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CHANGING LANDSCAPES IN THE COLLINE METALLIFERE (SOUTHERN TUSCANY, ITALY): EARLY MEDIEVAL PALAEOHYDROLOGY AND LAND MANAGEMENT ALONG THE PECORA RIVER VALLEY

1. INTRODUCTION

One of the most important aspects of geoarchaeological research is the modelling of the landscape evolution in the past (Van Andel 1994; French 2003). Landscape changes are investigated coupling the paleoenvironmental signal coming from geological records such as sediments and soils, and the biological signal coming from the proxies found within the geological record itself. Finally, stratigraphy and geochronology provide the sequence of events which occurred both before, during and/or after the settlements.

Therefore, sedimentology, stratigraphy, geomorphology and palaeopedology are the main branches of earth science that provide sets of information about palaeoenvironmental settings and their evolution through time and space.

This kind of analysis area is a useful archaeological tool as well, providing the information needed for a more extensive geoarchaeological approach at the regional and site level. In fact, archaeological observations are usually limited to a site environmental approach with little regard to meso- and macro-scale landscape dynamics (French 2003; Rapp, Hill 2006; Goldberg, Macphail 2006).

In this context, river valleys have strongly influenced the strategies of the populations for exploitation of the inland slopes and valley floors, the latter being a natural migration, commercial and communication paths or due to factors such as the availability of water, favourable topography, presence of "soft" soils and suitable areas for settlements and productive activities.

The Pecora river offers a unique chance to reconstruct the fluvial landscape before and during the Early Middle Ages in this Mediterranean area and to evaluate the influence of human impact on the environment of the river basin due to its proximity to the medieval archaeological site of Vetricella (Marasco *et al.* this volume). The importance of this area is also marked by the presence of fiscal and public estates from the mid-9thc AD network of earlier settlements (Hodges, Bianchi; Collavini in this volume). A new environment became suitable for productive large kernelled crops as well as fruit tree growing, serving the landlords' will to achieve the highest production of any possible lands and to optimize surpluses from their estates (Buonincontri *et al.* 2015, 2017).

Thus, the main objective of this work is the reconstruction of the changes which occurred to the alluvial environments and dynamics, including channel patterns, at the scale of the river basin. As explained further on in this work, the investigations carried out in the distal reach provide strong constraints for the evaluation of the changing dynamics in the mid- and upper reaches of the Percora valley. Therefore, unravelling the changes in the landscape and river dynamics at such macro-scale, that is the whole valley system, provides information about the effects of and relationships between human behaviour (land use) and environment.

2. STUDY AREA AND ENVIRONMENTAL BACKGROUND

2.1 Geological and Geomorphological background

The Pecora river basin extends between the towns of Follonica to the SW and Massa Marittima to the NE with a catchment of about 250 km² (*fig.* 1). The bedrock of the basin is mainly made of Cretaceous marine shales and limestones belonging to the Ligurian lithostructural Units ("Argille a Palombini Fm.", Ispra 2002) that rest uncomfortably on the massive Triassic limestones belonging to the Tuscan lithostructural Units ("Calcare Cavernoso Fm.", Ispra 2002). The unconformity is related to the eastward migration of compressional tectonic movements until the Early Miocene. At the end of the Miocene the area underwent a vertical uplift and the onset of continental conditions are testified in the area by the presence of thick alluvial fan conglomerates of the Messinian age ("Conglomerati di Monte Bamboli Fm", Ispra 2002). Marine transgression occurred during the Pliocene, although in the Pecora basin the associated sediments ("Argille Azzurre Fm.", Ispra 2002) are not present due to erosion.

The area is known also as part of "Colline Metallifere", a mining district exploited in the last three thousand years (Lattanzi *et al.* 1994 and ref. therein) for ore deposits of pyrite, Fe, Cu-Pb-Zn, Ag, Sb, Hg, Sn and Au. Their occurrence is related to hydrothermal fluids circulating along extensional faults that affect the bedrock following the emplacement of Plio-Quaternary magmatic bodies (Benvenuti *et al.* 2009).

The definitive emersion of the area is recorded during the Quaternary period with the deposition of a complex of continental Unconformity Bounded Stratigraphic Units including

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alluvial fan, fluvial and Calcareous Tufaterraces and barrages (Benvenuti *et al.* 2009). The present-day hilly landscape is mainly controlled by selective erosion and fluvial dynamics with formations of steeper slopes on the harder pre-Miocene and Miocene bedrock and wide, flat alluvial and Calcareous Tufa terraces along the valleys. Moreover, karst processes deeply influenced landscape evolution as indicated by the presence of wide coalescent doline depressions, karst springs (i.e. "Le Venelle" and "Aronne", *fig.* 1) and related depositional environments. The evolution of the present-day drainage network is controlled by tectonic uplift coupled with Quaternary climatic changes through alternating phases of fluvial incision and aggradation, river captures and terrigenous and carbonate deposition (Benvenuti *et al.* 2009). The historical and present-day slope and river dynamics are mainly controlled by land use and hydraulic regulations (*fig.* 1). In this paper we focus on the early medieval fluvial landscape evolution including continental carbonatic depositional environments. The latter is characterised by Calcareous Tufa (CT from now on) sediments characterized by physio-chemical and microbiological carbonate precipitation by fluvial and spring-fed fresh and cool water carbonates, generally restricted to localized karstic areas (Ford, Pedley 1996; Pedley 2009; Capezzuoli *et al.* 2014). The typical landscape associated with the deposition of CT is formed by terraced flat palustrine environments bound by barrages and waterfalls. Such landscapes were widely present along the Pecora and the Le Venelle-Ferriere tributary (*fig.* 1). CT deposition is usually associated with the presence of carbonate-rich waters and humid and warm phases since CO_2, necessary for $CaCo_3$ dissolution and precipitation, is normally enriched under forest cover and the associated soils. However, human activity, namely deforestation, agricultural practices and drainage regulations, is the main factor that triggers their depositional decline in proto-historical and historical times (Goudie *et al.* 1993).

2.2 Climate and vegetation

According to the weather station of Follonica (4.34 m a.s.l., UTM 643775 E, 4753770 N, data source http://www.sir.toscana.it/), the area is characterised by a Mediterranean climate, with an average minimum temperature of 3.1°C during the coldest month (25 years observations) and an average annual precipitation of 592 mm (observed over 80 years). Arable crops, vineyards and olive groves are present in the flat valley floors and/or on the gentler slopes. The evergreen sclerophyllous forest, dominated by *Quercus ilex* L. with *Arbutus unedo* L., prevails on the steeper slopes of the Pecora river basin. Small stands of deciduous broadleaved species, such as *Q. cerris* L., *Q. pubescens* Willd., and *Fraxinus ornus* L. are sparse, whereas the deciduous oak forest, dominated by *Q. cerris* L., is located only on the cooler north-western slopes of the basin.

3. MATERIALS AND TOOLS

3.1 Sedimentology and Geomorphology

The investigations have been mainly carried out in a retention basin excavated ca. 500 m to the NW of the Vetricella site (*fig.* 1) on the hydrographic left of the Pecora river. The

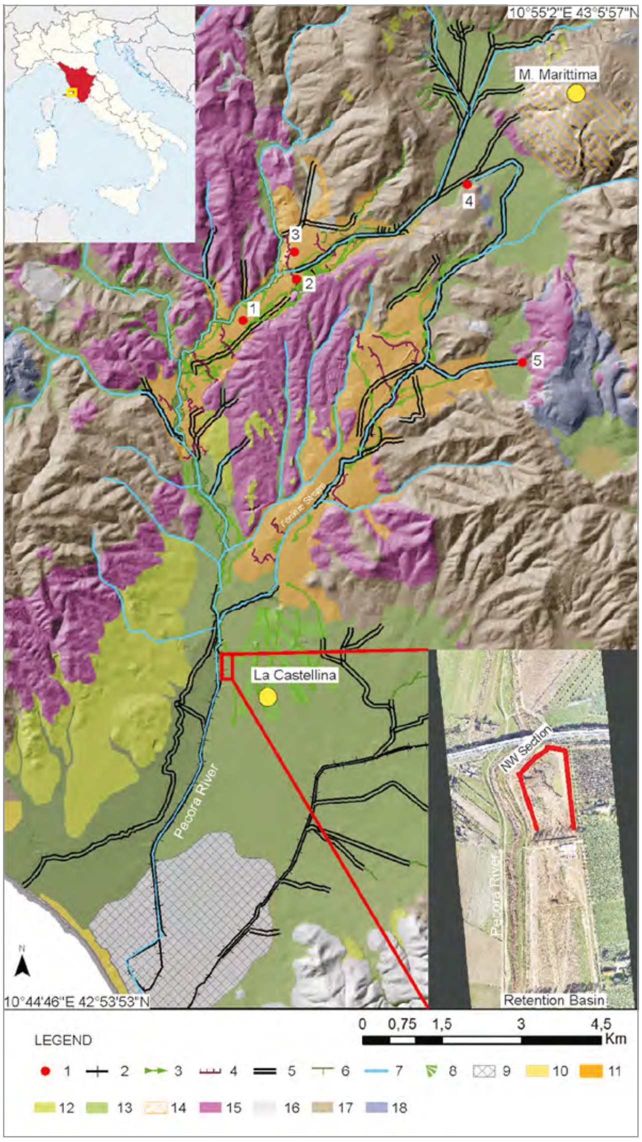

fig. 1 – Geological and geomorphological sketch of the studied area. Legend: 1) Localities cited in the text (1-Pian del Padule; 2-Padule del Moreta; 3-La Cascata; 4-Le Venelle Spring; 5-Aronne Spring); 2) Artificial levees; 3) Pecora river palaeochannels; 4) CT barrage; 5) Artificial channles; 6) Fluvial scarps; 7) Pecora and Le Venelle-Ferriere rivers and major tributaries; 8) Alluvia fan; 9) Lagoonal deposit reclaimed after1950; 10) Beach deposit (Holocene); 11) CT (Holocene); 12) Unactive alluvial deposit (Late Pleistocene-Holocene); 13) Active alluvial deposit (Late Pleistocene-Holocene); 14) CT (Late Pleistocene); 15) Polygenic conglomerates (Messinian); 16) Macigno Fm (Upper Oligocene – Lower Miocene); 17) Argille a Palombini Fm (Upper Cretaceous – Paleocene); 18) Calcare Cavernoso Fm (Upper Triassic).

retention basin is c. 400 m long parallel and c. 100 m wide perpendicular to the Pecora river. The works started in 2015 and ended in 2016. During the excavations our research group was granted special access to these sections thanks to the kind collaboration of the "Consorzio di Bonifica 5 Toscana Coste" and the "Soprintendenza Archeologia, Belle Arti e Paesaggio per le Province di Siena, Grosseto e Arezzo". The excavations allowed the observation of a sedimentary section, around 8 m thick, cutting the alluvial terrace on top of which is located the Vetricella site (Section E, *fig.* 1) and c. 3 m thick sequence perpendicular to the river flow direction (Sections

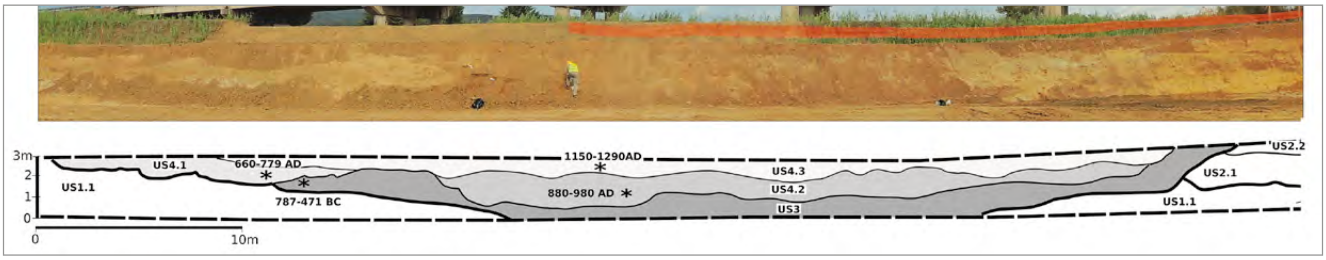

fig. 2 – The NW section studied within the retention basin (for location see *fig.* 1). The US numbering follows the description in the text whereas the asterisks indicates the radiocarbon dates on charcoal samples.

NW, *figg.* 1 and 2). The outcropping sequence was analysed in the field, drawing the sedimentological characteristics in terms of facies analysis following the method proposed by Miall (1996). Samples of sediments were taken for routine analysis whereas charcoals were sampled both for radiometric dating and anthracological analysis. Facies analysis allows the reconstruction of the depositional environment starting from the sedimentological characteristics (grain size, composition, shape of clasts, internal geometry and fabric) or lithofacies that indicate the flow dynamics; lithofacies are in turn grouped into associations or architectural elements that correspond to the characters of the internal depositional environments. Finally, the associations of architectural elements and the presence of bounding surfaces allow the definition of fluvial models or styles that correspond to the river dynamics and associated landscape.

To establish the relationships of the observed sedimentary characteristics within the valley, further investigations have been carried out along the thalweg. In the studied area the River Pecora is confined downflow within artificial levees and the river is hanging on the floodplain; this prevents the observation of the sediments. Upflow, the thalweg is downcut within the floodplain sediments allowing the description of further sedimentary sections. The analysis was also coupled with geomorphological investigations along the Pecora basin; these have been carried out in the field and in the laboratory by remote analysis of colour and black and white multitemporal aerial photos, spanning from 1954 to 2016. Moreover, the imagery was integrated with a highly detailed Digital Terrain Model derived by LiDAR and 10 m DTM. All the remote images and topographic models are available from the Regione Toscana Environmental Agency (http://www.regione.toscana.it/web/geoblog/-/open-geodata).

The geomorphological mapping was carried out following the guidelines of the Italian National Geological Survey for the 1:50,000 scale geomorphological maps of Italy (Ispra-Apat, 1994). Punctual, linear, polygonal landforms and related deposits are classified according to the prevalent geomorphic process (i.e. superficial running water, gravity, karst, anthropic etc.). The field and remote maps have now been digitalized in the ArcGIS© environment and the features classified within a geodatabase structured following the adopted legend.

3.2 Charcoal

The abundance of charcoal within the sediments is the result of the incomplete combustion of plant vegetation (Forbes *et al.* 2006). Usually, it is difficult to establish the source and the formation processes leading to the creation of the charcoal assemblage. The main source is generally forest fires naturally ignited or fired by humans in relation to anthropogenic activities (Pyne, Goldammer 1997; Moore 2000). The possible provenance of charcoals from nearby human-related contexts, such as archaeological sites or charcoal kilns, must also be taken into account when interpreting the charcoal record. Furthermore, in cases of forest fires, topographic conditions can influence the dispersion and deposition of charcoal during and after afire (Clark 1988; Thinon 1992; Scott *et al.* 2000).

In the case of Pecora river, bedforms were characterised by the abundance of very fine to very coarse charcoal. In the Section NW, 23 sediment samples were collected at different levels, ranging from 500 to 2390 ml of volume. The samples were firstly air-dried and weighed, and successively wet-sieved through two sieves with 1 and 0.4 mm mesh-size. Charcoal concentration and taxonomical identification were preliminarily performed for charcoal remains larger than 1 mm. Smaller charcoal fragments were excluded since they are usually not suitable for taxonomical identification and cannot provide information on past forest composition (Robin *et al.* 2014). Charcoal concentration is expressed as specific anthracomass (SA) in milligrams of charcoal per kilogram of dried sediment (Talon 2010). Specific anthracomass is calculated per sample layer (SAL).

Taxonomical identification was carried out with an incident light microscope at a 100×, 200× and 500× magnification and supported with wood anatomy atlases (Abbate Edlmann, De Luca, Lazzeri 1994; Schweingruber 1990; Vernet *et al.* 2001) and the reference collection at the Dipartimento di Agraria, Università di Napoli "Federico II". Charcoal fragments were identified at the species or genus level for the most part, thanks to their good preservation, whilst for only a few poorly preserved fragments (bad preservation or vitrification) the identification was possible at a family level, or no identification was possible at all.

4. DATA

4.1 Sedimentology and Facies analysis

The retention basins allowed the observation of 4 sections and the presence of 4 well distinguishable Stratigraphic Units (US) separated by important sedimentary unconformities (*fig.* 3).

Here, we mainly describe and discuss the palaeochannel, c. 50 m wide and 3 m deep, observed along a section (NW section) perpendicular to the Pecora flow direction excavated within a retention basin (*figg.* 1-2). The section is located in the distal reach of the Pecorariver where the thalweg is regulated by artificial levees and the landscape opens into a wide flat floodplain. The current geomorphological setting is the result of the reclamation of the wide lagoonal and swampy system that characterised the area at least until the beginning of the 19thc, as is also indicated by the Maps of the CatastoLeopoldino available for the area (http://www502.regione.toscana.it/castoreapp/). Up valley the watercourse is not regulated and becomes suddenly incised within the floodplain. The incision increases up to 10 m in the upper reach where the CT characterises the landscape with wide flat terraces alternated with barrages.

4.1.1 *US1*

US1 is made of massive to laminated, bioturbated, horizontally bedded greyish clays (Fm, Fl; Miall 1995), with rare sandy-silty lenses and blankets (Sm, Sh; Miall 1995). Rare vegetal fragments (woods, leaves) and charcoals are present. The overall sedimentary characteristics are typical of a very low-energy lagoonal environment, perennially flooded as indicated by the lack of any pedogenetical evidence.

A clear erosional unconformity cuts US1 on top. The unconformity is undulated and corresponds to a channel system more than 8 m deep that shows a planar geometry parallel to the river flow. This unconformity is buried under US2 (*figg.* 2-3).

4.1.2 *US2*

US2 is separated by a minor unconformity and characterised by different facies associations (US2.1 and US2.2). US2.1 is made of trough and planar cross-bedded, or massive sands and silts (Sp, St, Sh, Sm) with very rare polygenic fine gravels and very thin muddy lenses (Fm). The gravels represent the lithologies of the Ligurian and Tuscan Units outcropping in the catchment area. The facies association, mainly made of downstream accretion and sandy bedforms with minor floodplain architectural elements, are typical of a deep sand-bed braided river.

A minor unconformity is in turn buried under US2.2 sediments. They are packed, fine to coarse-grained, subrounded to rounded trough cross-bedded or massive, poorly sorted gravels (Gt, Gh, Gm) with abundant sandymatrix. The gravels are polygenic and represent all the Ligurian and Tuscan Units present in the drainage basin. The architectural elements made of gravelly bedforms indicate massive sedimentation within a multi-storey channel typical of a shallow gravel-bed braided river (Miall 1995). US2.2 constitutes the uppermost part of the alluvial terrace whose top surface is at a maximum elevation of about 5 m above the present-day thalweg and floodplain and gently sloping to the south,where the site of Vetricella is located. US2.2 is also weathered on top by a polycyclic, reddish, strongly leached argillic soil (Alfisol, Usda 2015, fig. 4).

4.1.3 *US3*

On the N section a ca. 4 m deep channel cuts both US2 and US1. This channel is filled by US3 sediments and, in turn, is cut by a further weakly undulated and shallower channel filled by US 4 sediments (*figg.* 2-3).

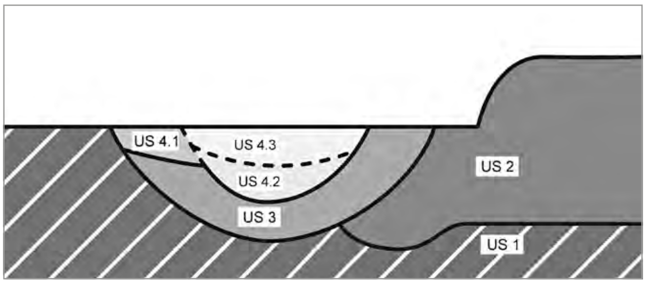

fig. 3 – The US observed within the retention basin and described in the text. Bold lines are the main unconformities, dotted lines represent the minor unconformities.

US3 is made of loose planar cross-bedded, poorly sorted, rounded to subrounded fine to coarse-grained gravels (Gp), variable amount of sandy matrix. Minor planar or low angle cross-bedded sands (Sp) and lenses and blanquets of massive to finely laminated silts and clays (Fm, Fl) are also present. The composition of the gravels also include rare clasts of CT and rare charcoal fragments. The facies association is typical of a gravel-sand wandering to meandering river (Miall 1995) with a westward lateral accretion of gravelly and sandy bars and filling of abandoned channels.

4.1.4 *US4*

US4 is composed of loose, unsorted, trough crossbedded to massive, fine to medium-grained, rounded to subrounded gravels (Gt, Gh), locally matrix supported (Gsm). Minor trough cross-bedded or massive sands (St, Sh) and lenses and blanquets of massive to finely laminated silts and clays (Fm, Fl) are also present. The gravels are made of very abundant clasts of CT, locally, filling entirely smaller channels. The bedforms are also characterised by the presence of very abundant fine to very coarse charcoals, both scattered within the sediments or concentrated along the base of the beds. The faciesassociation, made of fine gravelly and sandy downstream accretion and mass flows bedforms with minor floodplain sediments are typical of a distal shallow gravel/sand-bed braided river environment. The same sediments filling smaller channels have also been observed a few tens of metres downflowalternated to laminated clays and silts, weakly weathered by palaeosols with root tracks (*fig.* 4) typical of shallow swampy or lagoonal environment.

Although the sedimentary characteristics of US4 are homogeneous, a further subdivision has been made on the base of the presence of minor unconformities: US4.1 is observed in the western part of the section that buries a shallow and almost flat unconformity that cuts both the US1 and the US3 sediments. US4.2, towards the east, fills a deeper channel cutting entirely into the US3 sediments. US4.2 also represents the thicker sub-unit suggesting that this is the most important depositional phase. Finally, both US4.1 and US4.2 are cut by a further very shallow and slightly undulated unconformity buried under US4.3 sediments.

4.2 Chronology

The whole palaeochannel filled with US3 and US4 sediments is the last sedimentary event recorded in the succession investigated in the retention basin. For this reason,

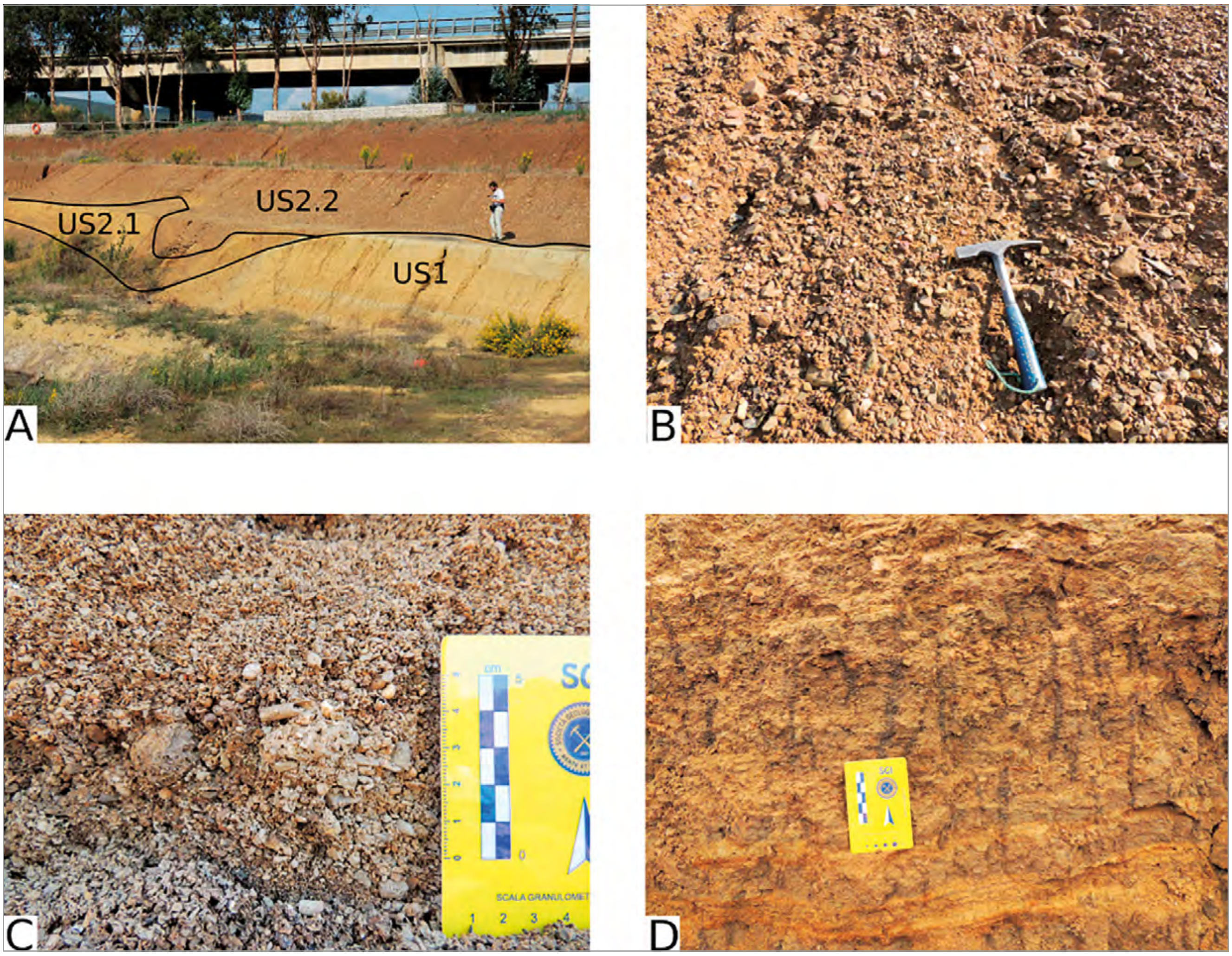

fig. 4 – A) The unconformity affecting the basal US1 sediments filled by US2 sediments subdivided into two minor sub-units. US2.2 is weathered by a reddish palaeosol on top. B) Angular, unsorted, polygenic gravels of the US2.2 unit. C) The almost monogenic composition of the US4 gravels and sands made of clasts coming from the erosion of the CT. D) Root tracks and weakly developed palaeosols affecting the shallow swampy or lagoonal deposits entered by the US4 sediments.

it has been investigated also to assess its chronology and the sedimentary changes observed. This was made through radiocarbon dating of the abundant charcoals found mixed with the sediments. Preliminary results (*fig.* 2; *tab.* 1) show that the US3 sediments were left at least until 787-471 CAL age BC (Sample Fi3497) whereas the filling of the upper palaeochannels (US4) can be dated between 660-779 CAL age AD (US4.1, Sample Fi3554) and 1150-1290 AD (US4.3, Sample Fi3451).

4.3 Sediment charcoal analysis

Sediment charcoal analysis was preliminarily carried on 14.5 litres of sediment from 13 samples, with ca. 19.4 g of extracted charcoal. The samples were collected from US4, characterised by braided shallow channel (sub-units US4.3 and US4.2) and braided sheet channel (sub-units US4.1; Table 1). The sample 1.3 collected in US4.1 was found to be sterile.

To assess the taxonomical information, 191 charcoal fragments were preliminarily analysed allowing the identification of 17 taxa. The results of the taxonomical identification, together with the SAL and the radiocarbon dating, are presented for each sample in the diagram (*fig.* 5). The main identified taxa useful to reconstruct the forest types, such as *Alnus*, *Erica*, *F.* cf. *oxycarpa*, *F.* cf. *ornus*, *Q.* cf. *cerris*, *Q.* cf. *ilex*, *Salix*, and *Ulmus* are presented in detail, whilst other identified broadleaved deciduous taxa (*Fraxinus*, Maloideae, Monocotyledon, *Prunus*, and *Quercus*) are grouped under the definition "Other broadleaves". Calculations and percentages are based on the charcoal frequencies (number of identified charcoal remains per sample). To better highlight the vegetation changes in the record, key taxa have been grouped based on their ecological significance.

Among the identified taxa, deciduous broadleaved trees prevail on the total of the charcoal remains. *Ulmus* is the most attested (23%), followed by *Alnus* (7.3%), *F.* cf. *oxycarpa* (6.8%), *Q.* cf. *cerris* (5.8%), *Salix* and *F.* cf. *ornus* (3.7%). Among sclerophyllous evergreen taxa, *Erica* (4.7%) and *Q.* cf. *ilex* (2.1%) are attested. Other broadleaves constitute 25.7% of the total. Unidentifiable charcoals (because of bad preservation status or vitrification) constitute 13.1% of the total.

5. DISCUSSION

Paleoenvironmental reconstruction of fluvial landscapes along the Pecora river valley was made possible by an integrated sedimentological, geomorphological, stratigraphical, geochronological and charcoal analysis. In particular, the sections opened in the retention basin along the distal reach of the Pecora river allowed a detailed modelling of the sedimentary history along the valley and its relationships with the changing environment in the upper reach of the drainage basin.

The older depositional environment (US1) is characterised by clayey sediments deposited within a stable palustrine/lagoon environment with no evidence of palaeosols or arrival of coarse-grained sediments. Such an environment can be related to a marine high-stand during periods of warm and wet climatic conditions, possibly associated with the Last Interglacial (Coltorti, Pieruccini 2006). US1 is abruptly cut by a major unconformity buried under US2 sediments. They are coarse-grained gravels and sands deposited in a high-energy fluvial environment typical of deep and shallow gravel and sand-bed braided rivers (Miall 1995). These sediments form an alluvial fan whose top surface is gently sloping to the south. US2 indicates an environmental change with an increase in gravelly bedload and the formation of a braidplain. This environment is associated with a wide alluvial fan filling the earlier lagoon. This phase can be linked to the onset of cool and arid climatic conditions typical of the cooler stages of the Last Glaciation that enhanced the production of debris from denudated slopes driving the sedimentary aggradation of the valley floors. The c. 120 m sea level fall due to the cool climatic conditions shifted the coastline to the south. The climatic amelioration at the beginning of the Holocene, due to the abrupt bedload decrease together with the rapid sea-level rise, enhanced the capacity of the river system to downcut the valley floors (Coltorti, Pieruccini 2006). Therefore, the previous alluvial fan forms an alluvial terrace where the Vetricella site is located, that in its apical part is c. 10 m high on the present-day thalweg.

A single channel, up to 3 m deep, cuts both the US1 and US2 and is filled by US3 sediments. These are gravels and sands with facies associations typical of a gravel-sand wandering to meandering river with the formation of point-bars and swamps along the valley floor following meander-cuts. The gravels, finer-grained than US2, are made of lithologies belonging to the bedrock of the basin and by scarce clasts deriving from the erosion of CT. This composition suggests that the CTsystems, present in the mid- and upper reaches of the Pecora and Le Venelle-Ferriere rivers (*fig.* 1), were already in formation although not strongly eroded by fluvial dynamics. US3 sediments also commonly contain charcoals that allowed the dating of this sedimentary phaseat least up to 787-471 BC Cal Age (Sample FI 3497) and possibly up to the Roman age. The presence of burnt vegetation also suggests the onset of land use practices related to fuel production or land clearing and vegetation opening.

US3 is cut by a further unconformity represented by a composite channel buried under c. 2.5 m of US4 sediments that can be subdivided into 3 main subunits bounded by minor unconformities (*figg.* 2-3). US4 sediments are characterised by unsorted fine-grained gravels, coarse-grained sands and silts deposited within shallow and small channels with cut-and-fill geometries that indicate an abrupt change from a sinuous wandering river to a shallow braided river testifying toan increase of bedload and fast deposition in a less confined channel system. The most striking feature of US4 is the composition of the sediments that shows an abrupt change becoming predominantly made of unsorted clasts coming from the erosion of the CT. This is the very first evidence of the erosion of the up-valley CT environments (*fig.* 1), although the amount of sediments and the geometry of the sedimentary body suggest that only minor changes occurred upstream. These environments are typically made of wide flat swampy areas alternated with barrages or waterfalls. Both environments enhance the deposition of calcium carbonate due to the biological activity of algal and microbial floras and faunas within the swamps and to turbulence in the correspondence of the waterfalls (Capezzuoli *et al.* 2014). The sedimentary characteristics and the chronology of US 4 indicates that the process of inactivation and erosion of the CT systems occurred in a very short time span that starts in the 8thc AD (US4.1) but is mostly concentrated in the 10th-11thc AD (US4.2), with sedimentation rates up to 0,7 cm/yr. The response of the fluvial system to the changes occurring in the upper reach of the cathchment lasted until the 13thc AD (US4.3).

The presence of swampy areas along the Pecora river valley is also testified by the place names reported in the topographic maps such as "Padule Moreta" and "Pian del Padule" ("Padule" is a Tuscan term for swamp, *fig.* 1). The drainage of these wet areas occurred by means of drainage regulations still observable today. Moreover, the main barrage of the CT system (named "La Cascata" meaning Waterfall, *fig.* 1) is bypassed by a deep artificial cut that diverted the natural course of the river to the west, draining the whole wetland up-valley (*fig.* 1). All these artificial water regulations are responsible for the drainage of the CT environments and for their erosion due to the subsequent river down-cut that led to the transport and deposition of the amazing amount of CT clasts found in the NW section down valley. Furthermore, the NW section is located very close to the mouth of the Pecora river entering the early medieval shallow swampy or lagoonal environment as testified by the interlayering of these deposits with the US4 sediments (*fig.* 4).

US4 sediments also contain very abundant charcoals, from very coarse to fine, concentrated within the troughs and beds. Charcoals are within sedimentary record and their abundance coupled with the absence of human artefacts allows us to exclude an archaeological-related contamination (i.e. there are not derived from a nearby archaeological site, see chapter 3.2.). Moreover, the dispersion and deposition of charcoal during and after the fire (Clark 1988; Thinon 1992; Scott *et al.* 2000) is strictly dependent on run-off processes and the capability of the river to re-distribute sediments and charcoals down-valley. Such fast and widespread vegetation fires linked to the erosion of the CT environments and their drainage cannot be attributed to climate changes also because the climatic signals in the Mediterranean are not strong enough (Luterbacher *et al.* 2012) to be able to generate such a rapid response of the fluvial system for the time interval under consideration.

The preliminary radiocarbon dating, pointed to the overlapping alluvial phases, shows a coherent and linear

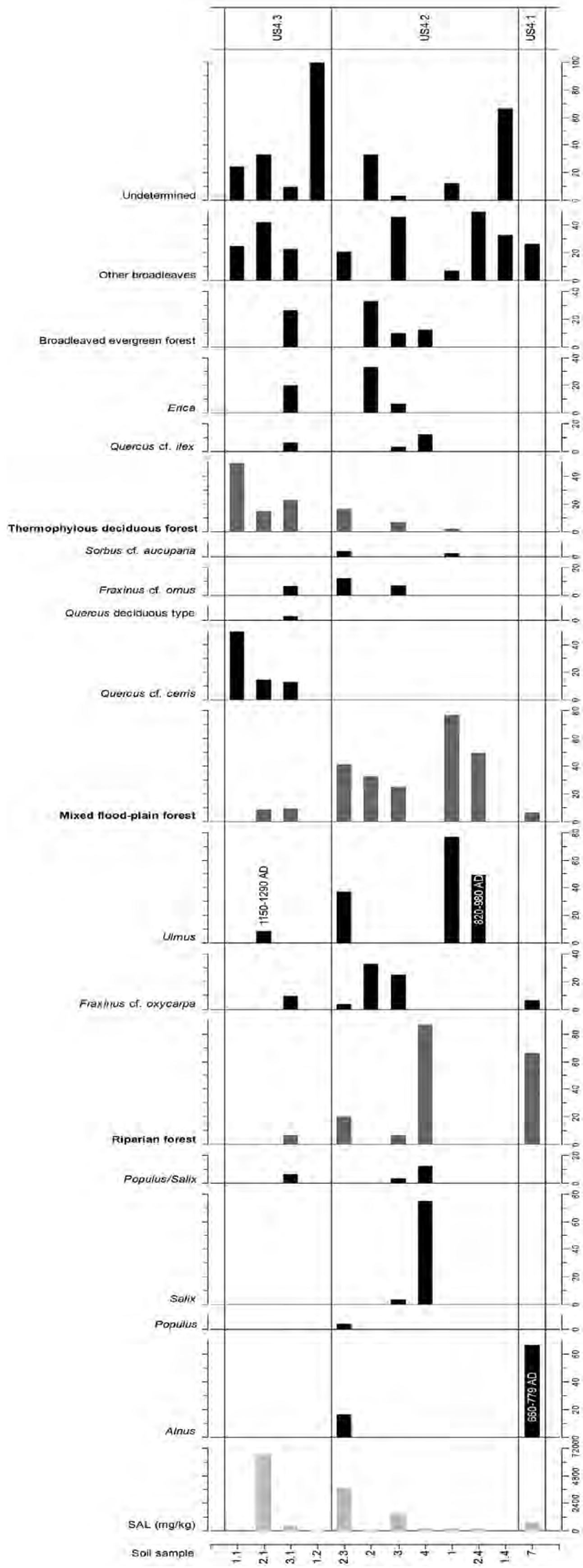

fig. 5 – Section NW charcoal analysis. From left to right: charcoal samples listed according to the depth; light grey bars: SAL (sample layer) values; black bars: percentage of most important taxa with indication of the AMS radiocarbon dates; dark grey bars: related ecological groups; stratigraphic units according to facies analysis.

chronological sequence. Assuming that the charcoal record is a result of forest fires, we can argue that the period between the end of the 8thc AD and the 13thc AD recorded the presence of fire activity within the Pecora river basin, with a peak of fire activity in the 9th-11thc AD period.

US4.1 is preserved on the right side of the palaeochannel and indicates a first phase of deposition occurring in a very shallow, flat and unconfined channel system dated to 660-779 AD Cal Age (Sample FI3554). This age postdates the beginning of the erosion of the CT systems and the onset of a braidplain in the distal reach of the Pecora river. However, the limited thickness of the sediments and the unconfined geometry of the depositional unit indicates only minor changes occurring in the upper catchment.

US4.1 taxonomical identifications document the presence of *Alnus* and, at a lesser extent, *F.* cf. *oxycarpa*, indicating that in this period mainly riparian and mixed floodplain vegetation is affected by fire, coupled with the onset of fluvial erosional events along the swampy areas within the CT environments. This suggests that the drainage and reclamation of these wet environments was also due to vegetation clearance along the floodplain, which could be evidence of woodland management carried out by 8thc AD settlements capable of seeking high-quality crop production in a period of involution of the medieval state (Buonincontri *et al.* 2017). However, fire activity and sedimentary processes increase in the following centuries.

In fact, US4.1 is in turn cut by a minor unconformity that indicates the formation of a deeper channel whose filling, US4.2, shows the same facies model, with the predominance of cut-and-fill bedforms made again of CT fine-grained gravels. Nevertheless, the increasing thickness of the sedimentary succession and its deposition within a deeper and more confined channel indicates that this is the main depositional phase, possibly associated with the major drainage and environmental changes occurring upstream. Also, the frequency and volume increase of charcoal fragments lead to the older dating of this depositional stage to 880-980 AD Cal Age (Sample FI3452).

US4.2 anthracomass shows that fire activity included more established forest vegetation made of *Ulmus*, *F.* cf. *oxycarpa*, *Alnus*, *Populus* and *Salix*. This indicates that fire events affected a wider environment involving the riparian and mixed flood-plain forest occurring along the riverbed, wetlands, and distal alluvial plain. The presence of *Erica*, *Q.* cf. *ilex* and *F.* cf. *ornus* suggests that broadleaved evergreen forest of the foothill areas was also affected by fire activity.

Thus, the observed evidence argues in favour of the clearing and reclaiming of woodland in the whole Pecora basin suitable for the cultivation of large kernelled crops as well as fruit tree cultivation (Buonincontri *et al.* 2015, 2017), probably due to the establishment of a new economic system (Hodges, Bianchi; Collavini *et al.* this volume). This hypothesis is also supported by the comparison of charcoal data with pollen analysis in the region, which show a noteworthy match of fire signals and forest clearance. At the Accesa lake the pollen sequence attests a decrease of wild arboreal pollen and an increase of cultivated tree pollen (olive and chestnut) from c. 850-950 AD (Magny *et al.* 2007).

US	Sub-Units	CT abundance	Facies model	^{14}C Age	Ch samples	Ch abundance	Fired vegetation
US4	US4.3	*****	Distal sheetflood unconfined gravel/sand-bed braided river	1150-1290 AD	1.1 2.1 3.1 1.2	***	Riparian, proximal, distal floodplain and foothill
	US4.2		Distal shallow gravel/sand-bed braided river	820-980 AD	2.3 2 3 1.3 4 1 2.4 1.4	****	Riparian, proximal and distal floodplain
	US4.1		Distal sheetflood unconfined gravel/sand-bed braided river	660-779 AD	7	***	Riparian and proximal floodplain
US 3		*	Gravel-sand wandering to meandering river	787-471 BC		*	

tab. 1 – Section NW sedimentary facies and related chronology and environments CT (Calcareous Tufa) and Ch (Charcoal) abundance: * rare; **scarce; ***common **** abundant *****very abundant.

A further minor unconformity is buried under US4.3 sediments that show the same sedimentary and compositional characteristics in the period of 1150-1290 AD Cal Age (Sample FI3451). However, the thickness of the sedimentary record is very limited and, as with US4.1, deposition occurred in an unconfined shallow channel, indicating a decreasing in sedimnetary and associated environmental dynamics in the surrounding landscape.

In this unit a strong presence of *Q.* cf. *cerris* and, at a lesser extent, *Erica*, *Ulmus*, *F.* cf. *oxycarpa*, *Populus* and/or *Salix*, *Q.* cf. *ilex* and *F.* cf. *ornus* is recorded. Overall, the data suggest that in this phase fire events occurred intensely on the foothill areas, affecting the thermophilous deciduous forest dominated by *Q. cerris*.

The reclamation of the CT environments seems to come to an end in the 12th and 13thc AD, when exchange, productive specialization and semi-industrial activity became very complex and affected agriculture. In the same period, the farming system reached the highest levels and its expansion reached the foothills (Di Pasquale *et al.* 2014; Buonincontri *et al.* 2015, 2017).

This is the last sedimentary stage recorded within the palaeochannel, although we cannot exclude the erosion of younger sediments. However, the geomorphological investigations indicate that after this moment the river dynamics were not confined within channels until the definitive reclamation occurred after the 19thc AD.

6. CONCLUSIONS

The analysis of the NW section within the retention basin allowed a detailed reconstruction of the physical and biological environments of the fluvial landscape in the distal reach of the Pecora river, which represents an exceptional case of study for the Early Medieval times for this Mediterranean area. Sedimentological investigations revealed the erosion of the CT systems in the mid-to proximal reach of the river indicated by the occurrence of CT clasts. The erosion must be related to the disappearance of these environments that occurred in a short time span comprised between 8th and 13hc AD together with an abrupt change from sinuous-meandering to braided river model. These changes are also characterised by the appearance within the sedimentary record of abundant charcoal remnants. The processes related to the CT swamps and systems of barrages/waterfalls inactivation must be attributed to fast drainage of the swampy areas and bypass of the waterfalls that work as barrages for the wet environments. Such processes cannot be attributed to natural events (i.e. climate changes) due to the very short time duration necessary for the erosion, transport and deposition downvalley of such an abundant sedimentary record and charcoals associated with vegetation fires. Moreover, for the time span under consideration there is no global or local climatic signal able to trigger such strong environmental changes. On the other hand, artificial run-off regulations for the improvement of wet environments drainage and bypassing of waterfalls can serve as the determinant factor for the recorded changes. Furthermore, these processes occurred at the same time with widespread vegetation fires that can be easily attributed to land clearance for agricultural purposes as suggested by the selective fire activities along the ecological vegetation groups typical of environments proximal to the valley floors such as riparian, floodplains and foothills. Within the medieval palaeochannel we recognised 3 main depositional events that embrace respectively the 8thc, 9th-11thc and 12th-13thc AD. The older event is characterised by a limited thickness of sediments and the minor amount of associated charcoals, suggesting as in this chronological interval that the drainage and vegetational changes in the upper catchment were at an embrional stage. The most important event in terms of sedimentary response and charcoal amount is associated with the 9th-11thc AD when the CT environments become strongly eroded and mostly drained, as suggested also by the broader ecological groups affected by fires. Finally, the last evidence of this sedimentary history spans the 12th-13thc centuries AD, when the depositional processes decreased and the fires also affected the hilly landscape.

This analysis revealed that the fluvial dynamics and associated landscapes changed in the Early Medieval times, with major changes occurring at the Vetricella settlement providing information about site formation processes and landscape exploitation strategies.

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Abstract

Sedimentary filling within fluvial valleys are excellent archives for landscape changes along the river basins since the valleys work as traps for sediments coming from the slopes and later re-worked, distributed and deposited by fluvial processes. In terms of physical and associated biological landscapes, fluvial sediments reveal if and how the riverine dynamics changed, providing information about different fluvial styles. At La Vetricella we had the chance to observe thick sedimentary records in the distal reach of the Pecora river basin. At c. 1 km to the NW from the site, engineering works for the excavation of a retention basin on the left bank of the river revealed the presence of a wide palaeochannel filled with up to 3 m of sediments. The combined sedimentological, geomorphological, anthracological and geochronological analyses revealed an abrupt change of the river dynamics and associated landscape that mainly occurred between the 8^{th} and 13^{th}c, testifyingtostrong human impact on the surface hydrology and vegetation in the mid- and upper reach of the Pecora river basin.