a-b, 8a and 8c).

Another suitable way to represent field data are drawings. In some cases drawings pointing out meaningful outlines accompany photographs (Fig. 8b). At other times, drawings may represent cross-sections (Fig. 7), which are useful in order to show a particular morphology and/or stratigraphic units and the tectonic features in depth. Drawings can also be used to show the stratigraphic column of the site, i.e. the vertical distribution of the sediments and their mutual relations in the investigated area (stratigraphic framework).

One of the most interesting types of drawing is the block-diagram. This is a 3D picture generally used to show wide areas of smoothed morphology and/or peculiar features. With regard to 3D images, the DTM (Digital Terrain Model) -also known as DEM (Digital Elevation Map)- should in particular be mentioned, as the most advanced technology used for representing surface morphology.

The Digital Terrain Models presented in this work were created using the TN3D desktop software produced by Terranova S.r.l. 3D modelling is based on elevation data (spatial and attribute data) obtained from vectorial CTR information at the scales 1:5,000 and 1:25,000, kindly supplied by the Cartographic Office of the Regione Autonoma Friuli-Venezia Giulia.

The elevation data were framed to create the Triangular Irregular Network (TIN), consisting of a continuous polygonal surface obtained from the level control points and linear data. As a spin-off, the program produces a ‘coloured hill shading chart’, where the pixel colours show elevation values and the hill shading varies with sun position. Both of these variables can be set arbitrarily. The ‘coloured hill shading chart’, which is generally accompanied by 2D vectorial data (hydrology, buildings, roads, etc.), is draped over a TIN surface and represented in a 3D axonometrical view to produce the 3D computer images shown here (Figs. 11a and 12a).

The symbols included in both the photos and the drawings must always be briefly explained in the captions or by a legend in order to make the images easily intelligible.

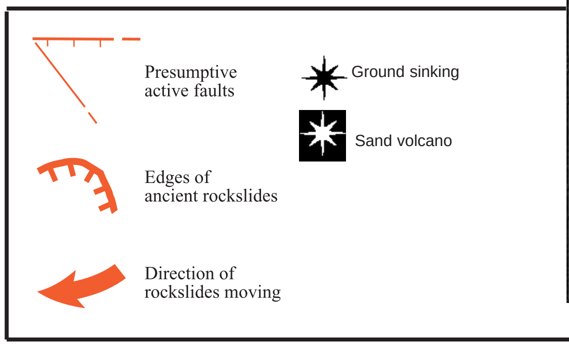
In addition, texts should always be preferably brief but exhaustive, summarizing a concept and describing a situation in a few words.

In actual fact, the best way of proceeding in drafting a geosite would be to first select iconographical material and then produce the texts, taking into account the above-mentioned suggestions. At times, the effects of a given process will require a general explanation to make them plainly understandable, e.g. the genesis of a rockslide (Fig. 7), or the development of a terraced surface (Fig. 13a).

The many images (with the relevant captions) collected for the drafting of a composite geosite may be divided into two categories: 1) low-rank data, specifically illustrating single clusters of data and their significance (next two pages); 2) high-rank data, briefly portraying the evolutionary history of the geosite; the latter data are generally a synthesis of the former.

LOW-RANK DATA

These are groups of homogeneous data that take into account cause and effect relationships, i.e. the development of a geological process. In order to illustrate this we take as an example a single main group of data among the many collected for this composite geosite and discuss its significance.
The data are those concerning active tectonics and its inferred importance in the evolution of the geosite.



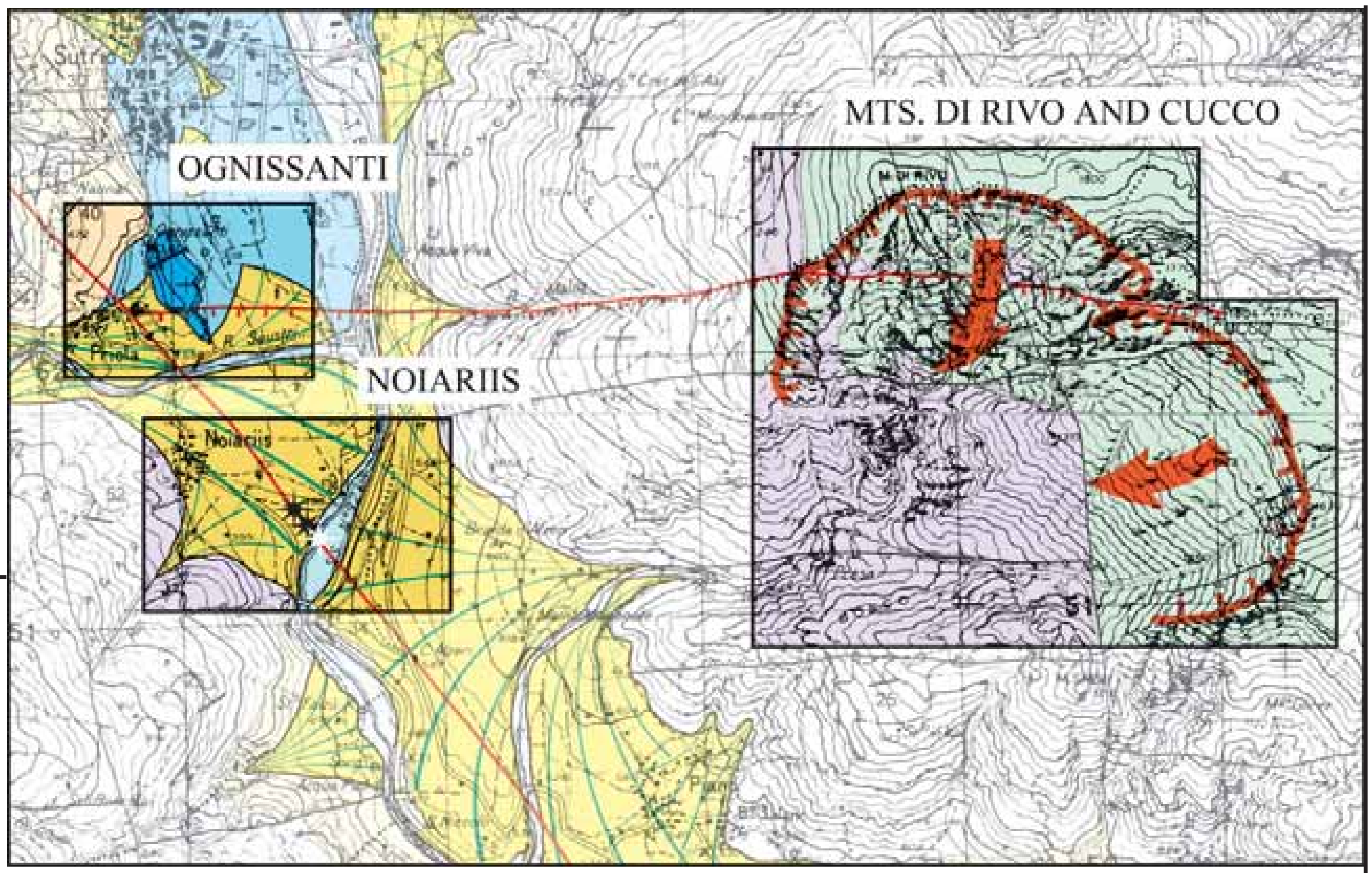
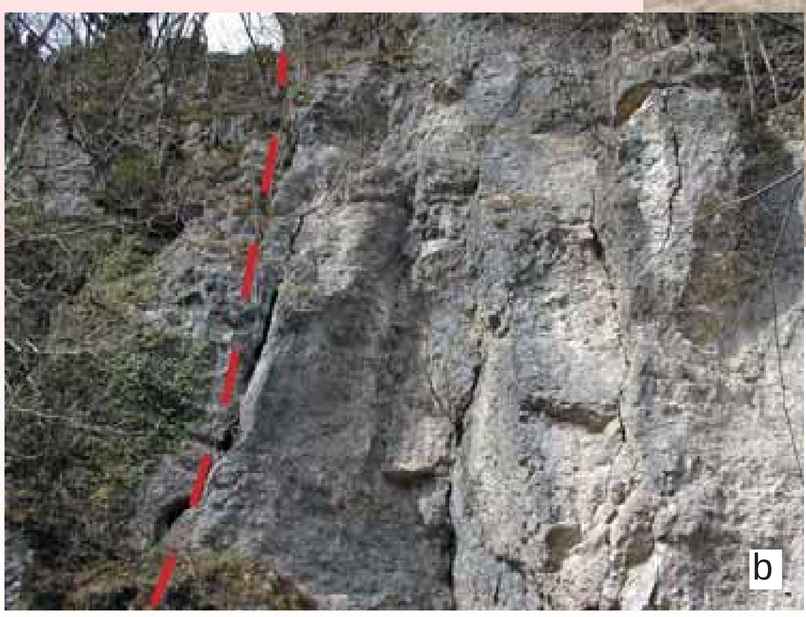


Fig. 4 - *Every geosite has particular zones where low-rank data are plainly exposed. Three suitable zones have been selected in the middle But Valley. The data collected and exposed in three different areas of the geosite are useful towards illustrating the Quaternary tectonics of the area. Among the low-rank data, active tectonics is one of the main information sets, as it comprises the starting point in the geosite evolution.*



Ognissanti

Fig. 5 - *Here the recent scarp fault is visible in the southernmost Ognissanti cliff* (a), *just south of Sutrio. The fault plainly cuts the Upper Pleistocene conglomerates of the steep relief* (b). *The trace of the fault surface is marked in red.*

Noiariis

Fig. 6 - *The two pictures show present surface features visible near the Noiariis village, south of Sutrio. These consist of* (a) *a number of sand volcanoes (white star in Fig. 4) and* (b) *several ground sinkings (black stars in Fig. 4) aligned along a NNW-SSE-trending fault which cuts the bedrock. These features may suggest a moderate tectonic rejuvenation of the fault. The scale bar* (a) *is 15 cm long.*

ACTIVE TECTONICS AND ITS EFFECTS

A number of particular tectonically-induced features can be found in the area surrounding the village of Noiariis (Fig. 4). The scarp of an extensional fault (2 m offset) is visible on the southern side of the Ognissanti cliff (Fig. 5a), which consists of Upper Pleistocene conglomerates (Fig. 5b). The fault is E-W-oriented and ties eastwards in the normal fault (about 150 m offset) which cuts the Lower-Middle Triassic succession of the Mts. di Rivo and Cucco (Figs. 1, 4 and 7).

These may be interpreted as being two segments of the same tectonic surface, that originated in Mio-Pliocene times and was reactivated in recent times.

It should be noted that the fault intersects the large main scarp of the slide which beheaded Mt. di Rivo in early Holocene times (Fig. 8b). Consequently, it is likely that a seismic shock was the cause of the Mts. di Rivo and Cucco rockslide.

In addition, a number of recent sand volcanoes (Fig. 6a) and ground sinkings (Fig. 6b) found in the Holocene alluvial deposits of the geosite area also appear to be tectonically-induced features, and are all lined up with a regional NNW-SSE trending Neoalpine vertical fault (the S. Floriano fault), which cut the Permian-Triassic succession NW to Noiariis (Fig. 4). Moreover, in the geosite area the epicentres of many recent seismic shocks (=VI MCS) are clustered only in the limited area where the ground sinkings and sand volcanoes are confined (SLEJKO *et alii*, 1987).

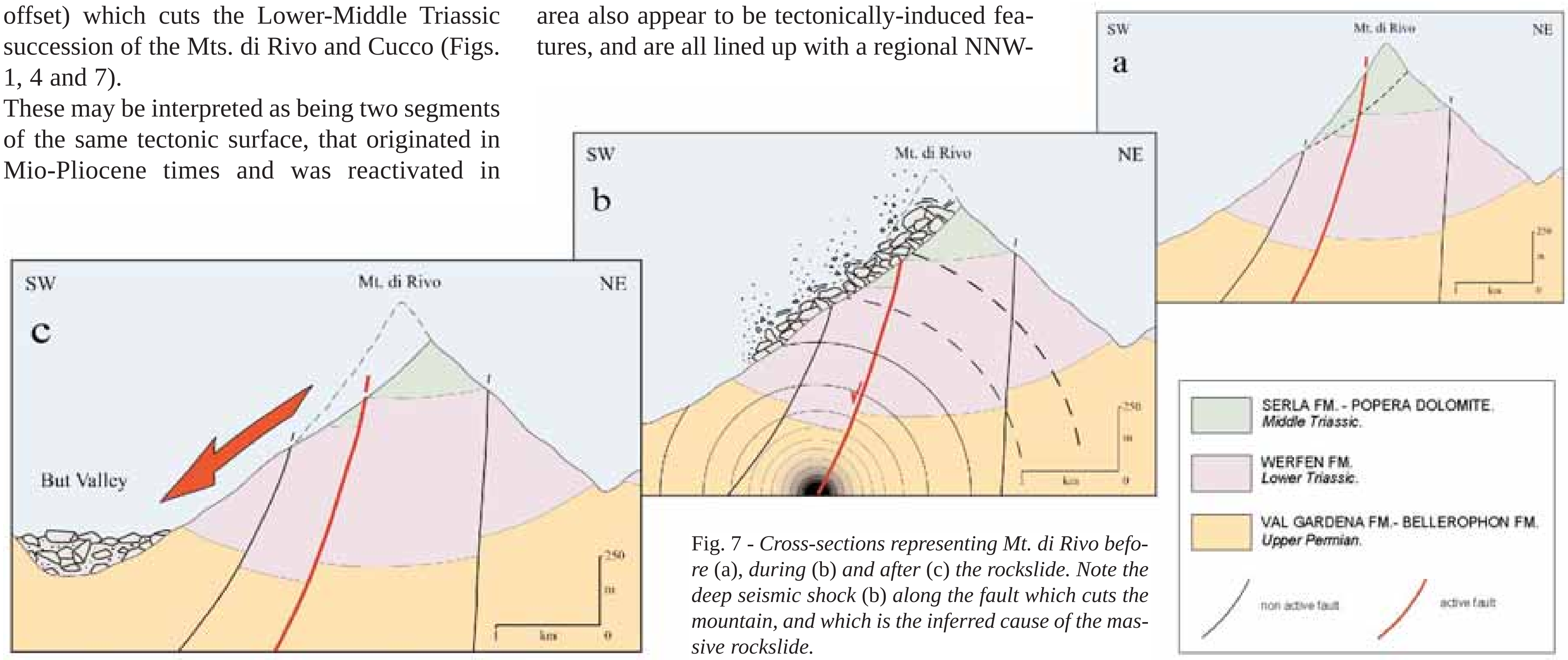


Fig. 7 - *Cross-sections representing Mt. di Rivo before* (a), *during* (b) *and after* (c) *the rockslide. Note the deep seismic shock* (b) *along the fault which cuts the mountain, and which is the inferred cause of the massive rockslide.*

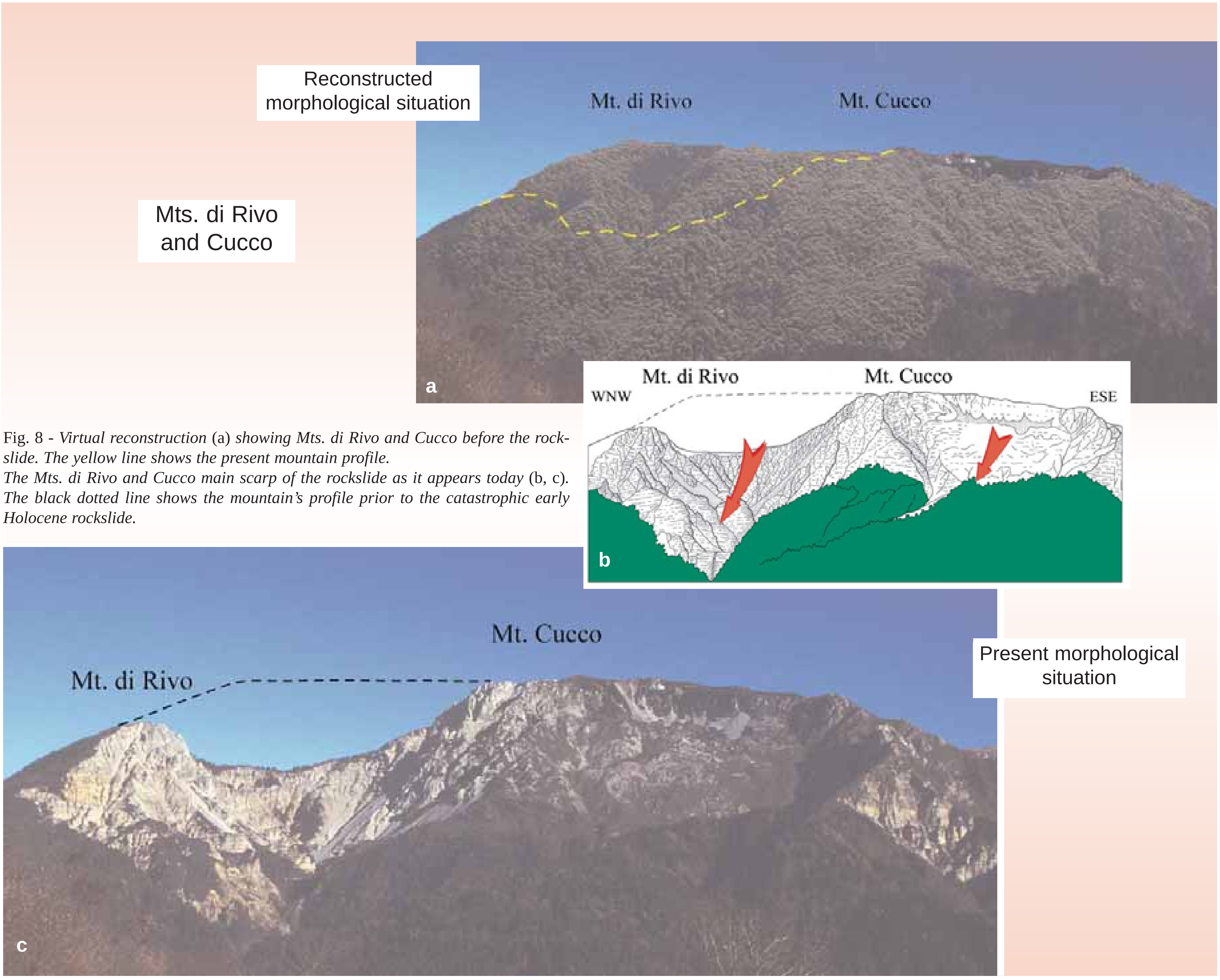


Fig. 8 - *Virtual reconstruction* (a) *showing Mts. di Rivo and Cucco before the rockslide. The yellow line shows the present mountain profile.*
The Mts. di Rivo and Cucco main scarp of the rockslide as it appears today (b, c). *The black dotted line shows the mountain's profile prior to the catastrophic early Holocene rockslide.*

HIGH-RANK DATA

These are based on the combining of several sets of low-rank data to provide an overall illustration of the main evolutionary stages for the whole geosite area by means of pictures, captions and commentary notes.
Sometime a "naïve style", such as that shown here, helps making geosite information more easily understandable. By way of example, we will apply the educational strategy mentioned to the case study of the middle But Valley. To this end, it is useful to relate the three evolutionary stages mentioned and refer them to various features on the field, illustrating ways of dealing with the various groups of data. Low-rank and high-rank information will be combined with iconographic materials (photos, drawings, 3D images and so on) to prepare the layout of the geosite poster.

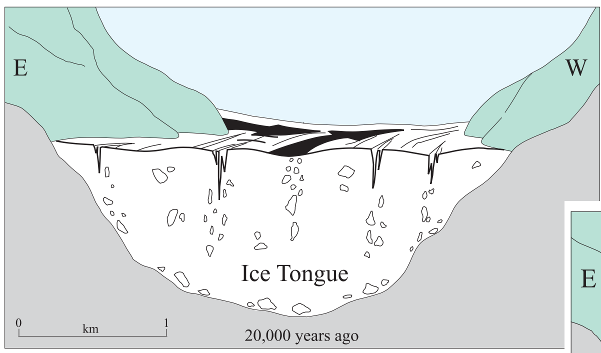


Fig. 9 - *The Wiirmian glacial tongue (20,000 years ago) filled the lower part of the But Valley and flowed from the N to the S. A few thousand years later it had disappeared completely. The viewpoint of the reconstruction is from the position where the village of Sutrio now lies, toward the S.*

THREE EVOL
FOR A GEOSITE

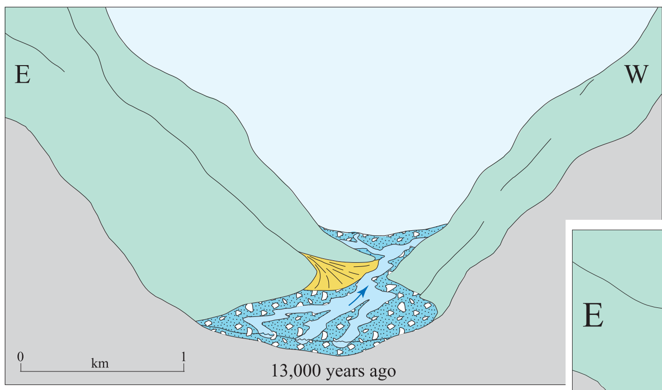
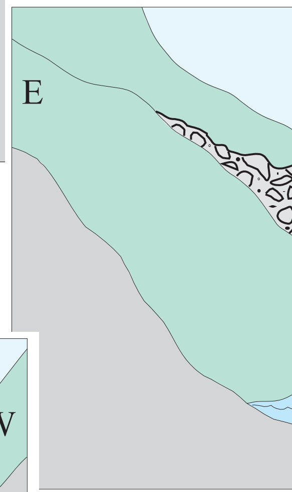


Fig. 10 - *In the But Valley the glacial retreat was completed about 13,000 years ago, and the River But became the main stream of the valley. The River Chiarsò's confluence can be seen in the view.*



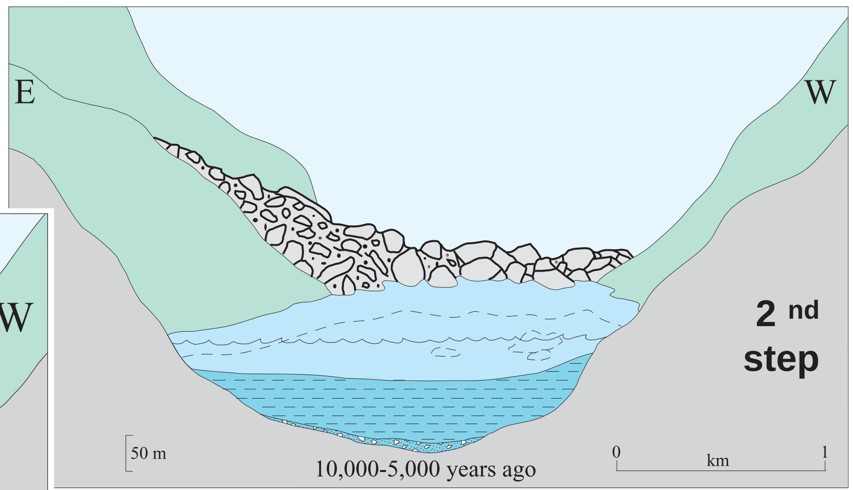


Fig. 12 - *The rockslide mass formed a dam which stopped the River But stream, creating a 6km² lake which remained for 5,000 years. The lake age was estimated through the ¹⁴C radiometric analysis of some woody fragments found in the old lacustrine sediments, which are over 100 m thick and consist of muds and sands.*

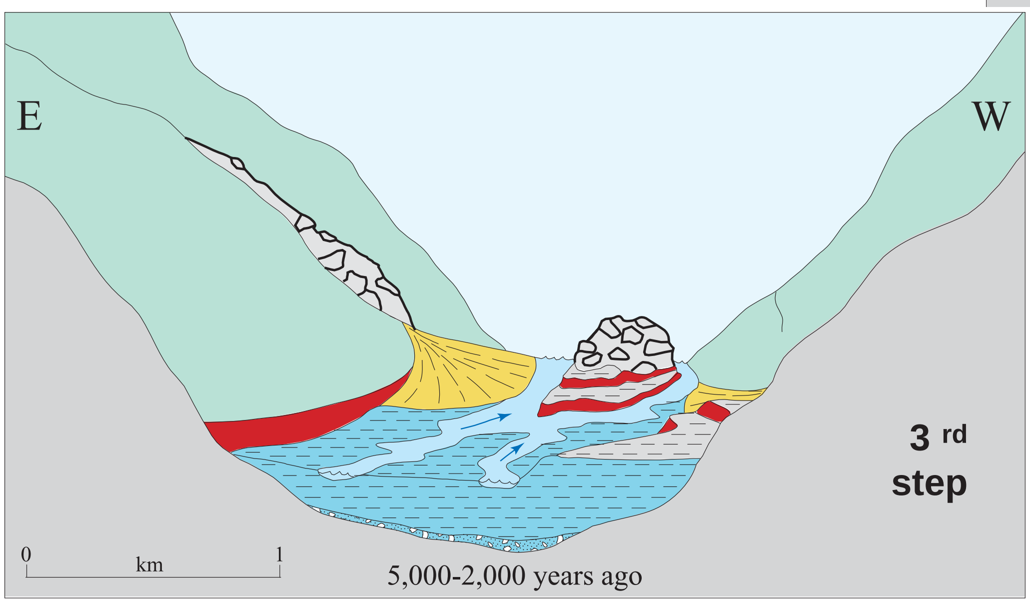
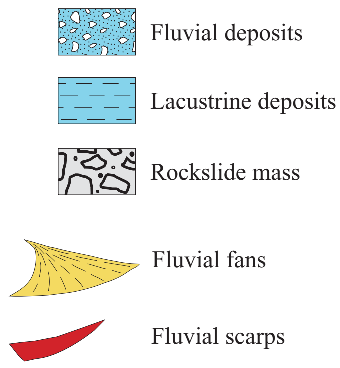


Fig. 13 - *About 5,000 years ago, the natural dam collapsed. The lake waters rapidly flowed out, cutting both the rockslide deposit and the lacustrine sediments. In the latter, characteristic terraced surfaces formed. At the same time, the side streams began once more to supply the valley bottom with alluvial detritals.*



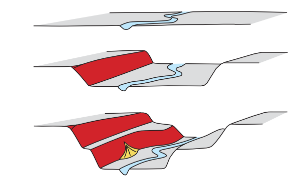


Fig. 13a - *Terraced surfaces formed by the lowering of the stream. This process is particularly rapid when erosion cuts loose materials, such as alluvial sediments.*

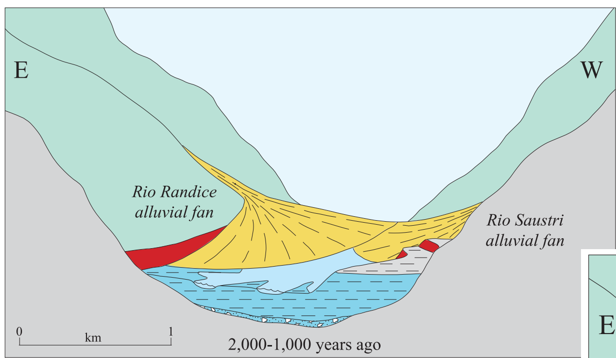


Fig. 14 - *The side streams (Rio Randice and Rio Saustri) formed large alluvial fans. Occasionally they would temporarily stop the River But flow. As a consequence, ephemeral marshes also formed in historical times.*

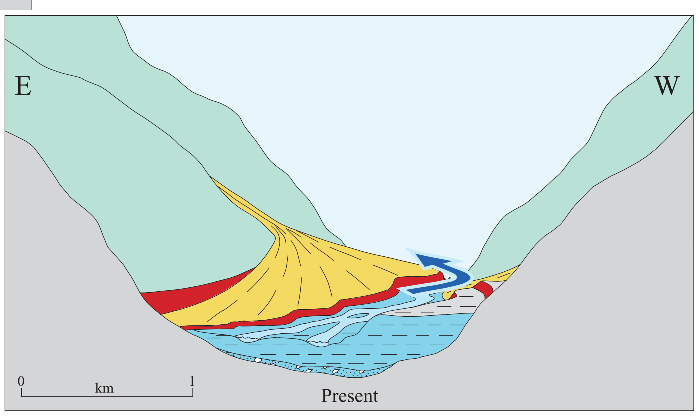


Fig. 15 - *The volumetric increase of the Rio Randice alluvial fan caused the River But stream to shift to the W. The most recent effects are erosion both on the right side of the valley and in the alluvial fan deposits.*

1st stage

Massive rockslide of Mts. di Rivo and Cucco

The main scarp of the rockslide is still clearly visible on the general map in Fig. 2. Particular attention should be paid to the morphological aspect, as the starting-point for the particular changes underwent by the middle But Valley in the early post-glacial times (early Holocene). The characteristics and dimensions of this aspect should be highlighted by several means, using photographs, explanatory drawings, DEMs and so on. Exhaustive captions should provide further information by focusing on the images' significance.

2nd stage

Palaeolake life

This stage should show those features attesting to the long life of the palaeolake. These are the remnants of the former lake sediments, mainly muds and sands containing radiometrically-datable wood fragments. These sediments crop out along the bottom of the present valley up to 595 m a.s.l. It is important to emphasise their highest elevation, as this would have been the level of the original lake surface.

UTIONARY STAGES
DRAFTING PROJECT

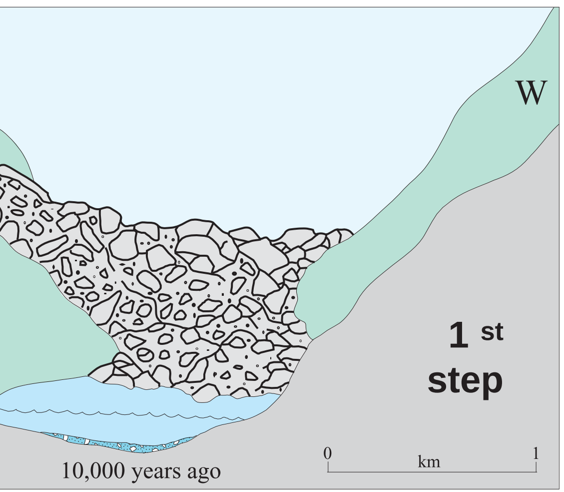


Fig. 11 - *About 10,000 years ago, in the Alzeri-Noiariis bridge area, a thick rockslide mass that crashed down from the top of Mt. di Rivo infilled the valley.*

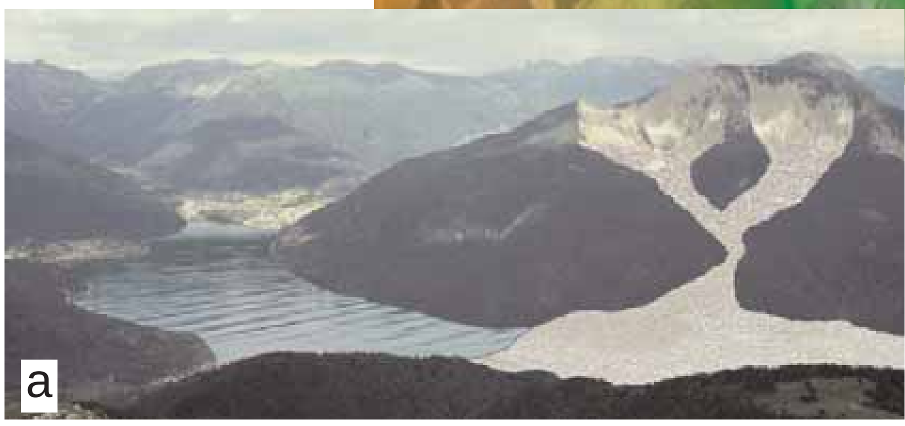


Fig. 11a - *The middle But Valley from 10,000 to 5,000 years ago. The large rockslide of Mts. di Rivo and Cucco formed a dam which stopped the River But's waters and resulted in the formation of a great lake. View from the south-west.*

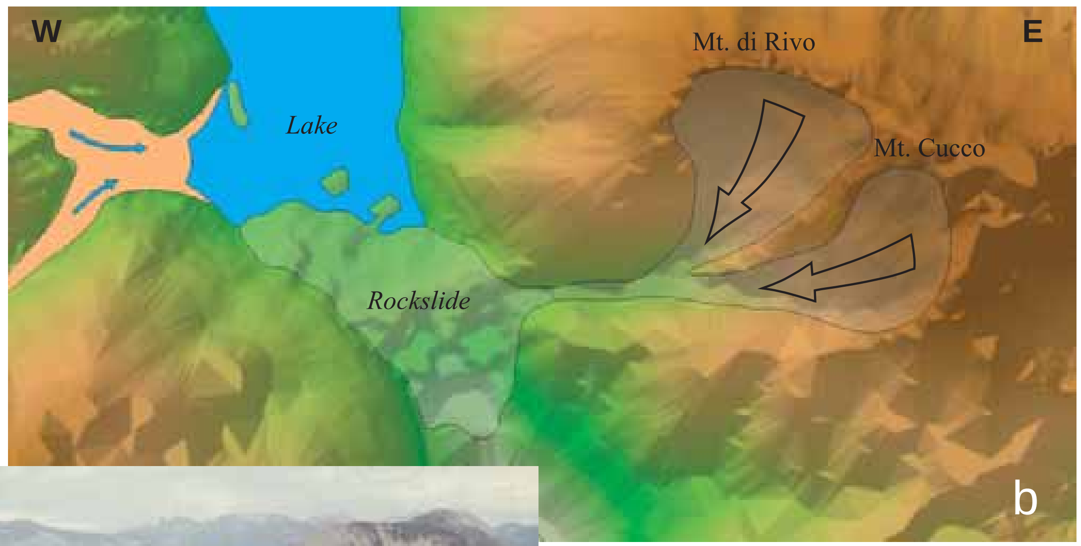


Fig. 11b - *DTM reconstruction of the slide area of Mts. di Rivo and Cucco (arrows). The collapsed material is visible in the valley bottom.*

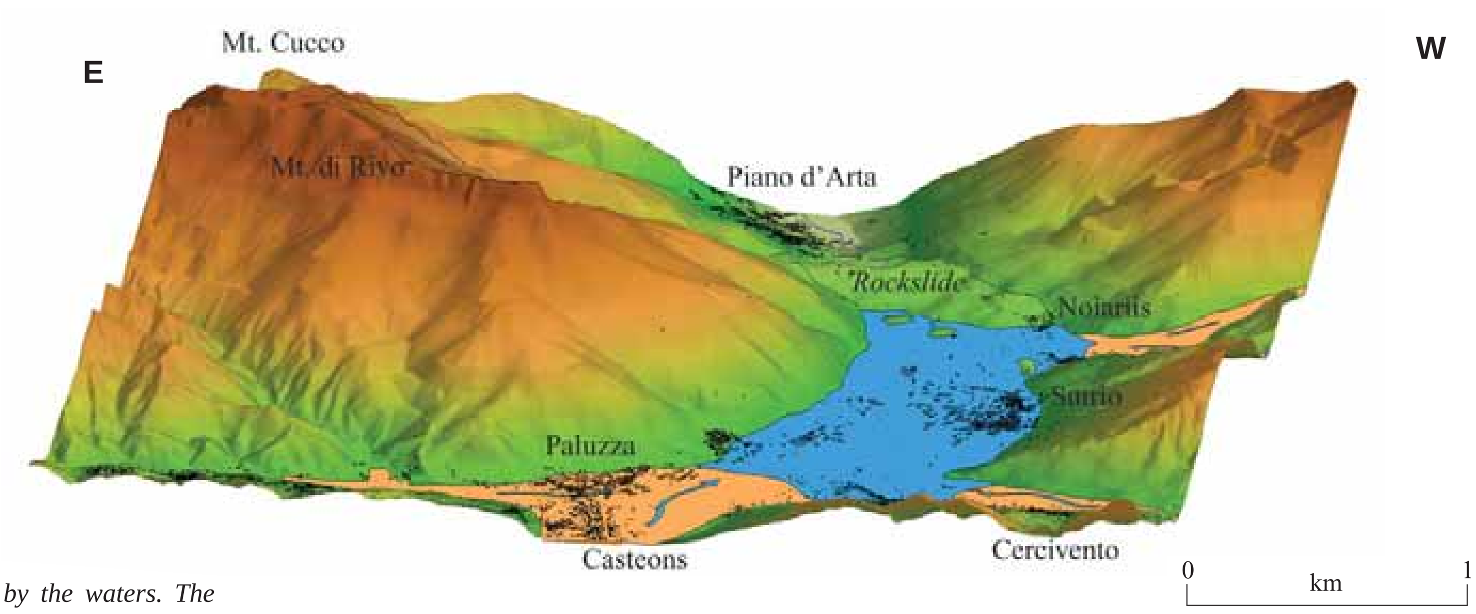


Fig. 12a - *The DTM restores the area covered by the Sutrio palaeolake about 10,000-5,000 years ago (early Holocene). Most of the areas where the nearby villages lie today would have been submerged by the waters. The palaeolake surface has been inferred as lying at about 600 m a.s.l.*

3rd stage

Emptying of the palaeolake

The final stage shows the territory returning to its aspect prior to the formation of the lake. This occurred owing to the cut-off of the rockslide dam due to the erosion of its upper wedge. The emptying of the palaeolake removed most of the lacustrine-deltaic sediments and the erosion produced terraced surfaces and steep scarps. Even the rockslide was almost completely destroyed. It should be noted how the rapid lowering of the local base level triggered renewed erosion also of the valley sides.

In particular, the western part of the main scarp of the rockslide was deeply eroded and the rock fragments formed the large Rio Randice alluvial fan. This covered the few remnants of the large rockslide fallen from the Mts. di Rivo and Cucco.

Fig. 16a - *The erosive scarp which bounds the main terraced surface is clearly visible. This is one of the most prominent morphological features caused by the emptying of the lake. View from the west.*

The Rio Randice fan caused a westwards shift of the River But stream, which began to erode the Triassic bedrock along the right riverside (Figs. 15 and 16b). In very recent times, the opposite prograding of the Rio Randice and Rio Saustri alluvial fans formed a temporary dam at about 520 m a.s.l. As a consequence, the water-flow of the River But slowed down. In historical times, wide temporary marshes formed up-stream, in the same area where the palaeolake was a long time ago.

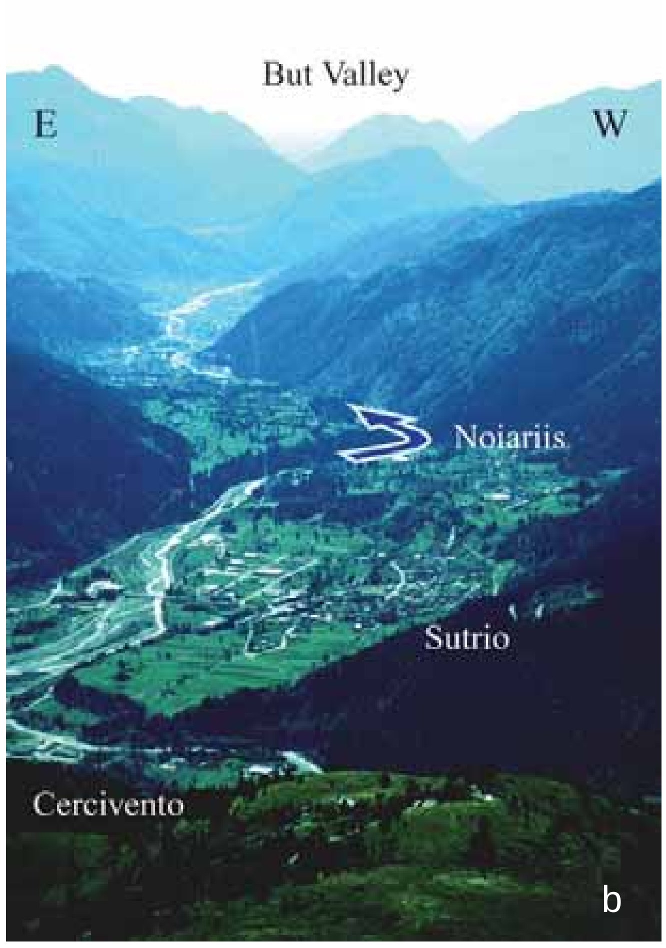


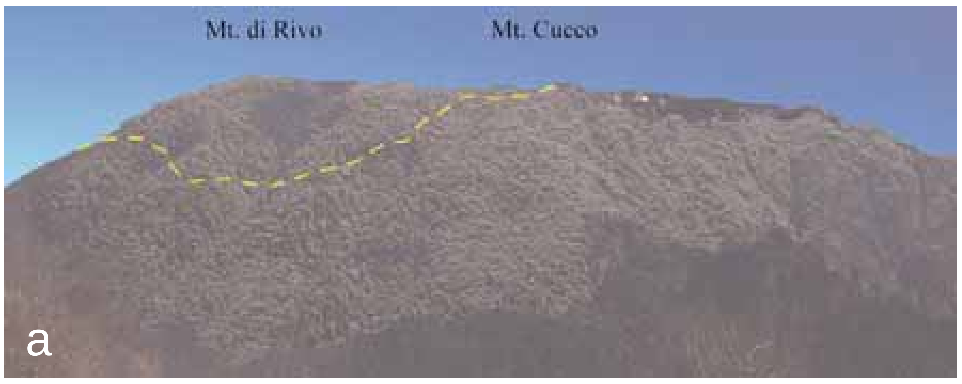
Fig. 16b - *The lowering trend of the But thalweg is still active and clearly visible at the Ponte di Noiariis gorge. Here erosion is carving even the Permo-Triassic limestones which crop out under the alluvial fan deposits.*

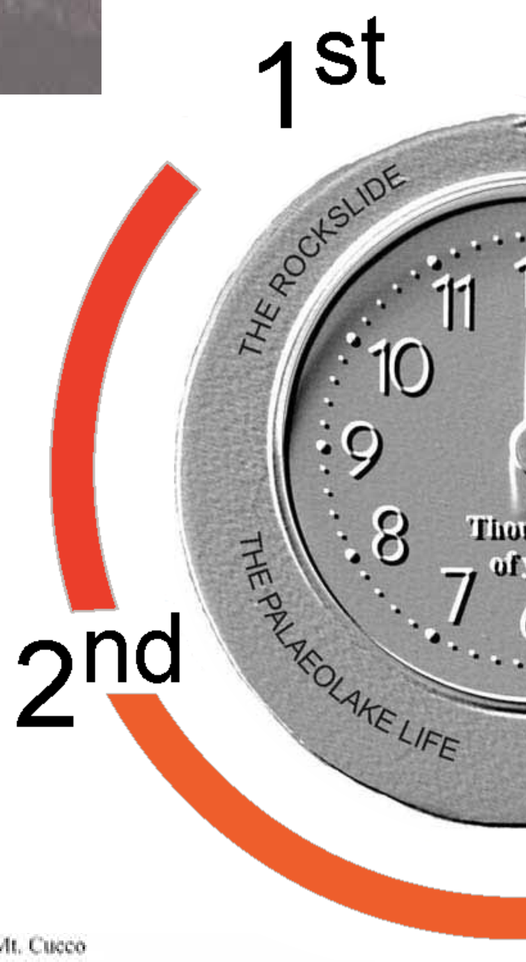
There follows an outline of the geological history the middle But Valley over the last 10,000 years. The River But flows from the N to the S through the central core of the Carnic Alps, not far from the Italian-Austrian border.
The valley widens near the villages of Paluzza, Cercivento, Sutrio and Arta, and its bottom lies at 450-600 m a.s.l. On the eastern side of the valley, between Arta and Paluzza, the Mts. di Rivo and Cucco rise. Up to 10,000 years ago, the southern side of the mountains appeared quite different from what it does today. Then, at about that time, a catastrophic change occurred suddenly, leaving the mountains and valley bottom completely transformed.

HISTORY OF THE MIDDLE BUT VALLEY GEOSITE (CARNIC ALPS)

1st stage - The last glacial retreat in the Alps started about 20,000 years ago, and about 13,000 years ago the But Valley was completely ice free. The ice tongues disappeared everywhere and rivers and streams like those we see today began to flow again.
Then, suddenly, a few thousands of years later (about 10,000 years ago), a catastrophic event took place in the middle But Valley. A tremendous seismic shock, with epicentre Mt. di Rivo, caused a massive rockslide, and more than 100 million m^3 of Triassic carbonatic rocks crashed down towards to the River But, leaving the middle But Valley radically changed.

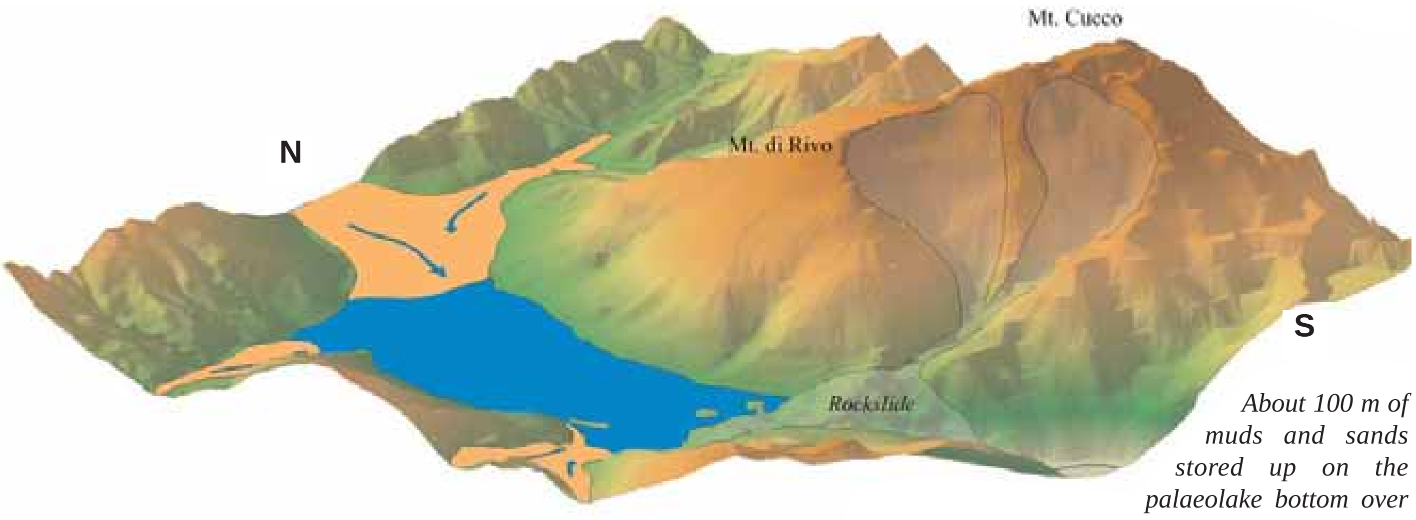
Reconstructed geomorphological situation of Mts. di Rivo and Cucco during the last glacial retreat and before the great rockslide which occurred about 10,000 year ago.



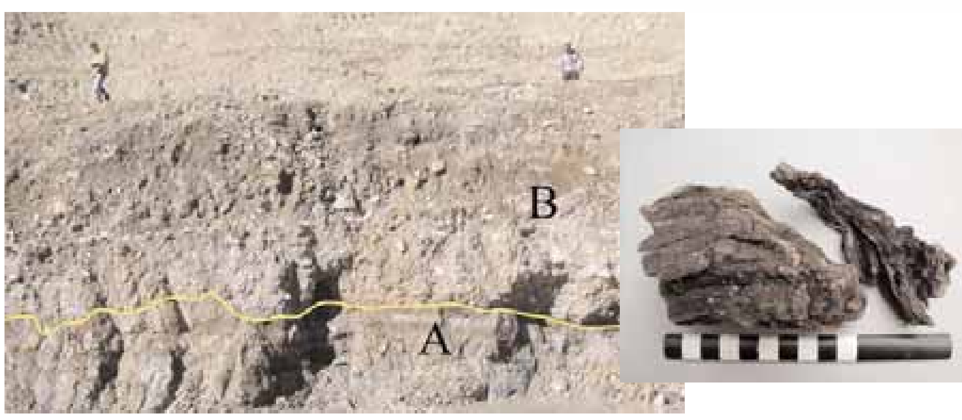


A seismic shock, with epicentre in the middle But Valley, caused the rockslide: about 500 million m^3 of rocks stopped the River But flow. The River But waters formed a 6-km^2 palaeolake (b) that remained for several thousands of years. The palaeolake would have submerged most of the area in which the villages of the area now lie, as shown in the DTM reconstruction (a). The red line shows the active fault which is presumed to have been responsible for the seismic shock that caused the rockslide.

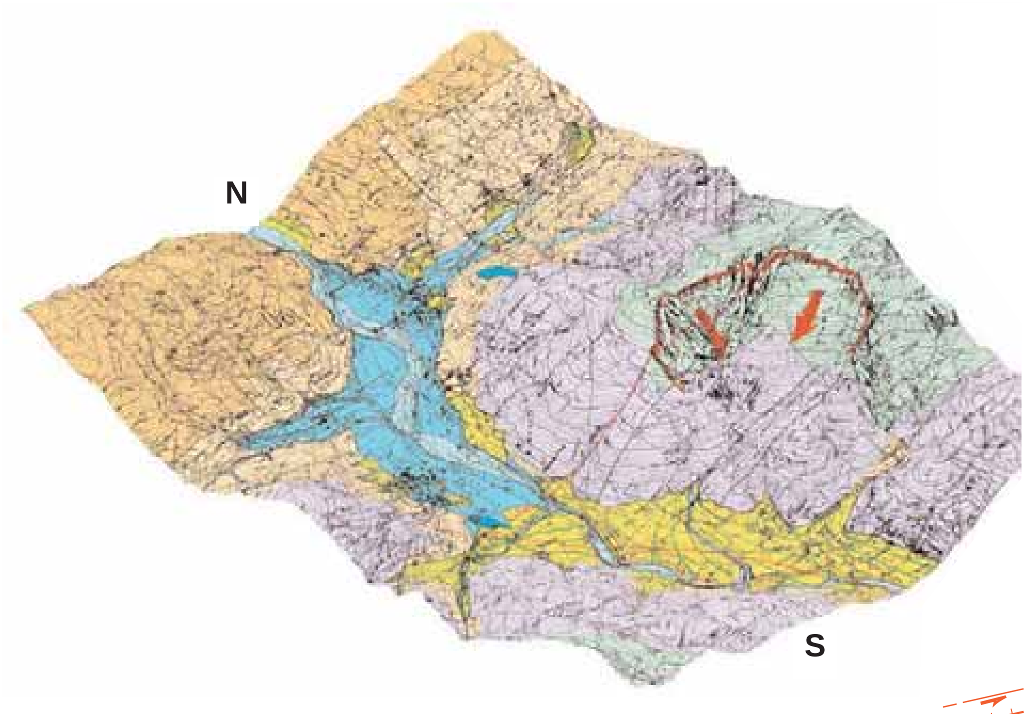
2nd stage - The Mts. di Rivo and Cucco rockslide mass set in 2 km south of the village of Sutrio, in the present Alzeri area. The chaotic mound formed a dam 150 m high which stopped the upstream flow of the River But.
As a consequence, a palaeolake more than 6 km wide formed and remained for about 5,000 years. Its surface lay at 600 m a.s.l., as testified by the highest lacustrine sediments onlapping the uppermost part of the Ognissanti cliff (595 m). The River But, together with the Gladegna and Pontaiba streams, supplied the palaeolake with about 100 m of laminated muds and sands.

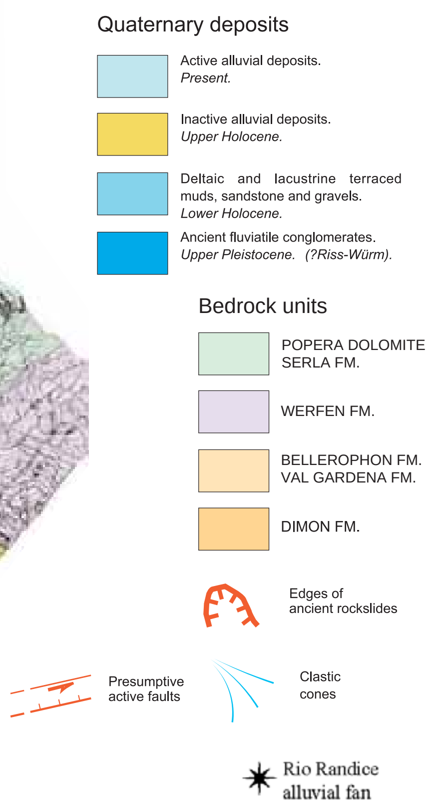


About 100 m of muds and sands stored up on the palaeolake bottom over more than 5,000 years. These are the finest sediments that flowed into the palaeolake through three different fluvial deltas (blue arrows).



At present, the ancient lake muds crop out only in certain quarries and scarps. The muds (A) shown in the photo (left) are found near the village of Noiariis, upstream from the bridge that crosses the River But. Scattered wood fragments, deposited together with the muds, provide the radiometric ages (^{14}C) useful in order to infer the lake's life (from about 10,000 to 5,000 years ago).
The yellow line shows the erosive surface caused by the palaeolake's emptying (early 3rd stage). The upper deposits (B) are the recent fluvial gravels of the Rio Saustri. Their wood content shows that they stored up 1739 +/- 88 years BP (late 3rd stage).

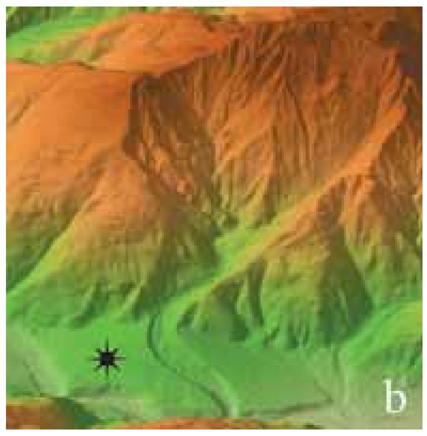




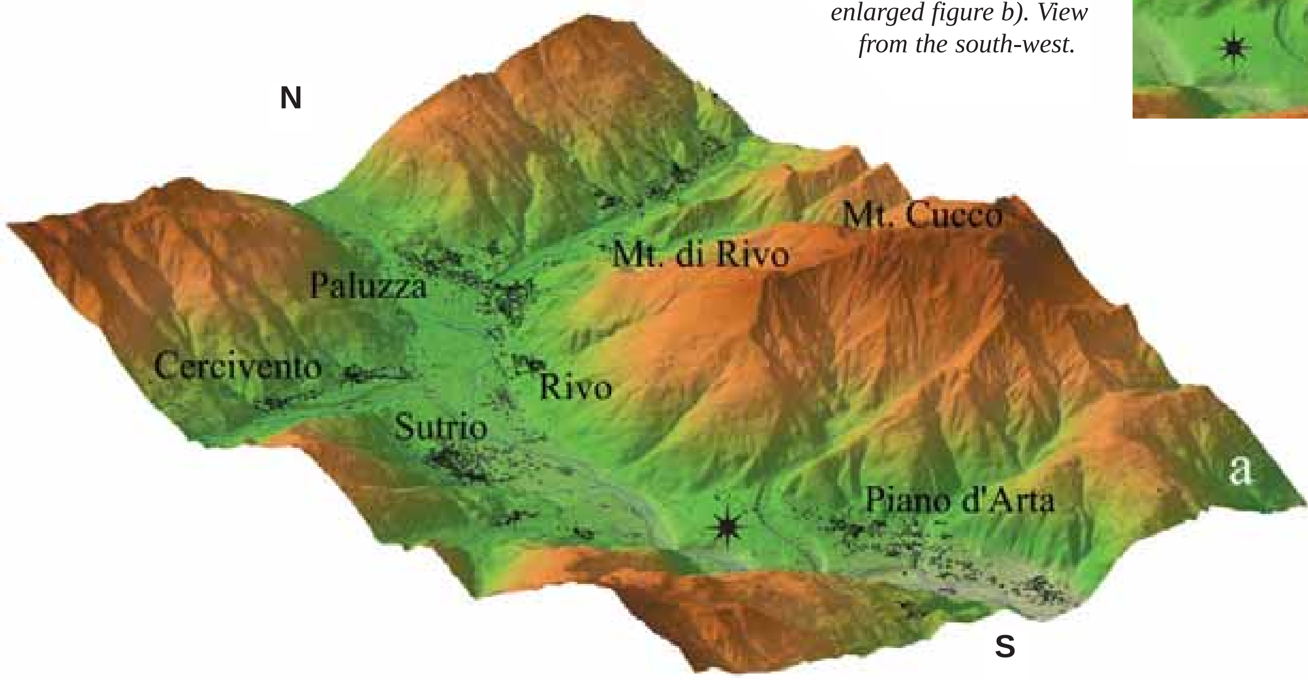
The 3D geological map shows the present-day distribution of the Holocene deposits in the middle But Valley, mainly covering Carboniferous to Middle Triassic rocks. The slide scarp of Mts. di Rivo and Cucco is highlighted (red arrows), as this was the starting point of the geosite's evolution. View from the south-west.

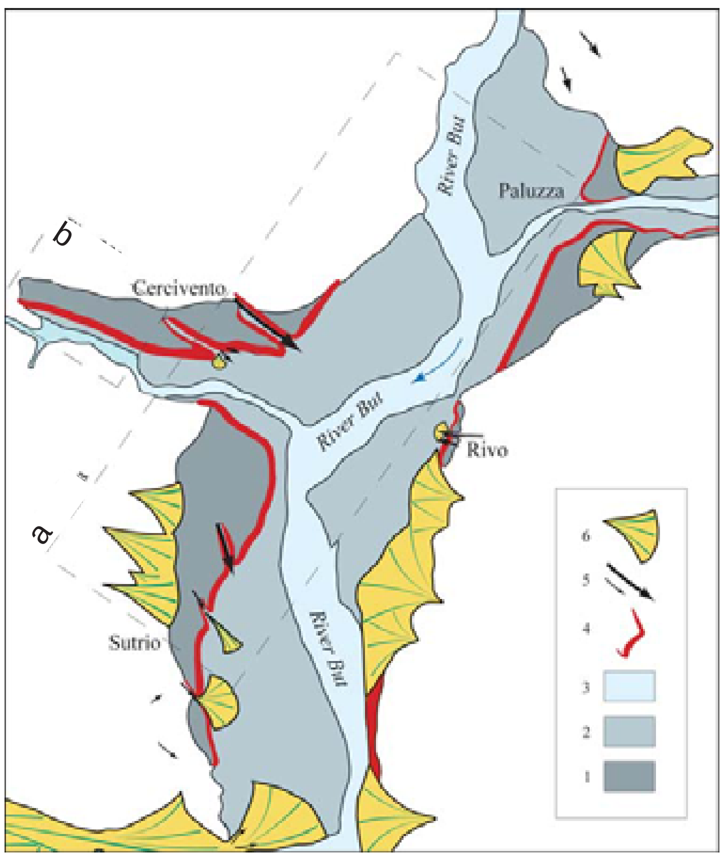
3rd stage - About 5,000 years ago the rockslide dam collapsed, letting out the water from the lake, and the River But flowed once more along the valley bottom. The river deepened, eroding the lacustrine soft sediments. The rockslide and most of the muds and sands were removed. Consequently, in the Sutrio-Paluzza-Cercivento area, terraced surfaces were formed in the lacustrine-deltaic sediments.

Fluvial erosion was also once more intensive along the valley slopes. The eroded materials piled up forming the wide alluvial cones of the Rio Randice and Rio Saustri fans. The former was supplied by the erosion of the northern portion of the Mts. di Rivo and Cucco main scarp of rockslide.



DTM virtual map of the present middle But Valley (a). About 5,000 years ago, a fan-shaped deposit formed in the place where the rockslide lay (Rio Randice alluvial fan, see also the enlarged figure b). View from the south-west.





The palaeolake remained in place for about 5,000 years, while the rockslide dam resisted. The dam's collapse then induced strong erosion of the lacustrine-deltaic sediments. As a consequence, several terraced surfaces formed. The most important of these (see the pictures on the right) is bounded by the steep erosive scarp (10 to 25 m high) still recognizable everywhere in the area.

White: Carboniferous-Middle Triassic succession.
Colour: Holocene deposits of the middle But Valley (see below).

1) *Main terraced surface shaped in lacustrine-deltaic deposits.*
2) *Recent and historical fluvial gravels.*
3) *Present-day fluvial gravels.*
4) *Morphological scarp due to the palaeolake's emptying.*
5) *Main and minor fluvial palaeoflow directions (no longer active).*
6) *Inactive alluvial fans.*

The two pictures (a, b) show the prominent scarps (arrows) due to the fluvial erosion. This morphological feature is an obvious effect of the palaeolake's emptying.

CONCLUSIONS

This work provides a description of the ways in which to make the contents of a geosite interesting and understandable to the layman. To this end, we have provided a particular case study by way of example. The geosite in question extends over an area of 40 km², in the Carnic Alps (Eastern-Southern Alps, Friuli Region).

The case study examined is that of the But Valley, a trunk valley which was affected by a massive, seismically-induced rockslide in post-glacial times (about 10,000 years ago).

The mass sliced down into the valley bottom cutting off the flow of the River But, and forming a 6 km² palaeolake. Over a period of 5,000 years, thick deltaic-lacustrine sediments stored up. These were later terraced as a result of fluvial erosion subsequent to the collapse of the natural dam.

This work illustrates the evolutionary history of the geosite area over the last 10,000 years. Results were obtained by matching causes and effects to produce a consistent mix of explanatory texts, figures (drawings, DTMs, shadow reliefs, photos, virtual reconstructions, maps and so on) and relevant captions.

In addition, the way to approach a geosite description, by illustrating field data and their interpretation, has been discussed.

More in detail, the first two pages introduce the reader to the significance of the geosite, explaining the importance of a simplified geological map in order to make basic information easily understandable.

The next pages consider a specific group of data, i.e. seismically induced features. These form part of the so-called low-rank data, as they consist of evidences all referred to a specific topic, and are fundamental in understanding the evolutionary history of the geosite: they comprise the starting point of the Holocene evolution of the middle But Valley.

The next pages are devoted to explaining the so-called high-rank data. These are based on the assemblage of several sets of low-rank data concerning tectonics, sedimentology, geomorphology, etc. The methodology used is functional towards describing the overall evolution of an area. The following pages have taken into account the same sets of data, in order to show a different way of introducing them.

What is described on the last two pages comprises the actual geosite drafting project for the illustration of the evolutionary history of the sector.

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