# UPLIFT AND EROSION RATES AND PALEOCLIMATE ANALYSIS FROM PLIO-QUATERNARY AULETTA BASIN (SOUTHERN APENNINES, ITALY)

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Recent study on tectonically active mountain chains have suggested strong coupling and feedbacks between climate, tectonics and topography. Understanding the roles of tectonics and climate in mountain building and erosion processes requires necessarily the acquisition of multidisciplinary data (Burbank & Anderson, 2001; Schiattarella *et al.*, 2008). The study of the interplay, links, and feedbacks between climate and erosion and among these factors and tectonics, and morphogenesis had already strongly addressed the international scientific community and the Italian geoscientists as well (*e.g.*, Burbank & Anderson, 2001; Pazzaglia & Brandon, 2001; Schiattarella *et al.*, 2003; 2006; Bishop, 2007) to get estimates of parameters, *i.e.* uplift and/or erosional rates in different climate scenarios. The comprehension of morphotectonic evolution of southern Italy is indeed strictly dependent on the estimation of such parameters.

The aim of this work is to reconstruct the Plio-Quaternary morphotectonic and sedimentary evolution of the Auletta basin (Ascione *et al.*, 1992; Barchi *et al.*, 2007), a wide tectonic depression of the axial zone of southern Italian Apennines. In addition, uplift and erosion rates have been calculated using geomorphological, stratigraphic and structural data. In order to better constrain the estimation of uplift and erosion rates, relative and absolute dating methods have been used for a better definition of the ages of the morphotectonic marker. To understand the role of different paleoclimate scenarios in controlling the landscape evolution, geomorphic and stratigraphic data have been integrated with a detailed mineralogical and geochemical study of soils, paleosols and weathering profiles. Information on the paleoclimatic evolution during Quaternary times has been obtained by the analysis of distribution of clay minerals in continental pelitic sediments, paleosols, and weathered horizons developed in depositional and erosional surfaces of different age from key-areas of the basin. In addition, the mineralogical data have been integrated with a detailed study of the geochemical properties of a selected number of samples.

The Auletta basin coincides with the lower valley of the Tanagro River, an hydrographic catchment of the axial zone of the southern Apennines. Upper Pliocene to lower-middle Pleistocene sediments, both of marine and continental origin filled the basin and are shaped by erosion land surfaces and fluvial dissection. The depression has a tectonic origin, being bordered by two main N 120-130° trending fault line scarps and/or recessed fault slopes, related to listric faults with polyphased kinematics. The master fault of the Auletta basin is a NE dipping high-angle listric fault, located at its SW margin. This fault controlled the stratigraphic, structural and morphological setting of the area. Structures with a similar orientation and also NE-SW striking faults are diffused in the Mesozoic carbonate mountains surrounding the basin and in the Quaternary basin itself. In addition, morphometric analysis of the drainage net demonstrated a general tilting of the Tanagro River toward the SW, related to the activity of the master (*i.e.* southern) fault of the basin. As a consequence of the Tanagro River migration, an asymmetric valley developed.

Besides faulting, both the carbonate bedrock and the Pliocene and Quaternary clastic sediments are affected by several order of regional planation and local erosion sub-horizontal surfaces. The morphostructural evolution of the Auletta basin is characterized by stages of uplift alternated with periods in which the erosional surfaces developed. In the catchment basin and surroundings, five generations of erosional land surfaces have been investigated on the basis of both field survey and map analysis. The age of these surfaces has been defined from their morpho-stratigraphic relationships with Pliocene and Quaternary deposits. The uplift rates have been calculated on the basis of the difference in height between the absolute (sea level) or local (present-day talweg) erosion base levels and the several generations of land surfaces. Regional uplift rates are settled on a value of about 0.6 mm/yr, whereas the local rates are nearly coincident with the magnitude of the fault slip rates. The similar values of the local and regional uplift rates suggests that the major part of energy of relief of the Auletta basin can be ascribed to the tectonic activity of the basin-bounding faults.

In order to relate the different erosion processes to tectonic mobility of the axial zone of the chain, a geomorphic quantitative analysis has been carried out and the eroded volumes of rocks forming both the Mesozoic-Cenozoic bedrock and the Pliocene to Quaternary clastic deposits have been calculated, using cartographic methods and also converting the fluvial turbid transport data as evaluated by geomorphic parameters (Schiattarella *et al.*, 2008). The annual average erosion rate is about 0.2 mm/yr. In order to understand the roles of paleoclimate in controlling the landscape evolution, morphotectonic data have been integrated with those derived from mineralogy and geochemistry. Such a multidisciplinary approach allow to define the weathering conditions of geological and morphological features in different times during their history. Being these conditions suitable proxies, it is therefore possible to get indirect information on paleoclimate scenarios which characterized the landscape through time. To this end, 56 samples of the late Pliocene to Holocene continental succession of the Auletta basin were collected. In particular, the sampled succession was composed by lacustrine and swamp deposits, weathered horizons and paleosols. XRD analysis of the mineralogy of bulk samples and of the clay fraction (< 2 μm grain-size fraction) allow to recognize three different arrangement of the mineralogical phases distribution of the samples (mineralogical assemblage A, B and C in Fig. 1).

The lacustrine deposits, late Pliocene in age, are composed by 40-60 wt.% of illite-smectite mixed layers, 20-35 wt.% of calcite and by a lower content of quartz. In all the sample, a small amount of plagioclase and k-feldspar was found. The clay mineralogy of these samples is mainly composed by smectite-rich illite-smectite mixed layers and by caolinite, illite and chlorite. The mineralogical assemblage of the late Pliocene deposits is similar with respect the lower Pleistocene swamp deposits, although the latter are characterized by a higher amount of illite e chlorite. However, weathering horizons developed within the lower Pleistocene fluvial deposits show a different mineralogical assemblage than both the lacustrine and swamp deposits, being characterized by a higher content of poorly crystallized kaolinite and kaolinite-smectite mixed layers and by the absence of the chlorite. In the weathering horizons, low content of goethite has been detected.

The mineralogy of the middle to late Pliocene paleosols is characterized by phyllosilicates (60-80%), quartz, K-feldspar, plagioclase and goethite. The phyllosilicates are represented by high amount of kaolinite-smectite mixed layers, illite and kaolinite with a low degree of crystallinity. Also, a lower halloysite content has been detected in some samples.

Holocene swamp deposits are mainly composed of phyllosilicates, calcite and quartz with a lower content of plagioclase and k-feldspar. The clay mineralogy of this samples is mainly illite-smectite mixed layers, illite, kaolinite, vermiculite and Al-vermiculite.

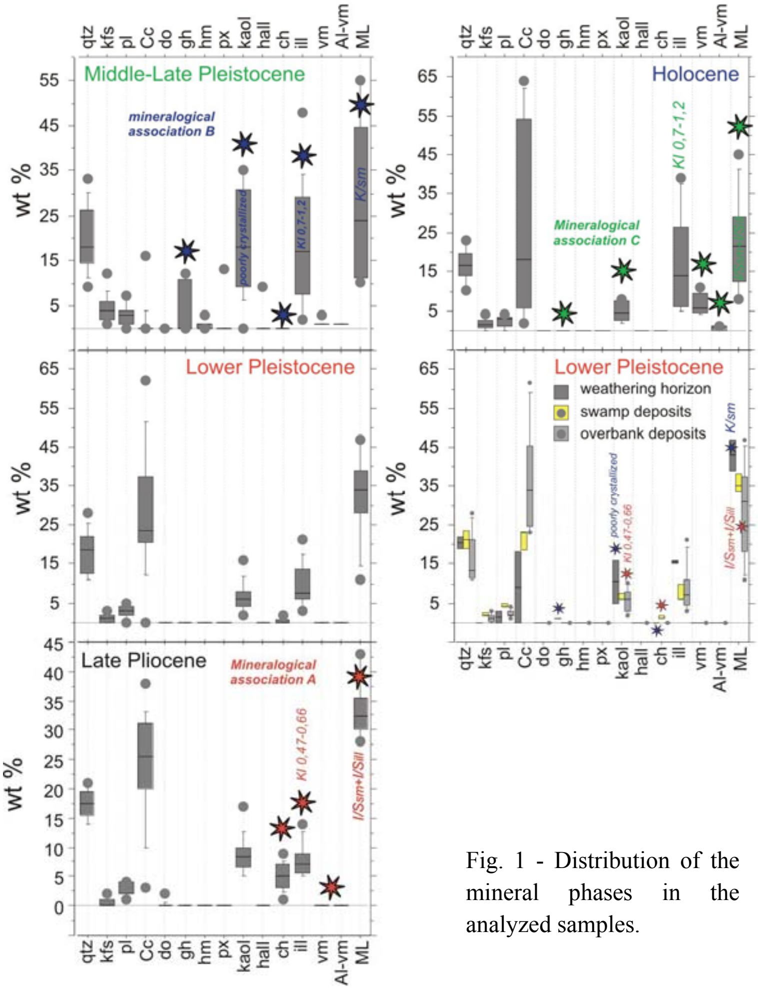

Fig. 1 - Distribution of the mineral phases in the analyzed samples.

In order to evaluate the degree of weathering of the studied samples, the CIA (Chemical Index of Alteration, Nesbitt & Young, 1989) and the A-CN-K diagram (Nesbitt & Young, 1989) have been analyzed. The highest values of the CIA have been observed in the middle to late Pleistocene paleosols, suggesting a strong degree of weathering that it is consistent with warm and humid climates with alternating rainy and dry seasons (Quaternary interglacials). These conditions are also in agreement with the mineralogical assemblage of this samples. Indeed, the results of the mineralogical analysis indicate that the main components of the samples are kaolinite-smectite mixed layers, kaolinite and goethite. Kaolinite minerals have shown low crystallinity, typical of very intense weathering conditions. These conditions promote intense weathering of primary minerals and leaching of cations released from crystal lattices (in turn enhancing the formation of these mineral species), growing in intensity according to an increase of the time span of pedogenesis (Scarciglia *et al.*, 2006, and references therein; Di Leo *et al.*, 2008). It is worthy of note that at the Monte Pozzillo quarry (*i.e.* eastern part of the basin) the paleosols are covered by a 20 cm thick tephra layer made of brown silt with small-size sanidine clasts. Radiometric dating using the $^{39}$Ar/$^{40}$Ar method indicate an age of the tephra of 106±1.6 Ka, suggesting that the stage of intense weathering responsible for the mineralogical arrangement of the paleosols was related to the Late Quaternary interglacials. A similar paleoclimate scenario characterized by temperatures and precipitation higher than today seems to be relate to the formation of the weathering horizons during Lower Pleistocene times. On the other hand, the distribution of mineral phases in the late Pliocene to lower Pleistocene lacustrine and swamp deposits suggests a weathering developed in more temperate conditions. Moreover, the abundance of chlorite and kaolinite with a high degree of crystallinity indicates a detrital origin of this mineral, probably related to the denudation of the sicilide units.

Geomorphological and stratigraphical data as well as chronological constraints based on radiocarbon dating indicate that the Holocene deposits ranging from the Boreal to the Subboreal periods. The assemblage of clay minerals within the Holocene swamp deposits, such as illite, illite-smectite mixed layers and vermiculite suggest a moderate weathering environment (Barnhisel & Bertsch, 1989) typical of the Early Holocene paleoclimate setting. However, the mineralogical and geochemical features of the younger samples - which on the basis of the radiocarbon dating can be dated at the Atlantic-Subboreal transition - suggest a more intense stage of weathering, related to the warmest phase of the entire Holocene where also the climatic optimum was reached (Ravazzi, 2003).

This results have been confirmed through a multivariate statistical analysis using PCA method. Using the distribution of the mineral phases in the samples and the sum of several mineral phases typical of temperate (vermiculite, Al-vermiculite, illite-smectite mixed layers and illite, 1st stage of weathering, see Fig. 2) and warm/humid (kaolinite-smectite mixed layer, goethite and kaolinite, 2nd stage of weathering, see Fig. 2) climate as variables in the input matrix of the PCA method, it can be observed that the first component (49% variance) groups together kaolinite-smectite mixed layers, kaolinite and 2nd stage of weathering with high positive component loadings, and 1st stage of weathering and illite-smectite mixed layers with a negative component loading. The second component (18% variance) shows illite with high positive component loadings, and chlorite with a negative component loading.

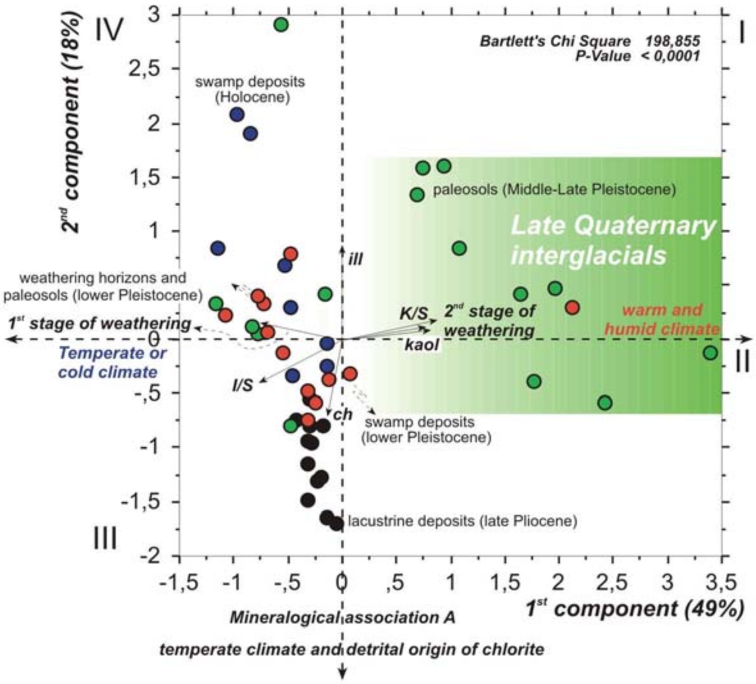

Fig. 2 - PCA analysis based on an input matrix composed by the wt.% of the mineralogical phases. Orthogonal plot of the multivariate statistical analysis carried out using Principal Component Analysis (PCA) as extraction method. As variables in the input matrix of the PCA method, the distribution of the mineral phases in the samples and the sum of several mineral phases typical of temperate (vermiculite, Al-vermiculite, illite-smectite mixed layers and illite, 1st stage of weathering) and warm/humid (kaolinite-smectite mixed layer, goethite and kaolinite, 2nd stage of weathering) climate have been used.

In the 1st component *vs.* 2nd component plot, most of the samples from middle to late Pleistocene paleosols group together in the direction of maximum variation of kaolinite-smectite, kaolinite and 2nd stage of weathering, representing the mineral phases typical of warm and humid climate setting. late Pliocene to lower Pleistocene lacustrine and swamp deposits group in the direction of the maximum variation of chlorite, testifying a strong influence of the sedimentary input related to the denudation of the sicilide units on the mineralogical features of this samples.

Similar information about paleoclimate scenario can be inferred from the results of geochemical analyses. In particular, the samples related to an intense stages of weathering (*i.e.* lower Pleistocene weathering horizons and middle to late Pleistocene paleosols) shown a light rare earth element (LREE)-enriched pattern of rare earth element (REE). In warm and humid climates, the high rare earth element (HREE) are indeed removed from the soil profile to result in a greater depletion in the medium rare earth element (MREE) and HREE than the LREE (Aubert *et al.*, 2001; Zhou *et al.*, 2008). Although this work is only preliminary and further investigations are needed in the future, the REE pattern appear to be a powerful proxy for past climate.

In this work, the multiproxy approach based on geomorphological, stratigraphical, mineralogical and geochemical data allow to reconstruct the paleoclimate conditions active in different stage of landscape evolution. Moreover, the comparison between uplift and erosion rates suggests that the fluvial erosion did not match the tectonic uplift of the study area, which therefore could result a non-steady system. In this key, landslides affecting also Holocene formations may be the effect of a system in an unrest state.

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