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Pleistocene versus Holocene: Geomorphological Change in a small but steep Watershed of Mediterranean Spain

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Abstract

The Pleistocene and Holocene records of the Rambla de Artana drainage basin in the Serra de Espadà are compared. The watershed is small (52 km²) but attains crest elevations of over 1000 m, with a relief of 850 m. This accentuates geomorphologic processes and introduces a strong component of Pleistocene cold-climate morphogenesis. Further, the overwhelming proportion of entrained sediment is siliciclastic, derived from quartzitic sandstones of Triassic age. Such sediments are more complex and representative of past processes than than those of limestone or dolomite catchments subject to chemical dissolution. Pleistocene sediment volume is several orders of magnitude greater than that of the Holocene, accumulating on all topographic segments, beginning with massive talus rubbles, continuing across lower slopes via various processes, to deposit and later rework a body of very coarse alluvium in the valley bottoms. Such sediments were repeatedly cemented or deeply weathered by argillic soils. The shifts between periods of active and passive slope balance reflected incisive climatic changes, with the bulk of the sediment produced and transported by cold-climate processes. By contrast, the Holocene record is small in volume and limited to lower slopes and valley bottoms. It consists mainly of soil-derived colluvia and minor channel fills. The oscillations between phases of passive and active slope balance were short and promoted net soil loss at a rate that could not be sustained. The hydrology shifted from perennial to seasonal, and then intermittent, without evidence for long-term climatic change. Despite periodic forest recovery, the ecosystem was repeatedly degraded by destructive land use, with erosion in a fragile environment probably triggered by clusters of high-magnitude rainfall events. Nevertheless, the stability of the stratigraphic record in siliciclastic sediments shows that far more of the soil resource of the Espadà, which is primarily of Pleistocene age, was reworked or destroyed by Pleistocene, cold-climate denudation than by anthropic erosion during the Holocene.

Resum

La conca de la Rambla d'Artana (52 km²), amb un desnivell que abasta 850 m i cims que superen els 1.000 m s.n.m. (Serra d'Espadà), permet la comparació dels registres holocènic i plistocènic, aquest, marcat per la morfogènesi freda. El volum del sediment plistocènic multiplica unes quantes vegades l'holocènic i comprèn des dels pedruscalls dels vessants alts fins als al·luvions grollers dels fons de vall, de vegades cimentats o meteoritzats. Uns canvis climàtics decisius han influït a la sedimentació de coster. El registre holocènic es limita als vessants més baixos i rebliments de canals amb oscil·lacions més modestes. Malgrat el recobrament de la coberta forestal, l'aprofitament destructiu ha degradat repetidament l'ecosistema, però el registre estratigràfic del sediment siliciclàstic demostra que la major part dels recursos del sòl (que pertanyen al plistocè) fou més afectada o destruïda per la denudació freda plistocènica que no per l'erosió antròpica holocènica.

Resumen

PLEISTOCENO VERSUS HOLOCENO: CAMBIO GEOMORFOLÓGICO EN UNA PEQUEÑA PERO ABRUPTA CUENCA DE LA ESPAÑA MEDITERRÁNEA. La cuenca de la Rambla d'Artana (52 km²), con un desnivel que llega a los 850 m y cumbres que exceden los 1.000 m s.n.m. (Serra d'Espadà), permite la comparación de los registros holoceno y pleistoceno, marcado este último por la morfogénesis fría. El volumen de sedimentos pleistocenos multiplica varias veces los holocenos y abarca desde canchales de las vertientes altas hasta aluviones groseros de los fondos de valle, a veces cementados o meteorizados. Ciertos cambios climáticos decisivos han influido en la sedimentación de ladera. El registro holoceno se limita a las laderas más bajas y rellenos de canales con oscilaciones más modestas. Pese a la recuperación de la cubierta forestal, el aprovechamiento destructivo ha degradado repetidamente el ecosistema, pero el registro estratigráfico del sedimento siliciclástico demuestra que la mayor parte de los recursos del suelo (que pertenecen al Pleistoceno) fue más afectada o incluso destruida por la denudación fría pleistocena que por la erosión antrópica holocena.

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1. INTRODUCTION

The landscapes of the Mediterranean world are among the most varied and striking anywhere, combining rough mountain and verdant plain, or white limestone with red soil or blue sea. Homer revelled in terraced hillsides, Plato mused on the destruction of soils. Two millennia later, Monet was enthralled by the relief, the vegetation, and the water, but George Perkins Marsh saw a world of denuded mountain slopes and rock-strewn valleys, ravaged by deforestation, livestock, and human improvidence or greed. Self-assured scholars from the industrializing world were less generous than the painters, proclaiming a great discrepancy between the impoverished landscapes they saw and the Classical Eden that they believed they knew. A new breed of colonial officials or international experts condemned the goat, while environmental historians explained the discrepancy between perceptions of past and present by desiccation or human destruction.

The unfolding debate among geomorphologists during the last 30 years has been no less polarized (MATEU, 1986). The notion that a synchronous climatic change gave rise to a massive geomorphologic response has been increasingly discredited, but the opposing view, that human activities triggered slope erosion and stream alluviation has not attracted unqualified support. The different thresholds becoming apparent between palynological and alluvial records lend increasing credibility to the early caution that human land use may have merely created fragile ecosystems that responded dramatically to relatively minor climatic stimuli (BUTZER, 1980: 136). Recent observation of high-magnitude weather events, with their particular recurrence patterns and spatial variability, suggest concrete avenues for future systemic studies. Similarly it has become apparent that demographic numbers and growth rates do not correlate well with the onset or intensity of landscape damage: conservationist versus exploitative land use practices reflect environmental information, historically-grounded experience, and external factors that favor the choice of long or short-term strategies (BUTZER, 1996).

The present study was initially conceived in 1980 and continued. at intervals, until 1991, with changing assumptions and directions. The watershed of the Rambla de Artana, in the Serra de Espadà, some 50 km north of Valencia, was originally chosen as a frame to a more comprehensive project. The overall design was to study societal-environmental interaction for the period of Muslim and Christian occupance, which proved to be a span of roughly 900 years. The research involved land
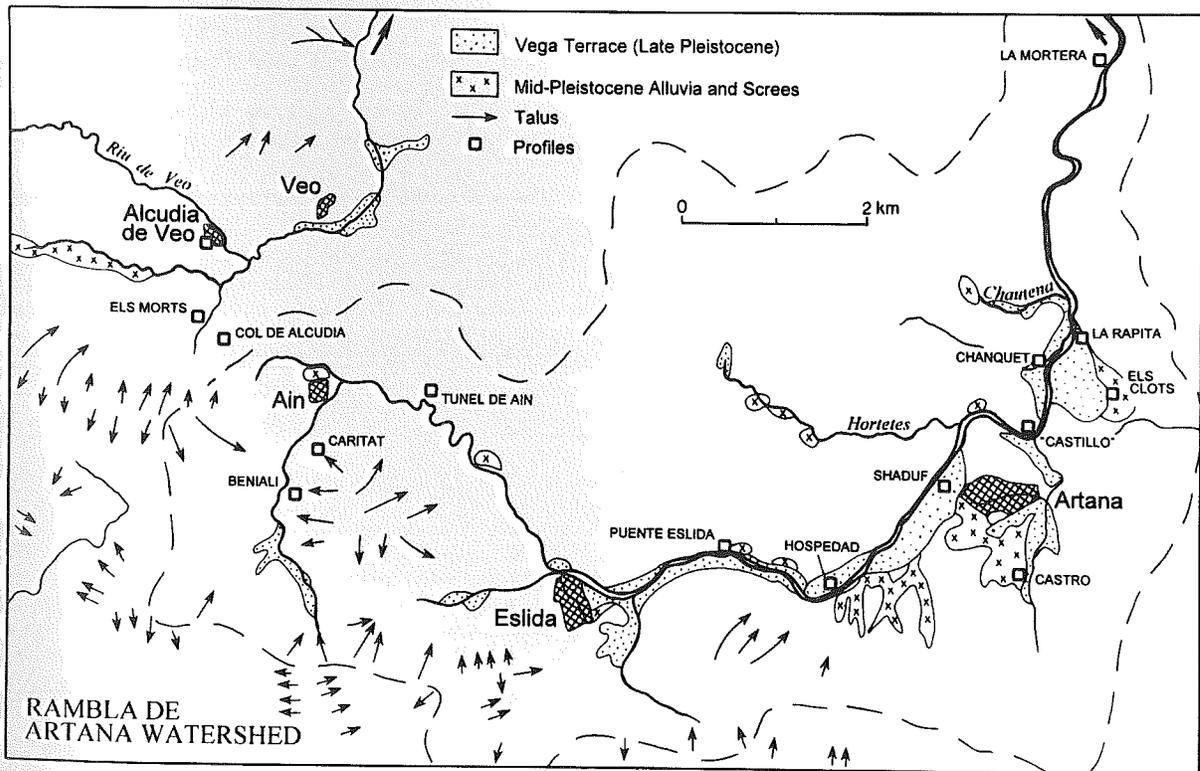

Fig. 1. The Rambla de Artana watershed, with simplified distribution of Pleistocene surficial deposits (mapped by authors).

use mapping, archival study, archaeological exploration and excavation, as well as geomorphological investigation, subsequently complemented by palynology and paleoethnobotany.

The Artana watershed (fig.1) lies within the mountains and is small, 52 km², with a strong vertical relief of 850 m. It proved a fortuitous choice as a microcosm to examine geomorphologic processes, primarily as reflected in the record of sediment and soils. The high potential energy served to magnify change over time, and crest elevations of 1000 m (including part of the adjacent Veo watershed) introduced significant vertical zonation. Further, the basin included two major lithologies, dolomites and quartzitic sandstones, both of Triassic age (see IGME, 1974). As the geomorphological research progressed, it became apparent that Pleistocene cold-climate processes dwarfed the Holocene sedimentary record of the basin, thanks in good measure to the durability of siliciclastic products, which completely dominate both the slope and alluvial deposits, even though sandstone lithologies account for only 32% of the surface area. In other words, the siliciclastic record is both more complete and more representative of the critical shifts between "active" and "passive" slope balance in the uplands, as well as the long-term residence of detrital sediment in the valley bottoms.

The Artana watershed may not be a model, Mediterranean catchment, but it is within the range of relief variability of tributary systems that debouch on coastal plains in Greece, for example, that already served as settlement foci in prehistoric times. The prominence of siliciclastic sediments, which is atypical of Mediterranean limestone terrains, provides a more discriminating record, that continues to document the unexpected role of Pleistocene cold-climate processes, without ultimately being conflated to an undecipherable palimpsest by solution. For these reasons we chose to inaugurate our study of societal-environmental interactions by one that is, first and foremost, geomorphological. Botanical data are only alluded to, where they point to more complex interpretations, and will be given their due in a subsequent, more comprehensive environmental study. Pottery inclusions are used to help date Holocene sediments, bearing in mind that sherds provide only a *terminus post quem*; but the archaeological evidence for historical and prehistoric settlement or abandonment is not developed here. Archival and archaeological documentation for the Muslim era is detailed by Butzer, Butzer and Mateu (1986), while the changing adaptations of the Christian period since 1610 are outlined in Butzer (1990).

2. SLOPE RUBBLES AND SOLIFLUTION MANTLES

The outliers of the Serra de Espadà rise fairly abruptly above the coastal plain of La Plana, as a consequence of structural and lithological controls. At first, the low but steep mountain slopes are relatively free of coarse detritus but, as crest elevations increase, fixed or mobile talus slopes appear. The threshold elevation above which talus has formed (rather than been transported) rises from 650-700 m in the east to 900 m in the west, preferentially with northerly exposures. As argued below, the talus slopes and cones of the Espadà, whether mobile or not, are fossil and of Pleistocene age. They are a result of cold-climate gelivation and transport; where still preserved under forest cover, interstices are commonly filled with finer detritus. The source of the talus is given by steep cliffs with jointed, quartzitic sandstones, that mainly pertain to the thick-bedded sandstones of the middle unit of the Triassic Buntsandstein (Bunter). Although gelivation has also produced block rubble below limestone and dolomite cliffs of the Muschelkalk or Jurassic, such detritus has been repeatedly subject to solution weathering, so as to be reduced in mass or removed altogether. The interbedded sandstones and shales of the lower, and especially the upper (Röt) units of the Bunter, have also produced less by way of durable, coarse talus, but may form debris cones on footslopes.

As a result, the quartzitic sandstones of the Bunter have acquired a singular importance in the Serra de Espadà. They not only accentuate the impression of a high-mountain landscape, but have also dominated the Pleistocene sediment supply and transport processes of the upper drainage basin. A representative exposure that links the talus with its corresponding alluvial facies is visible where remnants of an alluvial fan are preserved at 18-20 m (540 m.s.l.) above the Barranc de la Caritat, about 600 m S of Aín (fig.1).

The soil profile on this alluvium is that of a Haploxeralf (Rotlehm), with a 60-80 cm ochric horizon of pink loam over an argillic horizon of 60-75 cm. The latter is a yellowish red, clay loam, but preserves fine sandstone pebbles. It has strong prismatic structure, fine ferric mottling, and conspicuous clay skins. On the steep, adjacent slope this alluvial fan merges with a thick talus apron of crude sandstone blocks at angles of 26-30°, largely obscured by soil and forest cover. But fossil debris cones, topped by stranded and anchored blocks (up to 15 tons), come down to the margins of the 20 m fan. On slopes steeper than 28°, the talus matrix may be flushed out by throughflow or surface runoff, but heavy lichen growth on most rock faces indicates that only some clasts, all smaller than 15 cm diameter, are currently mobile. Even the highest, unvegetated slopes of block talus, at angles greater than 30°, are basically stable, judging by lichen development; but these are mainly younger than the debris cones.

This relationship is representative of the talus slopes of the Espadà. Talus production was a Pleistocene phenomenon, and at least two generations can be identi-
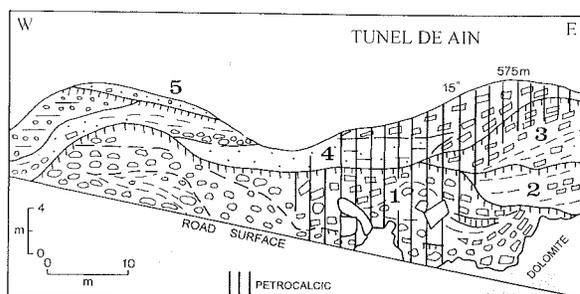
Fig. 2. Cross-Section of rubbles and alluvia at upper outlet of the Tunel de Aín. Subdivisions of units 1 and 4 not labelled.

fied. Major gelivation and slope transport were older than Haploxeralf pedogenesis that suggests an intensity of weathering that can be no younger than oxygen isotope stage 5. Talus accumulation subsequently resumed (isotope stage 2?), but Holocene mobilization was largely limited to flushing out fines in the wake of abrupt deforestation.

Below steep dolomite slopes (up to 38°), immediately downstream of the lithological boundary in the Caritat valley, slope rubble is instead embedded in a petrocalcic soil mass, with heavily recrystallized calcite. At angles of 15-18°, blocks of 10 or 20 tons are cemented into the top of this mantle, rotated at 50-55° to their horizontal planes. The decalcified matrix is a reddish brown clay, derived from a Rhodoxeralf or Terra Rossa soil. Here a combination of rotational sliding and solifluction in a wet substrate are indicated.

A second example serves to better illustrate the complex stratigraphy of these slope rubbles. A series of debris cones is cut by the road, immediately above the Tunel de Aín (fig.1), filling a small valley along the contact of the Muschelkalk and sandstones of the lower Bunter; they once projected to a high floodplain of the Rambla de Artana, and are best developed between 560 and 600 m.s.l. (fig. 2). The oldest accumulation (unit 1) has a thickness of 12 m, and began as an alluvial cone, with stratified coarse to boulder-grade sandstone debris, but was converted into a debris chute, with cobble to boulder-size sandstone rubble, mixed with great angular blocks of dolomite, mainly chaotic, but interrupted by lenticular interbeds of reddish brown loam or clay loam. It was moderately weathered, with eroded vestiges of a yellowish red loam, with angular blocky structure, prior to renewed accumulation of a well stratified alluvial fill of 3.5 m unit (2). This includes subrounded sandstone and dolomite clasts, with lateral, angular dolomite rubble. The matrix is a reddish yellow silty clay loam, with angular blocky structure, implying pedogenetic alteration. Unit (3) consists of 6 m of angular dolomite rubble, inclined at 12° to the dolomite slope. The upper half is a sorted gelivation scree, approximating grèzes litées.

With a basal erosional contact, unit (4) consists of 7 m of interstratified loams and subangular sandstone gravel, in part lenticular, but grading laterally into 4 m of cobble to boulder-grade, dolomite rubble, inclined as steeply as 15°. This is an alluvial cone, in part derived from gelivation rubble. It too has evidence for pedogenesis, with the top 50 cm weathered to a yellowish red loam, with coarse angular blocky structure. Parts of this and all the earlier units are petrocalcic, with croûtes zonaires (caliche) resulting from throughflow of calcium-rich waters from the dolomite slope. The final unit (5) is a minor, unconsolidated alluvial fill.

The Tunel de Aín documents the intimate links between cold climate, accelerated slope dynamism, and alluviation during Pleistocene times. There are three pedogenetic horizons, although no distinctive paleosol profiles have been preserved, so that correlations are not possible. But at this location only one period of major calcification remains evident, presumably dating to the terminal Pleistocene.

Several generations of solifluidal deposits are exposed along the road between the Coll de Alcudia and the Barranc dels Morts (570-600 m m.s.l.), with brecciated masses of Keuper marls at the base (fig. 3, top). Up to 2 m of reworked, red clay or clay loam (unit 3) rest on the cavitated and convoluted surface of two generations of petrocalcic rubble or rubbly loam (units 1 and 2), recording gelifluid and debris chute transport, on slopes of as little as 5°. The Rhodoxeralf-derived sediment is overlain by a cemented rubble colluvium (unit 4), with basal runnels and a boulder lag, that grades laterally into a thick gelifluction scree. This is overlain by an historical soil wash, linked to local terraces (unit 5).

The slope deposits of the Coll de Alcudia, with their interbedded paleosols, have a cumulative stratigraphic thickness of 10 m and conform to the modern topography. However, some older slope rubbles have been isolated by later solution or erosion. Thus, on the western side of the Barranc dels Morts (fig. 3, base) there is a 7 m accumulation of grèzes litées at the foot of a dolomite slope (550-570 m m.s.l.), consisting of 25-75 cm thick beds of cobble-grade rubble without matrix, alternating with 75-150 cm strata of dolomitic plaquettes de gel with a matrix of dolomitic sandy loam (unit 1). Internal dips range from 15-32°, marking a gelivation scree, but the dolomitic cliff that was the source has long been eroded away. The top 100-150 cm of this sorted talus form a silcrete duricrust (unit 2), with 91% of the acid and alkali-soluble matrix consisting of opaline silica and aluminum silicates. The whole was subsequently attacked by three periods of large-scale, karstic cavitation. The oldest karst phenomena form large caverns or galleries, mainly filled with partially-decalcified segments of unit (1) that are impregnated with a reworked soil, namely a reddish brown clay, with hema-

tite-stained quartz and glossy pyrite concretions (unit 3). This fill was then undermined by solution, before filling (at a lower level) with a stoney, Rhodoxeralf sediment of cemented, reddish brown, silty clay loam, with strong structure and ferric clay skins (unit 4). Finally, the whole complex was riddled by solution pipes up to 6 m deep and filled with a non-calcic, stoney soil wash (unit 5) that dips in from the surface above.

The three episodes of subsequent cavitation as well as the duricrust suggest that unit (1) is older than the petrocalcic rubbles (units 1 and 2) of the Coll de Alcudia profile.

These various outcrops serve to illustrate the scale and scope of Pleistocene cold-climate processes in the Serra de Espadà, at elevations as low as 500 m m.s.l. In areas of calcareous bedrock a cyclic evolution is evident, with gelivation rubble followed by calcification, and then karstic cavitation or intensive pedogenesis. Three such cycles are apparent, reaching back well into the Middle Pleistocene. The intensity of cold-climate processes during the last hemicycle of rubble formation, following the red, clay soils attributed to isotope stage 5, was somewhat less severe or effective than its mid-Pleistocene counterparts. By similar standards, subsequent, Holocene karstic solution or pedogenesis were modest.

3. ALLUVIAL TERRACES AND THEIR SOILS

Two distinct, Pleistocene alluvial terraces can be recognized in the drainage of the Rambla de Artana. The younger forms extensive floodplain surfaces near Artana
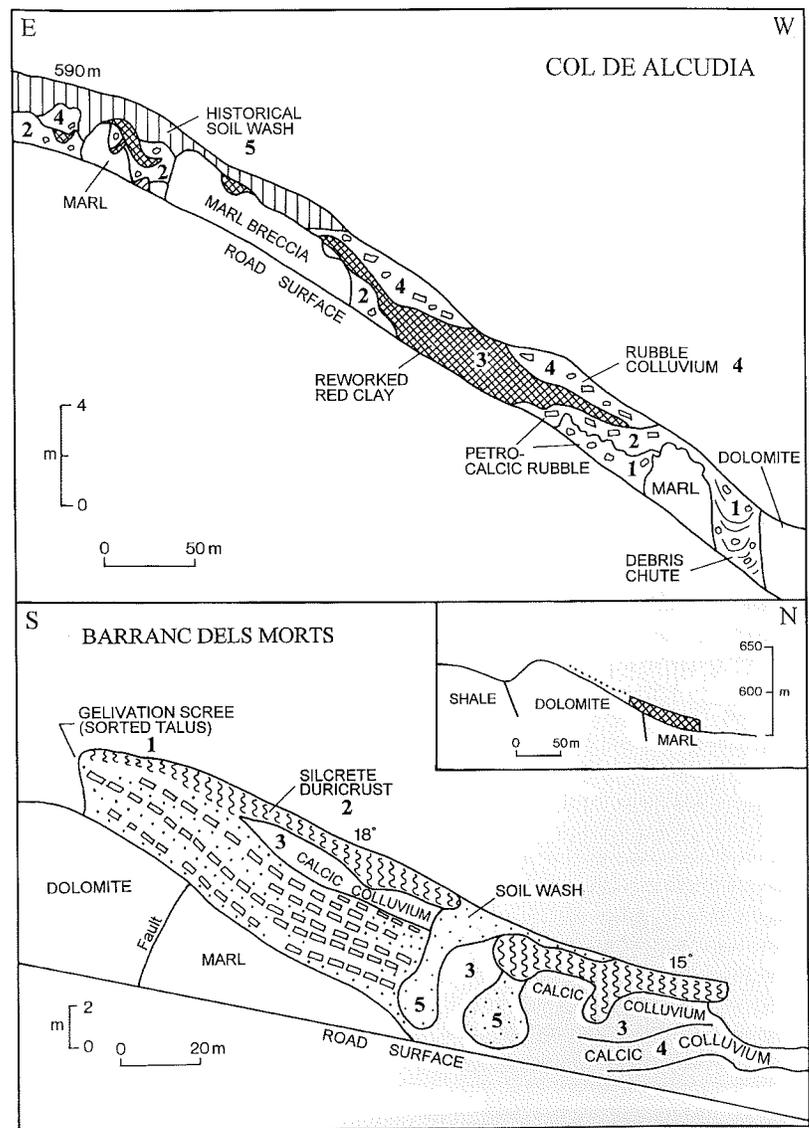

Fig. 3. (Top) Slope rubble west of the Col de Alcudia, at about kilometers 2.9 to 2.6. The contacts between units 1 and 2, and 2 and 3 are convoluted as a result of shear compression during sliding. (Base) Slope rubbles at Barranc dels Morts, with inset showing context.

itself and is represented by corresponding fans at the mouth of most larger tributaries. Informally designated as the Vega Terrace, the typical level is 3.5-6 m above the channel floor, and it shows only modest soil development. The older alluvium is fragmentarily preserved at 15-20 m above channel on valley-margin shoulders and typically grades laterally into screes or, in the upper valley, cold-climate slope rubbles, debris chutes, or alluvial cones. This older alluvium is visibly weathered, although intact soil profiles are uncommon, as a result of Late Pleistocene and Holocene mobilization on the footslopes.

The Vega Terrace comprises the flat, irrigated floodplain near Artana, where it consists of 4-6 m of coarse to cobble-grade clasts of subrounded sandstone, with a matrix of reddish yellow loam. Occasional, thin lenses of finer material suggest the cumulative product of peak flood events, with an episodic hydrological regime. The incomplete rounding of clasts argues for comparatively short transport distances. The densely-packed gravels imply that interstices were only filled with fines after peak discharge was over.

Under an anthropic A-horizon, the Vega Terrace has a cambic B2-horizon of a meter or more, consisting of a yellowish red silt loam, with little or no clay illuviation, and 25% calcium carbonate. Below that is a B3k-horizon with diffuse carbonate enrichment (35%), including opaline silica and translocated oxides. It is a Calcixerollic Xerochrept. In the Kubiena system it is intermediate between a Calcic Meridional Braunerde and a Red Vega soil. This is a typical Holocene soil profile, developed on a Late Pleistocene sedimentary unit. Since the sands and gravels are non-calcareous, the carbonates will have been carried in solution by the discharges that accumulated the fill.

One section in the older alluvium near Aín has already been mentioned. Downstream, an informative profile can be observed at the mouth of the tributary Barranc de Xanquet, which drains a Muschelkalk watershed. A truncated, petrocalcic fan emerges from the valley, projected to a thalweg elevation of 13 m. The lower part is exposed by a quarry in the axial stream bed and has at least 5 m of densely packed, crossbedded sandstone clasts in a calcified matrix. Laterally this channel facies may give way to as much as 4 m of reddish yellow, silt loam with gravel lenses. Above it is a 3 m petrocalcic unit, consisting mainly of a crossbedded conglomerate with subangular dolomite clasts, and intercalations of reddish yellow, gritty silt loam; these are under a meter or so of cemented pink loams with interbedded subangular or subrounded dolomite clasts. The conglomerate locally forms a marker horizon, and within the tributary valley it grades laterally into angular screes. Local thickness of this older alluvium is over 18 m.

In the main exposure, the surface of the petrocalcic fan is corroded and overlain by a reworked argillic horizon of yellowish red, non-calcic, clay loam, with strong angular blocky structure and oxic microconcretions. But downstream from the fan, other quarry pits show an intact sequence of B2 and B3 horizons, representing a Typic Haploxeralf soil. Next to the rambla channel this paleosol is covered by a meter of stratified gravels and pink loams at 6 m above thalweg; this is a lateral facies of the Vega Terrace, incorporating reworked materials from the petrocalcic fan, with the surface altered as a cambic soil horizon.

The last phase of significant carbonate saturation in Xanquet waters predated the youngest paleosol, as it does in the Hortetes and Xautena watersheds (fig. 1). But 5 km downstream, where the Rambla de Artana emerges on the coastal plain near La Mortera, the Vega Terrace also is calcified. But the older fill, at 8 m above channel, is more corroded and underlain by thick plant tufas with broadleaf impressions, interbedded with laminated, conchoidal clays; in areas of higher relief, this same fill grades into dolomite rubbles. This exposure implies low-energy sedimentation and accelerated spring discharge prior to slope denudation that supplied the bed-load facies characteristic of the older Pleistocene alluvium.

Other examples of intact, argillic soil profiles can be observed in the Barranc de Castro drainage, south of Artana, where there are coalescent alluvial fans at 8-12 m above the channel floor. Developed on cobble to block-grade sandstone detritus is a 1.5 m argillic horizon of red clay (52.5% clay fraction), with clay skins and coarse, angular blocky structure. The quartzitic sandstones have been comminuted to a grit-sand fraction of only 6%. The soil in this case qualifies as a Typic Palexeralf.

An even older paleosol is present across the valley from the Xanquet embouchure at El Pinar, exposed in a number of large quarries known as Els Clots. Here some 10 m of clay dip westwards under 7.5 m of the older alluvium, including crossbedded conglomerates, at 12 m above thalweg The clays suggest a small basin filling and have an oxic horizon of 4 m. It consists of red clay (44% clay fraction), with strong prismatic structure, red and black mottling, diffuse iron cementation, and glossy pyrite microconcretions. Stringers of fine pebbles are found at a depth of 200-450 cm, below which is a fragipan of at least 40 cm. At some exposures a fossil crack network extends vertically through most of the profile, the cracks now filled with secondary carbonate as well as pebbles of sandstone and chert, heavily stained with pyrolusite, that have been mistaken for artifacts; these clasts are much younger than the basin clays. This soil suggests a Haplustox, but requires further study.

Another remarkable soil profile is found 1.5 km south of Artana, in the abandoned development project known as the Urbanización La Loma. Here there are remnants of a very old alluvial fan at 40 m above the

Rambla de Artana. It preserves a meter of an argillic horizon, with red clay (42% clay fraction), strong prismatic structure, abundant clay skins, and pyrite microconcretions. All minerals other than quartz have been decomposed, and the soil is a Typic Palexeralf. These features suggest an alluvium earlier than the 12-20 m terrace, which would be consonant with the multiple generations of slope rubbles in the upper drainage basin.

4. DISCUSSION OF PLEISTOCENE PROCESSES

This outline of the Pleistocene sedimentary record of the Serra de Espadà, tentatively summarized in Table 1, speaks to repeated cycles of "active" and "passive" slope balance that conspicuously modified the geomorphic landscape. They accentuated landforms and generated surficial deposits that continue to dominate the region today.

(a) In terms of stratigraphy, there were at least two periods of Pleistocene valley-floor alluviation, separated by a strong paleosol. But two Pleistocene paleosols distinguish three major intervals of slope mobilization, with the formation of alluvial cones, debris chutes, gelivation screes, or solifluction mantles. The last of these episodes of denudation appears to have been less effective in terms of slope modification, implying that mid-Pleistocene processes were paramount in sculpturing the landscape visible today.

(b) The valley alluvia were not only contemporary with slope mobilization, but are directly linked to alluvial fans and debris cones, as well as mountain slope rubbles. Alluviation began with reworking of eroded soil sediments, and then proceded to transport part of the detritus produced on these slopes down into the fluvial medium of the axial valley.

(c) Talus aprons, gelivation screes, alluvial cones and solifluction mantles represent different vertical, topographic, and lithological expressions of similar basic processes, namely soil stripping, accelerated frost weathering, rubble production, and effective transport by both incremental and rapid but episodic agencies. They attest to periods of "active" slope balance, with net removal of regolith.

(d) The regular interlinkage of valley alluvia and slope debris documents an accelerated, cold-climate morphogenesis, with an accentuated, episodic hydrological regime. Although broadly correlated with glacial phases, active denudation probably spanned only a fraction of such glacial intervals. The critical issue appears to have been the crossing of a threshold, from one form of equilibrium to another, triggering a relatively rapid response in terms of erosion, transport, and sedimentation. Eventually, both the slopes and the streams returned to a steady state quasi-equilibrium, in balance with rainfall intensity and seasonality, vegetation and ground cover, and slope and channel gradients.

(e) Most of the slope rubbles and solifluction mantles described above are characteristic of the lower mountain slopes. But gelivation and solifluction were effective down to 500 m or so, with talus deposits only accumulating at higher elevations. Despite the active denudation associated with the switch from non-glacial to glacial climates, footslope accumulation inhibited the steepening of slope profiles.

(f) Instead, the accelerated sediment supply in the upper basin increased valley-floor gradients, while reducing the sharpness of valley-margin inflections. Once this steep channel gradient was established, alluviation probably tapered off, with normal seasonal runoff concen-

Table 1. A TENTATIVE STRATIGRAPHY OF PLEISTOCENE PHENOMENA

(8)	Local petrocalcic cementation and effective carbonate mobilization.
(7)	Younger alluvium (Vega Terrace), with high-energy discharge in axial valley, contemporary with alluvial cones, colluvial rubbles, gelivation screes, and talus formation in uplands. (mid-Upper Pleistocene)
(6)	Solifluction, in part with gelifluid erosion of argillic soils.
(5)	Pedogenesis, with formation of deeply-weathered, Typic Haploxeralfs (also Rhodoxeralfs or Palexeralfs), in part contemporary with major karstic solution. (early Upper Pleistocene)
(4)	Extensive petrocalcic cementation of older slope rubbles.
(3)	Older alluvium, with high-energy discharge in axial and tributary valleys, contemporary with full range of cold-climate processes in uplands. (late Middle Pleistocene)
(2)	Pedogenesis, with formation of deeply weathered Palexeralfs.
(1)	Petrocalcic cementation of older slope rubbles.
(0)	Rubble formation, including gelivation screes, in uplands. Record incomplete.

trated in established channels. At that point bed-load transport decreased in favor of suspended sediments.

(g) The paleosols of the region represent long periods of "passive" slope balance, during which soils formed faster than they could erode. This requires more than stabilization of slope rubbles and valley fans. Fundamentally different patterns of precipitation, ground cover, and hydrology are implied, namely a non-glacial module broadly comparable to that of the Holocene. But the different intensities of pedogenesis experienced during parts of some Pleistocene non-glacial intervals cannot be adequately explained by greater time spans, posing a non-analog problem that deserves more attention.

(h) Finally, it bears emphasis that the information on Quaternary processes provided by hillslopes and valley floors is different from that of cave microstratigraphies. The context, the processes and, above all, the thresholds are different in caves versus "in the open air." One type of record complements the other. There also is a different goal implied. Cave studies tend to focus on a temporally controlled climatic signal, analogous to such records sought in ocean and lake cores. Studies "in the landscape" are three-dimensional in that they focus on landform evolution across time.

Accumulation of the Vega Terrace and contemporaneous slope deposits ceased at some point during the terminal Pleistocene. Somewhat later, the younger, Pleistocene alluvia were entrenched, again at an unknown time. In areas of dolomite bedrock, Late Pleistocene slope deposits were heavily calcified with 30-40% calcium carbonate, so as to form cryptocrystalline, petrocalcic horizons. The Vega Terrace has an average of 30% $CaCO_3$, translocated into a Holocene B3k-horizon, but it is not cemented. In fact, the only cemented alluvium of this age is at La Mortera, which received spring discharge. Carbonate-supersaturation of stream waters either did not take place or, alternatively, was delayed until the Vega Terrace was no longer inundated, as a result of channel entrenchment. Carbonate precipitation is favored by highly seasonal precipitation. But the requisite acidity of percolating water to dissolve limestones requires a deep, organic soil mat as much as it does seasonally abundant water. Laminar calcification of slope debris by throughflow waters (*croûtes zonaires*), during the terminal Pleistocene, therefore argues for stable slopes and good vegetative cover, ideally combined with wet winters and warm, dry summers.

The Vega Terrace provides the datum for the Holocene alluvia, which occupy a channel entrenched below it. Elsewhere the Holocene record is formed by localized colluvial deposits on hill- or footslopes that are distinguishable from the various Pleistocene slope rubbles and fans by their lighter color, lack of calcification, finer texture, and an absence of surface morphology. The Holocene colluvia simply represent a stony soil wash. In all, the Holocene sediment mass is no more than a small fraction of that of the Pleistocene, and the number of morphostratigraphic units is minimal. But since the fine grain of minor environmental oscillations tends to be preserved in Holocene sequences, particularly in landscapes subject to changing patterns of prehistoric and historic land use, micro-stratigraphic detail within a single morphostratigraphic feature can be particularly complex.

5. HOLOCENE ALLUVIAL FILLS

The Holocene alluvial record of the Artana drainage is almost inconsequential in comparison with its late Pleistocene counterpart. In the sector of prominent alluvial development, between Eslida and 2 km downstream of Artana, Holocene deposits have a modal width of 40-70 m, and cover an area of 3.23 km², with an estimated mean thickness of 1.2 m. By comparison, the Vega Terrace segments preserved have a width of 150-200 m, a surface area of 16.25 km², and a thickness of at least 4 m. Thus the preserved volume of Late Pleistocene alluvium is almost 17 times greater. In effect, the Holocene fluvial deposits record little more than minor readjustments of the channel across 10 millennia or so.

The record of Holocene alluvial behavior can be reconstructed from four key sections. The first of these is found below, and east, of the Castillo de Artana, near the confluence of the Barranc de Castro (figs. 4 and 5). Holocene deposits are perched on the undulating surface of a 200 m expanse of cobble lag, probably last reworked by terminal Pleistocene or early Holocene channels, that maintain a relief of 2.5 m. Such a mass of large sandstone/quartzite clasts, including boulder-size components (over 30 cm diameter), is very difficult to remove. It suggests that terminal Pleistocene entrenchment involved little more than stripping out of fine material and the gravel (under 2 cm), until the remaining material exceeded the competence of the stream; it also raises the possibility that a part of the cobbles in the Vega Terrace was reworked from an even older lag.

Two palimpsests of Holocene alluvium are present. The older attains 4 m above thalweg, resting on a cobble lag (Castillo, 4 m Fill, unit 1, fig.4). It comprises 25 cm of calcified, light brown, sandy loam (unit 2a); a 10 cm lenticle of reworked cobbles with a loamy matrix (unit 2b); a 30 cm horizon of reddish brown, sandy loam, with fine, subrounded gravel, partly calcified (unit 3a); and 25 cm lenses of brown, sandy loam with moderate, coarse columnar structure (unit 3b). Unit (3b) represents a truncated A horizon, with distinctive structure and modest humification, while the underlying units mark a weak Ck horizon, with up to 11% carbonate enrichment. Unit (3) includes shell fragments or impressions, while unit (2a) has shells of *Melanopsis* cf. *dufouri* (identifications by Richard Preece). Since the
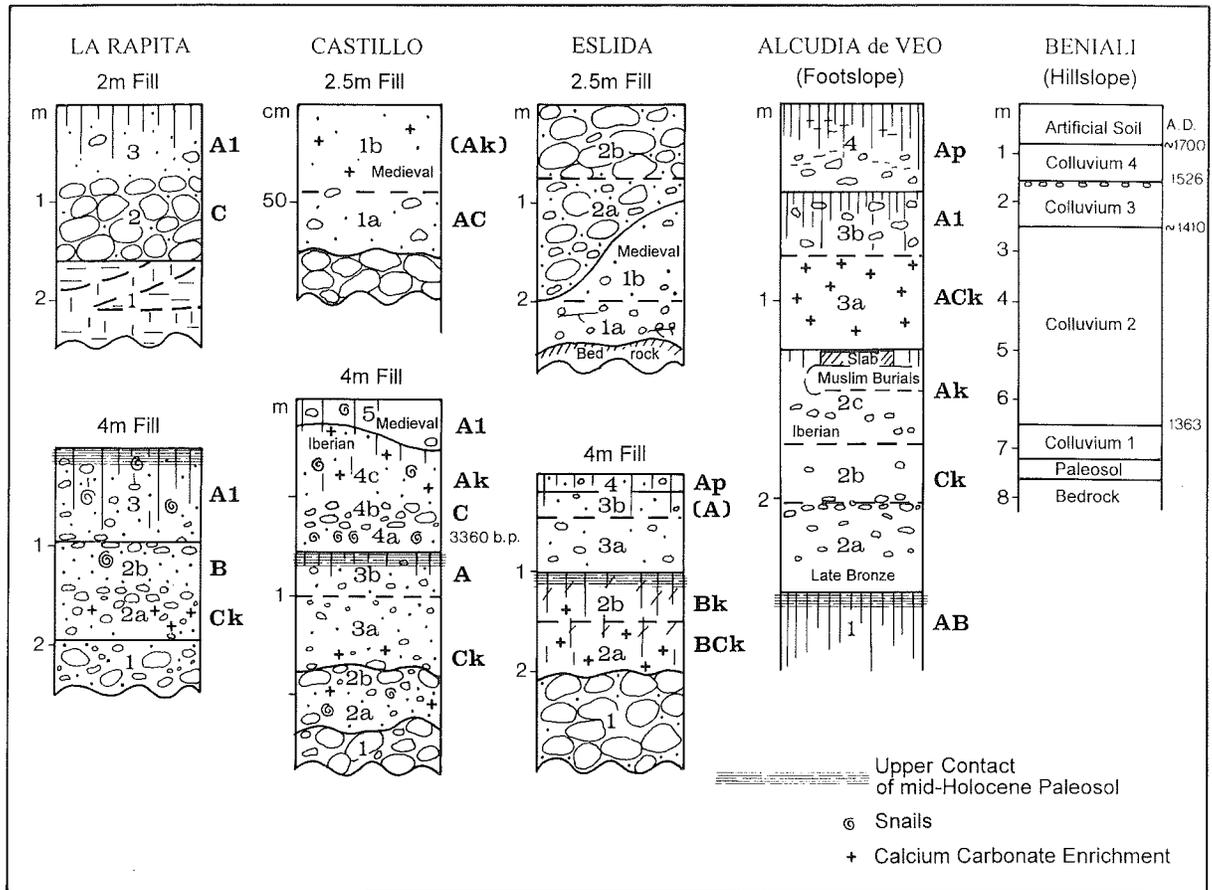
Fig. 4. Profiles of key Holocene sedimentary units and soils.

parent material consists largely of quartz, there are no authigenic clays. As a package, the sediments of units (2) and (3) suggest a moderately active stream channel, with some pulses of higher energy. *Melanopsis* today grows inside the irrigation canals of Valencia, and presupposes at least permanent pools of water in the channel of the Rambla de Artana.

Above unit (3b) is reworked sediment (unit 4a), but with a proliferation of *Melanopsis* shell that yielded a ^{14}C date of 3360 ± 90 b.p. (SI-4800), calibrated to 1650 ± 130 B.C. (or 1410 b.c. in the uncalibrated, Valencian Bronze Age chronology). Unit (4b) is a 10 cm gravel lense with a loamy matrix, and (4c) a 50 cm level of gritty loam with dispersed shells, some calcification, and weak soil structure. A thin, reddish yellow sherd of Late Bronze or Iberian age (identified by Carmen Olaria) was recovered from the upper part. The final unit (5), on an eroded surface, varies in thickness from 15-30 cm and is a medium-grade sandstone gravel with tabular crossbedding and a matrix of brown, loamy sand. It included two glazed sherds of "traditional" pottery, one green, the other yellowish red, that range in age from Medie-

val to modern. The surface is stablized under grassy cover and mature olive trees.

The *Melanopsis* shells of (4a) are up to 26 mm long, but most are subadults (10-17 mm), and are associated with smaller numbers of land snails (3 species of Helicellinae, including *Cernuella* cf. *virgata*, as well as rare *Rumina decollata* and *Pomatias elegans*), which indicate dry surfaces nearby. The mollusca of unit (4c) are dominated by terrestrial species (*Cernuella, Theba pisana*, and *Helix aspersa*), but include rare *Melanopsis*. The changing molluscan assemblages of unit (4) imply a shift from perennial to seasonal discharge. Much later, unusually high floods again topped this older channel fill, depositing unit (5).

The weak soil profile (A1-Ak-C) is compatible with a surface that has been stable and vegetated for at least a few centuries. At the same time the channel was incised, after which 50-75 cm of gravelly loam was deposited as a 2.5 m fill (figs. 4 and 5). Weakly calcified, this remains a minimally vegetated sand bar. It has rolled ceramics, including a handle of green-glazed "traditional" ware.
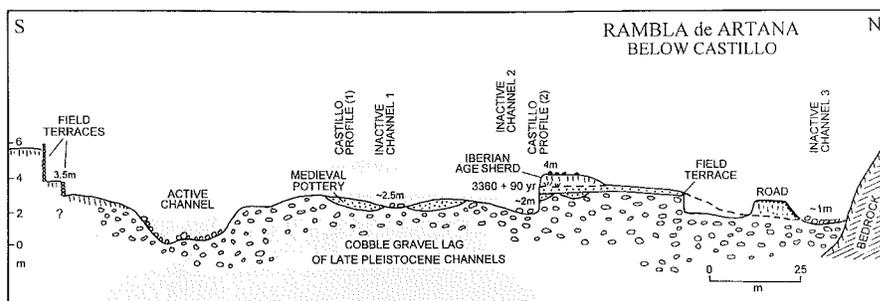
105

Fig. 5. Cross-section of the Rambla de Artana below the Castillo. The Holocene sediments are perched on the undulating cobble lag of Late Pleistocene channels.

This pattern of two Holocene channel fills, separated by entrenchment, is repeated 1 km downstream at La Ràpita. The development of the older, 4 m fill is similar to that below the Castillo: gravelly loams and gravel lenses (units 2a, 2b), topped by a thick loam with dispersed gravel (unit 3). Subrounded dolomite pebbles in the upper half imply a colluvial input, as do common terrestrial snails (*Helix* and several species of Helicellinae). The ochric A-horizon is modestly humified, while the cambic B-horizon has strong angular blocky structure, with thin clay skins indicating some downward, translocation of clays. Carbonates are enriched in a Ck-horizon (30% $CaCO_3$) at 1.5-2 m depth. This is a Calcixerollic Xerochrept (or Meridional Braunerde). *Melanopsis* reappears in the Ck-horizon of the same fill near La Mortera, 3 km further downvalley.

The younger, 2 m fill at La Ràpita forms a stable channel island, under grass and olive trees. Here cobble gravels (unit 2) thicken towards the channel axis from 80 to 120 cm, covering a colluvial soil wash (unit 1). The late Holocene fill itself is a brown sandy loam with dispersed gravel and some, diffuse secondary carbonates. This approximates a Xerofluvent (or Borovina), similar to the incipient alluvial soils on other outcrops of this young fill. The upper soil on the 4 m fill below the Castillo has more carbonate enrichment at depth and implies additional centuries of semiarid pedogenesis.

The third informative site is located 1.6 km upstream of the Castillo profile. Here a Medieval shaduf or *ciconya* was in operation while the channel floor was 1.8 m higher than today. The enclosure of the well was deepened twice, to compensate for continuing channel scour, and the superstructure rebuilt two or three times. The first or second construction mortar includes a sherd of Manises blue-on-white pottery (15th-16th century), while the last such mortar embeds all the pieces of a large vat or *lebrillo* of "traditional" manufacture (see BUTZER, BUTZER, MATEU and KRAUS, 1985). The shaduf appears to have remained functional until after the 16th century, even as the channel had begun to entrench. The original channel surface is preserved by adjacent, +1.9 m outcrops of the younger Holocene fill. These have modest humification and soil structure, with 6-10%

diffuse carbonates, and shells of *Cernuella*. Stripping of all fine material from the channel, to produce the characteristic, modern *rambla* of cobbles and boulders, appears to postdate A.D. 1600. The younger fill, by extension, dates to late Medieval times.

The last key sections of Holocene alluvium are exposed 2 km downvalley of Eslida, 100-200 m upstream of the bridge leading to Vilambuc and Monteral. The older Holocene fill consists of 2 m of deposit over a cobble lag (fig.4), and includes a truncated Bk-horizon (unit 2a) of light brown, silty clay loam with up to 55% of soft, diffuse carbonates. This is the same, pre-1700 B.C. soil as in the Castillo profile, except that here the Bk-horizon (unit 2b) is cumulic, with reworked clay. The upper half of the section (units 4 and 5) is sandier, includes dolomite-rich colluvium, and has an Ap-horizon, over a structured A with weak calcification —another Xerofluvent.

The younger Holocene fill below Eslida is exposed on the side of a plunge pool, below a rock ledge in the channel. At the base is a loamy sediment, with gravel that includes dolomite clasts in its upper half, together with a sherd of green-glazed pottery (units 1a, 1b). This gravelly loam is covered by up to 2m of sandstone cobbles with little matrix (units 2a, 2b), showing that the stream has switched back to a high-magnitude rambla regime during the last few centuries. Although this final, cobble horizon is unique to this special situation, it speaks to the nature of stream behavior in more recent times. No more than a short-term feature (possibly just two, peak-discharge events), followed by channel incision, it seems to imply that channel scour after c. A.D. 1600 was linked to extreme flood events.

The significance of these Holocene profiles will be summarized and highlighted below (Table 2), but it is pertinent to first examine the Holocene slope deposits of the Artana drainage.

6. HOLOCENE COLLUVIAL DEPOSITS

At a number of locations it is possible to observe thin mantles of soil wash or coarser colluvium over Pleistocene deposits. So, for example, there is a light brown, stony colluvium on top of mid-Pleistocene fill at 15 m above the channel opposite the Hospedad (fig. 1).

Table 2.   HOLOCENE MORPHOGENESIS AND SOIL PROCESSES IN THE SERRA DE ESPADÀ

(For profile units, see fig. 4)

After A. D. 1600

- Channel entrenchment, with scour of fine sediments, re-exposing Late Pleistocene cobble lag (Shaduf site). High-volume flood perturbations (Eslida, 2 m Fill, unit 2), with increasing sediment starvation as hillsides stabilized by terracing during 17th and 18th centuries, following Christian resettlement after 1610 (Alcudia de Veo, unit 4; Benialí, artificial soil).
- Formation of calcic alluvial soils (Xerofluvents) on stable floodplain segments (La Ràpita; Castillo); partial decalcification of anthropic soils on hillside terrace (Benialí).

A. D. 1350-1550

- Waves of slope soil erosion (Alcudia de Veo, unit 3; Benialí colluvia 2-4), reflecting devegetation after Muslim sierra colonization c. 1100; in part triggered by short-term settlement retraction in 1363; also probably affected by high-magnitude rainfall events.
- Accumulation of younger, +2 m channel fill (La Ràpita, Castillo, Shaduf, Eslida), with local colluvial components (Eslida, 2m fill, unit 1); reflecting accelerated sediment supply as well as extreme flood events, in part topping older channel fill (Castillo, 4 m fill, unit 5). Intermittent discharge.
- Localized episodes of active slope balance, promptly followed by pedogenesis in some contexts (Alcudia de Veo, unit 3b).

Roman to A.D. 1050

- Channel entrenchment, in part due to sediment starvation, as settlement shifted from hilltops down to the coastal plains, with forest regeneration (Benialí).
- Passive slope balance, with slow or interrupted pedogenesis on hillsides and on older channel fills.

Late Bronze to Iberian

- Waves of soil erosion on slopes (Alcudia de Veo, unit 2), in wake of woodland degradation, in part accelerated by high-magnitude rainfall events (unit 2a).
- Accumulation of second half of older, +4 m channel fill (La Ràpita, unit 3; Castillo, unit 4), with local colluvial components (La Ràpita), beginning c.1700 B.C. (1450 b.c., uncalibrated). Mainly medium-energy floods (except for Castillo, unit 4b). Discharge initially perennial, eventually seasonal.
- Active slope balance for part of time.

Early Bronze Age

- Channel in semi-equilibrium, with no evidence for mountain settlement, and intact woodland vegetation (supported by palynology).
- Passive slope balance, with deep leaching of carbonates and some clay mineral formation; non-calcic brown soil (Calci-xerollic Xerochrept or Meridional Braunerde) developing on floodplains. More high-magnitude rains possible.

Early Holocene

- Accumulation of first half of older, +4 m channel fill (La Ràpita, unit 2; Castillo, units 2 and 3; Eslida, unit 2); periodic flood surges and perennial discharge deposits mainly clastic materials. Chalcolithic settlement (mid-3rd millennium B.C.) near Artana and Eslida, possibly responsible for atypical, cumulic clays (Eslida, unit 2b); supported by palynological evidence for deforestation (Castillo, unit 3; Eslida, unit 2b).
- Mainly passive slope balance, with initial development of (non-calcic) brown soils on fresh sediments, and continuing development of such a soil on the Vega terrace, in part contemporary with karstic solution in uplands.

Terminal Pleistocene (to early Holocene ?)

- Channel entrenchment and reduction of Late Pleistocene alluvium to cobble lag (fig. 5)
- Passive slope balance implied by sediment starvation and effective carbonate mobilization.

Typically 75 cm thick, it deepens to 100-150 cm near the Orotana factory and becomes reddish yellow in color, exemplifying the erosion of Pleistocene soils. This undated colluvium is in turn veneered by anthropic soils used in the construction of artificial terraces. At the Coll de Alcudia (fig. 3, upper), there are 100-150 cm of reddish brown, stoney silt loam atop cemented, Late Pleistocene colluvium. Behind local field terraces, the same material is much more humic and brown in color, possibly embedding parts of the original A-horizon. And across the valley, in the Els Morts section (fig. 3, lower), the late Pleistocene colluvia are penetrated by deep solution pipes, filled with reddish brown, non-calcic, stoney clay loams.

These cases verify local but sometimes appreciable Holocene soil erosion on the footslopes. Such fine to

coarse colluvia may be either coeval with or older than terrace construction. Their specific explanation and dating are elusive, other than that they are fairly recent. It is therefore fortunate that colluvial deposits were more informatively exposed during the excavation of a space for a new garage at Alcudia de Veo, as well as in the archaeological excavations at Benialí, municipality of Aín (fig. 1).

The Alcudia de Veo site is located on the outer road, opposite the butchery, southwest of the pueblo, at the foot of a 50 m-high dolomite slope averaging 10°, supporting several tiers of artificial terraces. The 3 m exposures briefly visible here in 1982 (fig. 4) exposed a Muslim cemetery, with shallow graves oriented N20°E to N90°E and covered by dolomite slabs. But the burial horizon was midway in a profile of 2.5 m of fine-grained colluvium, indicating a much longer and more complicated history of slope erosion than anticipated. The geomorphologic interpretation offered here conforms with the pollen samples extracted and studied by Dupré (1987).

At the base was at least 50 cm of yellowish red, silty clay loam with grit (unit 1), in part derived from Bunter shales and sandstones exposed behind a fault at the top of the ridge, 400 m away. Distinctive soil properties include strong, coarse angular blocky structure, clay skins, weak reddish mottling, and some 4% organic matter. But the Bunter derivatives point to pedogenic modification of a soil sediment, rather than an undisturbed paleosol.

Above this are 45 cm of light brown clay, with basal pockets of eroded red sediment and a terminal gravel lense (unit 2a). Five pieces of a single pottery vessel were found 20cm from the base; the exteriors are grooved and burnished, with a reddish yellow color, and a black, coarse sandy temper. These were identified by M. Gil-Mascarell as Final Bronze Age, dated elsewhere in Valencia c. 1300-1200 b.c., about 1450 B.C., calibrated. Unit (2b) has 25 cm of light brown clay, followed by unit (2c) with close to 1m of very pale brown, clay loam, with stringers of dolomite and shale pebbles, moderate coarse angular blocky structure, yellowish mottling, and extensive rootlet impressions. Unit (2c) is a buried, 45 cm Ak-horizon, with 11-14% carbonates, and the 13-15% diffuse carbonates in unit (2b) point to an underlying Ck-horizon.

Unit (2c) has three rolled sherds with slip, rather than burnishing, and fabrics fired at high temperatures, using "washed" clays, characteristic of Iberian pottery (c. 500-50 B.C.). Pieces of rolled iron slag indicate local metallurgy, first introduced to the area during the 8th century B.C. The burials were cut into unit (2c) and thus provide a *terminus ante quem* for the buried soil. Unmodified Muslim (as opposed to Morisco) burial rites in a cemetery at this location should date between the founding of Alcudia de Veo (between A.D. 1329 and 1336, see BUTZER, BUTZER and MATEU, 1986) and the nominal conversion of the sierra Muslims during the mid-1500s. Pedogenesis therefore spanned a period no longer than c. 100 B.C. and A.D. 1400, and did not suffice for the development of conspicuous horizons.

Unit (3a) (45 cm) consists of very pale brown, silty clay loam, with moderate, coarse angular blocky structure and 21-29% $CaCO_3$. It is followed by unit (3b) with 40cm of pale brown, clay loam, with considerable sandstone and dolomite gravel, and abundant coarse sand. This level has the highest organic matter concentration (4.2%) of the profile, with extensive carbonized rootlets, and half the diffuse carbonates of unit (3b). With a stronger structure, this is an A horizon over an ACk (unit 3b), representing a period of slope stabilization, sufficient for substantial leaching. The final unit (4) is an artificial fill reflecting terrace construction, with 15 cm of brown, stoney clay under 20 cm of pink clay loam.

Documents from the Vall de Almonacid, directly west of Alcudia, mention terraces (*bancals*) in 1686 and 1731 (Elisabeth Butzer, personal communication), suggesting that terrace construction began not long after Christian resettlement of the area in 1610. That leaves only 200 years for almost a meter of colluvial sedimentation *and* the formation of a soil profile more conspicuous than that which formed across a millennium or more prior to use of the Muslim cemetery. This, in conjunction with the vigor of slope transport implied by unit (3b), suggests the possibility of repeated heavy rainfall events during the 16th century. A similar interpretation is possible for the stoney and coarse-sandy unit (2a), which incorporates lenticles of eroded soil.

The record of the cemetery of Alcudia de Veo is complemented by the various excavation profiles at Benialí, located on a midslope below late Bunter strata (Röt) of red sandstone and weakly metamorphosed shales, in part with quartz veins. The residual soil, prior to human activity at the site, is a pink clay loam, which grades up into a humified, light reddish brown loam with breccia lenses of sandstone, shale and quartz. This colluvium (1, fig. 4) also appears to be pre-settlement. The first houses were built shortly after 1342, and apparently abandoned in 1363 (BUTZER, BUTZER and MATEU, 1986). After that point, up to 4 m of pale red, colluvial loam (unit 2) accumulated within and around the abandoned structures, at first mixed with collapse rubble, later with artificial fill from the construction of a terraced site for the second settlement of Benialí, shortly before 1414. Across a little more than a century, cultural refuse then accumulated next to structure K2, intermixed with increments of soil wash, to form a pale red loam (unit 3). Before Benialí was destroyed and abandoned in 1526, structure K2 appears to have been unoccupied, judging by a veneer of gritty wash that continues from inside the house to terminate the colluvial unit (3) outside.

The initial destruction debris incorporates soil wash that eventually becomes another colluvial unit (4), again of pale red loam. During the late 17th or early 18th century the area was converted to a terraced slope, and any standing walls of Benialí were torn down and reused as a stoney fill. The terrace surface represents a 15 cm Ap-horizon of light reddish brown loam, over a filling of pale red, stony loam; the $CaCO_3$ content increases from 8.6% at 5 cm depth to 17.3% at 80 cm, at least in part due to leaching.

The geoarchaeology of Benialí documents strong erosion of relict Pleistocene soils from 1363 until the end of the 16th century. The sheets of soil colluvium that were trapped among the hillside structures maintain a fairly constant texture, very similar to that of weathered Pleistocene screes, from which they were in part derived. Filtering out the cultural debris from 38 sediment samples, the rate of local accumulation averaged 3.0 cm per year during the late 14th century, 0.5 cm per year during the 15th, with a spurt of accumulation after 1525, tapering off again to 0.5 cm until about 1600. A description of 1570 notes that the Serra de Espadà was treeless, which is confirmed by the paleoethnobotanical data from our excavations of three sites (Benialí, Castillo de Aín, Castillo de Xinquer), which span the period between A.D. 1100 and 1526: fuel wood consisted of orchard tree cuttings, thorny heath, and evergreen shrub oaks (Wilma Wetterstrom, personal communication). The substantial faunal record from all three sites is completely dominated by goat (see BUTZER, BUTZER and MATEU, 1986; KLEIN and CRUZ-URIBE, 1984, fig. 6.14, and R.G. Klein, personal communication)

The decline of soil erosion after c. 1400, despite a higher population and maximum pressure on the environment, is best interpreted by a threshold model: upslope soils that in this location had thickened and remained stable throughout the Holocene were rapidly stripped during a few decades after local cultivation on slopes of 22° was first initiated. Thereafter, upslope soils were much thinner and gained a new equilibrium, adjusted to a poor ground cover. At the same time, the presence of multiple, mortared terrace walls within the second settlement at Benialí strongly suggest that dry-wall terraces were also constructed above and below the settlement. These will have become derelict after 1526, yet without a significant effect on sedimentation rates.

The chronology of soil erosion at Benialí is different from that at Alcudia de Veo, where erosion peaked during the 15th century, reflecting a different settlement history, with no evidence for terrace construction (on these much gentler slopes) until the 17th century. But at Alcudia de Veo soil erosion ended well before the Morisco expulsion of 1609, which would also be compatible with a new, slope quasi-equilibrium. As to high rainfall events, one such interval is clearly recorded in Benialí, shortly before 1526.

The waves of soil erosion at Benialí during the late 14th century and at Alcudia de Veo during the 15th must be linked to accumulation of the younger channel fill in the Rambla de Artana. By about 1600 the shaduf was being undermined by sediment starvation and channel scour, hypothetically reflecting the new equilibrium between slope angles, degraded vegetation, and surviving soil cover in the drainage basin. The construction of extensive terrace systems after Christian resettlement (BUTZER, 1990; KRAUS, 1992) may have initially disturbed slope soils, but it soon protected the upland areas from further erosion, and the artificial terrace soils were ameliorated, so as to rehabilitate agricultural productivity. That in turn will have exacerbated sediment starvation and channel scour.

6. SYNOPSIS AND DISCUSSION OF THE HOLOCENE RECORD

The complex information outlined above is integrated by Table 2. The various thematic materials are presented separately, within broad periods of time.

It is apparent that pedogenesis during the span of Holocene time trended toward the development of non-calcic brown soils on Holocene sediments. But cambic horizons no longer formed after 1700 B.C., and leaching was increasingly ineffective on younger parent materials. A second pedogenic fact is that there were repeated alternations between passive and active slope balances. At least two intervals of soil erosion, rather than soil formation, are identified, the first from the Late Bronze Age to Iberian times (c. 1700-100 B.C.?), the second c. A.D. 1350-1550. Both are attributed to extensive devegetation, with possibly more recurrences of intensive rainfall events during the 17th century B.C. and again during the 16th century A.D. An even earlier episode of vegetation disturbance is suggested during the Chalcolithic, when palynological data by Louis Scott (personal communication) show a sharp forest decline and a corresponding expansion of degraded "weedy" plant cover.

Except for the initial construction of a small floodplain within the entrenched channel of the Rambla de Artana, the sedimentary units aggrading in the form of the older and younger channel fills were primarily an indirect consequence of upland soil erosion, affecting peak discharge and water volume-sediment supply ratios. The fact that the axial watercourse shifted from a perennial to a seasonal, and ultimately an intermittent stream, implies that the ecological system did not fully recuperate, even when forest cover was reconstituted during periods of settlement retraction or abandonment in the sierra. Thus six radiocarbon dates from Benialí are on old timbers, mainly of *Pinus silvestris*, that grew between the late 800s and early 1000s, but were used and reused until 1526. The forests recovered, but the

watershed never fully regained its original, systemic equilibrium level and, by implication, its overall productivity will have been progressively reduced. At the level of agricultural production this was partly compensated for by the animal manure from local and transhumant pastoralism, and by the construction of hillside terraces (BUTZER, 1990).

The amount of Holocene soil erosion cannot be quantified, because of the difficulty of field recognition without exposures, and the impossibility of distinguishing soil colluvium from soil in cultivated fields, that mix whatever may remain of the topsoil with the B-horizon. The cases of Alcudia de Veo and Benialí show that erosion was substantial in settlement proximity, but elsewhere soil removal may well have been considerably less. Even if the quantity of soil eroded was relatively small, stripping of the shallow, local A-horizons had potentially serious consequences for rainsplash, structure, percolation, and runoff ratios and velocity. Modest but extensive sheet erosion can remove far more Soil Organic Carbon than gullying, but it may be difficult to detect in the record, despite its agricultural implications.

The question of a climatic signal in the Holocene record remains ambiguous. It is our sense that significant pedogenesis during perhaps 500 years prior to 1700 B.C., or the rapid leaching of carbonates during the 16th century A.D., were facilitated by a recurrence of high precipitation events. Similarly, we suspect that Late Bronze and late Medieval soil erosion was accelerated by the impact of such events on an increasingly degraded and fragile environment. But this cannot be demonstrated beyond a reasonable doubt, at least not in this watershed, although the response of the Júcar and Turia rivers to high magnitude events in deforested catchments is a great deal clearer (see MATEU, 1983; BUTZER, MIRALLES and MATEU, 1983; CARMONA, 1990; BUTZER, 1993). But that does not represent a sustained climatic change, for which the Holocene record of the Artana watershed provides no tangible evidence.

8. COMPARISON OF THE PLEISTOCENE AND HOLOCENE SEDIMENTARY RECORDS

The contrast of the Pleistocene and Holocene geomorphologic picture is, simply put, striking. Pleistocene sediment volume is several orders of magnitude greater than that of the Holocene. Pleistocene deposits accumulated to a significant degree on all topographic segments of the landscape, beginning with massive talus rubbles, continuing across lower midslopes and footslopes via a range of different processes that left a mantle of variegated sediment, and terminating with the mobilization of coarse alluvial deposits in the valley bottoms. Such Pleistocene sediments were at times indurated by petrocalcic cementation, or partially dissolved and

deeply weathered by argillic soils. Pleistocene geomorphic processes, and the switch between periods of active and passive slope balance, were a function of incisive climatic changes, with the bulk of the sedimentary record produced and transported in direct or indirect response to cold-climate processes.

By contrast, the Holocene record is small in volume, and limited to the lower slopes and valley bottoms. It mainly consists of soil-derived colluvia and minor channel fills. But the oscillations between phases of passive and active slope balance were of short wave length (decades or centuries, rather than millennia) and of moderately high amplitude, and they promoted net soil loss at a rate that could not be reversed or, ultimately, sustained. The hydrology shifted from perennial to seasonal and then intermittent, without evidence for long-term climatic change. Despite periodic forest recovery, the ecosystem as a whole was being degraded. These patterns and impacts were first and foremost a result of destructive land use, presumably as a result of deteriorating ground cover and the extensive loss of humic topsoils, both of which would accelerate runoff and deplete spring discharge from shallow aquifers. A potential reduction in agricultural productivity was partly compensated for by elaboration of the pastoral economy, with its critical byproduct, manure, and eventually by agricultural intensification in the form of hillside terracing. A more comprehensive evaluation of these ecosystemic changes will require integration of our paleobotanical and archaeological data, which will be presented in a different venue.

In this small watershed the geomorphologic record is dominated by the Pleistocene. But the farmer must contend with an environment significantly impacted by the cumulative history of previous efforts to extract a living. For him, but without his conscious understanding of what went before, it is the imprint of changing Holocene land use that is of paramount importance.

Finally, we return to the matter of siliciclastic sediments in a basin with extensive lithologies of quartzitic sandstone. The Artana watershed amply demonstrates the prominence of Pleistocene landscape sculpture and sedimentary processes across several extended episodes of active slope balance. Preservation is to a large extent due to the resistance of siliciclastic material to weathering. The slope rubbles of the Coll de Alcudia are the exception; at Els Morts, a similar but older rubble deposit has been reduced to an isolated residual, its stratigraphy decipherable only because of unusually good, valley shoulder exposure, but greatly complicated by multiple, karstic cavitation and repeated, detrital infilling. Below the dolomite slope in the Caritat valley, most of the former rubble has been reduced to a petrocalcic soil mass. Argillic soils forming on siliciclastic footslope accumulations are not dissolved and "collap-

sed" from below, by throughflow waters, as calcareous sands and clasts would be over time. Siliciclastic alluvium collects and often thickens on valley floors, which become quasi-permanent sediment traps, that cannot be broken down by solution.

The Bunter sandstones of the Espadà Triassic clearly document the role of Pleistocene cold-climate processes. In a basin of hard Cretaceous limestones, which tend to be far more soluble than Triassic dolomites, such cold-climate sculpture is likely to be poorly visible and perhaps undiagnostic. If so, interpretation of cliff faces will favor solution weathering and, since rubble-free limestone slopes tend to look fresh, the impression would obtain that much of the visible denudation is Holocene. As mantles of coarse detritus on the footslopes are reduced to a stoney colluvium of red soil, only careful geomorphologic examination may reveal that these are of Pleistocene age, rather than Holocene erosional products. Whatever remains of valley-floor cobble alluvia may be obscured by reddish brown, suspended sediments.

Although these are idealized generalizations, that may only apply in a few catchments, they illustrate the basic point that Pleistocene landform evolution and cold-climate processes will be underestimated in limestone watersheds of the Mediterranean environment. By the same token, Holocene sculpture tends to be overemphasized, favoring misconceptions about the scope of anthropic impacts. So, for example, relict argillic soils in the Espadà were extensively eroded during subsequent episodes of Pleistocene, active slope balance. In fact, far more of the soil resource of the Espadà was reworked or destroyed during the Pleistocene than the Holocene. In terms of landscape interpretation that is critical — without minimizing the ecological impact of later, agricultural land use.

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