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Pedosedimentary development of part of a Late Quaternary loess-palaeosol sequence in northwest Argentina

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ABSTRACT: The field properties, magnetic susceptibility, particle size, calcium carbonate content, soil micromorphology and optical luminescence ages of the upper 6.1 m and lowermost 4.7 m of the 45 m loess–palaeosol sequence at El Lambedero in the Tafí del Valle region of Tucumán Province (Sierras Pampeanas, northwest Argentina) have been used to set up a partial stratigraphy and chronology, as well as a basic pedosedimentary model of loess accumulation, palaeosol development, reworking and erosion for the site. The minimum ages derived from the basal part of the section suggest that loess began to accumulate some time before 165 ka. A thick and well-developed pedocomplex in the upper profile is correlated with at least the latter part of marine isotope stage (MIS) 5, whereas the overlying palaeosol may be attributable to pedogenic activity during MIS 3. The absence of material younger than 33 ka close to the surface of this rounded spur landform is probably the result of either non-deposition or erosional stripping in response to climatic change, or episodic uplift in this seismically active region. Copyright © 2004 John Wiley & Sons, Ltd.

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KEYWORDS: pedosedimentary development; loess–palaeosol; luminescence ages; Argentina.

Introduction

The study of loess–palaeosol sequences from North America, Europe and Asia has contributed significantly to the recording and understanding of Quaternary palaeoclimatic change in the Northern Hemisphere (e.g. Kukla, 1989; Derbyshire *et al.*, 1997; Markewich *et al.*, 1998; Antoine *et al.*, 2001). As attention and emphasis switches to palaeoclimatic archives in the Southern Hemisphere, in order to obtain a better appreciation of hemispheric teleconnections and to develop truly global palaeoclimatic models, it is not surprising that there is increasing interest in the Quaternary of Argentina, the country with the largest expanse of loess cover south of the Equator (Iriondo, 1997, 1999; Muhs and Zárate, 2001; Sayago *et al.*, 2001).

Although recognised and described by numerous scientists (including Darwin, 1846) over the past two centuries, full appreciation of the extent and significance of the Argentinian loess had to await publication of the seminal paper by Terrugi (1957). Much of our current knowledge and understanding of the Pampean aeolian system has been derived from the extensive studies of Iriondo (e.g. 1997, 1999) and Kröhling (e.g. 1999a,b) centred on Santa Fé, Córdoba, San Luis and Entre Rios provinces (Fig. 1). They established a Late Quaternary stratigraphical framework for this region on the basis of widespread geomorphological mapping, section logging and a limited number of absolute dates. The Tezanos Pinto Formation (Iriondo, 1980) represents the main phase of loess deposition, a unit bracketed by thermoluminescence (TL) ages of ca. 36 ka and 9 ka (Kröhling, 1999a). Recent optically stimulated luminescence (OSL) ages obtained from the type-site (Kemp *et al.*, 2004), however, suggest that the base of this unit may be considerably older (ca. 150 ka). Kröhling (1999a) recognised palaeosols within and beneath the Tezanos Pinto Formation, yet did not define them as formal soil stratigraphical units.

Although there have been some attempts to extrapolate this stratigraphy across the whole of the Chaco-Pampean Plains (Iriondo and Garcia, 1993; Iriondo, 1999), these efforts have been hindered by limited absolute chronological controls (Muhs and Zárate, 2001) and a paucity of exposures of sufficient resolution. A number of palaeosols have been identified further south in Buenos Aires Province (e.g. Teruggi and Imbellone, 1987; Zárate and Blasi, 1991; Imbellone and Teruggi, 1993; Nabel *et al.*, 1999; Tonni *et al.*, 1999), yet they have not been widely correlated and used as stratigraphical markers in the manner typical of other loess regions of the world. More than six palaeosols of unknown

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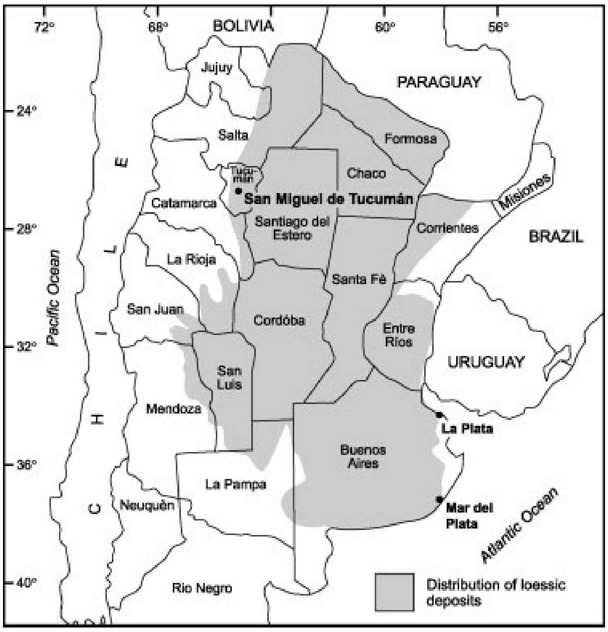

Figure 1 Distribution of loessic sediments in Argentina (after Terrugi, 1957; Zinck and Sayago, 1999; Zárate, 2003) and location of provinces and cities, including San Miguel de Tucumán, referred to in the text

age have been recorded within the >40-m thick loess cover near La Plata (Fig. 1). Here, micromorphological analysis by Teruggi and Imbellone (1987) has illustrated the pedosedimentary complexity of the loess record with evidence for reworking by fluvial and mass movement processes as well as truncation and welding of the palaeosols. Similar results were obtained by Zárate *et al.* (2002) from sequences in the same region and by Kemp and Zárate (2000) further south at Mar del Plata (Fig. 1). The significance of these two studies rests on the fact that they demonstrate that the Argentinian loess record extends back to before the Bruhnes–Matuyama magnetic boundary (La Plata) and into the Pliocene (Mar del Plata).

Although most international attention has centred traditionally on the 'Pampean' loess cover lying between 30°S and 40°S, it has long been recognised that there are extensive areas of so-called 'neotropical' loess further north in the Chaco Plains and the pre-Andean mountains and intermontane basins between 20°S and 30°S (Fig. 1; Sayago, 1995; Iriondo, 1997). One of the few detailed studies of a loess–palaeosol sequence in this region was undertaken by Zinck and Sayago (1999, 2001), who described a section 42 m thick comprising 28 palaeosol Bw or Bt horizons interbedded with loess (C horizons) at La Mesada near Tafí del Valle (Fig. 2), located in one of these intermontane basins between 1900 and 2800 m a.s.l. in the Sierras Pampeanas, about 50 km west of San Miguel de Tucumán (Fig. 1). On the basis of radiocarbon dates derived from the alkali-extract fractions of organic material, they proposed that the lowermost 37 m accumulated over only about 10 000 yr, between ca. 17.5 and 27.5 ka, thus implying an average rate of land-surface accretion significantly greater than even that proposed for the Loess Plateau of China. The basal part of this section was re-examined by Kemp *et al.* (2003) and the pedosedimentary framework broadly substantiated. The three OSL ages produced, however, ranging from ca. 150–195 ka, clearly conflict with the previously published radiocarbon chronology. Further controversy and uncertainty over the age and resolution of the loess–palaeosol record contained in the Tafí del Valle region has been stimulated by the publication of palaeomagnetic data from a different section that indicates a basal age of at least 1.15 Ma (Schellenberger *et al.*, 2003).

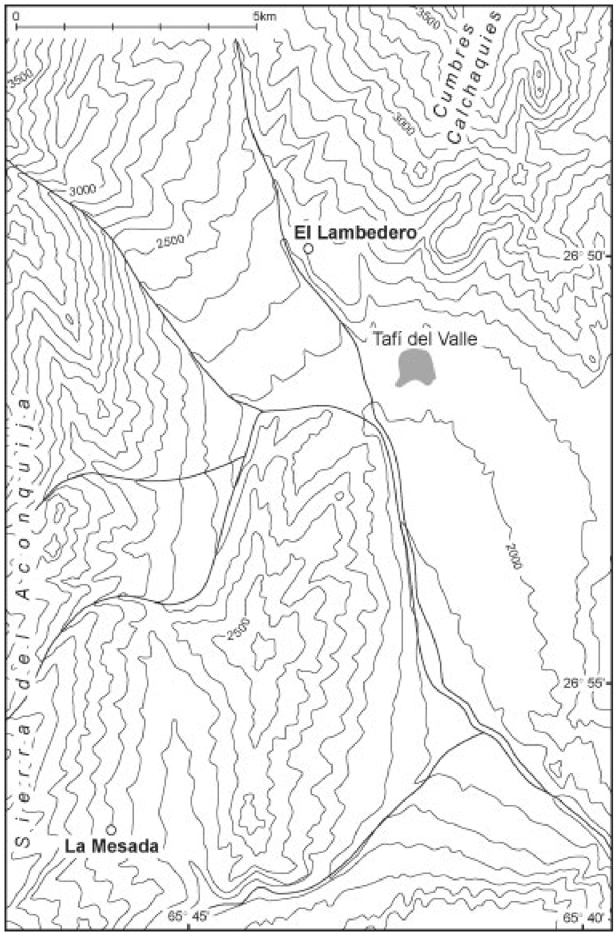

Figure 2 Location of El Lambedero and La Mesada in the Tafí del Valle basin

This paper reports the results of a detailed pedosedimentary and geochronological study of parts of a new 45-m section at El Lambedero, ca. 2.5 km northwest of the settlement of Tafí del Valle (Fig. 2). The upper 6.1 m were described and sampled for OSL age determinations and micromorphological, grain-size and geochemical analysis as part of a project that aims to establish a Late Pleistocene and Holocene loess–palaeosol stratigraphical framework for the Argentinian loess region as a whole. The objective of studying the lowermost 4.7 m was to provide a comparison with the basal part of the nearby section at La Mesada and to shed further light on the maximum age and resolution of the loess–palaeosol record in the Tafí del Valle basin.

Materials and methods

The Tafí-del-Valle region currently experiences a dry mid-montane climate with mean annual temperature and precipitation values of about 13.5 °C and 400–500 mm, respectively (Zinck and Sayago, 1999). Most of the rainfall is concentrated in the summer months between October and March.

The 45-m section at El Lambedero is exposed along the left (east) bank of the Rio Tafí del Valle (26°50'S, 65°43'W), which drains a small perched basin (20 × 10 km) separating the Cumbres Calchaquies range from the Sierra del Aconquija (Fig. 2). The section has been cut by the river into the western flank of a broad convex spur, the crest of which reaches over 2300 m a.s.l. Profiles of the upper 6.1 m and lower 4.7 m of the section were excavated, described and palaeosol horizons identified according to the criteria of the Soil Survey Staff

(1992, pp. 515–525). Low-frequency magnetic susceptibility and calcium carbonate content of bulk samples taken at 5-cm vertical intervals were measured with a Bartington MS2 meter and calcimeter, respectively (Gale and Hoare, 1991). Particle size analysis was undertaken on samples taken at the same interval using a Malvern Laser Granulometer, the results being expressed in terms of the ratio of sand (>63 μm) to silt (63–2 μm). Undisturbed blocks (7 × 5 × 4 cm) collected in Kubiena tins at approximately 25-cm vertical intervals were air-dried, impregnated with polyester resin and made into thin sections (7 × 5 cm) according to standard procedures (Lee and Kemp, 1992). The thin-sections were described using a petrological microscope and the terminology of Bullock *et al.* (1985).

Blocks of sediment (10 × 10 × 7.5 cm) were collected at 0.60, 2.40, 3.00, 5.00, 40.30 and 44.40 m depths for optical dating. The outer 0.5 cm of each block face was removed under controlled laboratory lighting conditions, and the 5–15 μm quartz fraction concentrated by removal of carbonate and organic components (using 10% HCl and 15% H_2O_2, respectively), sedimentation in acetone and immersion in H_2SiF_6 for 2 weeks in order to dissolve feldspars and amorphous silica (Jackson *et al.*, 1976; Berger *et al.*, 1980). Acid soluble fluorides were subsequently broken down using 10% HCl.

All luminescence measurements were undertaken on the 5–15 μm quartz fraction using an automated TL-DA-12 Risǿ set. Equivalent dose (D_e) estimates were obtained following a single-aliquot regenerative (SAR) dose based on that outlined by Murray and Wintle (2000) and described by Kemp *et al.* (2003). *In situ* measurements of gamma dose to each sample from the surrounding sediment were made using an EG&G MicroNOMAD portable NaI gamma spectrometer. Neutron activation analysis (NAA) was performed by Becquerel Laboratories (Australia) on subsamples to determine the local alpha and beta contributions. Estimates of cosmic dose contributions incorporated the computations of Prescott and Hutton (1994). Dose rate calculations followed those of Aitken (1985) and are outlined by Kemp *et al.* (2003). Luminescence ages were obtained by dividing the D_e value by the total dose rate value with associated systematic and experimental errors, expressed at 1σ confidence, combined in quadrature and integrated within the age uncertainty.

Stratigraphy and bulk analyses

Pedological features, including structural aggregates, clay coatings and secondary carbonate coatings and nodules, occur throughout the two profiles. The distribution of these features provides a basis for designation of genetic soil horizons and the division of the vertical column into a number of abutting or overlapping (welded) soils (Fig. 3). Each palaeosol (uS2, uS3, lS1, lS2 and lS3) comprises Bt or Btk horizons and BCk or Ck horizons, reflecting the dominance of clay translocation and carbonate redistribution processes. The absence of distinctive A or E horizons may be the result of truncation; alternatively, it may reflect pedogenic transformation to subsoil horizons as the pedosedimentary column accreted to new surface levels (Zinck and Sayago, 1999). In terms of the latter explanation, the lower parts of BCk or Ck horizons would represent converted surface horizons. Leaching and redistribution of carbonates below BCk and Ck horizons and into underlying palaeosols undoubtedly occurred, as evidenced by the presence of secondary carbonate on top of clay coatings in Btk horizons of lS2 and lS3.

The current landscape clearly has been influenced by recent and past agricultural activities such as irrigation and ploughing. For instance, the very thick A horizon of the surface soil in the sampled profile thins considerably from the exposure back into an arable field, suggesting that there may have been localised redistribution of soil, possibly during cultivation-induced erosion events. The significant accumulation of calcium carbonate in the Bk horizon (Fig. 3) is the result of leaching from overlying material. As clay particles are unlikely to be washed deeper than leachates, it follows that the clay coatings in the underlying Btk horizons probably originated from translocation processes associated with an earlier and lower surface. Thus, the stratigraphical boundary between the uppermost palaeosol (uS2) and the soil at the current surface (uS1) has been placed at the junction between the Btk1 and Bk horizons, even though some of the secondary carbonate from the most recent phase of leaching probably extends into, and welds on to, the palaeosol.

The depth function of calcium carbonate content (Fig. 3) accords with the assigned genetic horizonation, notably with the major carbonate peaks associated with the Bk and palaeosol BCk and Ck horizons. Vertical changes in magnetic susceptibility (MS) have been used elsewhere in the world to distinguish palaeosols from loess, e.g. in China where peak values have been attributed to pedogenic production of fine-grained magnetic minerals (Maher, 1998). The MS depth function from El Lambedero (Fig. 3), however, is not so clearly defined; this may simply be a reflection of its compressed and welded nature, although it is in keeping with results from previous studies on the Argentinian Pampa (e.g. Nabel *et al.*, 1999; Kemp *et al.*, 2004). The lower MS values in most BCk, Ck and Bk horizons may in part result from dilution of the magnetic minerals by secondary carbonate. It is noticeable that the most prominent MS peak occurs in the BCk of lS1 within a zone of relatively low calcium carbonate content. The generally higher MS values recorded in the lower profile might reflect a different source area for this older loess, although this would need to be confirmed by mineralogical or geochemical analysis.

Silty clay loam textures predominate in the illuvial-clay-enriched Bt and Btk horizons of both profiles, whereas A, Bk, BCk and Ck horizons tend to have silt loam textures. The depth function of sand:silt (Fig. 3), a parameter that filters out the effects of pedogenic clay translocation, displays a complex pattern that reflects temporal fluctuations in size of particles (transported and) deposited, and possibly *in situ* weathering. The ratio generally decreases upwards from the base of each palaeosol into a Bt or Btk horizon and then increases towards the junction with the overlying palaeosol. The upper 3 m is somewhat distinct, however, in that values are relatively uniform within the palaeosol (uS2) and across the boundary into the surface soil (uS1). Grain size fluctuations within loess–palaeosol sequences in other regions of the world are interpreted in terms of several factors. In the case of China, for instance, these include varying intensities of transporting winds and associated circulation patterns (Porter and An, 1995) and changing size and proximity of dust source regions (Ding *et al.*, 1999), although their exact palaeoenvironmental significance in the Argentinian context has yet to be established. Account undoubtedly needs to be taken of the differential concentration of coarser grains by surface wash and other processes that are frequently reported to be responsible for reworking of primary loess deposits in Argentina (Zárate, 2003), and indeed are inferred at this site from the micromorphological evidence presented below.

Micromorphology

The key micromorphological characteristics and features at El Lambedero are illustrated in Figs 4 and 5, and their depth

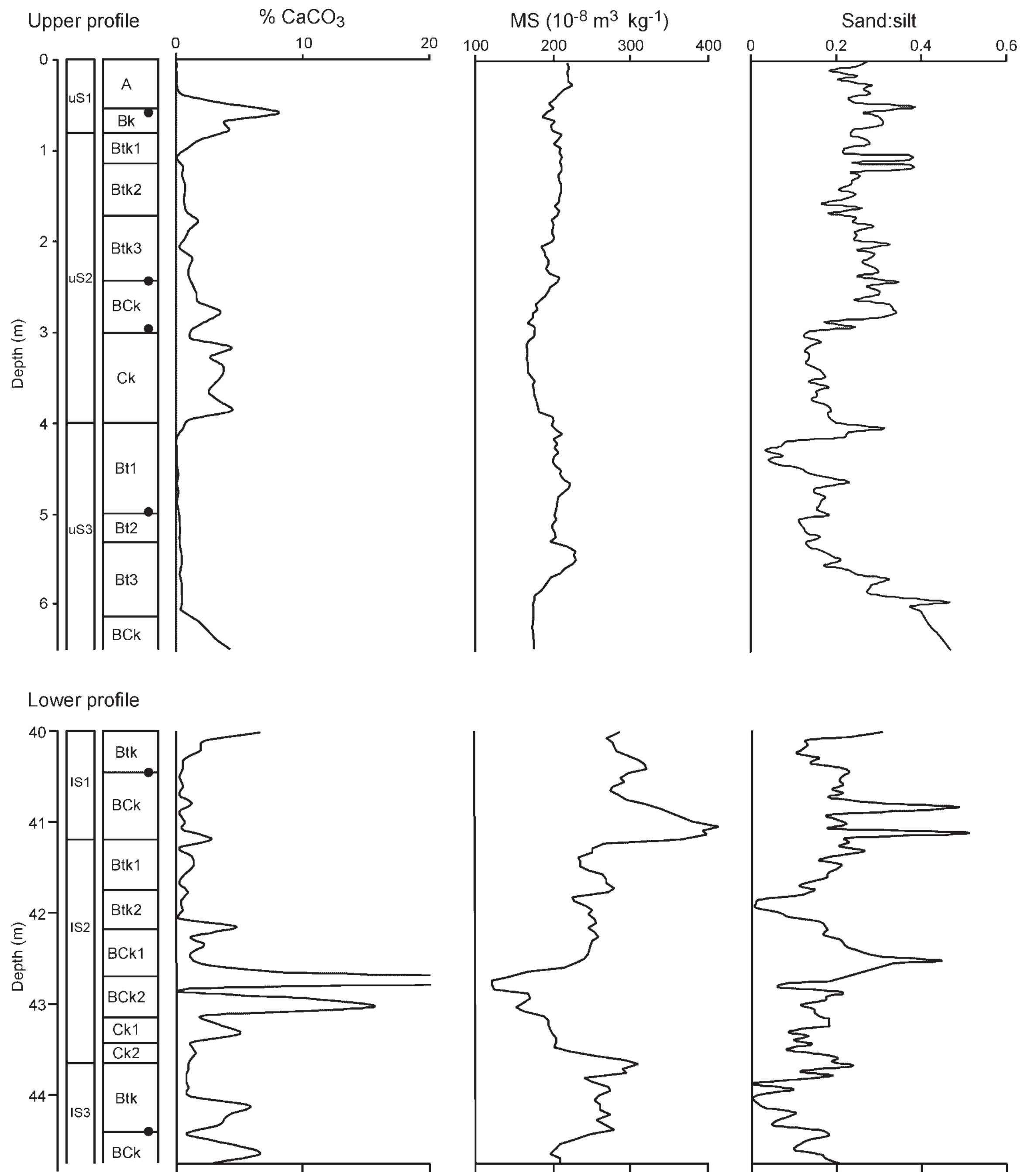

Figure 3 (i) Log of upper and lower profiles from El Lambedero, showing soil horizons, soil (palaeosol) units and locations of the OSL samples; (ii) depth functions of calcium carbonate content, magnetic susceptibility and sand:silt ratio

functions are recorded in Fig. 6. Spongy and channel microstructures (Fig. 4a) are characteristic of most horizons, reflecting the impact of faunal and root activity during periods of landscape stability and significant soil development as well as during phases of sediment accumulation. It is possible that there was also some syndepositional or even groundwater redistribution of carbonates, although most of the calcitic hypocoatings, coatings and diffuse impregnative nodules (Fig. 4b) probably relate to leaching processes associated with the formation of the palaeosols. The fine-grained (<5 μm) calcite responsible for the crystallitic b-fabric in several Btk, BCk and Ck horizons is also likely to be secondary. The depth function of calcitic concentration features (Fig. 6) is complicated to a certain extent, however, by the obvious welding of sola with leachates washed down from one soil and accumulating below in an older soil. This phenomenon is best illustrated by the frequent occurrence of calcitic coatings covering, and therefore post-dating, the clay coatings in Btk horizons (Fig. 4c). The micromorphological record and pattern of secondary carbonate concentrations is largely in accord with the field descriptions and bulk chemical data (Fig. 3). One noticeable discrepancy occurs at ca. 5 m depth in the upper profile where significant quantities of carbonate were identified in the micromorphological record, but were not measured at the 5-cm bulk sampling interval.

The non-laminated, discontinuous or flecked continuous silty clay coatings (Fig. 4d) in the surface A horizon are probably relatively recent features created by aggregate slaking and migration of poorly sorted suspensions during agricultural disturbance (Bullock *et al.*, 1985). They contrast markedly with

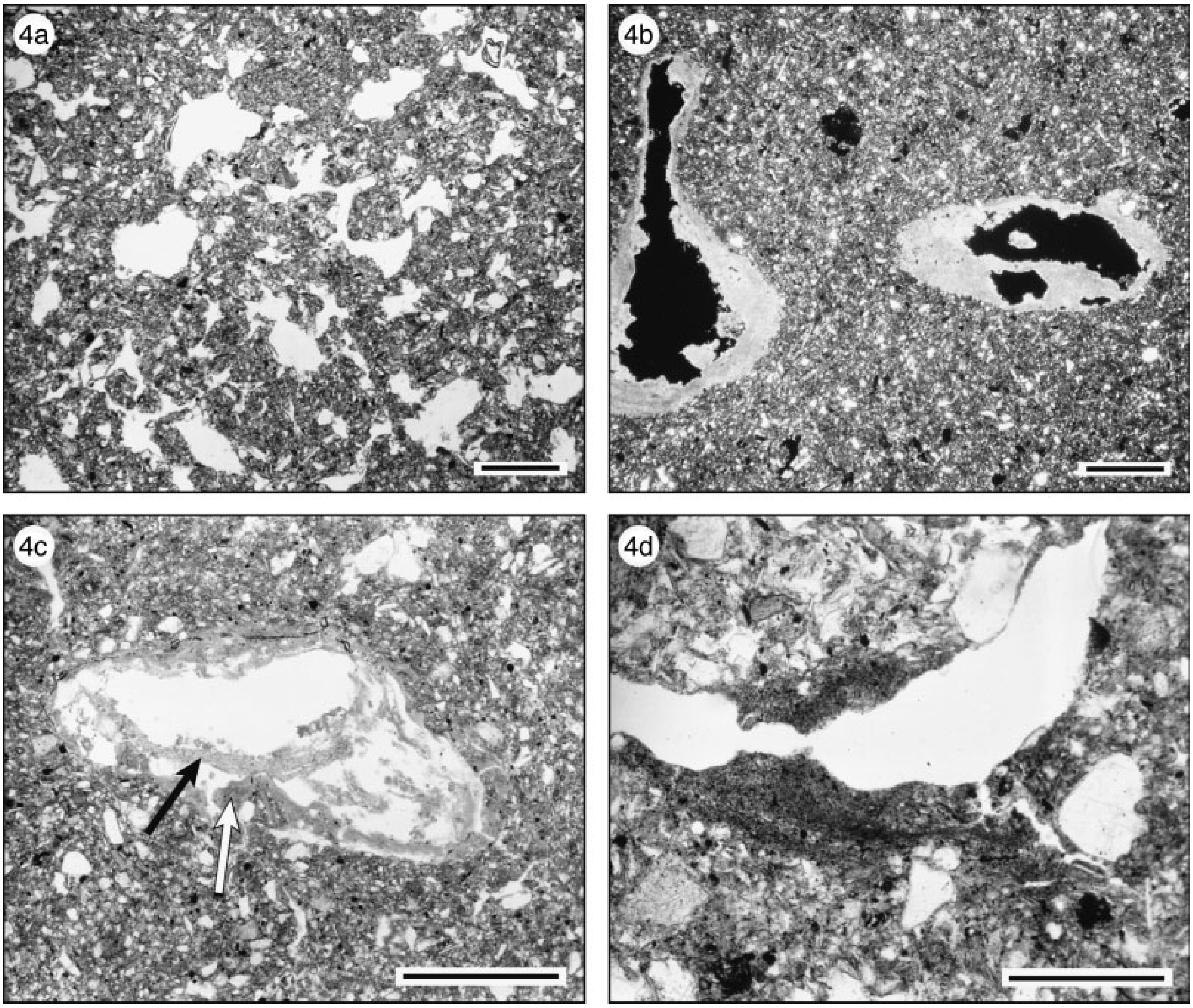

Figure 4 Photomicrographs of key micromorphological features from horizons in the lower and upper profiles at El Lambedero: plane polarised light (PPL); crossed polarised light (XPL); scale bar = 600 µm. (a) Spongy and channel microstructure (PPL); uS1, Btk1. (b) Calcitic hypocoatings around channels (XPL); uS2, Ck. (c) Calcitic coatings (black arrow) covering (and therefore post-dating) clay coatings (white arrow) around channels (PPL); lS1, Btk. (d) Silty clay coatings around a channel (PPL); uS1, A

the well-developed microlaminated, continuous, limpid or speckled clay coatings, typical of classic pedogenic eluviation–illuviation processes, that are prevalent around channels and on aggregate surfaces (Fig. 5a) in the palaeosol Bt(k) horizons. As noted above, the absence of clearly defined palaeosol A or E horizons from which the clay was eluviated is commonly attributed either to subsequent removal by erosion or pedogenic transformation to subsoil horizons as the pedosedimentary column accreted to form new surfaces at higher levels. The occurrence of sharply bounded, subrounded aggregates (1–20 mm diameter) embedded in the groundmass (Fig. 5b) immediately above the upper Bt horizon and boundary of uS3, lS3 and lS2 (Fig. 6) provides some support for the erosion hypothesis. Although such features might have a variety of origins, including faunal turbation, their depth distribution and restriction to BCk and Ck horizons at El Lambedero, and the fact that many aggregates contain clay coatings (Fig. 5c), are consistent with a model of land surface instability, erosion and incorporation of surface and subsurface soil material during the initial phases of loess accumulation following a 'stable' 'soil-forming interval'. The silty clay fabric units (Fig. 5d) dispersed in the groundmass in a number of thin-sections also probably reflect some form of water-reworking of aeolian sediments during aggradation phases.

Chronology

Finite and stratigraphically consistent OSL ages were obtained from the upper profile at El Lambedero (Table 1). These dates (GL00035, GL00036, RH0001, GL00037) constrain the development of the two palaeosols to some time between approximately 73 and 96 ka for uS3 and between approximately 33 and 61 ka for uS2. The natural optical signals of both samples (GL00039, GL00040) from the lower profile appear to be equivalent to the saturated region of the laboratory generated dose–response curves. Minimum ages (Table 1) were therefore derived from the characteristic saturation dose (Grün and Brumby, 1994), suggesting that this part of the sequence formed prior to 165 ka.

Pedosedimentary reconstruction

The field, bulk-property and micromorphological data discussed above provide the basis for reconstructing the evolution of each profile at El Lambedero in terms of successive

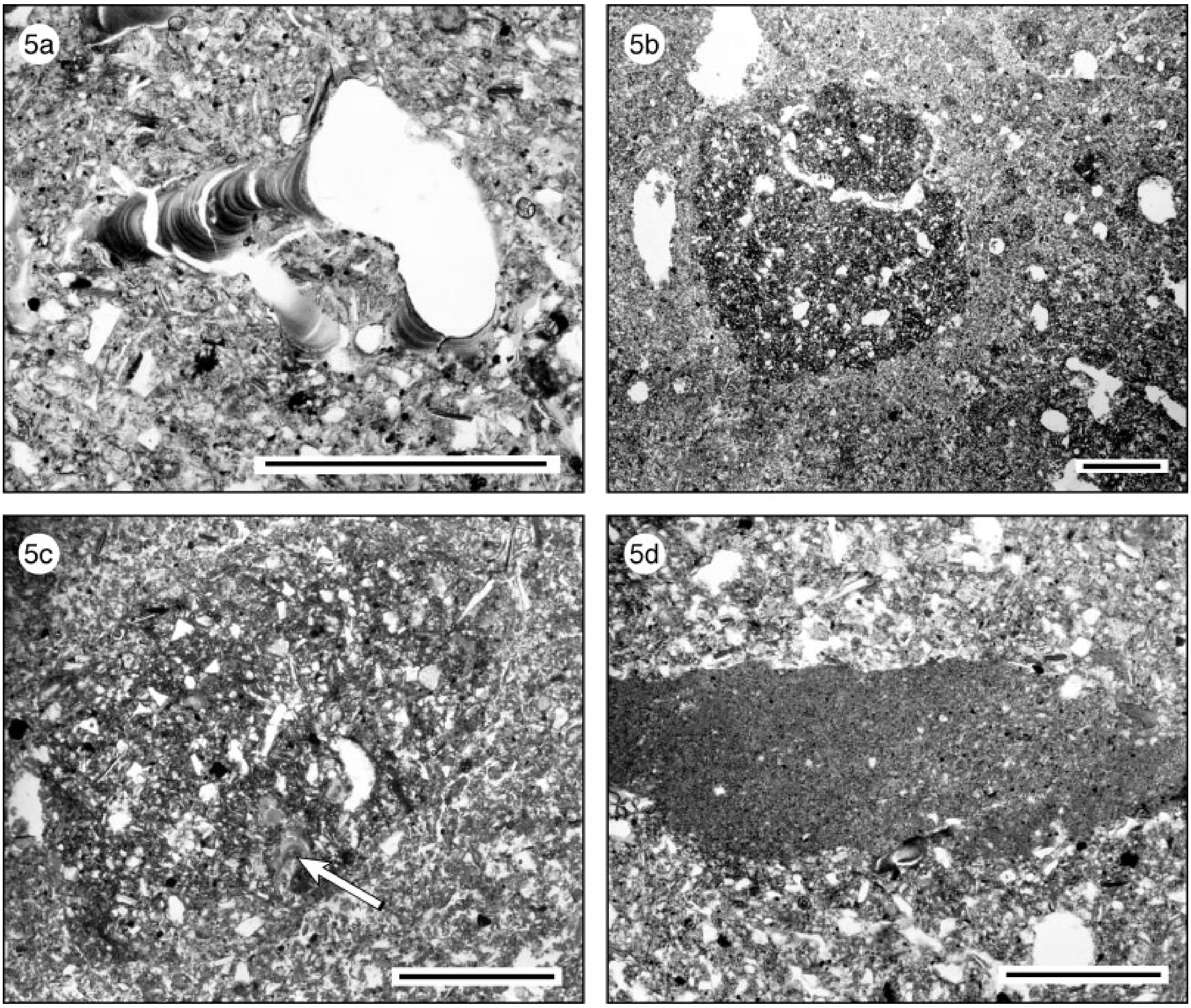

Figure 5 Photomicrographs of key micromorphological features from horizons in the lower and upper profiles at El Lambedero: all plane polarised light; scale bar = 600 μm. (a) Microlaminated clay coatings around channels; lS2, Btk2. (b) Aggregates embedded in the groundmass; uS2, Ck. (c) Clay coatings (white arrow) around channels within embedded aggregates; uS2, Ck. (d) Silty clay fabric units; lS2, BCk1

pedosedimentary stages (Fig. 7). The lower profile appears to have followed a cyclical development pathway with each pedosedimentary stage comprising an initial phase of land surface instability when upper soil horizons were eroded and residual fragments incorporated into accumulating loessic sediments. As rates of aeolian deposition diminished and the land surface stabilised, pedogenic leaching and clay-translocation processes became dominant. Solutes leached down into older palaeosols where they precipitated out to form calcitic concentration features, thus welding subjacent sola. Unfortunately, the minimum OSL age estimates obtained from this profile preclude the possibility of correlating the pedosedimentary record with that of the basal section at La Mesada (Kemp *et* al., 2003) or even with marine isotope stages (MIS) of the marine record. The results, however, do support the notion of Kemp *et al.* (2003) and Schellenberger *et al.* (2003) that the loess–palaeosol sequences in the Tafí-del-Valle region are significantly older than reported by Zinck and Sayago (1999, 2001).

Pedosedimentary stages 1 and 2 followed a similar pattern in the upper profile, although the zone of reworking recorded in the lower part of uS2 is considerably thicker than elsewhere. Although the possibility of the incorporated soil aggregates ('pedorelicts') increasing the apparent OSL age of this part of the unit cannot be completely discounted, there are compelling reasons for accepting the inferred maximum soil-forming interval of approximately 73 to 96 ka for uS3, and thus correlating it with MIS 5a (Martinson *et al.*, 1987; Winograd *et al.*, 1997). In fact, the appreciable thickness of the Bt horizons and the occurrence of a secondary carbonate concentration at 5 m might indicate that uS3 is a (welded) pedocomplex that began its development during earlier substages of MIS 5. Additional dates below 5 m would help to evaluate this possibility.

The two uppermost OSL ages of ca. 33 ka and 61 ka suggest that uS2 may be correlated with MIS 3. The surface soil (uS1), however, appears to be significantly less developed than the underlying palaeosols with no evidence of clay translocation. This might reflect a drier climate or shorter duration compared with past soil-forming intervals. Rather than being welded on top of a Pleistocene palaeosol (uS2), the surface soil may in fact be considerably thicker and comprise both uS1 and uS2 with its upper part (uS1) thickened and transformed by recent agricultural activity, the secondary carbonate peak at 70 cm having been induced by precipitation from percolating irrigation water. If this proves to be the case, pedosedimentary stage 3 might span only the past century or so and, instead of indicating an approximate timing of burial of uS2, the 33 ka OSL age at 0.5 m may simply provide a maximum age for the surface soil.

The dearth of sediments younger than ca. 33 ka at El Lambedero indicates a significant reduction in accretion rate over the

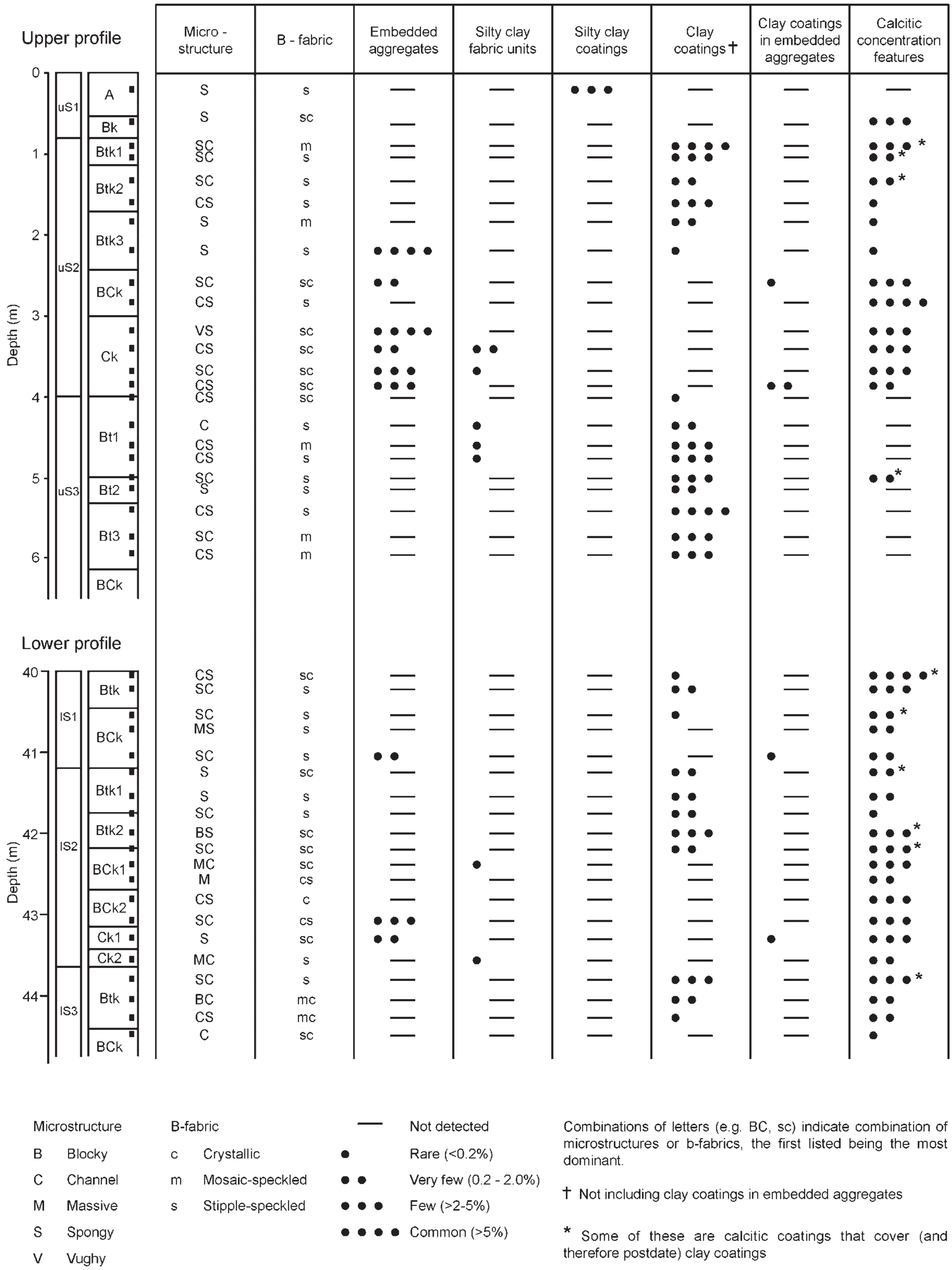

Figure 6 Depth functions of the main micromorphological features from the two profiles at El Lambedero. Thin-section locations are shown by solid squares

past 30–40 kyr and/or removal by erosion. Certainly, the well-rounded form of interfluves in this gullied landscape, including the broad ridge into which the section at El Lambedero is cut, is consistent with erosional stripping. Bearing in mind its location within the Sierras Pampeanas, a region of active faulting in the late Cenozoic including intense seismicity in the Holocene (Ramos *et al.*, 2002), it is feasible that such erosion may have been induced by episodic uplift. Although no data are available from the immediate vicinity of Tafí del Valle, river terraces arising from incision of the Rio San Juan into Tertiary bedrock (San Juan Province: 31°S, 69°W, about 500 km southwest of the Tafí basin) have been used to suggest high rates of recent tectonic uplift and a resultant mean exhumation rate for the past 43 kyr of 0.9–1.0 mm yr^{-1} (Colombo *et al.*, 2000). Alternatively, the period(s) of truncation might correspond to identified regional phases of extensive erosion (ca. 35–25 ka and 5 ka) involving slope instability induced by wetter conditions linked to increased activity of the El Niño–Southern Oscillation (ENSO) (Trauth *et al.*, 2000, 2003). There is of course local evidence for recent soil redistribution linked to agricultural disturbance, although it is unlikely that significant amounts of material were removed via this pathway.

Table 1 OSL ages obtained from samples at El Lambedero

OSL sample depth/code	Dose rate (Gy kyr^{-1})					D_e (Gy)	Age (ka)
	γ^{c}	β^{b}	$\alpha^{a,b}$	Cosmic^{d}	Total		
0.6 m/GL00035	1.29 ± 0.02	1.82 ± 0.16	0.54 ± 0.05	0.28 ± 0.03	3.91 ± 0.17	128.4 ± 6.2	33 ± 2
2.4 m/GL00036	1.44 ± 0.02	2.27 ± 0.18	0.74 ± 0.07	0.21 ± 0.02	4.65 ± 0.19	283.8 ± 14.6	61 ± 4
3.0 m/RH00001	1.30 ± 0.02	1.93 ± 0.19	0.55 ± 0.06	0.21 ± 0.02	3.98 ± 0.20	290.9 ± 16.8	73 ± 6
5.0 m/GL00037	1.36 ± 0.02	1.79 ± 0.13	0.56 ± 0.04	0.14 ± 0.01	3.85 ± 0.13	370.8 ± 16.7	96 ± 5
40.3 m/GL00039	1.26 ± 0.02	2.19 ± 0.15	0.65 ± 0.05	0.01 ± 0.00	4.10 ± 0.16	>677.6	>165
44.4 m/GL00040	1.04 ± 0.01	2.01 ± 0.19	0.55 ± 0.06	<0.01	3.61 ± 0.20	>603.0	>167

[a] An α value of 0.051 ± 0.002 was assumed for all samples.
[b] Calculated from concentrations of U, Th and K determined by neutron activation analysis.
[c] Calculated from concentrations of U, Th and K determined by *in situ* NaI gamma spectrometry.
[d] Estimates obtained using the method described by Prescott and Hutton (1994).

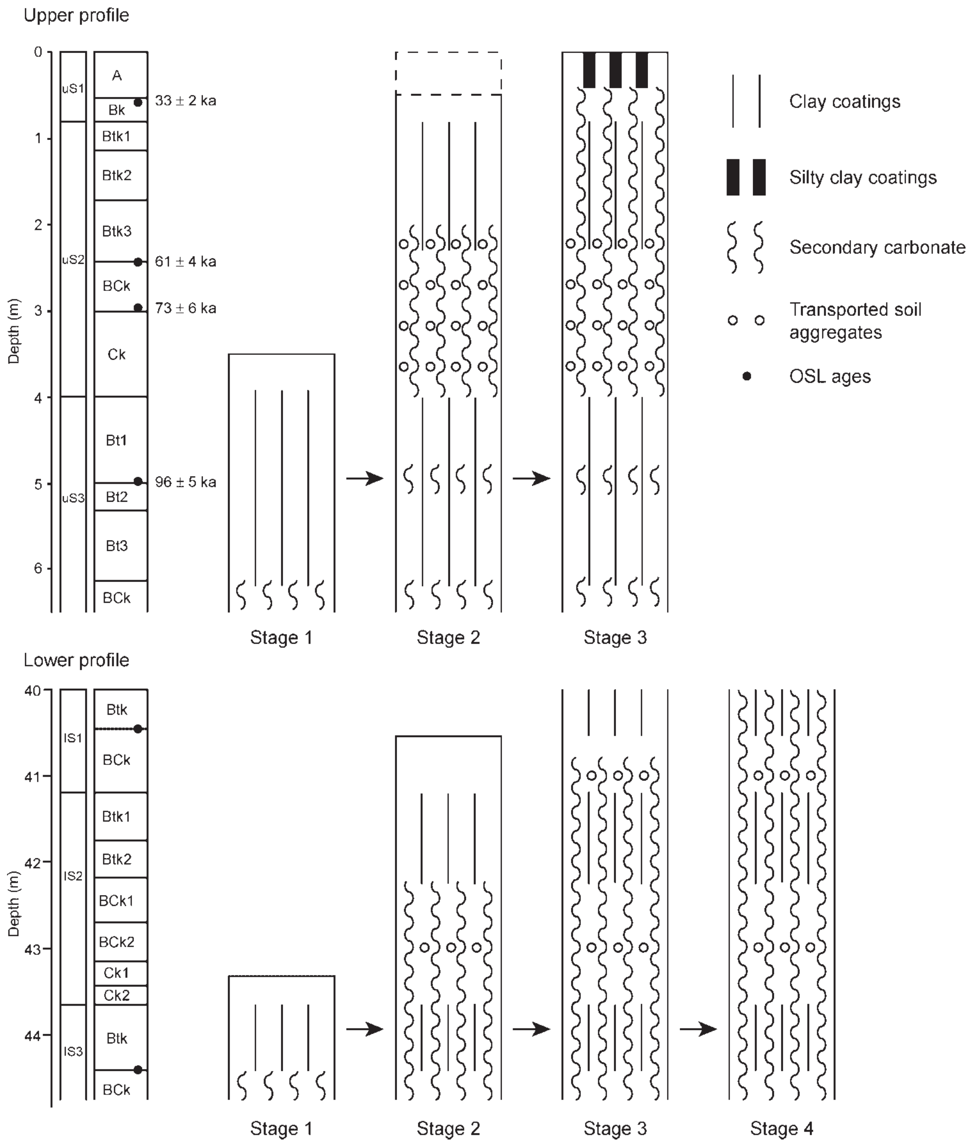

Figure 7 Reconstruction of the sequence of pedosedimentary stages responsible for the development of the two profiles at El Lambedero. Note that possible erosional and complex multiphase pedogenic events are not shown

The basic pedosedimentary model applicable to both profiles at El Lambedero can easily be accommodated within the broad palaeoclimatic interpretation of loess–palaeosol sequences proposed for this part of Argentina, namely pedogenic activity associated with relatively humid phases and loess accumulation with drier conditions, the changes being brought about by latitudinal migrations of the polar front generated by fluctuations in intensity of the South Pacific anticyclonic centre (Iriondo and García, 1993; Zinck and Sayago, 1999, 2001). As we begin to understand more about different potential loess source areas in Argentina (Iriondo, 1999; Muhs and Zárate, 2001; Smith *et al.*, 2003), regional palaeoclimatic gradients

(Iriondo, 1999; Muhs and Zárate, 2001) and palaeo-ENSO conditions (Trauth *et al.*, 2000, 2003), however, it is likely that such a simple 'dry-humid' model will need to be elaborated and refined. Indeed, enhanced ENSO activity may well be a factor in explaining the truncation and reworking phases identified within the MIS 5 and older palaeosols at El Lambedero.

Conclusions

The field, grain-size, magnetic susceptibility, geochemical and micromorphological characteristics of the upper and lower parts of the 45 m section at El Lambedero, Tafí del Valle basin, northwestern Argentina, indicate a cyclical pedosedimentary history. Each pedosedimentary stage comprised an initial phase of land surface instability with erosion of upper horizons of existing soils and incorporation of residual fragments into accumulating loessic sediments. As aeolian accumulation rates diminished and the land surface stabilised, pedogenic leaching and clay translocation progressively dominated.

The optical ages derived from the upper profile suggest that uS3 might be correlated with at least the latter part of MIS 5, although additional bracketing ages within and below this palaeosol (complex) are required for confirmation. In view of uncertainties concerning the depth of development of the surface soil (uS1) at El Lambedero, as well as the lack of grounds for discriminating between erosional stripping and non-deposition of loess since ca. 33 ka, the suggested temporal correlation of uS2 with MIS3 must be regarded as provisional. Although the minimum nature of the OSL ages obtained from the lower profile preclude the possibility of correlating the basal units at El Lambedero with those at La Mesada, their relative antiquity do provide some support for suggestions by Kemp *et al.* (2003) and Schellenberger *et al.* (2003) that the loess–palaeosol sequences in the Tafí del Valle region are significantly older than indicated by previously reported radiocarbon-based ages.

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