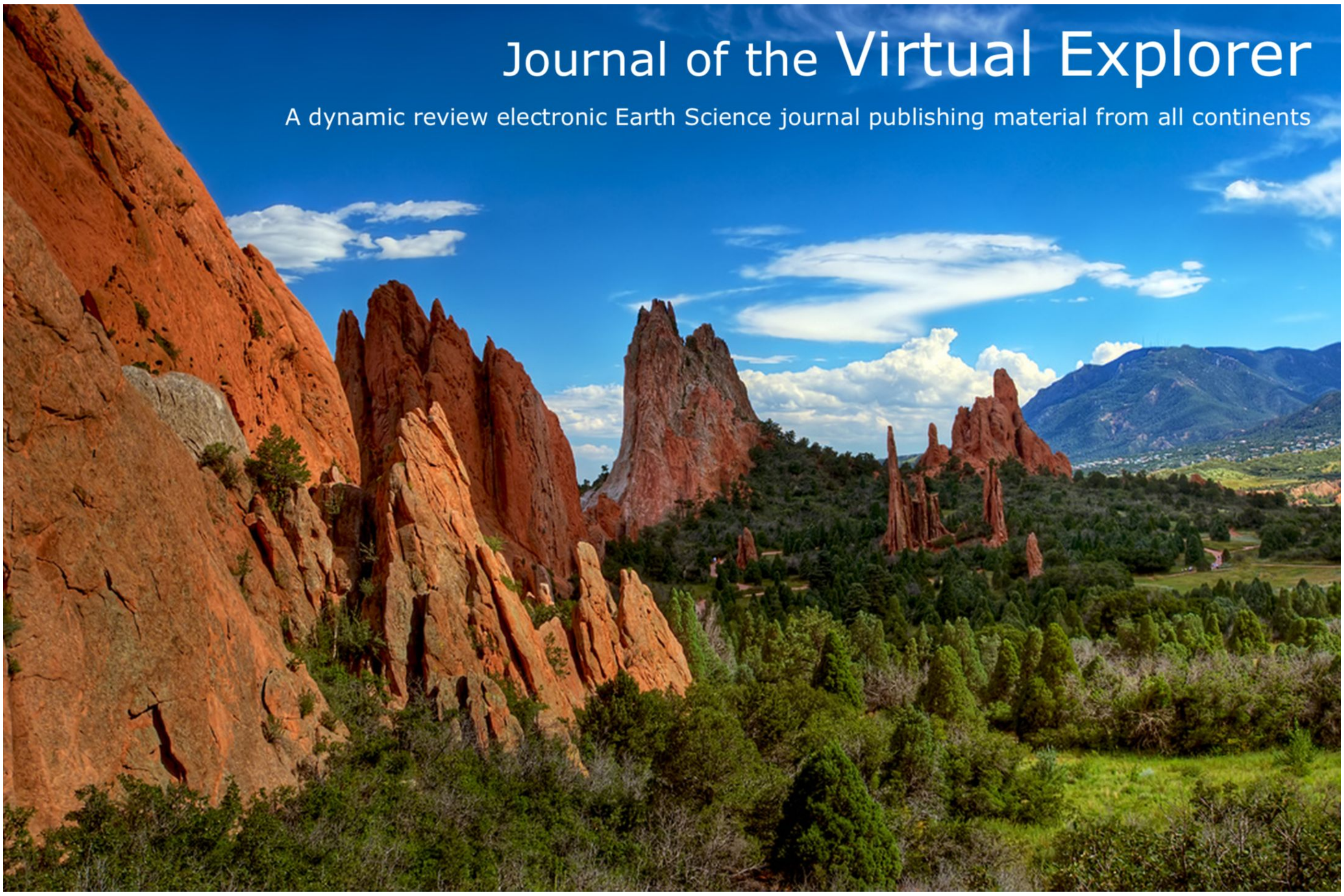

Outline of Italy's Geomorphology

Carlo Bartolini

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Outline of Italy's Geomorphology

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Abstract: The general setting of the Italian territory is illustrated by means of a DEM, a map of relief types and a map of local relief analyzed at the 100 km^2 grid scale.

Beside recent tectonic activity, geologically controlled relief forms result from regional uplift, a prerequisite of lithostructural landforms. In order to outline this prompter of morphogenesis as to the Italian region, a brief outlook on present day rock and surface uplift rates both in the Alps and in the Apennines follows.

The present uplift and denudation rates cope at large with the Alps relief. This is in line with the circumstance that the uplift pattern resembles that of apatite fission track age distribution, which would suggest long-term stability of the uplift process at the Ma timescale. Rates of denudation worked out with various methods in Northern and Central Apennines over timescales ranging from 10 to 106 years range from 0.2 to 0.5 mm/y.

Lithostructural and volcanic features are shown by means of a map prepared on purpose. The same applies to landforms due to geomorphic processes. A description of Italy main geomorphic units is also included.

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General setting

Approximately 40 percent of Italy’s surface is occupied by mountains. These are mostly everywhere fringed by hills which occupy another 40 percent of the total surface. The remaining 20 percent is made up by plains and mostly by the Po plain. The latter, as well as most of the minor plains, are intermountain and/or coastal plains genetically related to the nearby mountains. A SRTM image of Italy is shown in Fig. 1.

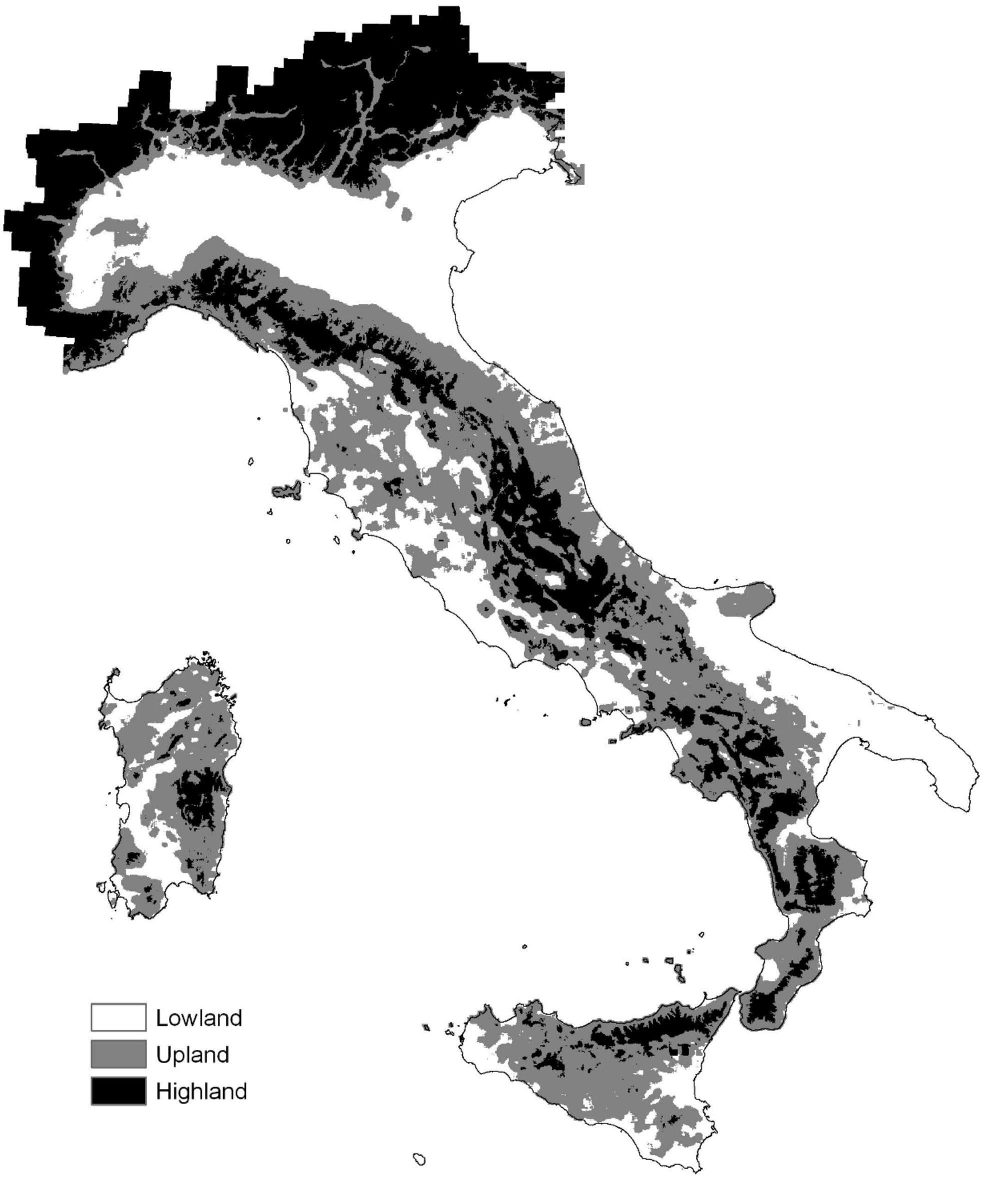
Figure 1. Shaded relief and colored elevation map of Italy

Shaded relief and colored elevation map of Italy generated from NASA SRTM, 90 m resolution.

Following the classification of Hammond (1964), Guzzetti and Reichenbach (1994) made a quantitative analysis of a 230 m DEM, which resulted in the image of Fig. 2. In the Apennines, just the backbone is classified as upland, while the whole Alpine region virtually belongs to the third type of terrain physiography. The dichotomy mainly reflects the different lithologies prevailing in the two chains.

As a matter of fact, only over the Alps (except for two small areas of the Central Apennine – see ahead) the highest relief class is widely attained, since the Alpine region features both competent rocks and relevant exhumation surface uplift and denudation rates, reaching and at places outpacing 1 mm/y (Bernet *et al.*, 2001; Schlunegger, Hinderer, 200; Hinderer, 2001; Wittmann *et al.*, 2007).

Figure 2. Map of Italian topography



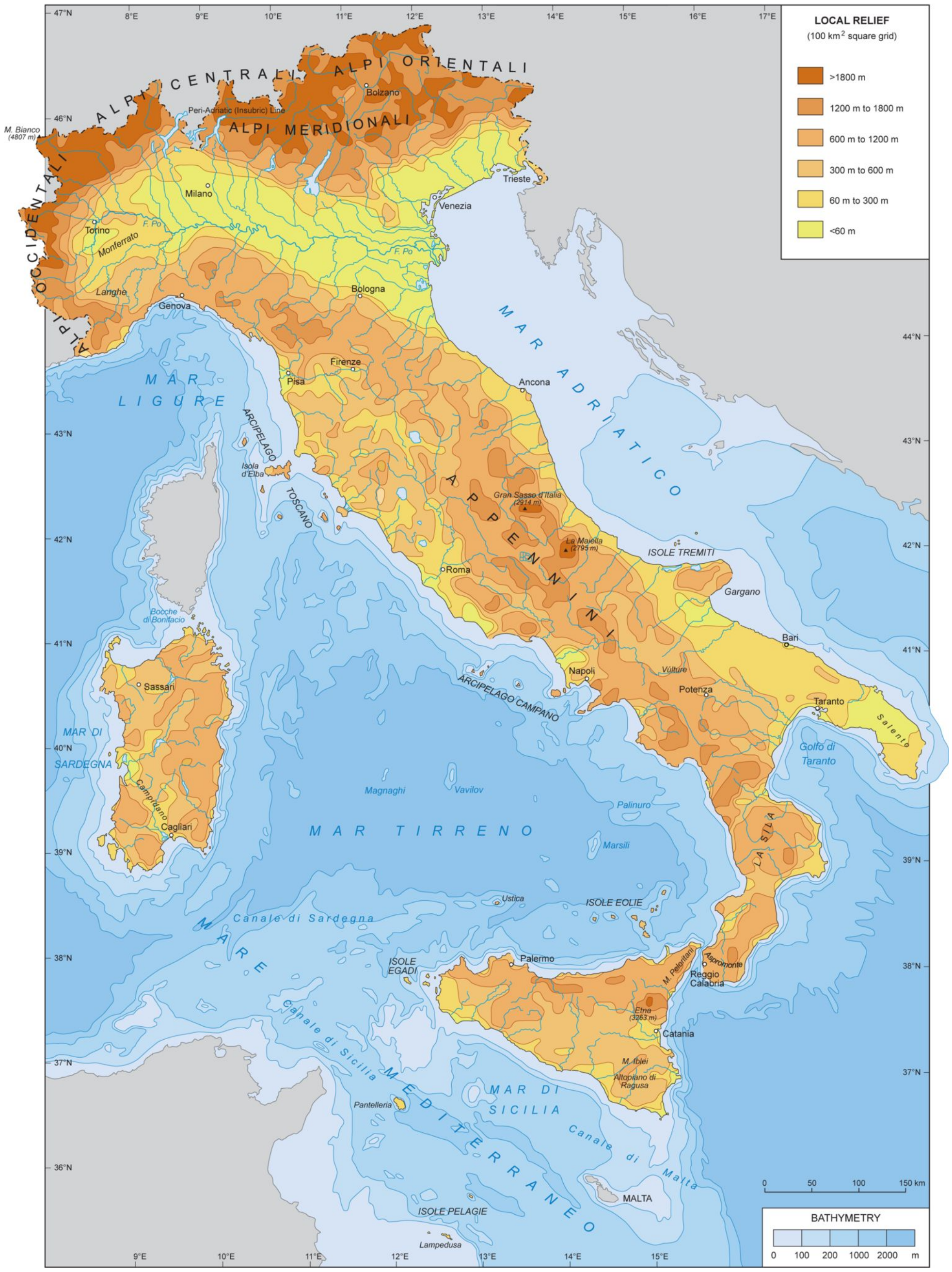
Map of Italian topography based on four variables: elevation, slope curvature, frequency of slope reversal and elevation/relief ratio. Reprinted from Geomorphology, Vol. 11, Guzzetti, Reichenbach, (1994), Towards a definition of topographic divisions for Italy, 57-74. Copyright with permission from Elsevier.

It should be noticed that the average dimension of the glacial throughs, a characteristic feature of the relief in the Alpine region, is well suited to the chosen grid scale. This is not the case in peninsular Italy, which features a rather minute relief that cannot be accurately evidenced with such a relatively large grid scale of local relief analysis.

Beside the Po plain, low relief areas are scatterd all over peninsular Italy in intermountain and coastal plains. The low relief Salento peninsula is a litho-structurally controlled erosion surface.

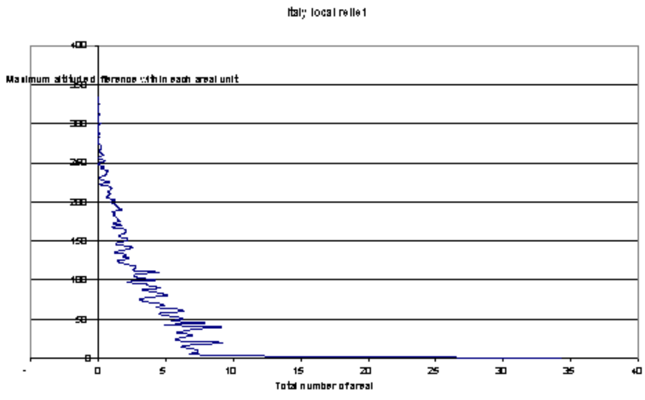
Local relief, analyzed at the 100 km^2 grid scale (Fig. 3), appears to be mostly influenced by rock competence and secondarily by present rock uplift rates.

Figure 3. Local relief map



Local relief (i.e. maximum altitude difference computed over 3536 10x10 km areas)

Figure 4. Frequency distribution (25 m interval classes) of local relief



Six-hundred ninety unit areas – over a total of 3536 – feature a relief ≤ of 75 m.

Uplift and denudation rates as driving factors of present day morphology

Beside recent tectonic activity, geologically controlled relief forms (as for instance described in Bartolini, Peccerillo, 2002) result from regional uplift, a prerequisite of lithostructural landforms (see Fig. 9).

In order to outline this prompter of morphogenesis as to the Italian region, a brief outlook on present day rock and surface uplift rates both in the Alps and in the Apennines follows.

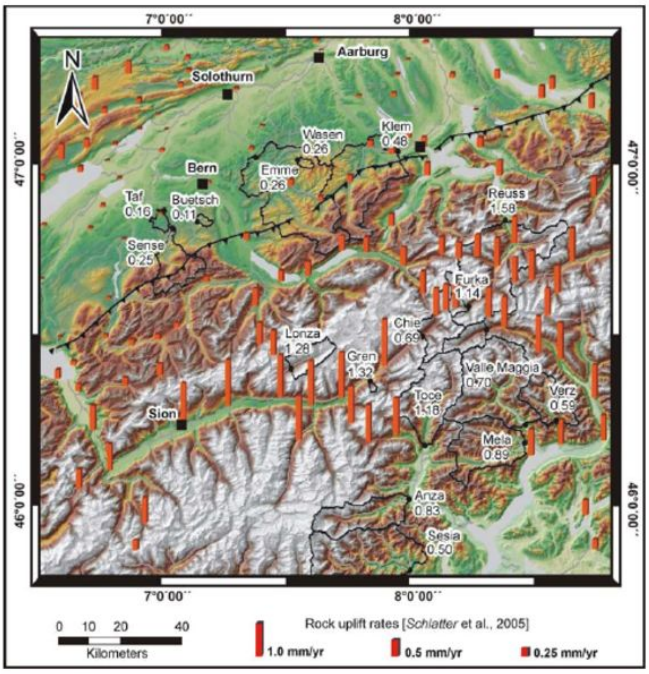
Alps

In the Central Alps, on either side of the chain, Wittmann *et al.* (2007) pointed out that a fair correlation relies on geodetic measurements of surface uplift and denudation rates as obtained by 10Be cosmogenic nuclide-derived denudation rates, computed on a millennial scale.

As shown in Figure 5, the present uplift and denudation rates cope at large with the Alps relief. This is in line with the circumstance that, according to the same authors, the uplift pattern resembles that of apatite fission track age distribution, which would suggest long-term stability of the uplift process at the Ma timescale.

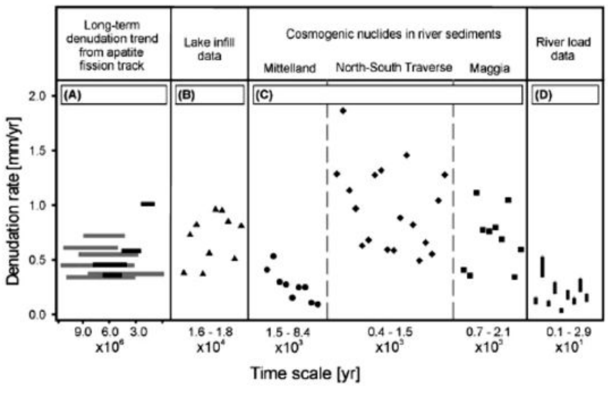
Wittmann *et al.* (2007) compared the denudation rates affecting the Alps, estimated with various methods at different timescales (Fig.6). Long term denudation rates estimated from apatite fission tracks compare fairly well with lake infill dates, although the latter refer to a much more recent time span. Cosmogenic radionuclides data show, instead, a large spread of values probably connected with the pitfalls of the method. Present day denudation rates based on river load data are surprisingly low. This may be due to the short time interval they represent and to the ensuing influence of the anthropic impact; but also, as pointed out by Bartolini and Fontanelli (2009), to the limits inherent to the method.

Figure 5. Recent vertical movements in the Central Alps.



Bar heights give the rate of rock uplift relative to the benchmark at Aarburg. Denudation rates, based on catchment-wide cosmogenic nuclide analysis, are given in mm/a. From Wittmann *et al.*, 2007, JGR, 112, F04010, doi:10.1029/2006JF000729.

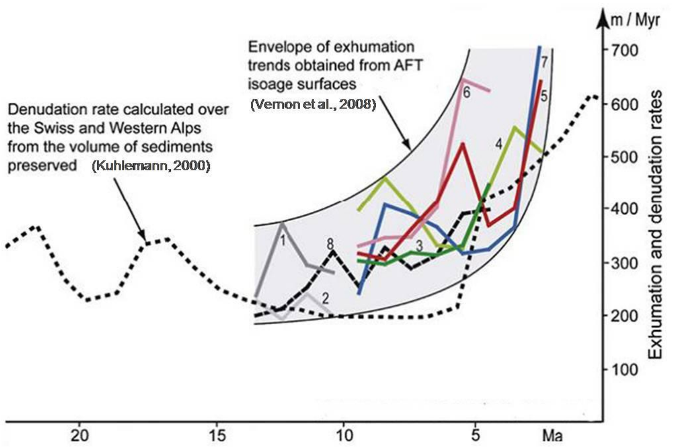
Figure 6. Denudation rates estimates from different methods plotted against their corresponding timescale.



From Wittmann *et al.*, 2007, JGR, 112, F04010, doi: 10.1029/2006JF000729.

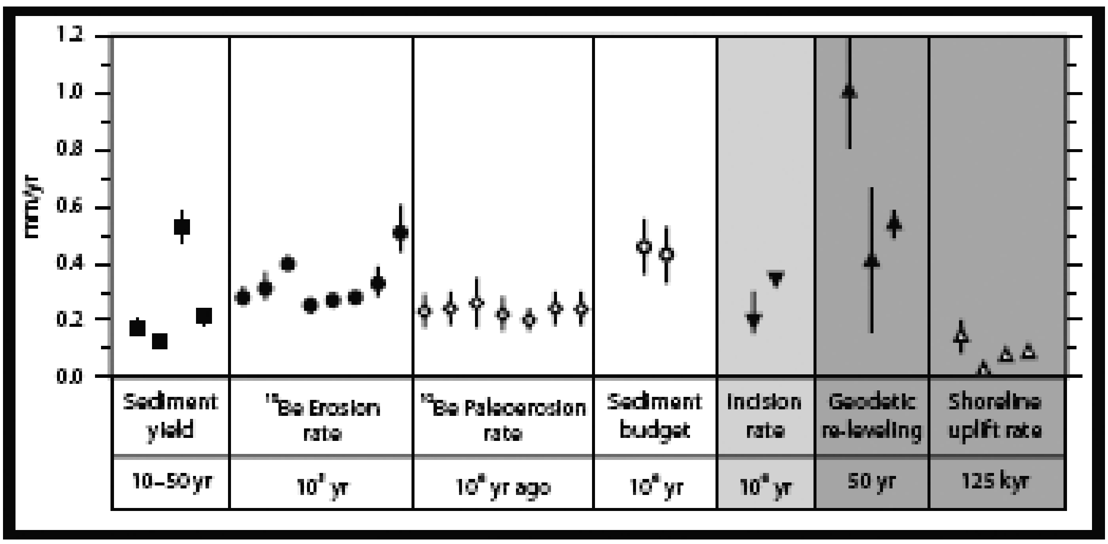
As shown by Vernon *et al.* (2008), Fig. 7, the envelope of exhumation trend and the denudation curve show an increase centered before 5 Ma.

Figure 7. Comparison between the estimates of average denudation rate (recorded in sediment volume) and exhumation rate (using AFT isoage surfaces) over the Western Alps.



The average Western Alps denudation rate calculated by Kuhlemann (2000) is the ratio between the peri-Alpine sedimentation rates and the provenance area. Both the envelope of exhumation trend and the denudation curve show an increase centered before 5 Ma. From Vernon *et al.*, 2008.

Figure 8. Denudation, fluvial incision and uplift.



Rates of denudation (white area), fluvial incision (medium grey area) and uplift (dark grey area) in the Northern and Central Apennines inferred from seven different techniques over decadal to million-year time scales. From Cyr and Granger (2008), Geology 36, 103 – 106.

As to the factors influencing the denudation rates, Malusà and Vezzoli (2006) pointed out that in the Western Alps, rather than lithology and climate, the differential upward motion of crustal blocks is the main agent. The study area, the authors state, shows in fact a close spatial relationship between the pattern of short term rates and that inferred from fission track dating.

Apennines

Several methods aimed at evaluating related variables concerning the erosion rates affecting the Northern and Central Apennines at timescales ranging from the present day to one Myr have been matched by Cyr and Granger (2008), as reported in Figure 8.

Excluding the three columns shaded in grey, which refer to data affected by various limitations, most rates range from 0.2 to 0.5 mm/y. Similar results have been worked out by numerous other authors based both on sediment budgets (Bartolini *et al.*, 1986; Bartolini, 1999; Bartolini, Fontanelli, 2009) and on thermochronologic methods. (Balestrieri *et al.*, 2003; Ventura *et al.*, 2001; Zattin *et al.*, 2002).

Northern Apennines: is local relief a proxy for uplift history?

Apennine backbone vs Apuan Alps

The present, subdued relief of Northern Apennine depends on:

- the Basin and Range type structure of the inner sector of the Apenninic Chain
- the prevailing flysch lithology
- the current – mild - morphoclimatic regime

These factors hamper a high relief to set out, despite the high rock uplift rates that affect the Chain, as exhumation rates obtained from low temperature thermochronological methods have recently pointed out.

Exhumation rates were often confidently translated into rock uplift rates implying that surface uplift was mainly negligible. As a matter of fact, the term "uplift" has been often referred in the past to either surface and rock uplift. England and Molnar (1990) pointed to the importance of a clear distinction. They defined "surface uplift" as the displacement of Earth’s surface with respect to the geoid; "exhumation" as the displacement of rocks with respect to the surface. The sum of the rates of these two processes gives the rate of "rock uplift", that is the displacement of rocks with respect to the geoid:

$$Su + Exh = Ru$$

Since in mountain ranges exhumation occurs at a fast pace, the distinction between uplift of rocks (i.e. crustal uplift) and surface uplift cannot be overlooked. The reason it used to be lies in a naturally conservative attitude which hampered most geologists to take into account, while tracing paleogeographic settings, that through geologic times relevant rock masses are being wiped off.

This attitude may typically be detected whenever the feeding to a Quaternary sedimentary basin is discussed: the surface geology to which the source rocks are referred is commonly the present day one, despite the fact that in most mountain areas, not less than 1 km of rocks, on average, has been wiped off since early Quaternary.

Another case is that of the Messinian deposits of the Tyrrhenian area. Although they were feeded from the West, as proven by clast lithologies which never outcropped in the mainland (Pandeli *et al.*, 2009), apparently no one ever ventured to think that the Tuscan area could have been, at the time, part of the inner shelf of the Apennine foredeep. The line of reasoning had apparently be that, since Messinian outcrops are lacking all over the Chain, the latter emerged at that time. It may well be, instead, that Messinian deposits were blanketing the Ligurids as late Epiligurids.

Recent investigations in the Apuane Alps area (Balestrieri *et al.*, 2003) allowed a most interesting time scan of exhumation rates to be worked out. Between about 11 Ma and about 6 Ma, the cooling rate was between 10° and 16°C/Myr, which correspond, assuming a geothermal gradient of 25°C/km, to exhumation rates of 0.4-0.6 mm/y. Between 6 Ma and 4 Ma, cooling rates increased to between 38° and 55°C/Myr, equivalent to an exhumation rate of 1.3-1.8 mm/y, presuming a geothermal gradient of 30°C/km (such an increase of the geothermal gradient from the Messinian onwards is consistent with the onset of the Tuscan geothermal anomaly as well as with the higher exhumation rates). The last part of the thermal path (4 MA to present) is not well constrained due to lack of AHe data, but the average exhumation rate is between 0.6 and 0.9 mm/y (assuming a geothermal gradient of 30°C/km). The slowing down of the exhumation rate since Middle Pliocene is certainly related to the surface exposure of the highly resistant rocks belonging to the Tuscan Metamorphic Unit and to the Paleozoic Basement which began to occur at that time, as proven by the lithologic composition of the continental basin sediments fed to the east by the Apuane Alps erosion.

In the Apuan Alps, the last major incision of streams occurred during the Middle Pleistocene while no significant uplift took place during the Late Pleistocene (Piccini *et al.*, 2003).

As geomorphic and thermochronologic evidence points out, the higher rock and surface uplift rates occur at present over the drainage divide of the Northern Apennine. A wealth of apatite fission-track data has been worked out recently in the central and eastern sector of the Northern Apennine (e.g. Zattin *et al.*, 2002). Mt. Falterona, consisting of Miocene foredeep deposits (Marnoso Arenacea Fm.), is located along the present drainage divide on the north-eastern edge of the Mugello Basin. According to Zattin *et al.* (2002), the pre-exhumation configuration features a 4 to 5 km thick cover (depending whether a geothermal gradient of 20°C/km or 25°C/km is assumed) of overlying Ligurian and Epiligurian Units, which was completely eroded in the last 5 Myr at a mean rate of 0.8 to 1 mm/y. Since geological data suggest that little or no relief was present in the area between 5.0 and 2.0 Ma BP, rock uplift rates should have been quite similar during that period to the computed exhumation rates of approximately 0.8 mm/y. Surface uplift was therefore negligible. As a matter of fact, a residual veneer of Ligurids at places presently buried under the fluvial deposits both in Mugello and in the nearby Casentino basin indicate that the 5 km thick Ligurids cover had not been completely wiped out when the basin became the site of flood plain sedimentation, that is around 2.0 Ma. The high exhumation rates occurring between 5.0 and 2.0 Ma despite the prevailing low relief was made possible by the high erodibility of most lithotypes which make up the Liguride Complex.

Conclusive remarks on local relief as a proxy of present uplift rates

The slowing down of rock uplift rates in the Apuan area, compared with the present chain divide, fits the well established eastward-younging foredeep and synrift deposits and the migration of the orogenic processes and related features as well.

Despite the much lower rock uplift rates, the present average altitude of the Apuan peaks (1500 to 1900 m) is very close to that of the Apennine divide. As a matter of fact, the higher rock uplift is here largely compensated by the higher erodibility of the turbiditic sandstones which make up the Chain backbone. Because of the prevailing low erodibility, the local relief of the Apuan Alps is to such an extent greater than that of the typical Apennine chain, to deserve their odd name whereby a crumble of “Alps” lies well within the Apennines.

Geomorphic features

Lithostructural features are widespread even when looking at a small scale such as in Fig. 9. This is not surprising in a country which is mostly everywhere uplifting and where lithology strongly controls, at local scale, the erosion rates.

Volcanic features, connected with the ongoing and/or recent magmatic activity, characterize only the central and southern sectors of peninsular Italy and several large and minor islands as well.

Virtually all morphogenic processes, including karst and eolic, left their footprint over the Country (Fig. 10).

Morphologic description of the geomorphic units

The Alps

This mountain system forms a broad arc extending from the Ligurian coast and the French Riviera to Austria and Slovenia. The width of the belt is increasing eastward; where the chain sharply bends around Piedmont, the width is approximately 150 km. Only one main range occurs to the south of the Mont Blanc, while two broadly parallel ranges may be found eastward, divided by the Rhone-Rhine alignement. A remarkable feature is the asymmetry of the two watersheds, the southern being steeper than the northern. The difference is mostly due to the lithologic control of the ongoing erosion rates as shown for instance by Vernon *et al.* (2008).

In the Central Alps the morphology is more complex and the width of the chain is some 300 km. In this area and farther to the east the less deformed Southern Calcareous Alps are fringing to the south the Chain proper. The peri-Adriatic or Insubric line marks the limit.

The core of the Alps is formed of exhumed Hercynian basement rocks belonging to the European margin. Either side of the core, sedimentary rocks derived from Tetidean sediments widely outcrop. Because of the low erodibility of the basement rocks, all the highest peaks occur in the basement massifs.

The main drainage network is mostly longitudinal to the chain in the central sectors while on the Alpine margins most valleys show a centripetal trend. This is especially evident in the Southern Alps, where remnants of longitudinal valleys have been incorporated in the present southward trending drainage. Quite a few valleys appear misfit due to river captures operated by southbounding rivers activated by the uplift. Glacial scouring of the main Alpine valleys led to the buildup of extensive morainic arcs in the piedmont areas, where they fringe several large lakes.

Figure 9. Italy main lithostructural and volcanic landforms.

Figure 10. Italy surface processes and coastal-marine landforms.

The Po Valley

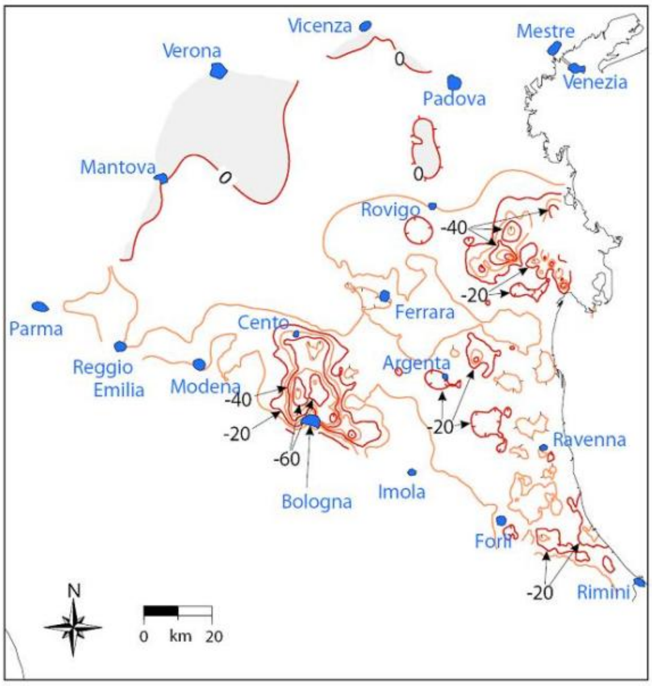
This is not actually a valley scoured by the Po river but a rather complex foredeep structure of both the Alpine and the Apenninic chains, filled by mostly marine Pliocene and Quaternary sediments and drained by the Po river. The location of the river in the valley is largely structurally controlled but also driven by the opposed thrust of the Alpine and Apenninic river sediments which make up the two facing piedmont plains. The Quaternary uplift of the Apenninic front in the western portion of the Plain resulted in the hilly Piedmont regions of Langhe and Monferrato. A Geomorphological map of the Po Plain at scale 1:250.000, a breakthrough in plains mapping, was published in 1997, Fig. 11 (MURST, 1997; see also Castiglioni *et al.*, 1999).

Figure 11. Geomorphological map of the Po plain.

Part of the coastal belt, as represented in the Geomorphological map of the Po plain 1:250.000. (Copyright S.El.Ca., Firenze, 1997, reproduced with permission).

Holocene Po river terraces make up the southern, lower limit of the high plain on the Alpine piedmont. A line of springs occurs on the high plain, where ground waters percolating through the fluvio-glacial coarse deposits of the inner high plain are forced to emerge where the finer sediment of the outer high plain occurs. The central-eastern Po Plain is rapidly subsiding. Modern subsidence is at least an order of magnitude higher than due solely to long-term natural processes. This implies that most subsidence in the Po Plain has been induced by human activities (Carminati, Martinelli, 2002).

Figure 12. Central – Eastern Po Plain present-day vertical velocities in mm/year.



Courtesy of Eugenio Carminati.

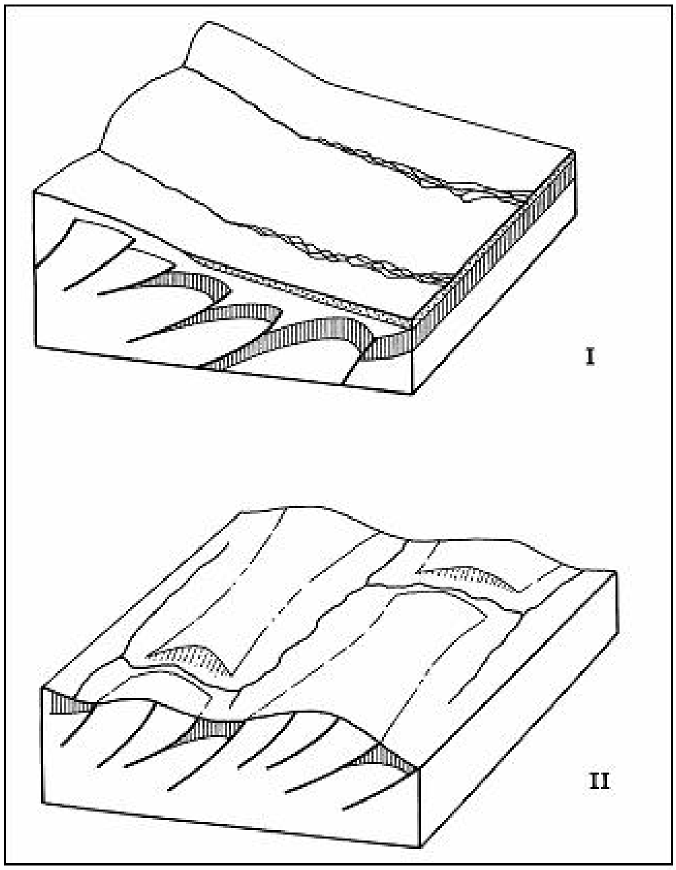
The Apennines

They make up the backbone of peninsular Italy, including Sicily. Due to their young, though complex tectonic history, they rather make up – from a morphostructural point of view - a mountain system rather a mountain range. From a geological standpoint, the Apennines and the adjoining seas can be regarded as an evolutive outcome of the eastward translation of the western portion of the Alpine chain. As a matter of fact, they are made of Hercynian basement rocks - largely outcropping in the Sardinia-Corsica massifs, in the Calabrian Aspromonte and in the Peloritani Mts. of Sicily, and locally elsewhere - by ubiquitous Tetidean Mesozoic – Early Tertiary units and by the flysches of Middle and Late Tertiary age. These units were lately overridden by slabs of Jurassic oceanic crust and by their associated sedimentary units.

The marked difference in geomorphological texture which affects the Tyrrhenian and Adriatic watersheds derive from a different tectonic and uplift history and thence from a marked difference of the outcropping lithologies.

Because of the extensive outcrops of late Tertiary turbidites and postorogenic sediments, the Adriatic watershed from Piedmont to Puglia shows a striking morphological continuity, enhanced by a mostly consequent drainage pattern, which is being progressively replaced by a trellis geometry wherever the Mesozoic folded and faulted bedrock has been exhumed (Fig.13).

Figure 13. Sketch of the drainage evolution on the Adriatic watershed of the Apennines.



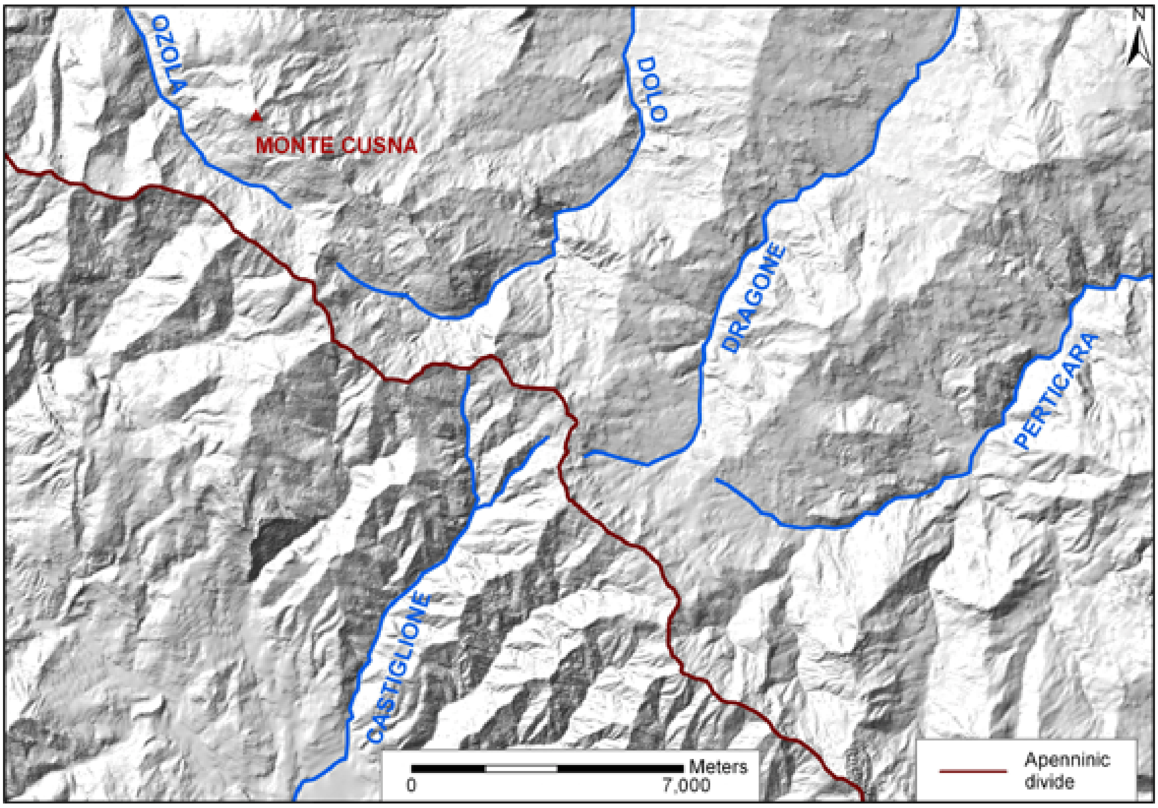
Consequent drainage being replaced through time by trellis on the Adriatic watershed, due to the swift rock uplift and the ongoing tectonic activity as well. Water-gaps result from epigenesis and antecedence at the same time. Modified from Bartolini and Peccerillo (2002).

The generally eastward younging age of the rocks outcropping on this watershed applies also to the present day marine sedimentation occurring in the shallow Adriatic Sea, outer remnant of the Apennine peri-Adriatic Foredeep, which has been largely incorporated in the chain, less so in the Bradanic trough and the Gulf of Taranto.

The characteristic feature of the Tyrrhenian watershed is its basin- and range-morphology. The basins, presently bounded by normal faults, are actually often located in front of the NE verging Apenninic thrusts. The basins are typically offset from one another, as common in the extensional settings worldwide. The drainage pattern is closely controlled by the NNW trending tectonic structures.

In the fringe of the Northern Apenninic divide, a few river segments trend along strike although in the progress of being beheaded by streams flowing at right angles (Fig. 14). The occurrence of such segments, until present unaffected by the orographic consequence of the ongoing uplift, points both to its recent age (Bartolini 2003, references therein, Bartolini *et al.*, 2003) and to its fast pace (Balestrieri *et al.*, 2003; Carminati et al, 1999; Zattin *et al.*, 2002). Both differential uplift and lithology play a relevant role in driving a relentless reorganization of the drainage pattern.

Figure 14. River segments on the fringe of the Northern Apenninic divide.



In the Northern Apennine watershed area, Dolo, Dragone and Perticara headwaters stretched out until reaching a shale-marly weakness belt, there disrupting an along-strike river system located along the present Apenninic divide.

As to the Ligurian and the Northern Tyrrhenian Sea, they are the inner, drowned portions of the eastward translated Alpine chain. The farther translation of such chain in its southern segment gave rise to the partially oceanized Southern Tyrrhenian Basin, featuring large submarine volcanoes such as the Magnaghi, Vavilov and the still active Marsili, Palinuro and Eolian islands (see Fig.9). Magmatic activity took place, since Late Miocene times, also in the Northern Tyrrhenian area, both on land and at sea, as a consequence of the crustal thinning resulting from the eastward translation of the tectonic units which were piling up in the Apennine peri-Adriatic Foredeep.

The local relief of peninsular Italy is controlled by the present uplift rate but also by rock erodability. Because of their carbonate lithology and of the current uplift rate of approximately 1 mm/y, the Gran Sasso and Maiella massifs have a high relief (> 1800 m, see Fig. 3) and are the highest peaks of the Apennines as well.

The Puglia Plateau and the Gargano Promontory, located beyond the Bradanic trough, do not belong, from the geological standpoint, to the Apennine. They make up, instead, the emerged sector of the Southern Apennine Foreland.

The variety of landscapes which make peninsular Italy a fascinating place to visit and to live in is also due to the different geologic histories which affected each single portion of the region.

Sicily

The island may be considered as the East-West trending southerly extension of the Apennines. The Ragusa Plateau make up, here, the emerged sector of the Apennine Foreland, which contributes to the triangular shape of the Island.

A striking feature is obviously made up by the Etna Volcano. Its location, on thickened crust on the outer side of the chain, is not obvious; it is connected to a sinistral wrench fault responsible also for the shift affecting the Aspromonte versus Peloritani Mts. and of Sicily's insularity as well. The extinct volcano of Mt. Vulture, located on the inner fringe of the Bradanic Trough, has a similar – odd - structural setting.

Sardinia

This island is - along with its northerly sister, Corsica, and like the Aspromonte and Peloritani Mts. - a southeasterly translated portion of Hercynian basement rocks supporting, at places, relicts of their highly tectonized Alpine Mesozoic and Tertiary cover. Remnants of the Paleozoic planation surface carved in the Hercynian basement may be traced here and there (see, for instance, Bartolini, Peccerillo, 2002).

The Campidano Graben, filled with Pliocene and Quaternary sediments, is a large extensional feature pointing out that Sardinia shares, at present, the same structural setting of the whole Tyrrhenian area.

Acknowledgements

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