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Cave Sediments, Upper Pleistocene Stratigraphy and Mousterian Facies in Cantabrian Spain

Karl W. Butzer[a]

Archaeological sediments are analysed from karst cave columns in Cantabrian Spain: Cueva Morín, El Pendo, the Castillo cave complex (including La Flecha, Las Chimeneas, La Pasiega, Las Monedas), Hornos de la Peña and Cobalejos. External sediment influx, including loess, is calibrated by an index of cave and slope run-off energy, while other features (slope and roof rubble, chemical precipitates, cryoturbations, fine soil derivatives, and cultural components) are discussed. The key sequences (Morín, El Pendo, Castillo) are each interpreted in local terms and then combined into a regional climatostratigraphy that includes 40 environmental phases within deep-sea isotope stages 2–5. Trends in run-off energy (reflecting slope stability), temperature, and summer-moisture are rarely in phase, indicating complex environmental change. Mid-Pleistocene and older deposits exist but have largely been destroyed, explaining the apparent absence of Acheulian settlement. Mousterian occupation is verified by isotope stage 5b, and two or three Mousterian facies that span 25–50,000 years are coeval in several caves, regardless of the direction of climatic oscillations. This suggests the flexible lithic technology of a single population, maintaining an adaptive steady state despite repeated environmental changes. By contrast, the distinct upper palaeolithic industries each span only a few millennia, but in part overlap temporally within the region between 35,000 and 9500 bp.

Keywords: CANTABRIA, CASTILLO, MORIN, EL PENDO, MOUSTERIAN, UPPER PALAEOLITHIC, UPPER PLEISTOCENE, GEO-ARCHAEOLOGY, CAVE SEDIMENTOLOGY, KARST, LOESS, SLOPE STABILITY.

Introduction

The great complexity of European cave stratigraphies was demonstrated in the syntheses of F. E. Zeuner (1945, 1946), at a time when other Pleistocene continental sequences identified no more than a rudimentary trace of glacial tills, palaeosols, and pollen-yielding lake or bog deposits (Woldstedt, 1929). More detailed resolution was subsequently provided by analysis of deep-sea cores (Emiliani, 1955; Shackleton and Opdyke, 1973), and particularly by microstratigraphic loess studies (see Kukla, 1975), long pollen cores (see Wijmstra, 1969; Woillard, 1978), and glacial ice cores (see Johnsen, Dansgaard & Clausen, 1972).

[a]Chair of Human Geography, Swiss Federal Institute of Technology, 8092-Zurich, Switzerland.

Increasingly meticulous cave sedimentology since the 1950s, particularly in southwestern France, further served to document that successive upper palaeolithic industries were temporally defined, whereas middle palaeolithic (Mousterian) assemblages appeared to be time-transgressive (see Bordes, 1961; Laville, 1973). So for example, distinct stages of the Aurignacian, Perigordian, Solutrean and Magdalenian spanned only a few millennia, with repeated replacement, and even the major industrial complexes had a longevity of only six to nine millennia (see Sonneville-Bordes, 1966; Laville, 1975; de Lumley, 1976). Mousterian industries could also be subdivided, but several such variants were often coeval in adjacent caves, and collectively they spanned more than 40 millennia (see Bordes, 1972; Laville, 1975). Eventually two major modes of interpretation were offered for these Mousterian variants or "facies" (here defined archaeologically as artifact assemblages that share some common morphological traits), one school favouring several contemporary ethnic groups or "tribes" (see Bordes, 1961, 1972; Bordes & de Sonneville-Bordes, 1970), the other, functionally distinct, activity-related toolkits (see Binford & Binford, 1966; Freeman, 1966). In any event, Mousterian material culture suggested a fundamentally different (steady-state) dynamism from that of the upper palaeolithic industries, when turnover was rapid and comparable to the "half-life" of two or three millennia typical for late prehistoric and historical European cultures (Butzer, 1977).

The Mousterian facies variability first established for the French Dordogne has subsequently been documented for other areas of southern France (de Lumley, 1976), as well as Spain, specifically the Cantabrian area adjacent to the Bay of Biscay (Freeman, 1966; Echegaray & Freeman, 1973). This paper provides a first detailed archaeo-sedimentological analysis of the longer limestone cave sequences of Cantabrian Spain, based on fieldwork in 1968–69. Included were Cueva Morín, El Pendo, El Castillo, La Flecha, Hornos de la Peña and Cobalejos (all in central Santander Province). The results serve to outline a regional micro-stratigraphy for the Upper Pleistocene (here defined chronometrically as 130,000 to 10,000 bp, Butzer, 1974). Applied to the industrial sequence, this climato-stratigraphic framework opens some new perspectives on Mousterian variability.

Synopsis of the Regional Pleistocene

Due to the exploratory nature of Quaternary research in almost all parts of continental Spain, much of the fieldwork was devoted to semi-detailed mapping and recording of marine beaches, alluvial terraces, periglacial slope deposits, and glacial features in western Santander (Figure 1) (summary in Butzer, 1973). The salient data are as follows.

(a) Montane glaciation. Upper Pleistocene snowline (Höfer method) in the Montañas de Reinosa (2175 m above sea level): 1500 m in northwest (Nansa) quadrant, 1200 m in northeast (Saja) quadrant, and 1650 m in southern (Híjar-Ebro) sector. Traces of an older glaciation, with 1450 m snowline, in upper Híjar.

(b) Periglacial phenomena. Widespread, compact or calcrete slopes screes, including *grèzes litées*, and creep or slide-assisted, colluvial rubbles at all elevations, with nivational niches and blockstreams in high country, and cryoturbations (but no true involutions or ice wedges) down to near sea level.

(c) Alluvial terraces. As much as 130 m above modern talweg, downstream mainly linked to marine controls, with relict Braunlehm palaeosols. Two low terraces with Braunerde soils, the older (LTI, +7–8 m) interdigitated with periglacial screes, the other (LTII, +3–6 m) related to non-functional Holocene coastal deposits at +1·5–2·5 m.

(d) Marine terraces. Rock-cut benches and platforms from 15 to 220 m above sea level, probably Mio-Pliocene to mid-Pleistocene. Eustatic, +9 m stream terraces with palaeosols may reflect the last Interglacial maximum transgression (here defined as deep-sea isotope stage 5e), locally recorded at +5·5–7 m in marine caves (Mary, 1971; Mary *et al.*, 1975).

These geomorphologic data provide no more than a gross regional stratigraphy, but they serve to document a cold and snowy, but non-permafrost climate during the last Glacial (defined as isotope stages 2 to 4), in part coincident with vigorous, almost ubiquitous slope denudation. This is consonant with the deep-sea micro-palaeontological reconstruction, according to which the Bay of Biscay was 10–11 °C colder than it is at present about 18,000 bp (McIntyre *et al.*, 1976).

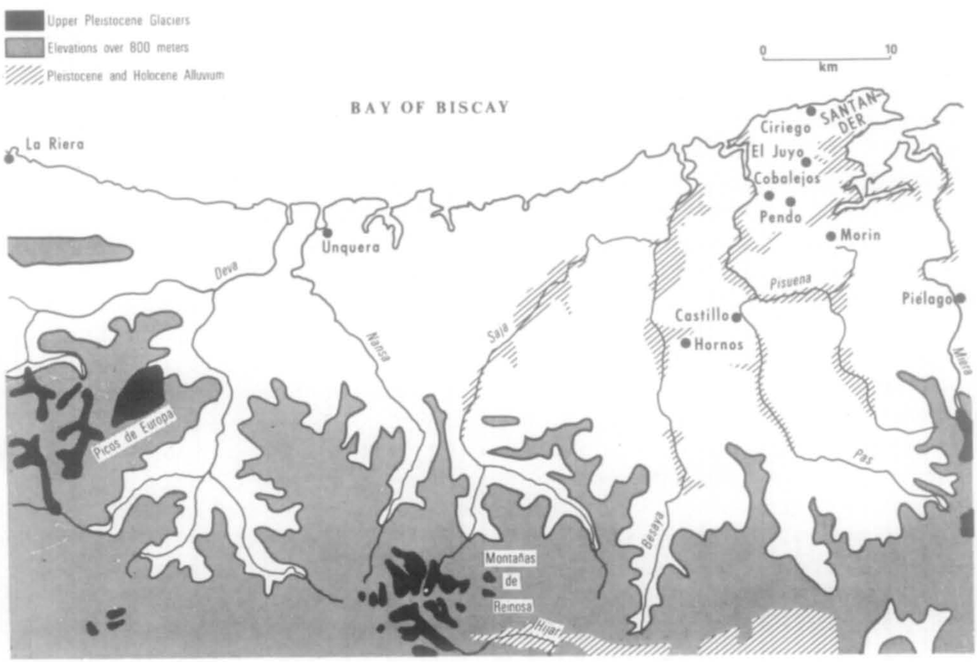

Figure 1. Mousterian sites of Santander Province, Spain. Glaciation of Montañas de Reinosa and valley alluvia (schematic) mapped by author.

Sedimentological Procedures

In addition to macroscopic field recording, sediment descriptions are based on textural analysis of some 275 samples from central and western Santander, 178 of these from archaeological sites.

The standard procedure began with decalcification (in 20% hydrochloric acid), because many samples were variably cemented, and decalcification cannot be selectively applied without producing inhomogeneous data in the clay fraction. External soils rarely include primary limestone particles finer than 2 mm, and calcium carbonate is overwhelmingly secondary. Cave sediments frequently include lime sands, grit, or gravel derived exclusively from roof weathering; in order to obtain information on the external environment, this material had to be filtered out, by removing limestone particles coarser than 2 mm (for examination of bulk and morphology) prior to decalcification of the remainder. Decalcification also served to remove other, organic and mineral solubles, so filtering out much of the cultural fraction in the cave sediments; hydrogen peroxide was not applied, because of its negative impact on the clay fraction and peptizing qualities, but organic debris was subsequently removed from the sieve fraction by sodium hydroxide. In this way all the samples were pretreated and essentially "cleaned" in a uniform manner.

The decalcified residual sediment was then processed by the hydrometer method (peptizing in a 5% sodium hexametaphosphate solution), followed by wet-sieve calibration of the sand fraction (using standard 37, 63, 210, 595 μm, 2 and 6·35 mm sieves for all samples, and additional 105 and 420 μm sieves where sand content exceeded 40%). Textural classes follow those of the U.S. Department of Agriculture. Parameters for mean grain size (Mz), sorting (So), skewness (Sk), and kurtosis (Kg), were computed for decalcified residues under 6·3 mm by the Folk (1966) indices (Mz, σ, Ski, Kg in original notation). Sorting, skewness and kurtosis properties are only reported below when they fall outside the modal range: So 2·1–2·8 (very poor); Sk 0 to +0·25 (positive, i.e. with coarse sediment "tail"), and Kg 0·75–1·00 (moderately platykurtic, i.e. with a grain-size distribution "flatter" than normal). Colours follow the Munsell Soil Colour Charts (dry state), while pH values were determined for aqueous sediment pastes with distilled water, and calcium carbonate was approximated from bulk loss in acid.

The morphology of cave limestone rubble could only be estimated from small samples, in part because the excavations did not save such materials, in part because the small witness sections could not be destroyed to provide masses of mixed sediment. Furthermore, the Cantabrian caves reported on here are wet, unlike any in the Dordogne. Thick spall horizons in entrance areas are, as a result, heavily cemented; those further inside are increasingly corroded with increasing depth within the profiles, as a result of post-depositional alteration, often to the point where they are reduced to soft, chalky aggregates that barely preserve original structure. Detailed analyses would only provide information on such alteration, not on the original conditions of detachment from a cave roof. Estimates of relative abundance and size of rubble were made during field profile recording and again during preprocessing of the 200 g samples of raw sediment. Applied to anywhere between a half dozen and 50 pieces, the Lüttig index of rounding (ρ) (see Butzer, 1971*a*, pp. 164–69) provides a first approximation of angular versus corroded rubble. The unsystematic but often semiquantitative descriptions of rubble provided below are as follows: fine grade (2–6·4 mm); medium grade (6·4–20 mm); coarse grade (20–60 mm); angular (ρ 0–10%); partly corroded (ρ 10–20%, i.e. subangular); corroded (ρ 20–40%, i.e. subrounded); rounded (ρ 40–60%); and well-rounded (ρ over 60%).

Clay mineralogy was not studied systematically. Published X-ray diffractogram data from French caves generally show less variability than that to be expected in a sample range from local bedrock (see Laville, 1975; Farrand, 1975*a*, *b*)—an inconclusive technique to separate external derivatives from pedogenetic modification or cultural and animal contributions. Microscopic scanning of all sample residues showed few heavy minerals other than "opaques", i.e. ferricrete sand grains which provided a useful variable for Cueva Morín. Small samples of quartz from each sample were classified and counted in terms of micromorphometry. These probes showed that the bulk of the quartz sand was polycyclic in origin, reflecting solution from local limestones; distinctive aeolian components were not apparent under low magnification (see also Butzer & Gladfelter, 1968), even in samples containing loessic silts [however, see Creer & Kopper (1976) in regard to scanning electron microscopy].

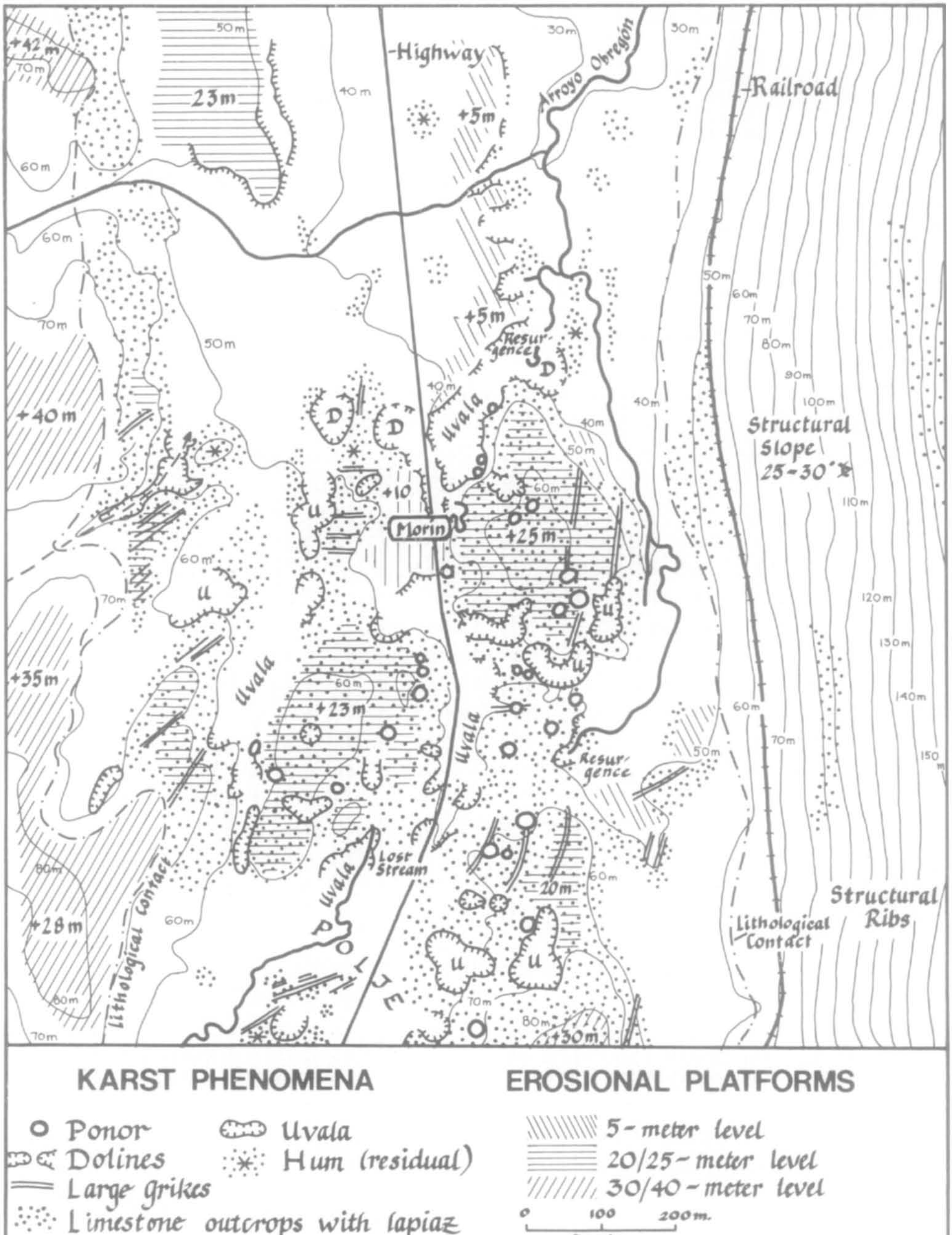

Figure 2. The karstic setting of Cueva Morín in the upper Soliá drainage; sandstones are exposed in the western sector.

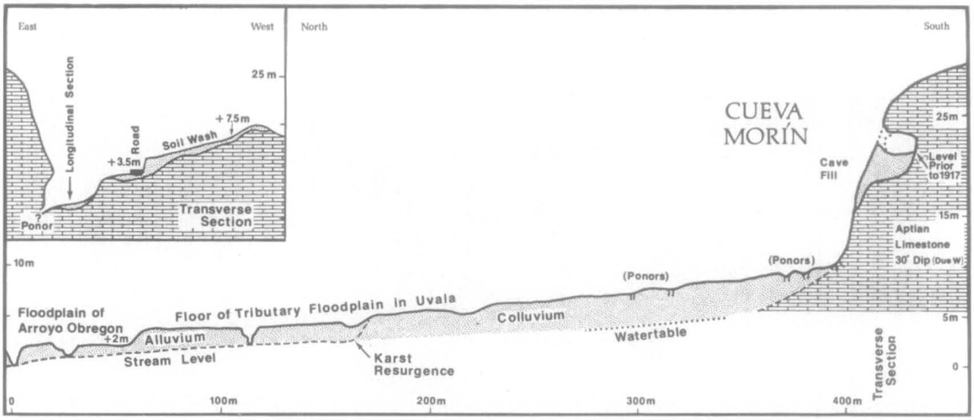

Figure 3. Transect from Cueva Morín northward to the Arroyo Obregón.

The Setting of Cueva Morín

The most detailed study was carried out in and around Cueva Morín, excavated by Echegaray & Freeman (1971, 1973) during 1968–69. The research and sediment-catchment strategy described for this site applies, with minor variations, to El Pendo, Castillo and other cave sites.

Cueva Morín is situated 11 km south-southwest of Santander, and 1 km south of Villanueva. A karstic valley is developed in folded Aptian (Cretaceous) limestones; its floor is studded with limestone residuals (*hums*), with a relief of 10–30 m and badly etched by micro-karstic (*lapiaz*) corrosion. Cueva Morín faces north-northwest on the flank of such a *hum*, 20 m above the Obregón floodplain and 57 m above sea level (Figures 2 and 3). The crests of residuals form a crude set of accordant platforms—complicated by lapiaz, multiple sinkholes (*dolines*) and swallow holes (*ponors*), and large solution fissures (*grikes*)—at 20–25 m above the modern floodplain. Some limestone residuals and as well as the sandstone ridges on the western margin of Figure 2 also preserve platforms at +30–40 m. The two surfaces so defined were mapped at 1 : 5000. Although lacking deposits, they can be placed within the framework of alluvial terraces established for central and western Santander by my fieldwork: both surfaces are evidently older than the +9 m terrace, with relict Braunlehm soil and linked to the 7 m last Interglacial sea level. Instead they match the criteria of +32–38 m and +20–25 m eustatically-controlled terraces of probable mid-Pleistocene age found in the lower river valleys. Younger surfaces of uncertain significance are represented by unconsolidated benches of terra fusca sediment (see Guerra and Montouriol, 1959) at +5 and +10 m.

Cueva Morín is situated in a large, multiple sinkhole (*uvala*), dissolved beneath the 30–40 m surface. A lateral cavern formed within this uvala, while the watertable fluctuated near the level of the modern cave floor, evidently at the time the 20–25 m surface was developing. Eventually the watertable dropped sharply and the cavern was opened to subaerial processes. Finally, a minor stream breached the uvala from the north. Consequently, the cave originated during mid-Pleistocene time, and sedimentation presumably began not long thereafter.

External Sediment Sequences at Morín

The nature of the sediments in the soil catchment of Cueva Morín can be determined by surface sampling and from natural sediment traps. However, the soils on top of Morín

Hill have been repeatedly denuded by erosion, and now consist of stoney, organic A-horizons of silt loam texture, directly on bedrock or above truncated soil pipes that represent B-horizons or fissure fillings. Similarly, the agricultural soils of the multiple, lowland terraces are heavily ameliorated with fertilizers, mixed by deep ploughing, or amplified by B-horizon material artificially obtained from quarries, such as those on the hillside east of the Arroyo Obregón. The modal agricultural soil at 30 cm depth is a brown (7·5 YR), poorly-sorted silt loam, secondarily calcified and alkaline (pH 7·7) (Figure 4).

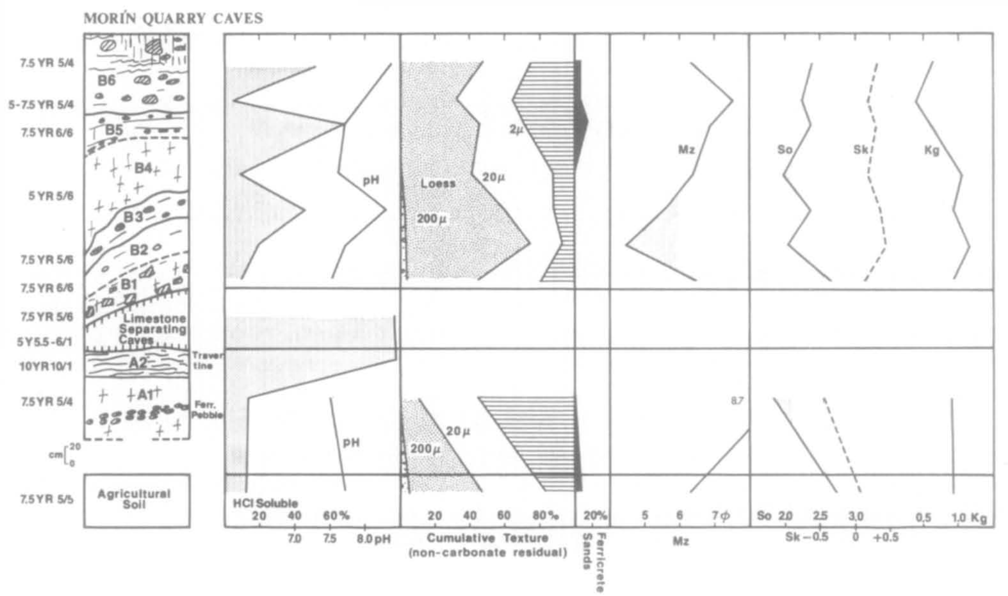

Figure 4. Analytical data from caves exposed in quarry 70 m south of Cueva Morín.

More informative are the footslope, fissure, and cavern fills exposed in the quarry 70 m south of Cueva Morín. A particularly instructive section (B) is exposed in a former sealed cave, on the northwest side of this quarry. The units are described in Table 1, with analytical data presented in Figure 4. Unit B1 corresponds roughly to the modern agricultural soil, but includes fresh, mechanically-weathered rubble, probably derived from the cave roof or the fissure above it. Units B2 and B3 represent a coarser facies rich in fine sands, that reflect sorting or mobilization or both by faster-moving waters. Unit B4 matches the physical criteria of a true loess: a vertically-structured silt or silt loam, with less than 20% clay, at least 70% finer than 60 μm and at least 97% finer than 200 μm (see Swineford & Frye, 1945). Unit B5 includes alternating lenses of mixed, loess-derived silts and stoney-clayey soil wash. Finally, unit B6 is a typical colluvium, virtually indistinguishable from the hillwash near the top of section A; whereas B6i derives primarily from a deep clayey B-horizon, B6ii comes from a thinner soil or a sandier and lower horizon; both subunits include abundant, corroded rubble from the base of a soil profile. Together, these six facies provide prototypes for most non-cultural residues represented inside Cueva Morín.

This cave sequence is partly equivalent to a 2·5 m suite of footslope deposits exposed in section (A) of the northeastern quarry face, at the base of a 15–25° incline. Resting

Table 1. Analytical description of Morín Quarry Cave "B"

B6.	*90 cm.* (i) Reddish brown (7·5–10 YR), poorly stratified, silty clay loam grading up into (ii) well-stratified, brown (7·5 YR) silt loam, very positively skewed, with some ferricrete sands and interbedded with very pale brown (10 YR), primary, banded travertine. Both subunits contain much dispersed, medium-to-coarse grade, corroded limestone and travertine rubble.
B5.	*30 cm.* Well-stratified lenses of yellowish red (5 YR) silt loam and reddish yellow (7·5 YR), silty clay loam with abundant ferricrete sands, lime grit, and dispersed, fine-to-medium grade, corroded travertine rubble. Lower contact indistinct.
B4.	*85 cm.* Yellowish red (5 YR) silt loam; massive bedded, with coarse prismatic structure; a typical loess with moderately good sorting.
B3.	*30 cm.* Strong brown (7·5 YR), well-stratified silt loam, very positively skewed, with lime grit and medium-grade, corroded travertine rubble.
B2.	*40 cm.* Reddish yellow (7·5 YR) loam, moderately well sorted, very positively skewed and leptokurtic; with dispersed, coarse-grade angular limestone rubble.
B1.	*40 cm.* Strong brown (7·5 YR), silt loam, with angular blocky structure, and abundant coarse-grade, angular limestone rubble.

on bedrock, 60 cm of brown, stoney silt loam are embedded in a secondary, laminated and undulating caliche, followed by 50 cm of primary, white travertine (extending up the hillside), and finally by 140 cm of decalcified, reddish brown (5 YR), silty clay loam with dispersed rubble and an organic AB-horizon. These subaerial deposits are continued at depth by about 3 m of fissure fills; facies are highly variable and include: (i) homogeneous, brown (7·5 YR) silty clay (A1, Figure 4), with strong angular, blocky structure and manganese staining of ped facies; (ii) stoney to sandy soil wash, ranging from sandy to silt loams, generally well stratified; (iii) gravel horizons of well-rounded, flat, and patinated ferricrete pebbles (2–40 mm major axis), mixed with coarse-grade, subrounded limestone and fine, rounded quartz granules; and (iv) thin-bedded, white travertine (A2, Figure 4).

Interpretation of External Facies at Morín

The facies and disposition of the sediment in sections (A) and (B) are critical to interpretation of the Morín sequence and require discussion.

(1) *Ferricrete detritus*

Ferricrete sands, calculated as a fraction of material coarser than 60 µm, are relatively abundant in units (B5) and (B6). However, ferricrete pebbles are absent in (B), in the younger units of (A), as well as in all unconsolidated soil-pipe fillings exposed in the quarry; they are only present in the basal units of Cueva Morín, although ferricrete sand components are also prominent in several higher units. These ferricrete gravels and sands represent detritus washed into fissures and caves at times of vigorous colluvial transport and denudation. The pebbles are ferruginous nodules originally formed in the horizon of fluctuating groundwater, within deep soils over limestone bedrock. Pedogenic iron ore, initially in siderite form, is transformed to haematitic or limonitic concretions in deep karstic fissures of the Cretaceous landscapes of Santander (see Rat, 1959, pp. 43–44). In their well-rounded form, with an acid-soluble, smooth black surface and a dark brown interior, the ferricrete pebbles on Morín Hill represent former stream gravels, once transported in a sandy bed load, judging by the consistently flat shapes. Together with well-rounded quartz granules found dispersed in sections (A) and (B), the ferricrete detritus is the reworked lag of a former alluvial veneer on top of the

20–25 m surface. The quartz pebbles were probably derived from Buntsandstein (Triassic) exposures to the south, before the upper Obregón drainage deteriorated into a series of closed karstic depressions. The ferricrete sands include both primary, well-rounded grains and angular fragments of disintegrated pebbles; such sands are still relatively common in coarse local sediments. The ferricrete detritus inside Cueva Morín demonstrates that other non-carbonate residues have a similar, external origin to those in the obvious sediment traps sampled in the Morín quarry.

(2) *Flowstones*

Although dripstones (stalactites and stalagmites) are rare in caves within Aptian limestone, flowstones, mainly banded travertines, are relatively common. During the Holocene, flowstones formed at the entrance of Cueva Morín, where they dip into the cave. Other flowstones are interbedded with hillwash in (A), covering the slope and thickening at the base; some of these travertines are almost pure calcite and the horizontal bands consist of coarse laminae separated by vertical crystals. Both facts argue for a degree of primary, i.e. surface accumulation, rather than pedogenetic accretion in the subsoil by lateral seepage; others, however, are finely laminated, post-depositional caliche (*croûtes zonaires*). Lime precipitation, with little or no detrital sediment, is the antithesis of mechanical weathering, erosion, and the accumulation of rubble derived from flowstones. Prerequisites for such precipitation are stable soil mantles and supersaturation of water with calcium bicarbonate. Most favourable in this regard are dense ground cover, low-intensity rains, and periods of strong evaporation (see Butzer, *et al.* 1978, for discussion of lime accretion and denudation cycles). Since carbonates are not being precipitated or enriched at the surface or in the cave today, despite abundant water and vegetation, periodic drought appears to be essential for stronger evaporation. Ancient carbonates therefore argue for relatively dry and at least reasonably warm summers. External travertines additionally require closed ground cover.

(3) *Rubble*

Local debris, of limestone or fragmented travertine, is a major component of most superficial and cave deposits. Travertine-derived rubble is rare inside Cueva Morín, presumably a result of the limited flowstone and dripstone development. In the external environment such rubble is common in colluvial deposits, mainly in a corroded state. In (B), rubble begins with angular limestone, then shifts to corroded travertine, and then to a combination of limestone (of all grades) and travertine, both extensively corroded; caliche subsequently formed, followed by primary flowstone. This argues that the corroded travertine and limestone rubbles are not a result of intensive mechanical weathering but erosion of stoney BC-horizons, in which corroded rubble is typical. These rubbles are, then, a good index for net erosion and protracted slope denudation. Limestone rubbles inside Cueva Morín are angular or edge-corroded, and overwhelmingly of local, cave origin, since cliff-face run-off cannot be expected to wash much crude rubble into the entrance. At any rate, there is no direct link between frost-weathered roof spall inside the cave and hillwash rubbles outside. Since there is no correlation between the quantity of rubble and intensity of occupation, but rather a distinct increase in rubble towards the cave entrance, frost shattering is the only obvious agent.

(4) *Loess*

Unit B4 is a typical loess, even by a more rigid definition applied here, requiring at least 60% of the sediment between 6 and 62 μm, and So no poorer than 2·10. However, Mollusca are absent, and the reddish-yellow colour is unusual by mid-latitude European or Midwestern U.S.A. standards. Thick loesses are not conspicuous in Santander, and they have not been reported from the northern coast of Spain. Regressive shorelines or glaciofluvial waterways could, however, be expected to generate quantities of aeolian silt during the Pleistocene. Such material would normally have been integrated into surface soils, except where penecontemporaneous redeposition by water would have trapped lenses in fissures or caves, or concentrated them in footslope deposits.

A typical loess is exposed at Unquera, near Km 75·2 of the coastal railway, within a low terrace 3 m above the estuarine flats of the Rio Tina Mayor, below a 25 m hillside of Eocene sandstones. The site is that of a now-destroyed and undescribed Mousterian site (Alcalde del Rio, Breuil & Sierra, 1911, p. 53), that included woolly rhino (*Coelodonta antiquitatis*), under a thick bed of "clay". However, the pertinent sediment is a massive, prismatic-structured, pale yellow (2·5 Y), non-calcareous, silt loam with 67% in the 6–62 μm fraction, moderately sorted (Mz 5·30, clay 9·5%, sand 19·5%, So 1·84). This loess differs markedly from the B-horizon on the slope above: a prismatic-structured, brownish yellow (10 YR), non-calcareous silty clay loam, poorly sorted (Mz 6·77, clay 29·5%, sand 15·5%, So 2·66).

It is probable that the loessic lenses within profile B and inside Cueva Morín are indicative of active marine regression along the Biscay coast or of glacial expansion in the highlands. Typically, in northern Europe, loess accumulation followed upon hillwash and solifluction deposits, implying increased slope stability marked by little chemical weathering. The quasi-absence of detritus coarser than 200 m in the Morín and Unquera loesses matches this facies pattern.

(5) *Fine soil components*

The lowland surface soils of Santander are dominated by brown to reddish brown (5–7·5 YR) silt loams, silty clay loams, and even clayey silts (see also Guerra & Montouriol, 1959). As often as not such soils represent derivative sediments, reworked from decalcified terra fusca soils, including their degraded, rendzina or lithosolic variants. Intact terra fusca profiles develop optimally under relatively warm and humid conditions and at times of slope stability—by inference, during stable interglacial phases (see Butzer, 1975). Erosion of such soil materials evidently was significant in Santander during several episodes of the glacial Upper Pleistocene, and all intergrades between fine soil and silty rubbles can be observed.

Silty to clayey cave fills with Mz 6·4 to 7·8 presumably reflect on slow soil erosion above the entrance (dense ground cover), while sandy fills with Mz 3·4 to 6·2 suggest more rapid erosion (incomplete ground cover). Today, Morín Hill is densely vegetated by an impenetrable tangle of deciduous trees, shrubs, and grass, and the Cueva Morín record shows that only fine-grained detritus with Mz 6·6 to 7·1 has entered the cave during the last 9000 years. Consequently coarse-grained influx indicates a departure from the Holocene norm, specifically an incomplete vegetation mat or more intensive rains or both.

The Archaeo-Sedimentary Sequence of Cueva Morín

The archaeo-sedimentary strata inside Cueva Morín are described in Table 2 and Figures 5–7, which also includes organic matter (by the Walkley-Black method), available phosphorus (by the Bray method), and soluble potassium. In addition, free Fe_2O_3 was determined for 18 samples (by reduction to ferrous Fe). Bed contacts in Table 2 are wavy and abrupt, unless otherwise noted, so for example, irregular or indistinct. The sedimentary units are numbered in Arabic numerals from base to top, with archaeological levels designated from top to bottom in Roman form. For a floor plan, see Freeman & Echegaray (in press).

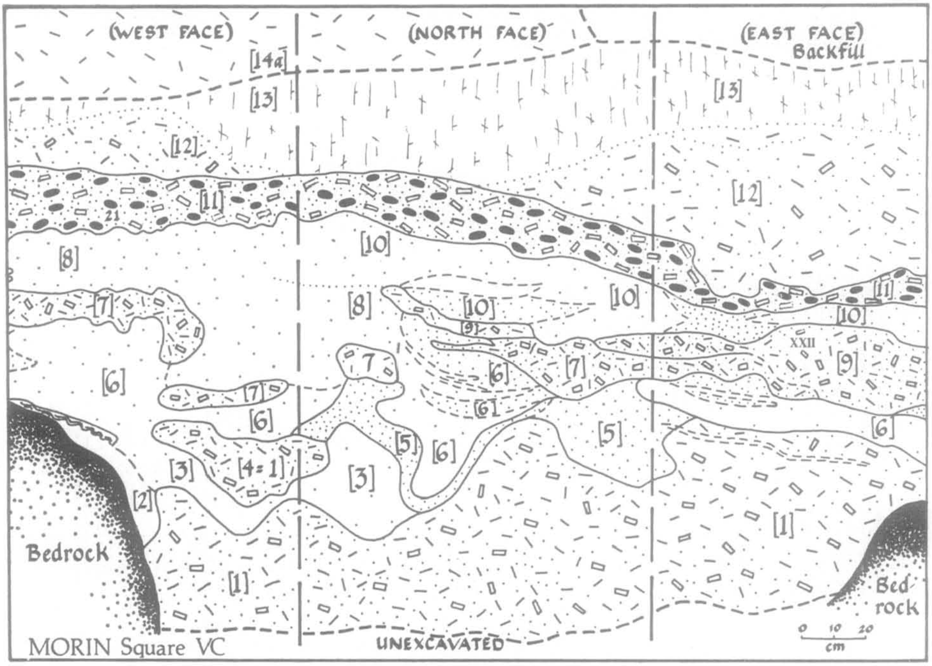

Figure 5. Three contiguous profile faces from square VC, lower Cueva Morín. Rubble is indicated schematically by open triangles (limestone spall) and black ellipses (ferricrete pebbles).

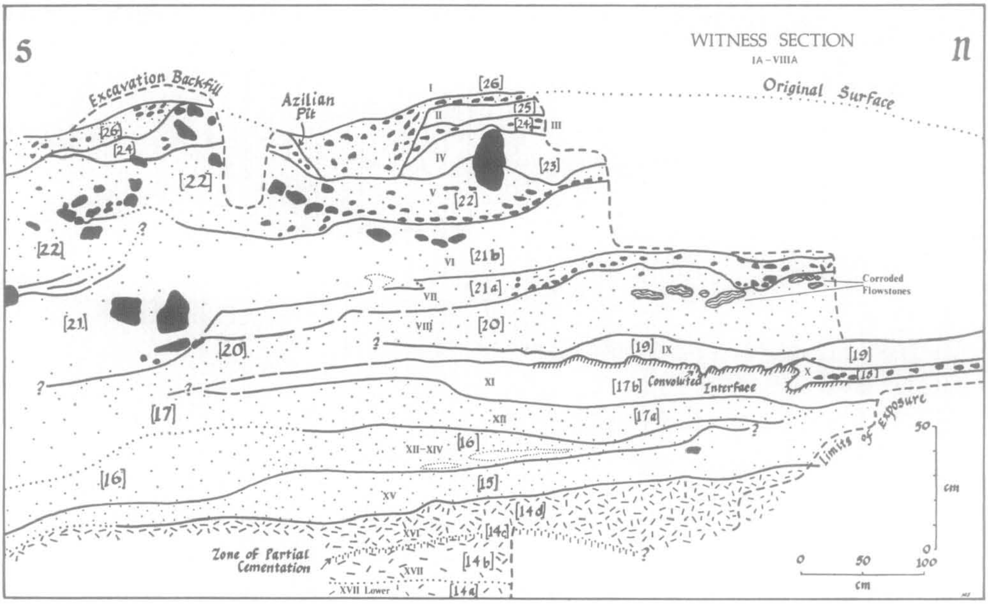

Figure 6. Profile of Witness Section (IA–VIIA), upper Cueva Morín.

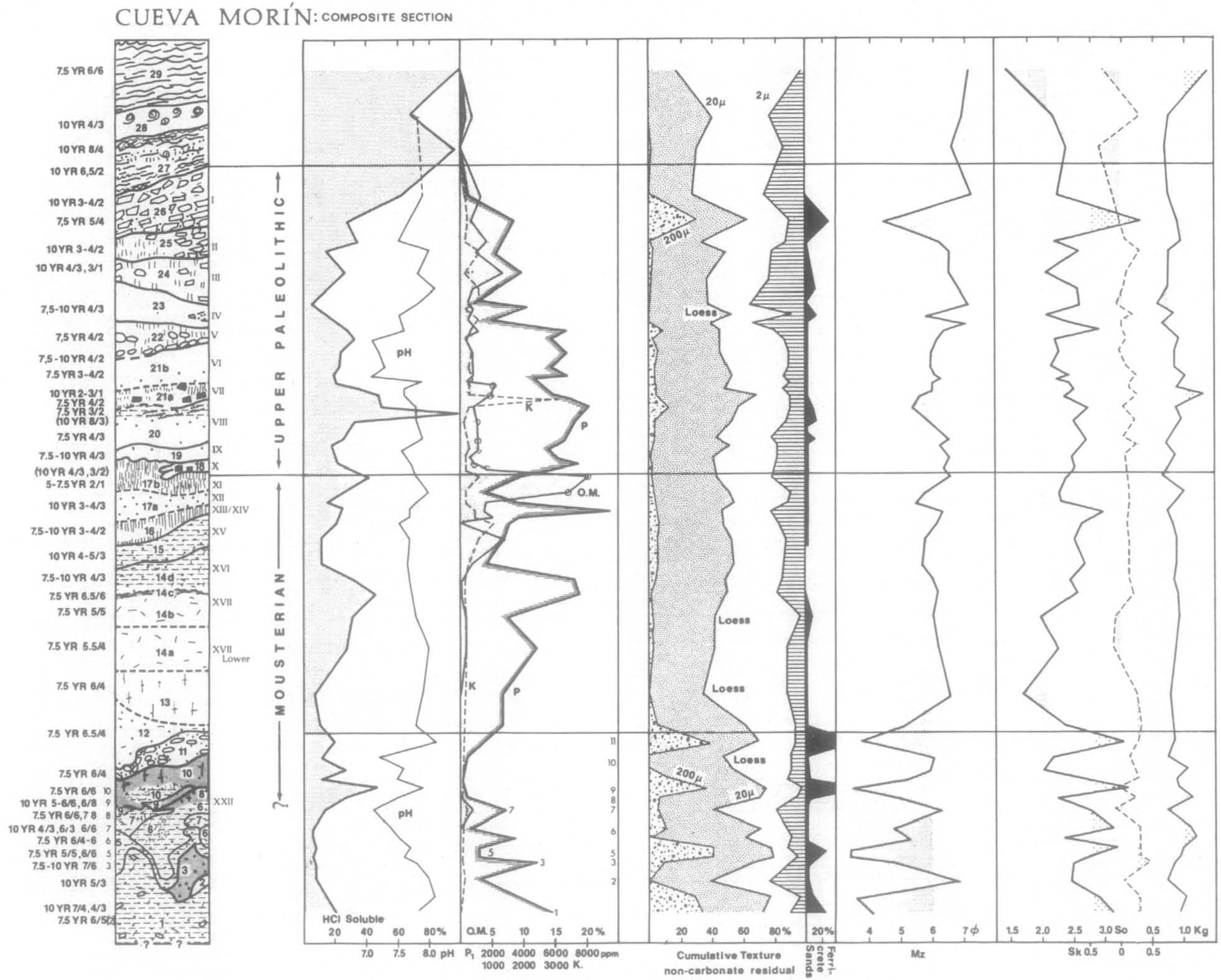

Figure 7. Composite analytical data from Cueva Morín.

Table 2. Analytical description of the archaeo-sedimentary column of Cueva Morín, Santander

29. *40 cm.* Reddish yellow (7·5 YR), cemented but porous flowstone with non-parallel bedding; residue of moderately sorted, negatively skewed, and leptokurtic silt.

28. *15 cm.* Brown (10 YR), calcified silt loam, highly platykurtic. Light occupation component, of undetermined nature, possibly Neolithic; large snails (*Helix nemoralis*) prominent (Archaeological Level 0).

27. *20 cm.* Very pale brown (10 YR), cemented and banded (2–4 mm laminae) flowstone with broad-leaf impressions and a residue of negatively skewed and highly platykurtic, silt loam. Light occupation component mid-way, including indistinct hearths and land snails in a light brownish grey matrix. ^{14}C date of 9000±150 bp (I–5150) on inorganic carbonates.

26. *15–40 cm.* Angular limestone spall in a matrix of partly calcified, brown to very dark grey (7·5–10 YR), loam (basal part) and silt loam (top part, near entrance, and pit fills of interior). The coarser facies with abundant ferricrete sands and granules is very poorly sorted, the finer facies negatively skewed and very platykurtic. Moderate to heavy occupation, including prominent storage (?) pits cuts up to 30 cm into underlying strata 25 and 24 (Figure 6); late Azilian (Level I).

25. *15 cm.* Dark brown (10 YR), silt loam with abundant angular spall near entrance. Moderately intensive occupation, with some distinct hearth lenticles; upper Magdalenian (Level II).

24. *20 cm.* Dark brown (10 YR), silt loam with dispersed, angular but partly corroded spall; some ferricrete sands and conspicuous loessic components. Moderate to heavy occupation; upper Solutrean (Level III).

23. *20 cm.* Dark brown (7·5–10 YR), homogeneous, silty clay loam, negatively skewed and very platykurtic. Near the entrance shifts to a moderately well-sorted, loess-textured silt loam with some ferricrete sands. Moderately intensive occupation, with a distinct occupation level; Final Gravettian (Level IV).

22. Dark brown (7·5 YR), silt loam with locally abundant, corroded spall and dispersed roof blocks. Probably contaminated ^{14}C date of 20, 105±340 bp (SI–953) on carbonaceous earth, from upper part of bed (R. Stuckenrath, pers. comm.). Heavy occupation; Final Gravettian over Evolved Aurignacian (Level V), presumably due to destruction of original contact by disturbance. Lower contact indistinct in interior, also due to artificial disturbance, related to several hearths in an apparent pit (Figure 6).

21b. *25 cm.* Dark brown (7·5 YR), silt loam with some, heavily corroded spall or roof blocks. Heavy occupation; Typical Aurignacian (Level VI). Lower contact partly indistinct due to disturbance, including a shallow excavation cutting into units 21a and 20 (Figure 6).

21a. *21 cm.* Dark grey (7·5–10 YR), silt loam with abundant, corroded spall in coarser-grained, leptokurtic, lower half. ^{14}C date of 28,665±840 bp (SI–955) on carbonaceous earth reasonably consistent with date on NaOH-soluble fraction (27,310±1490 bp, SI–955A) (R. Stuckenrath, pers. comm.). Heavy occupation with well-defined hearths; Typical Aurignacian (Level VII). Lower contact partly irregular in front, indistinct due to disturbance in back.

20. *25 cm.* Dark brown (7·5 YR), silt loam, increasingly coarse grained and less platykurtic with time (unit 20b); includes ferricrete sands and a layer of banded flowstone near the top, oxidized and now largely dissolved, forming chalky, amorphous masses of relatively clean lime. ^{14}C dates from carbonaceous earth of upper unit 20 are 27,685±1285 bp (SI–956) with 30,805±2830 bp (SI–956A) on the NaOH-soluble fraction, and 27,605±540 bp (SI–952) with 27,335±735 bp (SI–952A) on the alkali-soluble residue (R. Stuckenrath, pers. comm.). The oldest date of 30,800 is probably least contaminated. Heavy occupation, with well-defined hearths and some elaborate structures cutting through units 15–19 (Freeman & Echegaray, in press); Early Aurignacian (Level VIII). Lower contact indistinct at back due to disturbance.

19. *12 cm.* Dark brown (7·5–10 YR), silt loam, somewhat platykurtic. Heavy occupation; Early Aurignacian (Level IX). Lower contact with 17b irregular and convoluted, due to cryoturbation; contact to 18 indistinct, due to artificial disturbance. Since the cryoturbation affects beds 17b, 18 and 19 (Figure 6), it can be no older than early in the sedimentation of 19.

Table 2. continued

18. *0–10 cm.* Dark brown (10 YR), silt loam, very platykurtic, with dispersed, partly corroded, angular spall. A mixture of charcoal fragments and humic earth dated 27,775 ± 560 bp (SI–951), the small NaOH-soluble fraction of the same sample 42,590 ± 6580 bp (SI–951A) (Stuckenrath, pers. comm.), indicating substantial contamination by younger, intrusive charcoal and mixing at the convoluted bed 17b/18 contact. Implies that top of 17b is no younger than 35,000 years. A lens, recording heavy occupation; Chatelperronian (Level X). Lower contact partly convoluted by later cryoturbation.

17b. *20 cm.* Black (5·0–7·5 YR) silt loam with 17–20% organic matter, permitting high water absorption ratio conducive to frost heaving. Intensively altered and disturbed by very heavy occupation, with few recognizable features; Denticulate Mousterian (Level XI). Lower contact indistinct due to disturbance.

17a. *15 cm.* Dark brown (10 YR) loam. Heavy but dispersed occupation residues; Denticulate Mousterian (Level XII). Lower contact indistinct due to disturbance.

16. *10 cm.* Very dark brown (7·5–10 YR), silt loam. Heavy occupation with well-defined hearths in several interfingering organic horizons; Typical Mousterian with cleaver flakes (Levels XIII–XIV). Lower contact indistinct due to disturbance.

15. *20 cm.* Brown (10 YR) silt loam, with localized, extensive pale yellowish (5 Y), limonitic mottling. Heavy occupation, concentrated in one lense near top; sidescraper-rich Typical Mousterian (Level XV).

14d. *20 cm.* Brown (7·5–10 YR) silt loam, with lime grit and variable but extensive, reddish to brownish yellow (7·5–10 YR), limonitic mottling. Moderate to heavy occupation; Typical Mousterian with cleaver flakes (Level XVI).

14c. *5 cm.* Reddish yellow (7·5 YR), silt loam, representing a mottled, partly calcified segment of 14b, locally interbedded with thin flowstone, now partly decomposed and heavily oxidized; includes corroded limestone splices. Moderately intensive occupation; Typical Mousterian (top of Level XVII).

14b. *25 cm.* Brown (7·5 YR) silt, moderately well sorted and negatively skewed, with loess texture; locally mottled as 14c; some lime grit and dispersed limestone splices, some ferricrete sands. Moderately intensive occupation, concentrated in one 5 cm horizon with stone and artifact clusters suggesting a structure; Typical Mousterian with cleaver flakes (Level XVII). Lower contact indistinct and often arbitrary.

14a. *25 cm.* Light brown (7·5 YR), silt loam, negatively skewed; with lime grit and occasional, corroded splices. Moderately intensive occupation, concentrated in one horizon (0·5–2·0 cm thick, Denticulate Mousterian (Level XVII–Lower). Basal contact indistinct.

13. *35 cm.* Light brown (7·5 YR) silt, a typical loess, homogeneous and moderately well sorted; unstratified, compact, coarse prismatic structure, and 69% in 6–62 μm fraction. Moderate phosphate levels due to illuviation or animal occupation. Lower contact undulating but indistinct.

12. *0–50 cm.* Light brown (7·5 YR), silt loam, strongly positively skewed, and compact; with dispersed lime grit and splices. Moderate phosphate levels due to illuviation or animal occupation. Lower contact convoluted by cryoturbation.

11. *12 cm.* Light brown (7·5 YR), calcified sandy loam, very poorly sorted and strongly negatively skewed. Dispersed to abundant ferricrete fine-to-medium grade, rounded gravel, some angular fragments of red haematite and yellow limonite (derived concretions), and local concentrations of medium-to-coarse, partly corroded limestone spall. Some limonitic mottling, mainly brownish yellow (10 YR). Dips 0–20° to interior, with sharp but convoluted upper and lower boundaries (Figure 5).

10. *20 cm.* Reddish yellow (7·5 YR), partly calcified, silt loam, with basal or intermediate lenticles of laminated loam. Unlaminated samples 56–63% in 6–62 μm fraction and better sorted, in part typical loess. Saturated with limonitic staining; some laminar concentrations of brownish yellow (10 YR) colour; cryptocrystalline calcite in vertical, frost cracks.

Table 2. continued

9. *0–25 cm.* Yellowish brown to brownish yellow (10 YR), calcified silt loam as matrix to fine ferricrete gravel and lime grit; very poorly sorted and negatively skewed; thoroughly oxidized, with alternating, parallel bands of calcite and ferricrete cementation. Forms interrupted and convoluted segments, dipping 10–30° to cave interior (Figure 5).

8. *0–30 cm.* Reddish yellow (7·5–10 YR), partly calcified, silt loam; leptokurtic, and thoroughly oxidized. Forms pockets between the discontinuous segments of beds 7 and 9, from which it is sharply delimited, but in direct contact with 6 and 10, with which boundaries are indistinct to obscure.

7. *10–15 cm.* Brown (10 YR), partly calcified silt loam, negatively skewed; with limestone grit and extensive, yellowish brown (10 YR) mottling. Discontinuous and convoluted by cryoturbation, with median dip of 12–15° to interior. Moderately intensive occupation; probably Mousterian (Level XXII).

6. *10–40 cm.* Light brown (7·5 YR), silt loam, strongly positively skewed and leptokurtic; interstratified with lenticles of very poorly sorted loam; extensive reddish yellow (7·5 YR) mottling. Arranged as pockets, with abrupt contacts to units 1, 2, 5 and 7, but indistinct transition to 3 and 6; original dips probably 6–11° to interior. The sandy facies are enriched in phosphates, probably illuvial.

5. *5–30 cm.* Brown to reddish yellow (7·5 YR), sandy loam, very poorly sorted and very positively skewed, with abundant ferricrete sands; conspicuously not oxidized. Disposition in strongly convoluted lenticles, injected by lateral squeezing in wake of cryoturbation, after the oxidation of units 3 and 6–10. There is no separate unit 4, which is a mass of unit 1, detached by severe cryoturbation (see Figure 5).

3. *10–30 cm.* Yellow (7·5–10 YR) loam, strongly positively skewed, and extensively oxidized, with ferricrete bedding planes. Found in convoluted pockets only. Moderate phosphate concentrations are probably illuvial.

2. *0–10 cm.* Brown (10 YR), silt loam, laminated, with discontinuous band of corroded flowstone near abrupt contact with 6. Contact with 3 is indistinct.

1. At least *70 cm.* Brown (10 YR), calcified sandy loam, with abundant limestone grit and ferricrete sands, and dispersed angular spall; very poorly sorted and very positively skewed. Extensive, light brown (7·5 YR) limonitic mottling. Distorted bedding and convoluted surface, with detached, probably previously cemented, sediment blocks churned within overlying beds during intense cryoturbation. High phosphate level may indicate owl, bat or Cave bear occupance. Base not exposed, although units 1 and 2 locally abut or rest on bedrock.

Environmental Interpretation of Cueva Morín Sediments

Throughout the accumulation of the Cueva Morín sequence, external sediment continued to enter the cave across the irregular slope above the entrance, and finer sediment components are overwhelmingly of external origin. The decalcified facies conform closely to a range of external prototypes and so provide substantial information on external processes. Frost-weathering, cryoturbation, limestone precipitates and pedogenic features inside the cave amplify the environmental record. Discussion of these internal, non-cultural processes follows.

(1) *Cave Spall and Grit*

Small to moderate amounts of medium-to-coarse grade limestone spall were generated by frost-weathering during the accumulation of units 1, 9, 11, 18, 21a to 22, and 24; more substantial amounts are present in 25 and 26. On the other hand, lime grit and small limestone splices are prominent in units 1, 7, 9, 11, 12 and 14. The presence of frost spall argues for a colder climate within a cave interior that now rarely experiences frost. But the absence of spall does not demonstrate the opposite, since frost-weathering requires a unique balance of available rock moisture and periodic temperature oscillation around the freezing point (see discussion in Farrand, 1975*b*). Empirical evidence of general validity has yet to be produced as to just exactly what this balance should be, since conditions on an exposed cliff, or under an overhang, or in a damp or dry cave, with variable aeration, are infinitely variable. Experimental work by Tricart (1956) suggests that coarse spall should result from protracted seasonal frost, at very low temperatures, whereas grit and smaller splices can be expected in response to frequent and rapid, daily freeze–thaw alternations with a smaller temperature range. The former conditions would be met in a cold continental climate, the latter in a cool maritime climate. But the variable impact of seasonal and total available moisture, and of freeze–thaw alternations of variable amplitude, could also confound such a generalization.

The Morín record shows three patterns of roof rubble accumulation: in the lower units (1–11), both grit and coarse spall are found together, possibly reflecting a cold, wet climate with frequent freeze–thaw oscillations of variable amplitude; in the middle units (12–14), grit and fine splices are the rule, suggesting a cool climate with frequent, daily freeze–thaw oscillations; finally, in the upper units (18–26), coarse spall is characteristic, possibly indicative of a climate with long and intense seasonal frost periods.

(2) *Cryoturbation*

The record of cold cave climate is complemented by striking evidence of large-scale frost-heaving (cryoturbation), resulting from rapid downward penetration of frost into wet sediments, or frost-generated, plastic flow of water-saturated sediment across gentle inclines (congelifluction). A particularly violent cryoturbation disrupted units 1–9, tearing apart segments of units 1, 7 and 9, injecting lenticles such as unit 5 into or between older strata. Cryoturbate contacts are evident for bed 11, and the disposition of this deposit, rich in frost-weathered limestone and external rubble, indicates a classic congelifluction sludge that oozed across the cave floor. On a smaller scale, unit 9 also indicates congelifluction. Since unit 9 was torn apart by the major episode of frost-heaving, that event must have been coeval with the influx of unit 11. A vertical freeze–thaw amplitude of at least 1 m in the sediment column of Cueva Morín points to an exceptionally severe climate. The small-scale cryoturbation that deformed the contacts between units 17b, 18 and 19 was aided by selective water absorption in the highly organic unit 17b; this was a subsoil phenomenon, probably coincident with the cold interval recorded by the external and internal rubble in units 20 upper and 21. Cryoturbation or congelifluction features are apparent in other Cantabrian caves as well.

(3) *Chemical precipitation*

Several episodes of calcification or flowstone accretion are indicated. Secondary calcification is prominent in units 9 to 11, mainly reflecting a phase of lateral seepage by carbonate saturated waters—penecontemporaneous with or following the deposition of unit 11, but certainly prior to accumulation of unit 12. Calcite then concentrated in the sandy beds, but units 1, 7, and 9 must have already been somewhat calcified prior to their cryoturbation, in order to avoid boundary mixing. Other periods of calcification, accompanied by thin and localized travertine formation, are recorded in units 2 upper, 14c and 20 upper. Finally, there are the cave entrance flowstones, of early to mid-Holocene age. In recent millennia this flowstone block was corroded, rather than enlarged. This indicates that both late Pleistocene and late Holocene conditions were less favourable for flowstone development, being too wet or too cool, or both.

(4) *Pedogenetic features*

Two kinds of internal "soil" formation can be identified: (i) oxidation in relation to a high but fluctuating local water table, and (ii) partial decalcification.

Oxidation phenomena include irregular patches of limonitic discoloration; wavy reddish, brownish, or yellowish, subhorizontal bands; as well as extensive or complete staining. Objective criteria other than colour are difficult to obtain, since total Fe would be a function of the ferricrete sands present, while free Fe_2O_3 provides only a partial measure, as most of the limonitic iron is precipitated in irreversible form. The 18 free Fe_2O_3 determinations from units 1 to 11 vary insignificantly between 0·75 and 0·86%, implying that the limonite is indeed mainly precipitated. Mottling or extensive staining are most prominent in units 3 and 8–10, but moderately prominent in units 1, 5–7, 11, 14c and 20 upper. The limonitization of units 1–11 argues for a perched water-table near the level of the cave floor, most probably at the time unit 11 was accumulating. The overall environment must have been phenomenally wet. Such gley conditions would have facilitated intensive frost-heaving at this time, if not made it possible. Calcification began shortly afterwards, in part even simultaneously, judging by the interlamination of limonite and calcite in unit 9. Later episodes of mottling, recorded in 14 upper and 15, and again in 20 upper, were limited to areas where flowstone was forming or had recently been laid down, probably in response to water periodically dripping down from the roof.

Partial decalcification is apparent in unit 2, where a flowstone was partly dissolved, probably during accretion of units 3–6, all low in carbonates. More prominent decalcification is evident in units 21b and 22, where spall is heavily corroded and pH an average of 0·5 lower, through a 30 cm column of sediment. (The moderately high bulk loss in acid is here largely due to organic solubles, such as free phosphates or collophane, since spot determinations of $CaCO_3$ by the Chittick method gave values of only 2–3%.) Secondary calcification is apparent in 20 upper and 21a, although *in situ* flowstones in 20 upper were initially corroded and partly destroyed, by abundant water, perennially undersaturated in carbonates. Decalcification and the absence of oxidation mottles argues for persistent downward percolation, without a dry season. Leaching probably accompanied or continued during the slow accumulation of clayey unit 23.

More difficult to interpret are situations where calcified beds also are intensively mottled (e.g., units 9 and 11, and several beds in Castillo Cave), or where corroded spall is embedded in a calcified matrix (common in El Pendo). In some cases profile analysis shows that such processes were sequential, e.g. oxidation of decomposing flowstones. Predepositional corrosion of spall is unlikely because all spall faces are equally affected and micro-joint corrosion is not apparent on the cave roofs today, where water only percolates through intersecting master-joints. Wherever alternative explanations are improbable, it is reasonable to assume that periodic changes in carbonate saturation or water availability were responsible for combinations of calcification with mottled beds or corroded spall. Such periodicity is most likely during warm summers.

(5) *Colluvial Influx*

The preceding evaluation of external and internal sedimentation processes implies that decalcified residues, as processed here, will overwhelmingly record external sediment introduced via the cave entrance. For one, the cave has been little enlarged during late Pleistocene time, judging by the absence of rockfalls in the excavation area, while the amount of detrital sediment released through decalcification of almost-pure limestone within the cave must have been minimal. Secondly, the roof is not fissured, and in the past water has dripped in at a very few points, below intersecting master-joints. In addition, Holocene sediment has accumulated exclusively at the cave entrance, while

Pleistocene deposits of the interior are locally and minimally capped by a millimetre or two of calcite, but no detrital sediment. This precludes a measurable component of clay or silt entering the cave by roof cracks, rather than from the entrance. Consequently, the decalcified cave sediments should provide a temporal record of changing ground cover and slope runoff energy, filtered by the mechanics of moving sediment diagonally across the irregular rock outcrops on either side of the cave mouth, or directly down the cliff face above the entrance. Two interrelated processes are therefore involved: (a) erosion and transport on the external slopes, and (b) runoff energy between the drip-line and the cave interior.

It should be possible to estimate these processes from the textural data, using the prototypes provided by sediments from the Morín quarry exposures. Mean grain size (Mz) should reflect external erosion and transport in a generalized way, providing an indirect parameter for slope energy. On the other hand, sand content should record peak runoff energy along the internal axis of the cave, while clay levels would probably reflect median or waning energy conditions. Finally, sorting (So) should be sensitive to the periodicity of hydrodynamic energy as well as to the potential input of mass movements.

In order to investigate the nature of sample clustering, Mz was plotted versus percentage clay on one graph, So versus percentage sand and grit on a second. Those samples conforming to the textural definition of a loess were first singled out as a separate population. The remaining samples were then divided on both graphs into six sequential

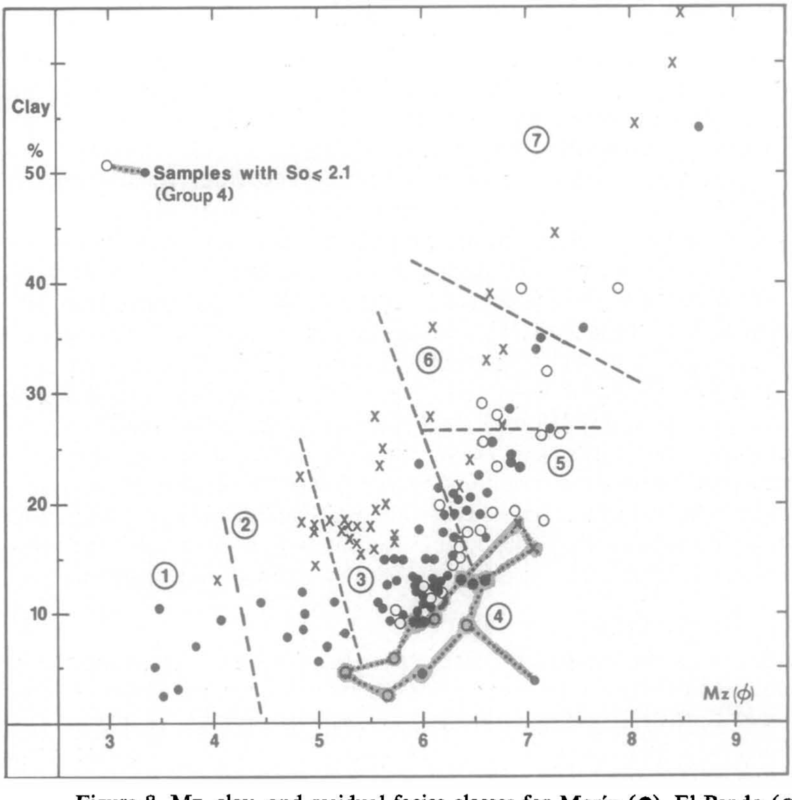

Figure 8. Mz, clay, and residual facies classes for Morín (●), El Pendo (○) and Castillo (×). The class 3 members for Castillo form an independent cluster and have distinct sorting and sand values, and so are treated as a separate subclass 3′.

classes, representing a gradation of energy conditions. The 30 samples from El Pendo and 38 from Castillo were then added to the 72 from Morín, and minor adjustments of class clusters made. In particular, it was found that the "intermediate" samples from Castillo on the Mz/clay graph clustered quite differently on the So/sand graph, due to exceptionally poor sorting and high sand content, requiring an extra subgroup.

The final Mz/clay graph for 140 samples, amplified by So data for loessic textures, is shown in Figure 8. The resulting eight classes and subclasses were then computer tested by the SPSS discriminant-function program. The parameter means and discriminant functions are shown in Table 3, and the computer scatterplot is reproduced in Figure 9. Finally, the computer classification for the sedimentary facies classes originally defined is given in Table 4. The programme identified 85·0% of the 140 samples as correctly classified, although all but nine are unambiguously defined on both of the original graphs. The classes are consistent and real.

The seven major facies classes are sensitive to Mz, clay, So and sand parameters, in that order, and serve to express a sequential gradient of differing energy conditions.

Class 1 (Figure 8) includes Morín units 1, 5, 9 and 11, for which the standard deviations show that Mz, So and sand content are most consistent (Table 3). There is no external prototype for this coarse, sandy and poorly sorted group. Clay content of the one congelifluction unit (11) is unusually low, suggesting that mass movements did not

Table 3. Parameter means and Standard Deviations, and canonical Discriminant Functions for residual facies classes

Class means (standard deviations)

Class	Mz (Mean)	Clay (%)	So (Sorting)	Sand–Grit (%)
1	3·71 (0·26)	7·21 (3·97)	3·08 (0·22)	58·51 (4·49)
2	4·95 (0·23)	12·39 (5·03)	2·93 (0·56)	44·82 (6·40)
3	6·01 (0·22)	13·71 (3·41)	2·40 (0·21)	20·69 (5·85)
3′	5·45 (0·18)	19·06 (3·52)	3·34 (0·30)	33·71 (6·02)
4	6·25 (0·55)	9·49 (4·50)	1·92 (0·20)	12·34 (5·40)
5	6·69 (0·29)	21·83 (3·06)	2·49 (0·26)	14·37 (6·02)
6	6·72 (0·37)	31·32 (3·27)	2·85 (0·38)	16·47 (7·91)
7	7·77 (0·70)	48·00 (10·57)	2·76 (0·51)	9·54 (5·98)

Standardized canonical discriminant function coefficients

	Function 1	Function 2	Function 3	Function 4
Mz	0·5420	−0·7253	0·4513	1·3785
Clay	0·2871	1·1944	−0·7381	−0·6316
So	0·3203	−0·2514	1·4578	0·0816
Sand–Grit	−0·5812	0·1968	−0·3564	1·2314

Canonical discriminant functions evaluated at group means

Class	Function 1	Function 2	Function 3	Function 4
1	−7·395	2·748	−1·200	−0·667
2	−3·914	1·164	−0·307	0·816
3	−0·324	−1·145	−0·086	−0·064
3′	−1·183	1·181	1·804	−0·216
4	0·100	−2·684	−0·785	−0·311
5	1·993	−0·699	0·255	0·305
6	2·810	1·585	0·228	−0·145
7	6·141	3·681	−1·179	0·048

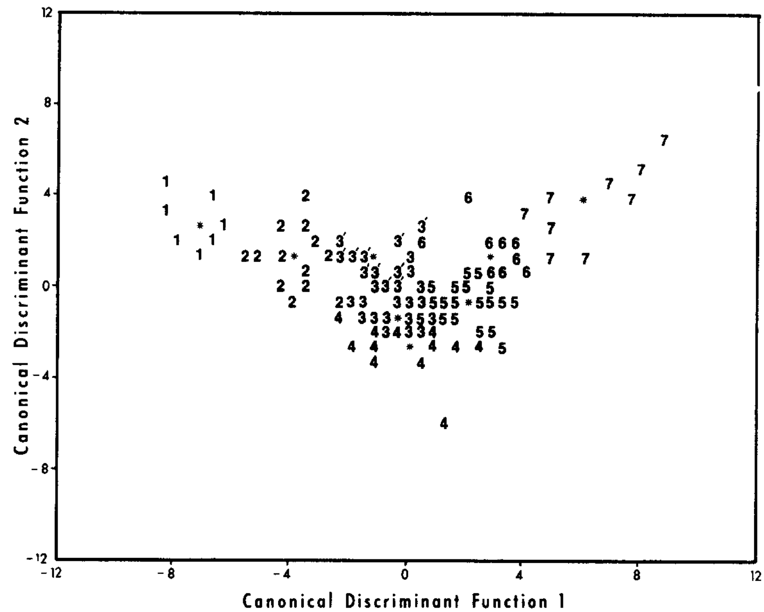

Figure 9. Scatterplot of facies classes defined according to discriminant functions 1 and 2. Class means indicated by stars.

Table 4. Classification results for residual facies by Distriminant Function programme

Actual class	Number	Predicted class membership (%) 1	2	3	3′	4	5	6	7
Class 1	7	100·0	0	0	0	0	0	0	0
2	14	7·1	78·6	7·1	7·1	0	0	0	0
3	43	0	0	86·0	2·3	11·6	0	0	0
3′	16	0	0	6·3	93·8	78·6	0	0	0
4	14	0	0	7·1	0	0	14·3	0	0
5	26	0	0	3·8	0	0	88·5	7·7	0
6	11	0	0	0	9·1	0	9·1	81·8	0
7	9	0	0	0	0	0	0	33·3	66·7

introduce the sediment to the cave but, rather, helped move it within the cave. This suggests that polymodality is primarily due to fluctuating runoff velocities. Accretion is best explained by periods of unusually high, overall hydrodynamic energy, during periods of exceptionally intensive rains, and at a time when surface soils had been stripped of all but their basal profiles.

Class 2 includes Morín units 3, 6, 8, 10 lower, 12, 20b, 26 lower, as well as unit B2. Mz and sand content are most consistent. The external prototype B2 falls out of the 1σ range of Mz (B2 is coarser) and So (B2 is better sorted). Fluctuating runoff velocities, despite high overall energy and intensive rains, are suggested to interpret this coarse-grained, polymodal cave facies with repeated, lenticular bedding.

Class 3 includes Morín units 7, 10 upper, 14a, 14d, 16–17a, 20a, 21a–22 lower, 25 lower, 26 upper, B3 and the modern agricultural soil. Mz and So are most consistent, and B3 only falls out of the range of Mz (coarser). Improved and consistent sorting suggest sustained, moderately vigorous slope runoff and repeated, small-scale bursts of cave runoff; the substantially higher silt content argues that loess as well as soil derivatives were being eroded during periods of heavy rains.

Class 4 includes Morín units 10 middle, 13, 14b, 23 middle, 24 upper, 29, and B4. Mz and So are most consistent, and B4 falls within 1σ of all four parameter means. These are loesses, loessic matrices (24 upper), or aberrant, silty flowstone residuals (29, diverging strongly from the modal pattern on Figure 8). Discounting the last case, relatively vigorous runoff over loessic surficial sediment is implied. The increase of silt from unit B3 to unit B4 in the Morín quarry cave suggests that aeolian accretion was penecontemporaneous with loess mobilization by running water.

Class 5 includes Morín units 2, 15, 17b upper, 18–19, 22 upper, 24 lower, 25 lower, 27–28, B1 and B6ii. Mz and So are most consistent. B1 falls within 1σ for all parameters, B6ii diverges only on clay content (higher); these external prototypes are dominated by soil derivatives, although some of the heavy silt component probably is of loessic origin, explaining the polymodality of the class. Although external runoff was sufficiently effective to erode B-horizon material of mixed calibre, inside the cave mobilization was mainly restricted to suspended sediment. Similar processes operated during most of early Holocene time, although external runoff was far more subdued, in order to allow flowstone development.

Class 6 is limited to Morín units 23 and B5. Mz, clay and So are most consistent for the class. B5 diverges through better sorting, with its loessic components, but is interstratified with class 7 lenticles. Interbedded with loess near the entrance, unit 23 also is polymodal and argues for variable, mainly low-energy mobilization within the cave, despite a measure of effective, external runoff.

Class 7 is only represented in the Morín quarry, and the group is heterogeneous, with a high clay content its most basic property (Table 3 and Figure 8). B6i diverges through its lower clay content, A1 through a higher Mz, better sorting, and less sand. Despite their polymodality, these are almost exclusively suspended sediments, derived from clayey B-horizons. The interbedded gravel in A1 and particularly the abundance of chaotic, crude rubble in B6i, argue for prominent mass movements, although class 7 terra rossa on the Castillo hillside fills a soil pipe in limestone (see Figure 14), and may be in more or less primary position. Of five cave examples in El Pendo, Castillo and La Flecha (see below), three are flowstone residuals, but the other two (El Pendo unit 2 and La Flecha unit 6) could well be due to viscous transfer of water-saturated clayey soil. Protracted heavy rainfalls today frequently lead to earthflows on pastures, with thick turf, on 10° inclines. Such mass movements are probably implicated in detrital cave deposits of type 7.

As defined and interpreted here, the seven classes of residual facies are more than ordinal numbers. They also provide a numerical index of 1 to 7 that is inversely proportional to the vigour of external denudation and internal sediment mobilization. Runoff energy is a function of (i) the effectiveness of ground cover (rainsplash interception, rooting network, infiltration capacity), (ii) the available sediment (B-horizons, lithosols, loess) and (iii) the intensity of rainfall (dependent upon rate, duration, drop size, and wind speed). Reasonable, even if highly general, inferences can be made for each of these variables, as argued above. The sedimentary facies class, in capitalized form (e.g. Facies 1), is consequently used below as a quantitative index of both runoff energy (1 high, 7 low) and slope stability (1 low, 6 high; 7 with qualifications). As such it provides a semicontinuous measure of environmental processes and conditions that substantially transcend the cave micro-environment.

Comprehensive interpretation of the Morín column is attempted in Figure 10, on the basis of facies class, frost indicators, chemical precipitates and alteration phenomena.

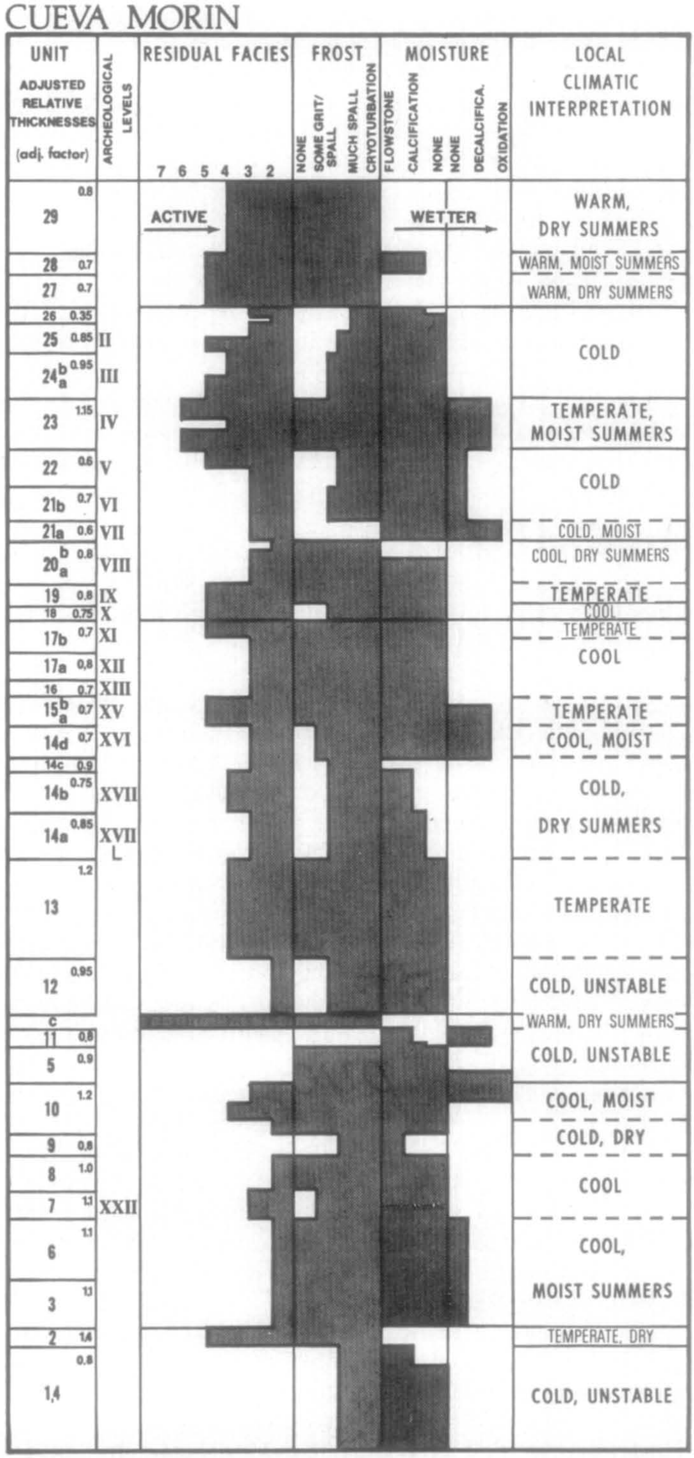

Figure 10. Synthetic evaluation of the Cueva Morín column.

These four measures, in combination, provide a replicable groundwork for the partial and explicitly local, climatic interpretation suggested in the right-hand column. To provide a better temporal measure for the individual beds, an adjustment factor (shown in the upper corner of the left-hand column) was applied to mean sediment thickness; this factor includes Mz, spall proportions, proximity to the entrance and the prominence of cultural components. The "adjusted relative thickness" of the left-hand column consequently provides a closer approximation of time than the mean thickness in the profile of Figure 4. This column does not, however, reflect sedimentary breaks or erosional disconformities, cultural or geological. The overall interpretation of Figure 10 is based on systematic geomorphic evaluation of both the external and the internal, cave-specific environment. It outlines an alternative synthetic methodology for the interpretation of cave sediments, one that is not grounded in mechanical assessment of a battery of analytical data applied exclusively to cave profiles. It can, of course, be improved upon by micromorphological studies (see Goldberg, 1979*a*, *b*) and scanning electron microscopy, provided that such specialized resources are available.

Cultural Components in Cueva Morín

The impact of human occupance can be considerable in a cave environment, leading to admixture of rock, bone, and a variety of micro-organic and biochemical components [see Butzer (1978) for a discussion of this organic fraction]. Intensive occupation horizons can accumulate rapidly, while intensive disturbance, sometimes deliberate, by later inhabitants can obscure long sedimentation breaks or simulate abrupt discontinuities of sediment properties. In Cueva Morín, the disposition and development of units 15–26 was significantly affected by repeated occupation, and a majority of the bed contacts were modified or even created by cultural disturbance (see Table 2). Discrete episodes of occupation favoured admixture of cultural components in mineral sediment that had already been accumulating slowly for centuries or millennia; in such cases coeval sedimentation may have been minimal. In other instances, renewed occupation led to disturbance of as much as 10 cm of older occupation residues, e.g. through human trampling after periods of rain, when water puddles on the cave floor; in this way substantial proportions of older sediment can be reworked into a significantly younger matrix. The implications of repeated but sporadic occupation are considerable, not only for interpretation of the sediment column but also for evaluation of "primary" archaeological contexts.

(1) Periods without occupance will be poorly represented, particularly with low-energy, external sediment mobilization (Facies classes 5, 6 or 7), so that the temporal record will be distorted or incomplete.

(2) Periods of repeated, intensive occupation will lead to "smudging" of the environmental trace and, in some cases, to "over-representation" of sedimentary thickness and complexity, with beds often composed primarily of cultural components and simulating detail that may be no more than background "noise".

(3) Disturbance commonly results in mixed artifactual assemblages in the lower part of individual strata, and the significance of modern mud trampling suggests that associations will be primary only if they are preserved in discrete and three-dimensionally intact lenticles.

Comparison, further below, with other cave columns indicates that the Morín profile is indeed incomplete, and there is some smudging effect. But over-representation is not a problem, judging by the thick and elaborate development of the late upper palaeolithic horizons of El Juyo (Klein *et al.*, 1981) and Piélago (Butzer, in preparation), in Santander, or Tito Bustillo (Moure & Cano, 1976), Balmori (Clark, 1975), and La Riera (Straus & Clark, 1978), in Asturias.

The organic matter, phosphorus and potassium data generated for Morín (Figure 4) are primarily intended to document the abundance of cultural components. Of geochemical interest is the fact that phosphorus has evidently been mobilized downward in the profile, judging by major concentrations as much as 80 cm below horizons of intensive occupation. Vertical and lateral variability of these cultural components within Morín will be considered elsewhere (Butzer, in press).

Lithic artifacts contribute significantly to the sand and grit component, as does fine chipping debris. This material, amounting to as much as 100% of some sieve fractions, was microscopically identified according to lithology and shape, and removed and excluded from the totals. Chert, a light grey quartzite and, less commonly, diabase, chalcedony, and vein quartz were used for stone working. All of these rock types had to be carried into the cave. Quartzite was probably obtained from Buntsandstein exposures or derivative sediments in the adjacent Pisueña drainage, or from Wealden (Cretaceous) conglomerates exposed just of the Obregón valley. The dark greenish diabase, locally called ophite or serpentine (*sic.*), comes from intrusions within Keuper (Triassic) shales exposed along the middle Pisueña. The chert and rare chalcedony derive from local limestones. Similar raw materials were employed for lithic manufacture in other caves reported on more briefly below.

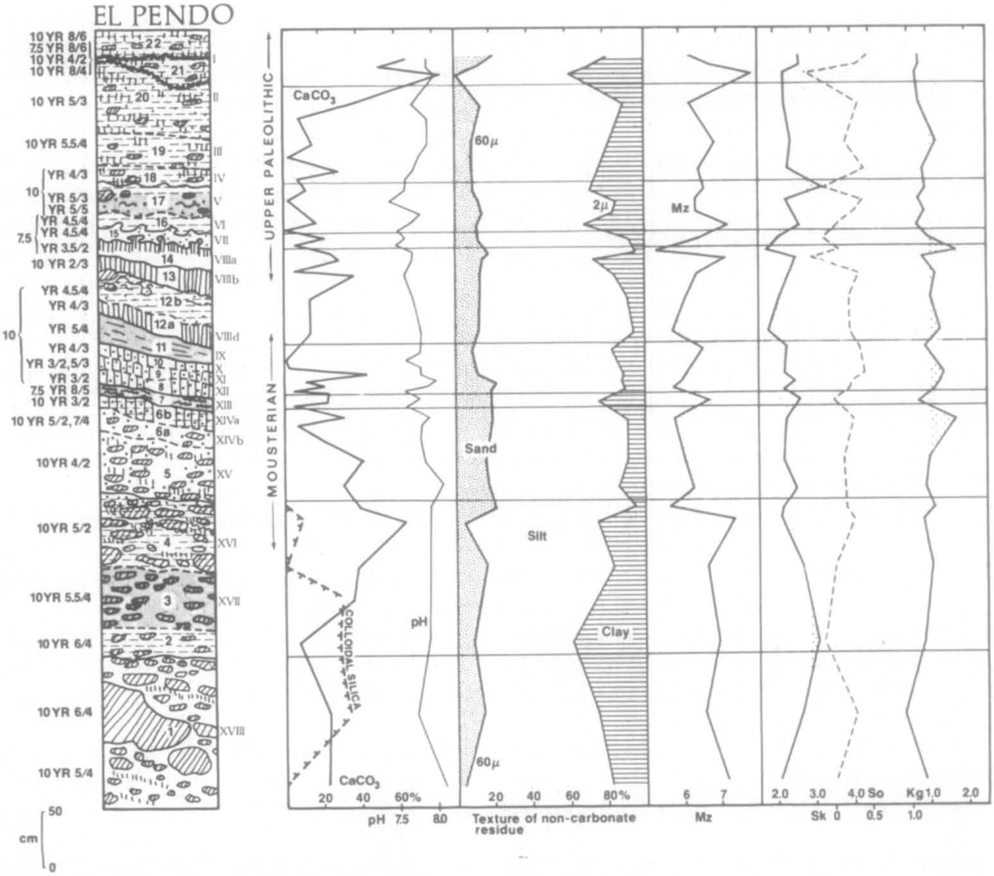

Figure 11. Analytical data from El Pendo Cave.

The Archaeo-Sedimentary Sequence of El Pendo

The cave of El Pendo is situated 2 km south of Escobedo, and 11 km southwest of Santander. This is an area of hilly karst topography, with numerous, large uvalas and short disappearing streams, also developed in Aptian limestones. Local relief of these depressions is in the order of 40 to 90 m, and the cave of El Pendo represents the tunnel carved by an underground stream draining such an uvala. Opening to the south, the 25 m wide, high and open cavern descends some 50 m vertically along a length of almost 150 m. Sill elevation is 85 to 88 m above sea level and 5 m and more above ground level on the outside, so impeding sediment influx.

The strata are presented in an analytical chart (Figure 11) and a synoptic Table 5, as based on study of 30 samples. Units 12–22 are exposed just inside of the sill, and thin out rapidly to the interior; units 4–11 were preserved as a witness section along the stairway leading down into the cave; the basal beds are only visible in a deep, 2 m pit but are probably far more extensive in the subsurface of the interior than are the richer archaeological horizons. The archaeology, fauna and pollen are described in Echegaray (1980), on the basis of re-study of materials excavated in 1955. The prominence of distinctive hearth stratification in units 2, 6 to 10, 12a, 13 to 14, 17b and 20 indicates that the archaeological residues of these levels are to a large degree primary.

Table 5. Analytical description of the archaeo-sedimentary column of Cueva del Pendo, Santander

22. *18 cm.* Yellowish brown (10 YR), silty clay loam, very positively skewed and platykurtic; with some dispersed, coarse-grade spall; with basal, partly decalcified and oxidized (reddish yellow, 7·5 YR), silty, laminated flowstone with residual clay texture. Heavy occupation; mixed Azilian and Bronze Age (archaeological Level I, upper).

21. *2–25 cm.* Dark greyish brown (10 YR), calcified silty clay with dispersed, partly corroded, coarse grade spall; very negatively skewed and platykurtic; with basal, partly decalcified, very pale brown (10 YR), laminated flowstone with residual clay texture. Heavy occupation; Azilian (Level I, lower).

20. *40 cm.* Brown (10 YR), well-stratified, silt loam, very positively skewed and platykurtic; with dispersed, partly corroded spall and travertine rubble; angular blocky structure; moderate, brownish yellow (10 YR) mottling. Heavy occupation with distinct hearths; lower Magdalenian (Level II). Lower contact indistinct due to artificial disturbance.

19. *25 cm.* Brown (10 YR), partly calcified silt loam, leptokurtic; with dispersed, corroded spall and travertine rubble; angular blocky structure; extensive brownish yellow to strong brown (7·5–10 YR) mottling. Moderately intensive occupation; Terminal Aurignacian? (Level III). Lower contact indistinct due to disturbance.

18. *15 cm.* Brown (10 YR), partly calcified, silty clay loam, very positively skewed; with intensively corroded spall. Moderately heavy occupation; Terminal Aurignacian? (Level IV).

17. *25 cm.* Brown (10 YR), well-stratified, silty clay loam, very poorly sorted, very negatively skewed, and leptokurtic (top, subunit 17b); and yellowish brown (10 YR) silt loam, very positively skewed (base, subunit 17a). Corroded lime grit and concentrations of corroded spall or blocks, with convoluted beds; extensive yellow (10 YR), limonitic banding in upper part, general staining in lower part. Moderately intensive occupation in upper part, with distinct hearths; light occupation in lower part; Gravettian, mixed with Evolved Aurignacian at base (Level V). Lower contact indistinct due to artificial disturbance or solifluction or both.

16. *15 cm.* Brown (7·5 YR), silty clay loam; diffuse, yellowish brown (10 YR) mottling. Light to moderate occupation; Evolved Aurignacian (Level VI). Lower contact irregular, convoluted but sub-horizontal, due to congelifluction or cryoturbation.

15. *10 cm.* Brown (7·5 YR) silt loam of typical loess texture, moderately well sorted and negatively skewed; with dispersed, corroded lime grit, diffuse brown (7·5 YR) mottling. Light to moderate occupation; Typical Aurignacian (Level VII). Lower contact convoluted and festooned by cryoturbation and congelifluction.

Table 5. continued

14. *15 cm.* Dark brown (7·5 YR), moderately well sorted and leptokurtic silt loam; and very negatively skewed silty clay loam. Moderate to heavy occupation, particularly in upper half, with typical loess texture and distinct hearths; Chatelperronian and early Aurignacian (Level VIIIa).

13. *10 cm.* Very dark brown (10 YR), silt loam, very positively skewed. Heavy occupation, with prominent hearths; early Aurignacian (Level VIIIb). Lower contact convoluted by congelifluction.

12b. *25 cm.* Brown (10 YR) silt loam of loess texture, moderately well sorted; with some corroded roof blocks linked to a rockfall; angular blocky structure. Light to moderate occupation, but no diagnostic artifacts.

12a. *15 cm.* Brown (10 YR) silt loam of loess texture, moderately good sorting and leptokurtic, with angular blocky structure. Moderate to heavy occupation, with prominent hearths; Denticulate Mousterian (Level VIIId).

11. *25 cm.* Yellowish brown (10 YR), stratified to laminated, silt loam, very positively skewed; angular blocky structure and diffuse yellow (10 YR) mottling. Light occupation; Mousterian (Level IX).

10. *7 cm.* Dark brown (10 YR) silt loam, very positively skewed and leptokurtic; Heavy occupation with prominent hearths; Mousterian (Level X). Lower contact indistinct due to disturbance.

9. *10 cm.* Brown (10 YR), laminated and partly calcified silt loam, leptokurtic. Moderate to heavy occupation, with many conspicuous hearths; Denticulate Mousterian (Level XI). Lower contact indistinct due to disturbance.

8. *15 cm.* Very dark greyish brown (10 YR), well-stratified, silt loam. Heavy occupation with many distinct hearths; Denticulate Mousterian (Level XII).

7. *10 cm.* Reddish yellow (7·5 YR) to pale brown (10 YR), well-stratified, largely decomposed and oxidized flowstone with residual texture of clay loam; with haematite microconcretions. Heavy occupation, with distinct hearths; sidescraper-rich Typical Mousterian with cleaver flakes (Level XIII).

6b. *10 cm.* Very dark greyish brown (19 YR), well-stratified, partly calcified, silt loam, very leptokurtic; extensive brownish yellow (10 YR) mottling. Heavy occupation, with prominent hearths; sidescraper-rich Typical Mousterian (Level XIVa). Lower contact indistinct due to disturbance.

6a. *15 cm.* Greyish to pale brown (10 YR), well-stratified, silt loam, with dispersed, angular spall. Moderate to heavy occupation, with distinct hearths; sidescraper-rich Typical Mousterian (Level XIVb). Lower contact indistinct due to disturbance.

5. *45 cm.* Dark greyish brown (10 YR), stratified, calcified, silt loam as matrix to coarse-grade, angular spall. Moderately intensive occupation; Mousterian (Level XV).

4. *60 cm.* Greyish brown (10 YR), stratified, heavily calcified, partial matrix of silty clay loam, intergrading with banded flowstone, to mass of coarse angular spall, slabs, and roof blocks; some yellowish brown (10 YR) mottling. Extensive voids indicate lack of fine sediment and rapid accumulation. Calcrete, with colloidal silica, is postdepositional. Light to moderate occupation throughout argues against a catastrophic rockfall; Denticulate Mousterian (Level XVI).

3. Yellowish brown (10 YR), calcified, silt loam as matrix to coarse, angular spall; extensive brownish yellow (10 YR) mottling. Postdepositional carbonates rich in colloidal silica. Light to moderate occupation, but no diagnostic artifacts (Level XVII). Lower contact gradational.

2. *20 cm.* Light yellowish brown (10 YR), partly calcified, silty clay, exceptionally poorly sorted and very negatively skewed; with dispersed, corroded spall; some brownish yellow (10 YR) mottling. Abundant, postdepositional colloidal silica. Light occupation, with some distinct hearths but no diagnostic artifacts.

1. At least *120 cm.* Light yellowish brown (10 YR), partly calcified, silt loam, with sorting decreasing and increasing platykurtic upwards; as matrix to coarse, partly-corroded spall, slabs, and roof blocks; faint but extensive brownish yellow (10 YR) mottling. Postdepositional colloidal silica decreases with depth. Light to moderate occupation indicated by weak hearths and undiagnostic artifacts, particularly near base, but other, heavy, localized concentrations of large bone splinters may also record Cave bear occupation.

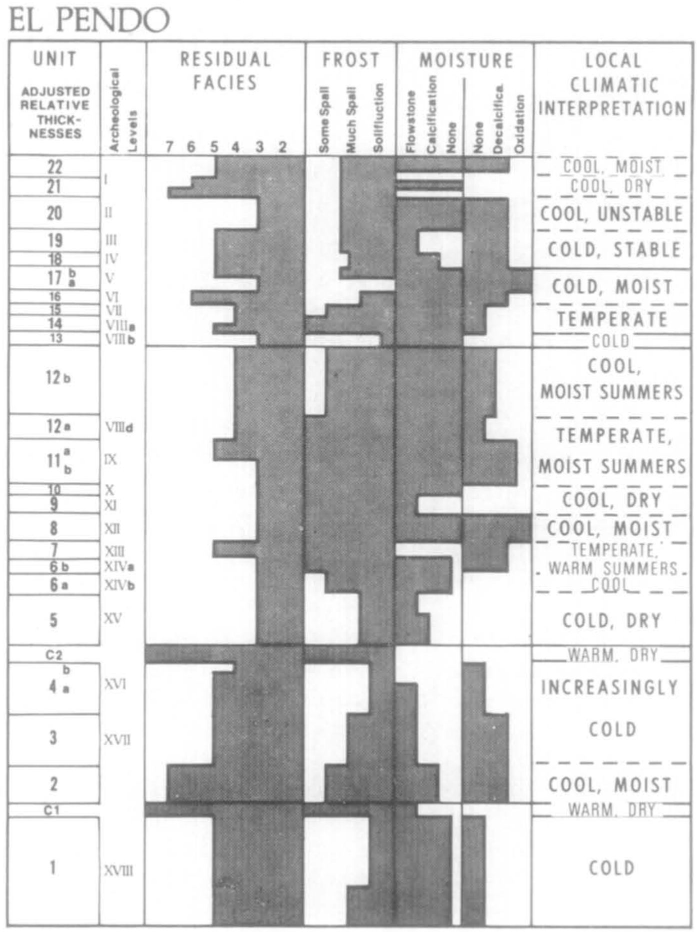

Figure 12. Synthetic evaluation of the El Pendo column.

Environmental Interpretation of the El Pendo Sediments

The basic problems of interpretation for Morín and El Pendo are similar, but the prominent sill has impeded sediment influx, and external sands are of finer grade than in Morín, particularly in units 1 to 4. Holocene accumulations are limited to a veneer of organic soil and some roof rubble on and just inside of the drip line. Despite the prominence of ancient rockfalls (at least five distinct episodes are suggested) along the length of the cave floor, little sediment accretion is evident today. The underground stream now enters the cave some 10 m lower than the Pleistocene sediments described here and played no role in their accumulation. Only part of the runoff coming directly down the external rock faces enters the cave, and the deep and enclosed uvala in front of El Pendo precludes aeolian transport into the cave. The concentration of late Pleistocene deposits near the entrance is consequently due in substantial part to accelerated weathering and preferential settlement just inside the drip line, where seepage moisture continues to be prominent.

The spall horizons, except for the block concentrations of unit 1, comprise typical frost-riven debris, in part with incomplete interstitial sediment; they are inclined and thin out to the cave interior. On the other hand, the great internal rockfalls suggest periodic roof collapse in response to progressive undermining, pressure release, and active corrosion along master-joint networks. This particularly applies to unit 1.

Other criteria of interpretation for Morín also apply to El Pendo. Analysis of the grain-size parameters critical to definition of residual facies indicates that the range of variation in El Pendo is very similar to that of Morín (Figure 8). Of particular interest are the lower levels of El Pendo, Figure 12, suggesting a marked increase of sediment influx near the top of unit 4. Heavily loessic sediments are incorporated into units 12a, 12b, 14 upper and 15, while loessic silts are also abundant in Facies 3, common in many of the units between 6a and 20. Fine roof grit is limited to units 15 and 17, partly coincident with congelifluction recorded by units 13 and 17a; the absence of any spall in the middle of the Mousterian column contrasts with Morín, and suggests a different frost-sensitivity inside El Pendo. The frost and moisture indices, derived as in the case of Cueva Morín, are also presented in Figure 12, together with a local climatic interpretation.

The enrichment of El Pendo units 1 upper, 2, and 3 with colloidal silica is unique among the Cantabrian caves studied. Values reach 35% of the non-carbonate residual, and vertical distribution is independent of the calcium carbonate curve; this profile suggests impregnation of the mineral matrix by mobilized, colloidal silica after its accumulation, in part prior to secondary calcification. Processes of silification are poorly understood. Abundant colloidal silica is produced during decalcification of the Aptian limestone, so that the issue is why and how enrichment took place. In my experience, colloidal silica is commonly encountered in surface caliches of semi-arid environments and it is prominent in dry limestone caves of southern Africa. In El Pendo, partial silicification probably relates to a relatively dry and warm environment, following upon deposition of unit 4. However, phosphorus and organic matter were not tested in El Pendo, so that the geochemical problems cannot be properly formulated without further analysis.

Radiometric dates are unavailable for El Pendo, but the archaeo-stratigraphy and palaeoclimatic phases allow several specific correlations with the Morín column (Figure 10). Particularly striking are the two major calcification phases in the lower part of the column, the minor flowstone midway in the Mousterian sequence, the surge of coarse sands prior to the second calcification phase, and the congelifluction episode at the base of the upper Palaeolithic succession. Although unit thicknesses are adjusted by similar factors to those employed in Morín, sedimentation rates were evidently not identical, and depositional breaks are again evident, e.g. in the upper palaeolithic occupations, where there is a lower but no upper Magdalenian or Solutrean. The cold-steppe antelope *Saiga tatarica* is present in the cold, stable unit 18.

Monte Castillo

El Castillo is a steep (average slope 35°) conical mountain (355 m elevation) of white, compact and massive-bedded, Liassic limestones. It rises abruptly from the western margin of the Rio Pas, 0·7 to 1 km south of Puente Viesgo. A string of caves opens up at about the 200 m contour, along the southeastern quadrant of the mountain face, beginning with Castillo Cave (strike N 40° E), Las Chimeneas (N 110° E), La Flecha (N 140° E), La Pasiega (N 185° E), and Las Monedas (N 120° W). Most dip into the mountain, or form a double tier of caverns with 20–30 m relief, or both. All have remnants of ancient, now largely destroyed dripstones, flowstones, and breccias—the oldest of which include coarse-to-cobble grade, exotic river pebbles of rounded, quartzitic sandstone within indurated crossbeds.

These conglomerates suggest initial formation of the caves in relation to a late Tertiary land surface about 120 m above the modern Pas floodplain. At this time detritus, from the Wealden (Lower Cretaceous) sandstone of the upstream basin, flushed directly into the Castillo caves. Morphometric analysis of such quartzite pebbles (re-worked in younger, unconsolidated deposits) gave an index of rounding of 58·7% (with coefficient of variation 26·7%), an index of flattening (ratio thickness to major axis) of 57·3% and a mean length of 4·82 cm; however, cobbles of up to 16 cm major axis are found in the primary facies, e.g. among the 2 m of crossbedded and imbricated conglomerates at Las Chimeneas (Figure 13). On these grounds the ancient flowstones and fluvial conglomerates of the Monte Castillo cave complex appear to be of Mio-Pliocene age, with little cave enlargement since.

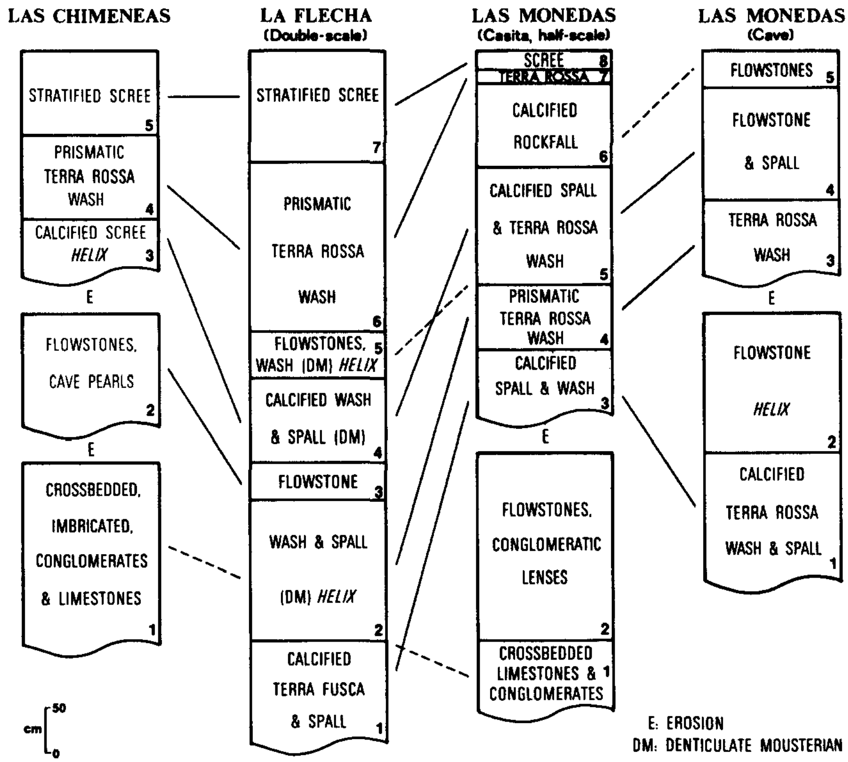

Figure 13. Stratigraphic columns of cave entrances, El Castillo hillside.

The complexity of the younger deposits preserved in the various cave entrances is shown by Figure 13. Lithosols are characteristic of the cliff slopes above, but the standard sediment profile of soil pipes and dissolved joint-lines on the hillside is: (a) humified limestone scree, commonly with a matrix of brown or light yellowish brown (7·5 to 10 YR), silt loam, clay loam or silty clay loam (Facies 5 or 6) of terra fusca type, typically 30 to 100 cm thick; on top of (b) prismatic, reddish brown to yellowish red (5 YR) clay (Facies 7) or rubbly loam (Facies 3) of terra rossa type (see Figure 14). In some fissures there also are kaolinitic, white (2·5 to 5 Y) clays or silty clays. More commonly, the cave entrances of Figure 13 record several older cycles of calcified rubble over terra rossa wash, sometimes capped by flowstones. In each case bedding gradients show that detritus was flushed into the caves from the outside, with scree cones grading into roof spall units. Most flowstones cascaded down the rock faces and into the entrances. although some developed below joints inside. Dripstones tend to be quite old, judging

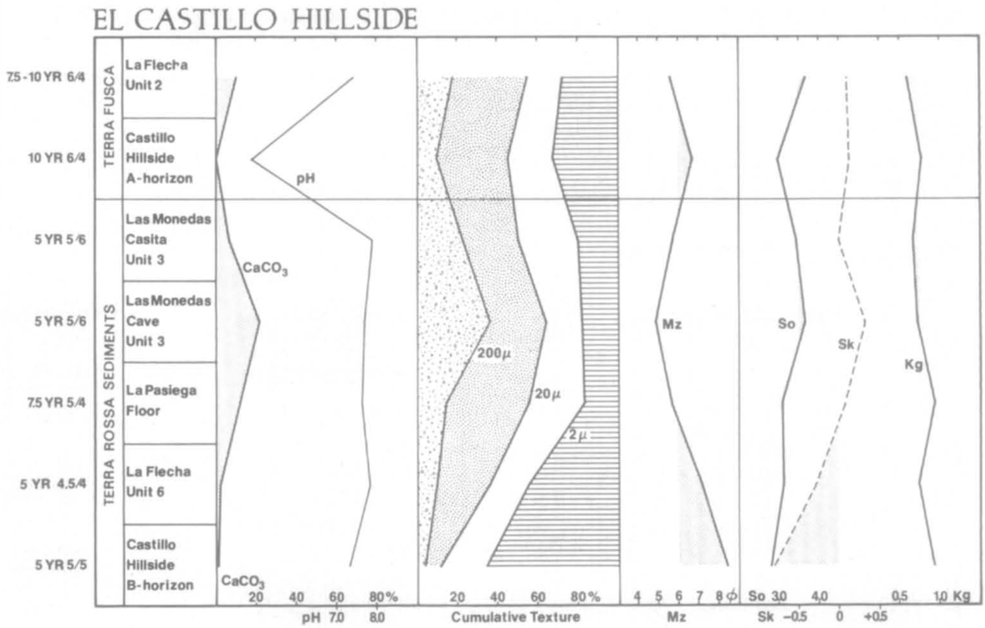

Figure 14. Analytical data for selected samples, El Castillo hillside.

by the Castillo Cave and La Flecha sequences outlined below. This even applies to the deep caverns, like Castillo Cave, where relative humidities remain constant near 99% all year round and where the external shell of one of the youngest major stalactites is dated 31,450 ± 1400 bp (I–5149), an age closely comparable to that of the terminal flowstones at La Flecha (see Table 8). Some slow dripstone formation continued inside La Pasiega and Las Chimeneas, where humidities remain near 95%; significant accretion is limited to the interior of Las Monedas, where humidities are lower and fluctuate between 90 and 95%. Each cave interior maintains constant temperatures of 14 ± 1 °C (all cave microclimatic data courtesy of D. Felipe Puente).

The Archaeo-sedimentary Sequence of Castillo Cave

The important archaeo-stratigraphy of Castillo Cave was summarized by Obermaier (1924, pp. 161–66) and has been widely reproduced in the secondary literature. Obermaier excavated an 18 m section from the centre of the great overhang in the entrance area, leaving a large intact section on the south side, where external screes and rockfalls are more prominent and where the rich upper palaeolithic units uncovered by Obermaier are only poorly developed. This face was recorded by Freeman (1964, pp. 232–36), who also re-studied the Mousterian collections (Echegaray & Freeman, 1973, p. 129). The sequence, based on 31 full sediment analyses (Table 6 and Figures 15 and 16), is essentially identical to that of Freeman (1964). It is younger than some 8 m of ancient flowstones, stalagmites and breccias, remnants of which are preserved south of the entrance.

Correlation of our units with the old excavation levels is possible as a result of a meticulous study by Cabrera (1978) of the unpublished notes of H. Obermaier and H. Breuil, and by Cabrera's analysis of the faunal material and particularly of the large artifact collections, now curated in various Spanish museums. A critical marker is provided by the flowstones ("stalagmite levels") and reddish detrital beds ("phosphatic sands") (our units 5a–5e) at the base of the conspicuous Mousterian hearths (our units 6–12) (Cabrera, 1978, p. 292). Scattered, undiagnostic artifacts were found as much as 1·75 m below unit 5a, i.e. in 2. A greater artifactual concentration (Obermaier, 1924, level a) at 1·1–1·3 m depth coincides with our unit 4a, and was described as a zone of hearths, with much Cave bear and rare reindeer (requiring confirmation), Red and Fallow deer, a large horse, *Bos/Bison*, ibex, and Cave lion. Levels at 40–75 cm depth, equivalent to our unit 4b, included some bone and flake tools, with end-scrapers, denticulates, Levallois pieces and rare, atypical bifaces. The levels at 20–40 cm, our unit 4c1, had more artifacts and, again, denticulates and Levallois points. The main, so-called

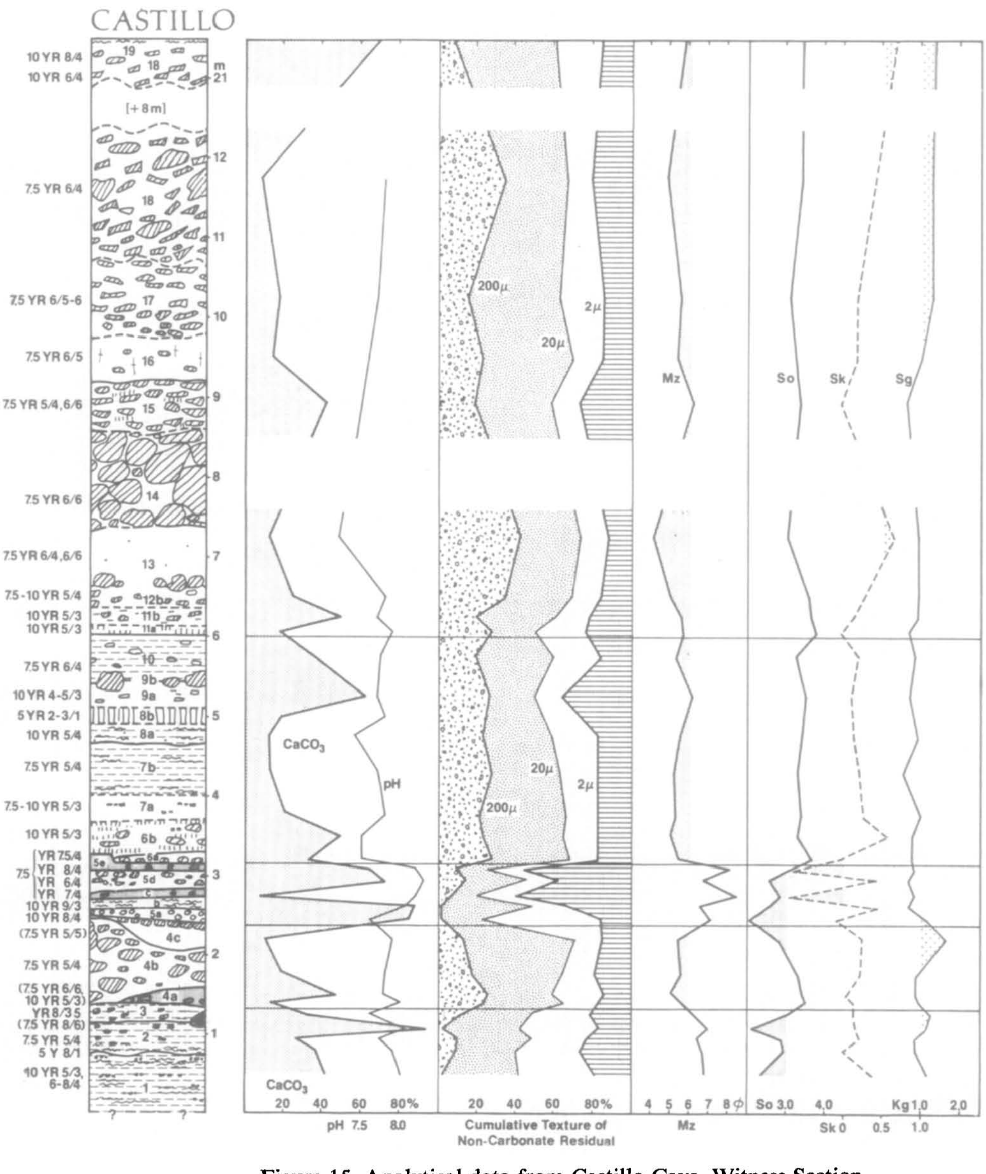

Figure 15. Analytical data from Castillo Cave, Witness Section.

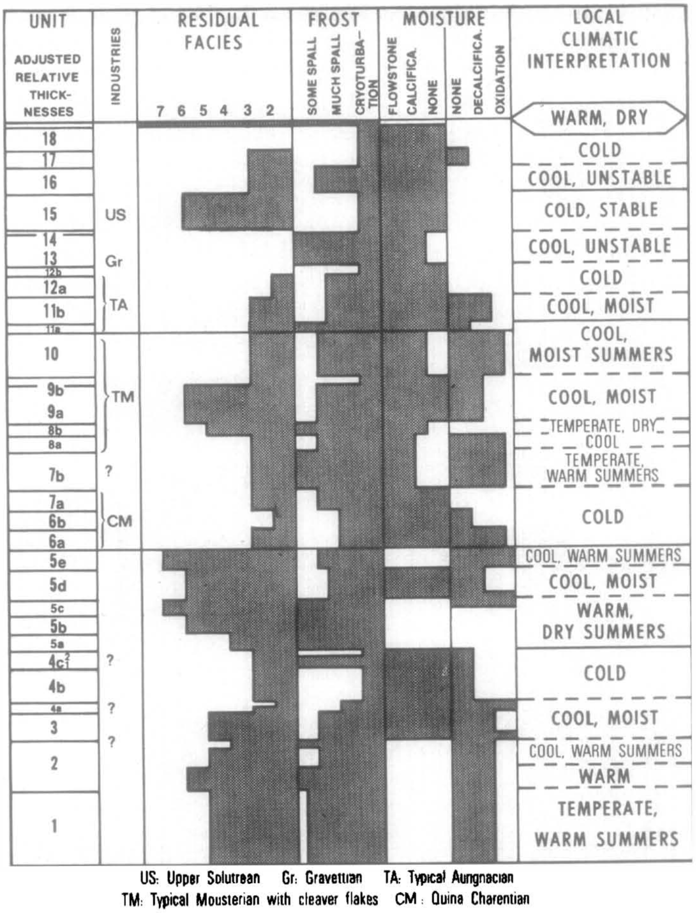

Figure 16. Synthetic evaluation of the Castillo Cave column.

Table 6. Analytical description of the archaeo-sedimentary column of Castillo Cave, Santander

19. *1·5 cm.* Laminated, vertically-crystallized, white (10 YR) flowstone cementing top of unit 18.

18. *950 cm.* Light yellowish brown (7·5–10 YR), sandy clay loam grading upwards to silt loam, very positively skewed and leptokurtic; as matrix to angular coarse-to-grade limestone rubble, forming part of a hillside scree cone. Lower contact irregular and erosional.

17. *100 cm.* Reddish yellow (7·5 YR) silt loam, leptokurtic; with angular blocky structure; as matrix to angular, coarse spall.

16. *50 cm.* Reddish yellow (7·5 YR) silt loam, with prismatic structure and dispersed, corroded medium-grade rubble. Lower contact sharp.

15. *65 cm.* Reddish yellow (7·5 YR) clay loam, negatively skewed, as matrix to angular, coarse spall of limestone and dripstone. Humified lenticles record light occupation; upper Solutrean. Lower contact irregular.

14. *120 cm.* Block rockfall, with limited matrix as unit 13. Lower contact irregular.

13. *50 cm.* Reddish yellow (7·5 YR) sandy loam, very positively skewed, and with angular blocky structure. Light occupation; Gravettian. Lower contact irregular.

Table 6. continued

12b. *25 cm.* Semicontinuous block rockfall.

12a. *25 cm.* Brown (7·5–10 YR) loam, with angular blocky structure and abundant dripstone-derived grit and angular, medium-grade spall. Humification and charcoal traces indicate moderately intensive occupation; Typical Aurignacian. Lower contact indistinct.

11b. *25 cm.* Brown (10 YR) loam, exceptionally poorly sorted, with angular blocky structure and abundant, heavily corroded, medium-grade spall of limestone and dripstone. Heavy occupation; Typical Aurignacian. Lower contact indistinct.

11a. *10 cm.* Brown (10 YR) to black (7·5 YR) loam, exceptionally poorly sorted and negatively skewed; broadleaf impressions. Heavy occupation with bone; Typical Aurignacian. Abrupt lower contact.

10. *55 cm.* Light brown (7·5 YR) loam, with angular blocky structure; fine, calcareous, reddish yellow (7·5 YR) concretions; dispersed, corroded, fine-to-medium-grade spall of limonite-stained dripstone. Light occupation. Lower contact irregular.

9b. *0–25 cm.* Discontinuous block rockfall.

9a. *25 cm.* Brown (10 YR) clay loam, with angular blocky structure and dispersed, partly-corroded spall of fine-to-medium-grade dripstone. Heavy occupation; Typical Mousterian with cleaver flakes. Lower contact indistinct.

8b. *20 cm.* Black (5 YR) loam, slightly calcified. Heavy occupation with lenticular hearths; Typical Mousterian with cleaver flakes. Lower contact indistinct.

8a. *25 cm.* Yellowish brown (10 YR) loam, with dispersed lime grit and rare flowstone laminae. Heavy occupation with weak lenticular hearths; Typical Mousterian with cleaver flakes. Lower contact sharp.

7b. *65 cm.* Brown (7·5 YR) loam, with angular blocky structure and rare laminae of corroded and limonite-stained flowstone. Moderately intensive occupation; Quina Charentian. Lower contact indistinct.

7a. *27 cm.* Brown (7·5–10 YR) loam, with angular blocky structure and local concentrations of lime grit. Moderately intensive occupation; Quina Charentian. Lower contact indistinct.

6b. *40 cm.* Brown (10 YR), sandy loam, very positively skewed; with abundant, angular lime grit and zones of corroded, coarse-to-block grade rubble. Heavy occupation, with prominent hearth lenses 3–5 cm thick; Quina Charentian. Lower contact indistinct.

6a. *0–20 cm.* Pink (7·5 YR), partly-calcified and extensively oxidized loam, exceptionally poorly sorted and negatively skewed; with abundant, partly-patinated lime grit and corroded, medium-to-coarse grade spall. Heavy occupation, with prominent hearths and reddish yellow (5 YR), baked lenticles 2–8 cm thick; Quina Charentian. Lower contact indistinct due to artificial disturbance.

5e. *20 cm.* Pink (7·5 YR), well-stratified, extensively oxidized marl with residue of very negatively skewed clay, with abundant "cave pearls" and dispersed, corroded medium-to-coarse-grade spall and flowstone laminae.

5d. *20 cm.* Light brown (7·5 YR), weakly oxidized, silty clay loam, very positively skewed, with angular blocky structure; as matrix to dripstone grit and locally abundant, partly-corroded, medium-grade dripstone and limestone rubble.

5c. *12 cm.* Pink (7·5 YR), oxidized, partly-calcified and laminated clay, very negatively skewed; with dispersed flowstone laminae and terminal crust; *Helix* casts.

5b. *7–16 cm.* White (10 YR), laminated, vertically-crystallized flowstone with residue of positively skewed, silty clay loam.

5a. *8–15 cm.* Very pale brown (10 YR), well-stratified marl with residue of moderately sorted, leptokurtic, silt loam; as matrix to agglomerate of chalky dripstone grit, oolites, and spheroidal "cave pearls" (1–12 mm diameter); top calcified. Lower contact abrupt and wavy.

Table 6. continued

4c.	*0–30 cm.* Brown (7·5 YR), silt loam, leptokurtic (unit 4c1); light occupation indicated by charcoal powder and bone fragments. Overlain by pavement (0–7 cm thick) of partly corroded coarse spall, bone fragments, and flake artifacts with rare, archaic bifaces (unit 4c2). Lower contact distinct and wavy.
4b.	*50–110 cm.* Brown (7·5 YR) loam, exceptionally poorly sorted, as matrix to partly corroded, coarse-to-block-grade rubble. Light occupation in middle section, but no diagnostic artifacts. Lower contact distinct.
4a.	*0–25 cm.* Reddish yellow (7·5 YR), oxidized loam, exceptionally poorly sorted, angular blocky structure; with dispersed, corroded medium-to-coarse-grade limestone and dripstone spall. Dispersed artifactual débitage and prominent, 2 cm hearth indicate moderately intensive occupation; with undiagnostic artifacts. Lower contact distinct.
3.	*20–25 cm.* Very pale brown (10 YR), mottled (reddish yellow, 7·5 YR), well-stratified marl with residue of exceptionally poorly sorted, leptokurtic, silt loam; dispersed, partly corroded, medium-grade dripstone rubble. Lower contact abrupt.
2.	*35–40 cm.* Brown (7·5 YR) silt loam, with angular blocky structure and abundant, heavily corroded and oxidized (reddish yellow, 5 YR), medium-grade, dripstone rubble (unit 2b). A stalagmite knob, consisting of reddish yellow (7·5 YR), oxidized and porous dripstone, with a residue of moderately sorted, leptokurtic, silt loam, began growing 2·5 cm below surface and extends 15 cm above the unit 2/3 contact, indicating a long hiatus (unit 2c). The lowermost 15 cm comprise a brown (7·5 YR) silt loam interbedded with laminae of decomposed, reddish yellow (7·5 YR), silty clay loam (units 2a). Light occupation in topmost 2 cm indicated by charcoal fragments and traces of bone; no diagnostic artifacts. Lower contact abrupt and wavy.
1.	Over *60 cm.* Light yellowish brown (10 YR), weakly mottled silt laminated, moderately sorted, leptokurtic, with angular blocky structure and dispersed lime grit; interbedded with thick flowstones, in part decomposed and oxidized (reddish yellow, 7·5 YR), in part white (10 YR) and preserving vertically-crystallized laminae intact.

Only So values greater than 3·5 are labelled "exceptionally poor"; values under 2·5 are described as "relatively good".

Acheulian level, some 10–30 cm thick, is our unit 4d2. The abundant fauna comprises the Steppe rhino, *Dicerorhinus hemitoechus* (identified by K. D. Adam and J. Altuna, L. G. Freeman, pers. comm.), Cave bear, Red deer, horse, ibex, *Bos/Bison*, and an unidentified elephant; purported marmot remains came from 4c1 or 4c2. The artifacts have a strong Mousterian of Levallois facies flavour (Mousterian index 37·1%), and the mainly atypical bifaces include one cleaver-flake and a single amygdaloid hand axe (Cabrera, 1978, pp. 258–70). The original Acheulian designation is improbable, because rough bifaces were still made in northern Spain at the very end of the Pleistocene and even during the early Holocene (see Butzer, 1967; Aguirre & Butzer, 1967; Echaide, 1971; Clark, 1975, 1976). A Mousterian industry is far more likely.

Cabrera's description (1978, pp. 291–96) shows that Obermaier's first Mousterian level (d), now identified as Quina Charentian, is equivalent to our units 6a through the middle of 7b, followed by 10 cm of sterile deposit (top of 7b). The Mousterian index is 67%, Levallois technique is absent, as are bifaces. Obermaier's second Mousterian level (f) is equivalent to our units 8a–9a; cleaver-flakes are common, and atypical or incomplete bifaces are again present. The rhinoceros bone from these Mousterian levels, generally dominated by horse and *Bos* (Cabrera, 1978; Altuna, 1972, p. 45), requires new identification.

Our calcified unit 10 corresponds to Obermaier's (g), described in his notes as a yellowish brown silt, thickening to 50 cm near the entrance, with a flowstone crust of

15–40 cm (Cabrera, 1978, p. 383). His first two Aurignacian levels and beds, (h) – (l), terminate with large blocks and are included in our units 11a–12b. The 882 tools from 11a/11b compare best with those of Morín VII, while the 83 tools from 12a match those of El Pendo VII; both represent a Typical Aurignacian (Cabrera, 1978, 390ff). The fauna is dominated by Cave bear and hyaena, with the last occurrence of *Dicerorhinus kirchbergensis*; the avifauna indicates a cold climate. Obermaier's other "Aurignacian" levels (his l – p) are subsumed in our unit 13 and qualify as Gravettian, most similar to Noaillian ["Perigordian V", whereas the final Gravettian of Morín IV and V is more similar to "Perigordian VI", Echegaray & Freeman (1973, p. 202)] (Cabrera, 1978, pp. 490–93). The avifauna and marine Mollusca, as well as reindeer, indicate cold conditions. Obermaier's very stony clay with upper Solutrean (q–r) is our unit 15; alpine forms are lacking but the marine Mollusca are cold (Cabrera, 1978, pp. 499–529). The lower Magdalenian levels, represented by up to 2·9 m of hearths, silts and rubble in Obermaier's excavation (Cabrera, 1978, pp. 542–44), were totally removed but presumably equivalent to our units 16 and 17. The fauna is dominated by Red deer, with some chamois, *Bos* and horse; *Helix nemoralis* is common. Cabrera (1978) classifies the artifacts as Magdalenian III, comparable to those of El Pendo level II, whereas Morín II has Magdalenian V. The upper Magdalenian (VI) and Azilian levels of Castillo (Obermaier's u and w) were concentrated well inside the cave, with Azilian also found in external rubble (our unit 18) (Cabrera, 1978, pp. 627–29); the upper Magdalenian fauna is cold in character, with reindeer, chamois and ibex (Cabrera, 1978, 671ff.).

This summary of the archaeo-stratigraphy of Castillo serves to clarify the significance of our Castillo column.

The 9·5 m of external scree represented by unit 18 is identical to the superficial, frost-generated screes of other Monte Castillo caves (Figure 13). The prismatic soilwash (Castillo unit 16, Facies 3) is similar to terra rossa sediments at Las Monedas (Casita) (unit 3) and La Pasiega, whereas the finer-grained matrix of Castillo unit 15 (Facies 6) is closer to that of La Flecha unit 6 (Figure 14). This part of the sequence was predominantly generated outside of Castillo Cave and entered after removal of part of the southern side of the roof, as a consequence of the rockfall recorded in unit 14. All the calcified deposits of the minor caves are no younger than Castillo unit 10.

Two of the units (2c and 5a) belong to Facies 4, but these are flowstone matrices; although loessic sediments are incorporated into most Facies 3′ units, there are no true textural loesses anywhere on the Castillo hillside. This is reasonable in view of the distance from the modern coast (16 km) and a location upwind of the Rio Pas. Roof rubble is mainly or exclusively in the grit to medium-grade spall category in units 1–3, 5–9a, and 10–12. Other spall horizons are coarse.

The Castillo sequence, as synthesized and interpreted in Figure 16, can now be combined with those from El Pendo (Figure 12) and Morín (Figure 10). Part of the premise of comparability between these sequences is that similar facies categories are applicable to all three (see Figures 8 and 9, and Tables 3 and 4). This comes as no surprise since two of the caves are in identical Aptian bedrock, and the Liassic limestone of the third is chemically almost identical (see Guerra & Montouriol, 1959). The deviation of Castillo Facies 3′ primarily reflects detritus derived from exotic Mio-Pliocene sands and gravels; in any event, Facies 3′ is distinctly polymodal, whereas Facies 3 is not. The variations of runoff energy documented in each sequence provide the basic tool for cross-correlation. Other criteria are the relative development of spall, flowstones, and alteration phenomena. A composite picture is generated in Table 7, which collates the three cave micro-stratigraphies and their local interpretations, to provide a sequence of climato-stratigraphic units of broader, regional validity. The archaeological data for Morín, El Pendo, and Castillo are also collated in Table 7.

Table 7. Synthetic chart of cave strata, external environments, and palaeolithic industries

G	M	P	C	Slopes	Climate	Industry
44	29	—	—	S	Warm, dry summers	—
43	28	—	—	S	Warm, moist summers	?
42	27	—	—	S	Warm, dry summers	—
41	26	22	18	U	Cold	Azilian
40	—	21	—	S	Cool, dry summers	Magdalenian, Azilian
39	25	20	16, 17	U	Cool to cold	Magdalenian
38	24b	—	—	U	Cold	Upper Solutrean
37	24a	19	14, 15	S	Cold	Upper Solutrean
36	23	17b, 18	—	S	Cool, moist summers	Final Gravettian, Terminal Aurignacian
35	22	17a	12b, 13	U	Cold, moist summers	Gravettian, Evolved Aurignacian
34	—	16	—	S	Cold, moist summers	Evolved Aurignacian
33	21a, b	15	11b, 12a	U	Cool to cold, moist summers	Typical Aurignacian
32	20	—	11a	U	Temperate, dry summers	Early, Typical Aurignacian
31	19	14	—	S	Temperate	Early Aurignacian, Chatelperronian
30	18	13	—	U	Cold	Early Aurignacian, Chatelperronian
29	17b2	—	—	S	Temperate	Denticulate Mousterian
28	17a, b1	12a, b	10	U	Cool, moist summers	Denticulate, Typical Mousterian (CF)
27	16	—	9b	U	Cool, moist summers	Denticulate, Typical Mousterian (CF)
26	15	—	—	S	Temperate	Typical Mousterian (ss or CF)
25	—	11b	9a	S	Cool, moist summers	Typical Mousterian (ss or CF)
24	14d	10, 11a	—	U	Cool, moister	Typical Mousterian (CF)
23	14c	9	8b	U	Cool, dry summers	Denticulate, Typical Mousterian (CF)
22	14b	—	—	S	Cool, dry summers	Typical Mousterian (CF)
21	14a	8	8a	U	Cool, moist summers	Denticulate, Typical Mousterian (CF)
20	13	7	—	S	Temperate, warm summers	Typical Mousterian (CF)
19	—	6b	7b	U	Temperate, warm summers	Typical Mousterian (ss)
18	—	6a	7a	U	Cool	Typical Mousterian (ss), Charentian
17	12	5	6b	U	Cold	Quina Charentian
16	—	—	6a	U	Cold, moist summers	Quina Charentian
15	—	—	5e	S	Cool, warm summers	—
14	—	—	5d	S	Cool, moist summers	—
13	—	—	5c	S	Warm	—
12	(C)	(C2)	5b	S	Warm, dry summers	—
11	—	—	5a	U	Warm, dry summers	—
10	5, 11	4b	4c2	U	Very cold	Denticulate Mousterian (?bifaces)
9	10	—	4c1	U	Temperate, moist	?Mousterian
8	9	—	4b	U	Cold	—
7	7, 8	—	—	U	Cool to temperate	—
6	—	4a	—	S	Cold	?Denticulate Mousterian
5	3, 6	3	4a	U	Cold, moist summers	?(flakes)
4	—	2	2b, 3	S	Cool, warm summers	?(large flakes)
3	2	(C1)	2a	S	Warm, dry summers	
2	—	—	1	S	Temperate, warm summers	
1	1	1	—	U	Cold	?(large flakes)

G: general, composite units; M: Cueva Morín units; P: El Pendo; C: Castillo; S: stable slopes; U: unstable slopes; ss: sidescraper-rich; CF: cleaver flakes.

The base of the Castillo column appears to rest directly on bedrock (Obermaier, 1924, p. 164), although not seen in our re-excavated 1969 pit. None of these beds is developed within the interior cavern where the cave paintings are all found. Here the floor is extensively mantled by a thick flowstone cascade (see 1911 plan reproduced by Sieveking & Sieveking, 1962, fig. 78). Fernández (1969) has described a test excavation 72 m within the interior cavern, below such a flowstone. The strata are as follows, from top to bottom:

(A) 3 m flowstone;
(B) 50 cm cryoturbated wash with angular limestone spall and rounded, coarse, sandstone gravel;
(C) 100 cm dark, ferruginous wash with rounded, coarse sandstone gravel;
(D) 50 cm flowstone with small sandstone pebbles;
(E) 70 cm yellowish, fine sands with dispersed dripstone rubble, coarse sandstone pebbles, and trace of bone;
(F) 20 cm dark, possibly humic, sandy clays;
(G) 10 cm very dark, clayey bed with small sandstone pebbles;
(H) 10 cm interdigitated, dark, clayey and sandy beds;
(I) 16 cm very dark, clayey beds.

This 6·3 m suite may be equivalent to the older sediments preserved along the walls of the entrance area. Or, equally likely, they record a sequence of earlier Pleistocene events, postdating the crossbedded conglomerates of Las Chimeneas and Las Monedas (Casita) (Figure 13). The nature of the "dark" beds requires clarification, as they may possibly record early, organic occupation levels.

La Flecha

The cave of La Flecha has a short archaeo-sedimentary sequence, important both because of Denticulate Mousterian occupations (Freeman & Echegaray, 1968) and on account of its explanatory value for the strata of the Castillo cave complex (Figure 13). The site consists of an overhang and a small cave.

The La Flecha sequence is outlined in Table 8 (on the basis of two completely analysed samples and six additional, partial analyses). All the detrital strata dip 1–12° into the cave, indicating external derivation by surface runoff. Three cycles of accumulation are represented. The first two begin with coarser wash and abundant, coarse rubble, indicative of higher runoff (units 1 and 4); eventually fine wash predominates and, ultimately, flowstones develop while colluvial influx terminates (units 2, 3 and 5). The third cycle, younger than 31,000 bp, differs in that unit 6 was derived from B-horizons upslope, possibly by mass movements, followed by a gelivation scree incorporating BC-horizon matrix (unit 7), and separated by an erosional disconformity that suggests a disjunction in geomorphic processes. Hillside denudation was remarkably severe during the terminal Upper Pleistocene, apparently dislodging a discontinuous sheet of frost rubble that must have formed on the slopes during an earlier, intensely cold interval. This interval is confirmed by the terminal alluvial cone in Castillo Cave, while certain parallels with the detrital Azilian level at Morín can be noted.

The main Denticulate occupation at La Flecha (unit 2) records cold, moist and unstable conditions (Facies 3′); the sediment characteristics match those of the Typical Mousterian unit 8b of Castillo Cave (phase 23 of Table 7), whereas the minor occupation of unit 4 was coeval with temperate, unstable conditions comparable to those of Castillo 10 (phase 28); the final occupation of unit 5 indicates stable conditions not recorded in Castillo (phase 29 of Table 7). In other words, the Denticulate Mousterian at La Flecha

Table 8. Provisional analytical description of archaeo-sedimentary strata at La Flecha, Santander

7. *60 cm.* Well-stratified scree of angular, very coarse limestone rubble with a partial matrix of gritty, light brown (7·5 YR) loam. Lower contact abrupt due to steep erosional truncation of half of original unit 6.
6. *45 cm.* Reddish brown (5 YR) clay, with angular blocky structure and rare, corroded limestone grit. Lower contact abrupt.
5. *25 cm.* Pink (7·5 YR), calcified clay loam with angular, fine limestone rubble and bone fragments, interstratified with and capped by light grey (10 YR), laminated flowstone with an apparent age of 31,640±890 bp (SI–4460) (R. Stuckenrath, pers. comm.); proliferations of *Helix*; external dips initially 7° outward, eventually 2° into cave, while internal dips 1–12° inwards. Light occupation; probably Denticulate Mousterian. Lower contact distinct.
4. *45 cm.* Pink (7·5 YR), calcified loam as matrix to corroded, coarse-grade limestone and dripstone rubble and rare, derived sandstone pebbles. Light occupation; probably Denticulate Mousterian. Lower contact abrupt.
3. *0–20 cm.* White (10 YR), chalky, spongy or laminated flowstone linked to formation of dripstone column near cave opening.
2. *57 cm.* Brown (7·5 YR) clay loam with angular blocky structure and abundant, partly-corroded grit and medium-to-coarse-grade spall (rounding index 11·1%, with 48·8% coefficient of variation; 50·4% index of flattening; mean length 5·63 cm); abundant snails, including *Helix*, as well as broad-leaf impressions. Moderately intensive occupation with abundant bone, artifacts, and charcoal fragments; Denticulate Mousterian. Lower contact distinct.
1. At least *55 cm.* Light brown (7·5 YR), calcified loam with abundant, angular, coarse-grade limestone and dripstone rubble. Traces of charcoal indicate light occupation.

was largely coeval with the Typical Mousterian at Castillo Cave, less than 200 m away. This suggests that the much smaller cave was periodically used for special activities, unimportant or not represented in the larger cave, although the faunas are identical (see Freeman & Echegaray, 1968; Cabrera, 1978) and in both instances overwhelmingly comprise species that could only be taken in the valley far below.

The only other archaeological sediment from Monte Castillo is the floor deposit with Solutrean and lower Magdalenian artifacts in La Pasiega (Echegaray & Ripoll, 1954). The top 10 cm sampled is a brown (10 YR) loam with some angular limestone grit, *Helix* shells, and charcoal fragments; Facies is 3′ (Mz 5·68, 17% clay). The sediment is almost identical to that of the lower Magdalenian unit 16 in Castillo Cave, and indicates cool, unstable conditions (phase 39).

Hornos de la Peña

A major archaeological site of western Santander is Hornos de la Peña, situated on the eastern slope of the Besaya valley, 1·7 km southeast of Tarriba, at about 250 m elevation on the southern slope of a 348 m mountain of Liassic limestone. A plan of 1911 is reproduced by Sieveking & Sieveking (1962, fig. 85), and the archaeo-stratigraphy is briefly reported by Obermaier (1924, pp. 168–69; see also Straus, 1975). Detrital deposits are limited to the entrance area, although rock paintings are found 70 m and more inside the interior cavern. The narrow, winding and level corridor suggests the erstwhile course of a small subterranean stream that followed the intersection of a master-joint and a major bedding plane.

The oldest deposits consist of 1·5 m of oxidized, reddish yellow (5 YR) flowstones, interbedded with two thick breccia horizons, and linked to massive stalactites by a number of dripstone columns. These beds are limited to the eastern wall and compare

Table 9. Provisional analytical description of the archaeo-sedimentary column of Hornos de la Peña, Santander

7.	*8 cm.* White (10 YR) flowstone, linked to small stalagmite, with *Helix* fragments. Lower contact abrupt.
6.	*10 cm.* Light to very dark greyish brown (10 YR), heavily calcified silty clay loam, as matrix to dripstone grit and corroded, medium-grade limestone spall. Heavy occupation, with masses of bone fragments; probably identical to Obermaier's Magdalenian level ("grey clay"). Lower contact sharp.
5.	*80 cm.* Very pale brown to dark greyish brown (10 YR), heavily calcified silty clay loam, as matrix to partly corroded, coarse-grade spall; capped by laminated crust. Light to heavy occupation in several lenses, rich in bone and charcoal, representing distinct hearths; probably identical to Obermaier's Solutrean level ("yellow clay"). Lower contact marked by rockfall horizon of partly-corroded roof blocks.
4.	*20–40 cm.* Light brownish grey (10 YR), calcified silty clay (residual Facies 6 or 7 with Mz 7·12, 41% clay, 18·5% sand, So 2·99); as matrix to corroded dripstone grit and coarse limestone spall. Moderately intensive occupation, with abundant bone; probably identical to Obermaier's "Middle" Aurignacian level ("yellow clay"). Lower contact abrupt due to interval of corrosion.
3b.	*5–55 cm.* Pink (7·5–10 YR) calcareous crust developed in unit 3a, thickening towards interior into a banded, reddish yellow (7·5 YR), oxidized, silty flowstone. Some occupation, with denticulates (L. G. Freeman, pers. comm.). Lower contact more or less conformable.
3a.	*75 cm.* Light brown (7·5 YR), partly calcified, well-stratified loam, interbedded with laminated flowstones (residual Facies 3 or 5, with Mz 6·38, 25·5% clay, 26·5% sand and grit, So 3·25); as matrix to partly corroded, coarse spall and occasional blocks. Two or more lenses with bones; identical with Obermaier's ("sandy") Mousterian horizon. Lower contact distinct.
2.	*25 cm.* Very pale brown (10 YR), partly calcified, stratified, silty clay loam (residual Facies 5 or 6, with Mz 7·03, 34% clay, 18% sand, So 2·88); with abundant corroded dripstone grit, rare medium-grade limestone spall, and occasional flowstone laminae. Sterile. Lower contact abrupt, marking long interval of corrosion.
1.	*60 cm.* Reddish yellow (5 YR), oxidized and banded, porous flowstones, including small-scale organ-pipe structures; linked to steep, flowstone cascades emerging from roof and wall joints. Sterile, resting on bedrock.

well with the oldest strata recorded on the Castillo hillside, only 6 km northeast. They suggest that the cave had already been fully formed by early Pleistocene times, with no subsequent enlargement. The ancient flowstones and breccias were largely removed by corrosion, prior to accumulation of the younger sequence described in Table 9 (on the basis of three full sample analyses and partial study of six more).

The Mousterian collection has been restudied by Freeman (Echegaray & Freeman, 1973, pp. 129), and is a sidescraper-rich Typical, with cleaver flakes, most similar to that of Morín level XVI. The deposits (units 3a, 3b) indicate increasingly stable conditions, with a cool climate and warm summers, such as recorded for phases 24 and 25 (Table 7). The underlying unit 2 suggests stable conditions, and a cool-temperate climate with warm summers, probably phase 20, while the warm and dry unit 1 may well pertain to phase 12. The "middle" Aurignacian unit 4 was cold, wet and stable, suggesting phase 34. Since all of the matrices in Hornos de la Peña are very fine grained, reflecting difficult direct access for external sediment, the facies classes are less reliable than in other caves analysed so far. Consequently the climato-stratigraphic assignments for the Mousterian units must be regarded with some caution.

Cobalejos

Another significant Mousterian and upper Palaeolithic site is that of Cobalejos, located amid wooded, karstic terrain east of the Pas floodplain, in a 30 m-deep doline at 60 m

Table 10. Provisional analytical description of the archaeo-sedimentary column of Cobalejos, Santander

6c. *10 cm.* Very pale brown (10 YR) flowstone and light grey (10 YR) laminated crust, terminating and capping unit 6b. Sterile.

6b. *310 cm.* Reddish yellow (7·5 YR), partly calcified clay loam (residual Facies 5, with Mz 6·87, 30% clay, 22% sand, So 2·84) with angular blocky structure; as matrix to angular, coarse spall. Sporadic occupation indicated by several humified levels with bone fragments, but no diagnostic artifacts. Fills in western side of cave but probably forms continuation of unit 6a on eastern side, intersected by artificial trench.

6a. *45 cm.* Brown (7·5 YR), partly calcified clay loam, with angular blocky structure and mottled (reddish yellow, 7·5 YR); as matrix to heavily corroded, coarse spall. Moderately intensive occupation, indicated by artifacts, bone, charcoal and haematitic ochre; probably identical with Obermaier's Magdalenian level. Lower contact abrupt.

5. *30 cm.* Dark greyish brown (10 YR), silt loam (residual Facies 5 or 6, with Mz 6·70, 25% clay, 20% sand and grit, So 3·11), some mottling (brownish yellow, 10 YR); dispersed, corroded, medium-to-coarse spall. Heavy occupation indicated by artifacts, charcoal, and abundant bone debris; probably identical with Obermaier's Solutrean level. Lower contact abrupt and irregular.

4. *30 cm.* White (10 YR), massive flowstone, with some small "cave pearls" and possible shell casts, cascading down from eastern wall. Covers much of level 3 with an abrupt contact, or fragments of yellowish brown (10 YR) breccia of an older infilling. still adhering to walls.

3. *25 cm.* Dark greyish brown (10 YR), silty clay loam (residual Facies 5, with Mz 6·88, 27% clay, 19% sand, So 2·76). Heavy occupation, with bone, Mousterian artifacts, and distinct hearths. Lower contact distinct.

2. *70 cm.* Yellow (10 YR), calcified silt loam (residual Facies 5, with M 6·33, 20% clay, 23% sand. So 2·84), with extensive, strong brown (10 YR) mottling, and coeval with formation of a 30 cm, stalagmite in upper half. Light to moderately intensive, but diffuse occupation with some bone; Mousterian. Lower contact not visible.

1. *15 cm.* White (10 YR), banded flowstone embedding breccioid zones of dripstone grit and corroded, coarse limestone spall, but next to no soil. Light occupation indicated by locally abundant bone and artifacts, including denticulates; Mousterian.

elevation, 1·5 km south-southeast of Puente Arce. The cave is a breached cavern, developed at the contact of fine-grained, micaceous sandstones and compact limestones, both of Aptian age. For a time, this cavern served as a sluice for surface waters funnelled down to a progressively lower watertable. After reaching its present dimensions, the cave was also largely filled in with 3 m or so of flowstones and coarse breccias, linked to the roof by massive dripstone columns.

The archaeo-sedimentary sequence postdates a major interval of corrosion, during which most of this older infilling was removed, leaving mainly a selection of undermined dripstones and flowstones, now attached to the ceiling. Obermaier's cursory reference (1924, p. 168) to three archaeological levels is of little use, but the artifacts are described by Moure (1968); Freeman (1964, and pers. comm.) was only able to retrieve 26 Mousterian artifacts in the Provincial Museum of Santander. The younger depositional suite begins on bedrock and is outlined in Table 10 (on the basis of four full sample analyses and partial study of six others).

The basal Mousterian unit with denticulates (L. G. Freeman, pers. comm.) suggests a cool climate with warm summers and stable slopes, similar to conditions during phases 15 or 20 (Table 7). The temperate climate with warm summers and stable conditions implied by unit 2 also compares with that of phase 20, while the temperate and stable conditions of unit 3 suggest phases 26 or 29. Two different types of matrix, one yellowish, the other dark and crumbly, attached to these Mousterian artifacts suggest two levels, but there are too few tools for adequate diagnosis (Freeman, pers. comm.); the absence of large tools or numerous denticulates favours a sidescraper-rich, Typical Mousterian. Bone of the Steppe rhino *Dicerorhinus hemitoechus* (Altuna, 1972, p. 46) very probably comes from unit 3.

The flowstone of unit 4 lacks residual sediment and implies a temperate and dry climate, probably phase 32. The subsequent units argue for an increasingly cold and dry climate, but with surprisingly persistent slope stability. Units 5 and 6 seem incongruent with other Solutrean and later levels, and possibly record intervals of intermediate climate not documented in Morín or El Pendo. It is more probable, however, that all sediment matrices in Cobalejos are unusually fine-grained, so that greater reliance must be placed on the macroscopic descriptions of the various levels.

Successful applicability of the facies classes to Cantabrian caves is conditional upon a sufficient range of microscopic matrix variability, in turn largely a reflection of access to external sediments. Provisional examination of sediments from the Cueva del Conde, near Tuñón in Asturias (Freeman, 1977), and from Balmori, also in Asturias (just west of La Riera, Figure 1) (Clark, 1975), confirms this opinion. Both these caves are in lower Carboniferous limestones. In Balmori, six samples from the lower Magdalenian levels range from Facies 2 to 3′, consonant with Magdalenian deposits in Castillo, El Pendo, and Morín. In Conde, the early Aurignacian is Facies 3, while the two Mousterian levels (Denticulate and Typical) are Facies 5 and 6 respectively. This emphasizes that cave sedimentology requires a comparative approach, with interpretation predicated on evaluation in a context of internal cave variability and external sediment catchments.

An Upper Pleistocene Climato-Stratigraphy for Cantabria

The late Pleistocene micro-stratigraphic columns analysed here, and particularly as generalized in Table 7, can now be synthesized in Figure 17 and discussed in both explanatory and interpretative terms.

The relative temporal axis of Figure 17 was obtained by equalizing the adjusted relative thickness for the Morín, Pendo, and Castillo columns (Figures 10, 12 and 16). The relative runoff energy curve was constructed by averaging the value for each unit that records a particular phase of Table 7. The trace for summer moisture represents semi-quantitative evaluation of the moisture criteria identified for the three most basic cave columns. Where there are features in the "calcification" or "alteration" column, but not in both, interpretation is relatively simple. So, for example, calcification or flowstone imply soil/rock water supersaturated with calcium bicarbonate, or a dry micro-environment, or both. When calcification coincided with limonitic oxidation, a combination of abundant water and warm summers is indicated. The semi-quantitative temperature trace was similarly constructed from the frost indicators of Figures 10, 12 and 16, as modified by moisture criteria suggesting warm summers.

The temporal dimension to Figure 17 is based on the ^{14}C date of 9000 bp date for phase 45, a greater than 35,000 bp date for the terminal Mousterian horizon of phase 29, and the Castillo stalactite and La Flecha flowstone of about 31,000 bp that pertain to phase 32. The radiometric vacuum beyond 35,000 bp is not unusual and I, for one, have little confidence in older ^{14}C assays as finite "dates" because of the almost insurmountable contamination problem. Extrapolating the sedimentation rates of 10–35,000 bp to cold-climate accumulation during phases 16–29, the switch from warm to cold conditions between phases 15 and 16 should date at least 70,000 bp. Comparison of the Cantabrian curve with the climato-stratigraphic markers of Woillard (1978), Kukla (1975), and Shackleton & Opdyke (1973), suggests a reasonable correlation between 15/16 and ^{18}O isotope contact 5a/4, and between 1/2 and isotope contact 6a/5e. The remaining

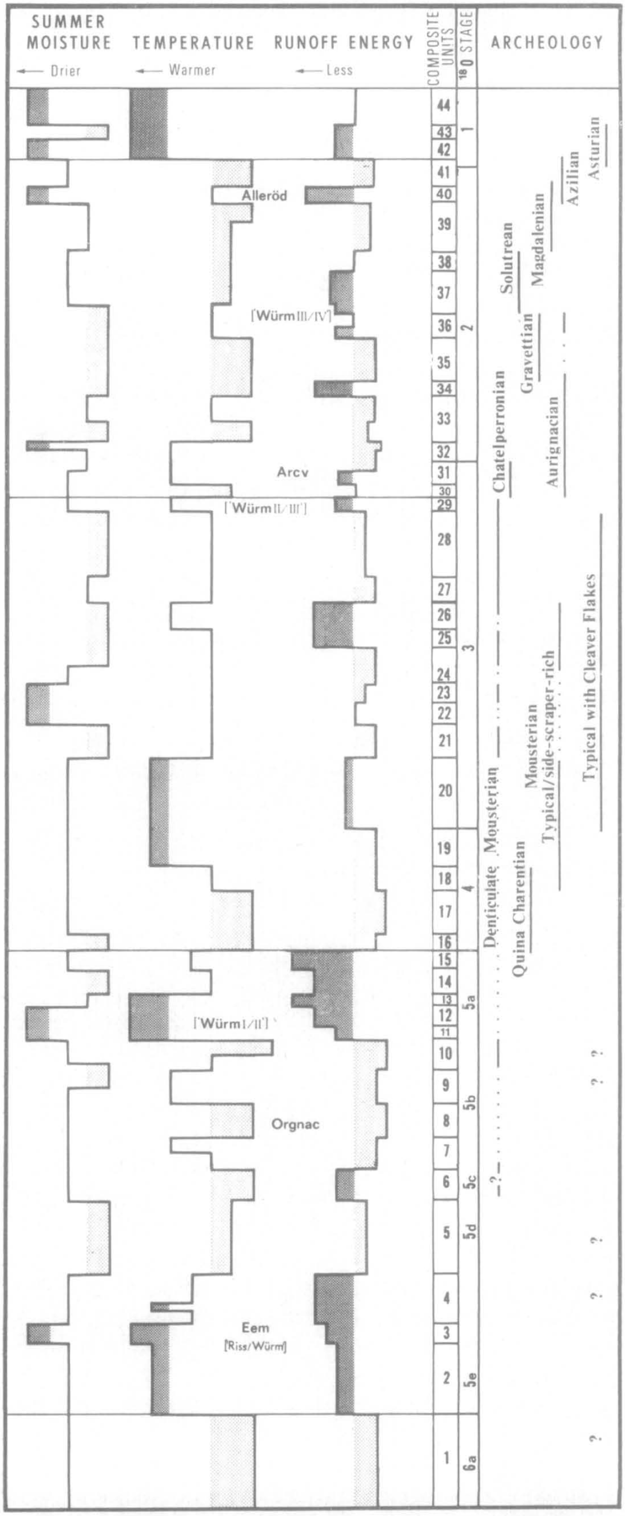

Figure 17. Composite, late Pleistocene climato-geomorphic trace and archaeo-stratigraphy for Santander.

sub-divisions of phases 2–15 in Figure 17 can be tentatively correlated with the ^{18}O stages as shown.

Linking the generalized cave climato-stratigraphy with the regional morpho-stratigraphy of Santander:

(a) The 9 m, fine-grained and eustatically-controlled fill of the lowermost river valleys probably formed during the warm phases 2 and 3, in relation to the +7 m sea level.

(b) The relict Braunlehm soil on the 9 m alluvial terrace argues for a warm, moist climate and stable conditions, possibly phase 14. The higher and older terraces are beyond the time range of Figure 17.

(c) Various peaty foreshore deposits, that imply a lower sea level, date "greater than 40,000", 28,400, 18,700 and 13,600 bp along the coasts of western Santander, Asturias (Mary *et al.*, 1975), and Galicia (Butzer, 1967). These littoral peats are incompatible with active regressional trends and pertain to the cool or cold, stable phases 25–26, 34, 37 and 40.

(d) The presence of loesses (Facies 4), and in a more qualified way, loessic components (as recorded by Facies 3 sediments), argues for considerable wind-blown dust along the Cantabrian coast during phases 9, 16, 18–22, 24, 28, 31–mid-33, mid-36 and 38–mid-39. The most important loess accumulation appears to have coincided with phases 9, 28 and 38. No strong temporal pattern is discernible, but thirteen of these 15 phases were times of cooling or cold climate, i.e., regressive sea levels.

(e) Congelifluction is recorded in one or other of the caves during phases 10, 30, 33 and 35, and is mainly linked to cold, wet and unstable environments.

(f) The 7–8 m alluvial terrace with massive periglacial components (LTI) culminated its development during the unstable phases 39 and 41, judging by the terminal Pleistocene screes of the Castillo hillside.

Finally,

(g) montane glaciation presumably attained maximum extension during the cold and wet phases 33 and 35. No direct field links exist between periglacial and glacio-fluvial terraces in the main river valleys, and the two types of alluviation may not have been entirely in phase.

Comparisons with the Dordogne nomenclature of Laville (1973, 1975) can be readily made, although the detail captured by Laville's meticulous work is generally finer. Our phases 5–10 unquestionably parallel Laville's "Würm I", our 16–28 his "Würm II", and our 30–41 his "Würm III and IV". Comparisons with other sedimentological, faunal, and pollen curves from southern France (see De Lumley, 1976) are equally apparent. Correlation with the French sequences is not only important for archaeological purposes, but also because it unequivocally equates the "Würm I" of these cave sequences with the cold phases of ^{18}O stage 5.

The palaeoclimatic resolution of Figure 17 is probably at the level of phases with a wave-length of two millennia or more, but finer details, such as those recognized in the short but complex sequence of La Riera (probably spanning 38–41) (Straus & Clark, 1978; Straus *et al.*, n.d.) are not recorded in our key caves, or have eluded the mesh of our sampling interval. At Piélago, sedimentation rates also were greater during the terminal Pleistocene. Here there are three distinct cold impulses during phases 41–43: cryoturbation and frost-cracks associated with the upper Magdalenian occupation, mild cryoturbation with the Azilian I, and a major roof spall horizon following immediately upon the Azilian II; the Azilian III was somewhat warmer (García, 1975; Butzer, in preparation). Apart from this important problem of temporal scale, a comparison of the three different cave contributions to the 44 phases of Table 7 shows that episodes with a "stable" external environment have only 57% the probability of representation that "unstable" slope contexts have (21 stable phases recorded in 32 discrete horizons, 23 unstable phases in 61 horizons); this undoubtedly reflects slower sedimentation rates during times of reduced runoff energy. In other words, resolution improves significantly as the number of cave microstratigraphic columns is increased. Conversely, it is improbable that any one cave column will be reasonably complete.

Another important implication of Figure 17 is that the traces of summer moisture, temperature, and runoff energy are rarely in phase. Laville's multiple methodology has already served to show that moisture and temperature are only in part consonant, e.g. cold–dry versus warm–wet, but the procedures employed here bear this out even more forcefully. However, Laville's methodology is not sensitive to runoff energy and therefore misses the significant and incontrovertible link between the cave subsystem and the overall geomorphic system of which it was an integral part. It can be argued that the comprehensive geomorphological evaluation developed here more than compensates for its shortcomings in detail by providing a powerful tool to delineate the essential sedimentological parameters that integrate the cave subsystem with the regional environment.

The environmental inferences of Figure 17 for Cantabrian Spain are equally thought-provoking. The oscillation of warm and cold phases (2–15) during ^{18}O stage 5 was dramatic, and the major cold spells were not only severe but geomorphologically effective. Then, following establishment of a glacial pattern (phases 16–17), the Cantabrian environment was persistently cool, frequently wet and rarely characterized by soil stability (phases 18–32) during ^{18}O stage 3. Winter climate at this time may have resembled that of Iceland. The maximum cold of the last glacial (phases 33–41) is recorded during ^{18}O stage 2; climate became progressively drier, with soils more often than not unstable. Summer surface water temperatures off Santander were 11 °C colder than today, but those off Lisbon were only 3·5 °C cooler (McIntyre *et al.*, 1976); this implies that the modern zonation of coastal climate over 17° latitude between northern Norway and the Loire were compressed into 5° latitude between Cantabria and Lisbon. Regional climate must have been highly unsettled and stormy during the summer and transitional seasons, probably with subarctic cold during the winter months. The severe climatic phase 41 postdates the disappearance of the last winter pack-ice in the Bay of Biscay *c.* 13,000 bp (see Ruddiman & McIntyre, 1973) and probably reflects on accentuated thermal contrasts between land and sea. Altogether, warm climates with groundcover that assured slope stability were of as brief duration as they were in the Czechoslovakian loess landscape (Kukla, 1975) or in the Macedonian biotic landscape (Wijmstra, 1969).

The biotic record from Cantabria and Asturias remains very incomplete. Fine-grained deposits overlying the 6 m, last Interglacial beach, and covered by coarse slope rubble, show a dominance of arboreal pollen, mainly birch and alder (Mary *et al.*, 1975). Cave sediments analysed by Leroi-Gourhan (Leroi-Gourhan, 1971; Leroi-Gourhan & Miskovsky, 1977; in Straus *et al.*, n.d.) and A. Boyer-Klein (in Moure & Cano, 1976, pp. 202–206) indicate an open woodland with pine, hazel and ferns during phases 30–32, a predominantly open and often ericaceous vegetation during phases 33–36, a cold steppe for most of phases 37–39 and expanding pine and oak woodland toward the close of the Pleistocene. Oak and hazel woodland, mainly open and generally rich in ferns, was characteristic of the mid-Holocene (Mary *et al.*, 1975).

The faunal record (Altuna, 1972; Straus, 1977; Cabrera, 1978; Klein *et al.*, 1981) suggests that the megafauna was dominated by *Bos/Bison*, horse, and Red deer during the Mousterian to Gravettian occupations (phases 25–37): Red deer, an adaptively "plastic", mixed grazer and browser (Klein *et al.*, 1981), ecologically equivalent to the reindeer in late Pleistocene France, was pre-eminent during the Solutrean, Magdalenian and Azilian (phases 38–41); ibex and chamois also were relatively important during phases 35 and 39. Red deer, boar and Fallow deer were dominant in Holocene times.

In general terms, these biotic data are compatible with the sedimentological inferences, but they are insufficiently detailed in regard to ground-cover changes that might explain the alternation of "stable" and "unstable" phases. Possibly the non-arboreal pollen, e.g. Gramineae vs. ferns, hold the clue to this dilemma, so that future palynological research may provide a better appreciation of the relationship between regional geomorphic processes and vegetation.

A Composite Archaeo-Stratigraphy

The time horizons of the different Cantabrian industries are also shown in Figure 17, based on Morín, El Pendo, Castillo and other sequences discussed here.

Cave occupation was sporadic during phases 1–15. Unequivocal industrial affinities during this span are limited to the Denticulate Mousterian in El Pendo, during phase 10. Mousterian cave occupation becomes commonplace with phase 18 and persisted to the end of 29. During this time, two and sometimes three Mousterian facies are contemporaneous, in several caves. Except for the Quina Charentian, which is only documented for a short while, each facies is present during cold and temperate, dry and wet, as well as unstable and stable episodes. Denticulate Mousterian spans phases 10–29, with interruptions, probably fortuitous, altogether some 50,000 years. If Morín level XXII proves to be Denticulate as well, this interval would increase to 70,000 years. Sidescraper-rich Typical Mousterian spans phases 18–26, about 25,000 years, and Typical Mousterian with cleaver flakes, phases 20–28, perhaps as much as 28,000 years. As in northern France (Tuffreau, 1979), there is no sound case in Cantabria for a persistence of Acheulian industries beyond the mid-Pleistocene.

An important implication of this paper is that none of the caves was first opened at the beginning of the Upper Pleistocene. Castillo, Hornos, and Cobalejos all have well-developed deposits of mid-Pleistocene age, while late Tertiary or early Pleistocene sediments are verified in several caves of the Castillo hillside. The caverns are, therefore, very old. They were repeatedly infilled, to some degree, perhaps even their entrances sealed, but they also were repeatedly opened and partially cleared, by natural erosion or corrosion. The fact that mid-Pleistocene deposits were largely removed in the process may explain why sporadic (true) Acheulian occupations cannot yet be verified. In any event, the geo-archaeological evidence cautions strongly against the common assumption that caves suitable for mid-Pleistocene settlement did not exist or that they simply were not utilized.

The upper Palaeolithic industries were of much shorter duration. The Chatelperronian overlapped with Early Aurignacian through phases 30 and 31, just as in France, while the Early, Typical and Evolved Aurignacian sequence continued to at least the end of phase 34. The Terminal Aurignacian is "isolated" in phase 38, as is the Aurignacian V of France (Laville, 1975). The Gravettian is present during 35 and 36, overlapping slightly with Evolved Aurignacian. The upper Solutrean is well documented between 21,000 and 17,000 bp (Straus & Clark, 1978; Straus *et al.*, n.d.), spanning 37 and 38.

Lower and upper Magdalenian extend from phase 39 into early 41, judging by the pollen profile and geomagnetic data from Tito Bustillo (Moure & Cano, 1976; Creer & Kopper, 1976). The Magdalenian to Azilian contact is gradational and complex (García, 1975; Straus *et al.*, in press): in terms of the well-established, final Pleistocene climato-stratigraphy of temperate Europe, Piélago demonstrates that the Azilian began during the cool, Bölling oscillation and concluded after the end of the upper Dryas, i.e. *c.* 12,500–9500 bp, the latter date substantiated by two ^{14}C determinations from Asturias (Tresguerres, 1976). This implies a transition or overlap of at least 2000 years between late Magdalenian and early Azilian. Another overlap is apparent between the Azilian and Asturian (see Clark, 1975, 1976; Straus *et al.*, n.d.): two Asturian calc-midden matrices that I analysed from Balmori are of Facies 2 or 3′ and closely comparable to sediments of the lower Magdalenian strata, while the open-air Asturian site of Leincres, at Ciriego, was buried in up to 60 cm of sandy colluvium, on a patently unstable surface, prior to formation of a deep terra fusca loam or silt loam. This suggests that the Asturian began during the unstable phase 41 and, in combination with available ^{14}C dates, implies an age of perhaps 10,500–7000 bp. This is not incompatible with the thermophile marine Mollusca generally found in Asturian shell middens, because surface waters of the eastern North Atlantic has already shifted from a glacial to a non-glacial temperature regime *c.* 13,000 bp (Ruddiman & McIntyre, 1973).

The micro-stratigraphy of the Cantabrian upper Palaeolithic documented here argues that distinct industries, such as the Chatelperronian and early Aurignacian, or the Aurignacian and Gravettian, overlapped in the area by several millennia, just as they did in France (Laville, 1975). Average-link cluster analyses (Hodson, 1969) and close-proximity seriation by the Brainerd-Robbins test (Sterud, 1977) show that the French Chatelperronian, Aurignacian, Gravettian (Upper Perigordian), Solutrean, and Magdalenian-Azilian represent distinct technocomplexes. The Brainerd-Robbins coefficient further distinguishes the Early and Terminal Aurignacian of France as distinct from the Typical/Evolved; it also provides some justification for differentiation of the lower and upper Magdalenian as separate industries, in agreement with the subdivision of the Cantabrian Magdalenian by Moure & Cano (1976). Even allowing for the fact that some industries represent phyletic replacements or activity variants, e.g. upper Magdalenian vs. Azilian, and possibly the Azilian and Asturian, there is a plausible case for repeated situations where two distinct technocomplexes were present in Cantabria after *c.* 35,000 bp. Finally, it appears that nine or ten distinct industries or technocomplexes can be verified for Cantabria within 25,000 years, i.e. with an average duration of only 2500 years.

The Mousterian Facies Problem

The preceding discussion sets the stage for a concluding discussion of the Cantabrian Mousterian facies in their specific geo-archaeological context.

(1) Unlike the upper Palaeolithic industries, the several facies of the Mousterian technocomplex span phenomenally long time ranges of 25 or even 70 millennia. In effect, the half-life of the Mousterian industrial variants was of an order of magnitude greater than that of the upper palaeolithic industries. The paucity of occupation during phases 1–15 compares with the limited utilization of caves during "Würm I" times in the Provence and Languedoc, as opposed to the Dordogne (see de Lumley, 1976).

(2) Two or three Mousterian facies tend to be coeval within Santander over tens of millennia, in some cases in directly adjacent caves, e.g. La Flecha and Castillo.

(3) The local Quina Charentian differs from the sidescraper-rich Typical Mousterian in stylistic terms, i.e. the presence of specific scraper types, rather than in numbers of functionally defined artifacts (Echegaray & Freeman, 1973; Freeman, 1980; for definitions of the pertinent facies, see Bordes, 1972; Guichard, 1976; De Lumley, 1976). Thus the Typical Mousterian appears to be a phyletic replacement of the Quina Charentian (see Figure 17), suggesting some limited temporal trends (see also Mellars, 1965).

(4) The Denticulate, sidescraper-rich Typical, and cleaver-flake Typical Mousterian each span several environmentally-distinct "phases", precluding an adaptational interpretation. This fact might be obscured if only a single cave sequence were analysed, so cautioning that the facies problem can only be approached on a broad, comparative basis.
(5) Unfortunately no open-air Mousterian sites have been documented in Cantabria. In France, for example, the Mousterian of Acheulian tradition is pre-eminent among open-air sites, but far less common inside caves (Bordes & Sonneville-Bordes, 1972; Guichard, 1976). This would argue for activity variants, presumably linked to external kill/butchering sites and interior occupation or special processing sites (see the site typology of Sivertsen, 1980). In Cantabria, the presence of Denticulate Mousterian in the small cave at La Flecha, during the same period that Typical Mousterian was characteristic in adjacent Castillo Cave, also suggests a difference in site function.

A Kolmogorov-Smirnov cluster analysis of the Cantabrian Mousterian facies shows that they are not fundamentally distinct, but overlapping variants on a basic theme (Echegaray & Freeman, 1973; Freeman, 1980). This is consonant with the above observations, and supports an argument that the facies are related to specific activities, so for example, assemblages with high frequencies of denticulates or sidescrapers, or the sporadic presence of heavy-duty tools such as cleaver-flakes or handaxes, Nonetheless, the temporal persistence of all facies during warm and cold, wet and dry, and stable and unstable phases suggests that distinct procurement strategies are not involved (see also Mellars, 1970). Season-specific toolkits also are implausible. Apart from the inherent lack of ecological sensitivity of the mixed stylistic-functional classification that F. Bordes developed for the Mousterian, it is probable that Mousterian lithic assemblages variability is first and foremost a function of processing rather than procurement activities. Interpreted in such terms, the minimal directional change of Mousterian variants over tens of millennia makes good sense—as the reflection of a flexible lithic technology of a single population that maintained an adaptive steady-state through a temporal trajectory of repeated environmental change.

Two corollary points deserve comment. One is that standard Mousterian excavation procedures are less than ideal to isolate meaningful variability. Most assemblages are defined on the basis of total aggregates from horizons that incorporate disturbed, semi-primary or even secondary mixes from multiple occupations, together with a few primary, single-phase occupations. Only three-dimensional excavation, that isolates successive, primary occupation episodes in fine detail, can hope to provide samples truly useful for facies interpretation, on the one hand, and for a realistic appraisal of the duration of occupation phases and their temporal periodicity, on the other. A second point is that geographical variability may well exist, as reflected in both stylistic and functional terms, e.g. between Cantabria and the Dordogne, or among various regions within France (see Freeman, 1966, 1980; De Lumley, 1976). More data and better analytical procedures might verify such differences in a replicable manner. If this were the case then, in conjunction with painstaking zoo-archaeological work, distinct ecological adaptations might be demonstrable in different regions and at different times. At present, no such case can be made.

In conclusion, it can be argued that the Mousterian maintained an adaptive steady-state (see Butzer, 1980) over as much as 70,000 years, despite repeated and significant environmental changes. Whether or not procurement strategies varied in response to ecological shifts could only be decided for Cantabria by better faunal collections and exacting zoo-archaeological analysis. The flexible Mousterian lithic technology appears to have varied in response to processing activities, and there is little directional change through time. In these respects the Mousterian adaptive system, as a set of adaptive behaviours adjusting in response to external and internal changes, evidently resembled that of lower palaeolithic technocomplexes.

Upper palaeolithic adaptive systems were fundamentally different in that five technocomplexes can be identified within a span of 25 millennia, with some temporal overlap, while the average duration of upper palaeolithic industries was only 2500 years. Whether these industries were more specifically adapted to procurement strategies is a moot point, because the basic lithic technology, as opposed to "diagnostic" procurement or processing artifacts (e.g. split-base bone points, bifacial foliate points, barbed harpoons, Noaillian burins, etc.), was basically conservative. But the cultural dynamism associated with this rapid industrial "turn-over" was fundamentally different from that of the Mousterian or lower palaeolithic technocomplexes. Whether or not there were biological or technological continuities between the Mousterian and upper palaeolithic, it is apparent that the socio-cultural components of the adaptive systems indigenous to Cantabria did indeed change *c.* 35,000 bp.

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References

Aguirre, E. de & Butzer, K. W. (1967). Problematical Pleistocene artifact assemblage from northwestern Spain. *Science* **157**, 430–431.

Alcalde del Rio, H., Breuil, H. & Sierra, L. (1911). *Les Cavernes de la Région Cantabrique (Espagne)*. Monaco: Musée d'Anthropologie préhistorique.

Altuna, J. (1972). Fauna de mamíferos de los yacimientos prehistoricos de Guipuzcoa. *Munibe* **24**, 1–464.

Binford, L. R. & Binford, S. R. (1966). A preliminary analysis of functional variability in Mousterian of Levallois facies. *American Anthropologist* **68**, 238–295.

Bordes, F. (1961). Mousterian cultures in France. *Science* **134**, 803–810.

Bordes, F. (1972). *A Tale of Two Caves*. New York: Harper and Row.

Bordes, F. & Sonneville-Bordes, D. de (1970). The significance of variability in Palaeolithic assemblages. *World Archaeology* **2**, 61–73.

Butzer, K. W. (1967). Geomorphology and stratigraphy of the Palaeolithic site of Budiño (Prov. Pontevedra), Spain. *Eiszeitalter und Gegenwart* **18**, 82–103.

Butzer, K. W. (1971*a*). *Environment and Archaeology*. Chicago: Aldine and London: Methuen.

Butzer, K. W. (1971*b*). Comunicación preliminar sobre la geologia de Cueva Morín (Santander). In (J. G. Echegaray & L. G. Freeman, Eds) *Cueva Morín: Excavaciones 1966–1968*. Santander: Patronato de las Cuevas, pp. 343–356.

Butzer, K. W. (1973). Notas sobre la geomorfologia regional de la parte occidental de la Provincia de Santander y la estratigrafia de Cueva Morín. In (J. G. Echegaray & L. G. Freeman, Eds) *Cueva Morín: Excavaciones 1966–1968*. Santander: Patronato de las Cuevas, pp. 267–276.

Butzer, K. W. (1974). Geological and ecological perspectives on the Middle Pleistocene. *Quaternary Research* **4**, 136–148.
Butzer, K. W. (1975). Pleistocene littoral-sedimentary cycles of the Mediterranean Basin: a Mallorquin view. In (K. W. Butzer & G. L. Isaac, Eds) *After the Australopithecines*. The Hague: Mouton, pp. 25–71.
Butzer, K. W. (1977). Environment, culture and human evolution. *American Scientist* **65**, 572–584.
Butzer, K. W. (1978). Sediment stratigraphy of the Middle Stone Age sequence at Klasies River Mouth, Tsitsikama Coast, South Africa. *South African Archaeological Bulletin* **33**, 141–151.
Butzer, K. W. (1980). Civilization: organisms or systems? *American Scientist* **68**, 517–523.
Butzer, K. W. (n.d.). Archeo-sedimentology of Cueva Morín, Santander, northern Spain. In (L. G. Freeman & J. G. Echegaray, Eds) *Life and Death at Cueva Morín*. Chicago: University of Chicago Press, in press.
Butzer, K. W. & Gladfelter, B. G. (1968). Quartz-grain micromorphology. In (K. W. Butzer & C. L. Hansen, Eds) *Desert and River in Nubia*. Madison: University of Wisconsin Press, pp. 473–481.
Butzer, K. W., Stuckenrath, R., Bruzewicz, A. J. & Helgren, D. M. (1978). Late Cenozoic paleoclimates of the Gaap Escarpment, Kalahari margin, South Africa. *Quaternary Research* **10**, 310–339.
Cabrera-Valdes, V. (1978). *La Cueva del Castillo (Puente Viesgo, Santander): estudio y revision de los materiales y documentacion de este yacimiento*. Doctoral dissertation, Universidad Complutense de Madrid.
Clark, G. A. (1975). Excavations in the late Pleistocene cave site of Balmori, Asturias (Spain). *Quaternaria* **18**, 383–426.
Clark, G. A. (1976). *El Asturiense Cantabrico. Bibliotheca Praehistorica Hispana* **13**, 1–372.
Creer, K. M. & Kopper, J. S. (1976). Secular oscillations of the geomagnetic field recorded by sediments deposited in caves of the Mediterranean region. *Geophysical Journal, Royal Astronomical Society* **45**, 35–58.
Echaide, M. D. (1977). La industria litica del yacimiento de Budiño (Pontevedra, Espana). *Munibe* **23**, 125–154.
Echegaray, J. González (Ed.) (1980). *La Cueva del Pendo. Santander*. Santander: Patronato de las Cuevas.
Echegaray, J. González & Freeman, L. G. (1971). *Cueva Morín: excavaciones 1966–1968*. Santander: Patronato de las Cuevas.
Echegaray, J. González & Freeman, L. G. (1973). *Cueva Morín: excavaciones 1969*. Santander: Patronato de las Cuevas.
Echegaray, J. González & Ripoll-Perello, E. (1954) Hallazgos en la cueva de la Pasiega. *Ampurias* **15–16**, 43–66.
Emiliani, C. (1955). Pleistocene temperatures. *Journal of Geology* **63**, 538–578.
Farrand, W. R. (1975*a*). Sediment analysis of a prehistoric rock-shelter: the Abri Pataud. *Quaternary Research* **5**, 1–26.
Farrand, W. R. (1975*b*). Analysis of the Abri Pataud sediments. In (H. L. Movius, Ed.) *Excavation of the Abri Pataud, Les Eyzies (Dordogne)*. Cambridge, Mass.: Peabody Museum of Archaeology and Ethnology, Harvard University, pp. 27–68.
Fernández-Gutiérrez, J. C. (1969). Nota sobre la estratigrafia desconocida de la caverna del Castillo (Puente Viesgo-Santander). *Boletín Read Sociedad Española de Historia Natural (Geologia)* **67**, 5–33.
Folk, R. L. (1966). A review of grain-size parameters. *Sedimentology* **6**, 73–93.
Freeman, L. G. (1964). *Mousterian Developments in Cantabrian Spain*. Doctoral Dissertation (Anthropology), University of Chicago.
Freeman, L. G. (1966). The nature of Mousterian facies in Cantabrian Spain. *American Anthropologist* **68**, 230–237.
Freeman, L. G. (1977). Contribución al estudio de niveles palaeolíticos en la Cueva del Conde (Oviedo). *Boletin, Instituto de Estudios Asturianos* **90–91**, 447–488.

Freeman, L. G. (1980). Mousterian occupations at the Cueva del Pendo. In (J. G. Echegaray, Ed.) *La Cueva del Pendo, Santander*. Santander: Patronato de las Cuevas, in press.

Freeman, L. G. & Echegaray, J. González (1968). La industria musteriense de la cueva de la Flecha. *Zephyrus* **18** (1967), 43–61.

Freeman, L. G. & Echegaray, J. González (n.d.). *Life and Death at Cueva Morín*. Chicago: University of Chicago Press, in press.

García-Guinea, M. A. (1975). El Mesolitico en Cantabria. In (M. A. García and M. A. Puente, Eds) *La Prehistoria en la Cornisa Cantabrica*. Santander: Instituto de Prehistoria y Arqueologia Sautuola, pp. 175–197.

Goldberg, P. (1979*a*). Micromorphology of Pêch de l'Azé sediments. *Journal of Archaeological Science* **6**, 17–47.

Goldberg, P. (1979*b*). Micromorphology of sediments from Hayonim Cave, Israel. *Catena* **6**, 167–181.

Guerra-Delgado, A. & Montouriol-Rodríguez, F. (1959). *Mapa de Suelos de la Provincia de Santander (1 : 125,000) y Memoria Explicativa*. Santander: Diputación Provincial de Santander.

Guichard, J. (1976). Les civilisations du Paléolithique moyen en Perigord. In (H. de Lumley, Ed.) *La Préhistoire Française*. Paris: Centre National de le Recherche scientifique, pp. 1053–1069.

Hodson, F. R. (1969). Searching for structure within multivariate archaeological data. *World Archaeology* **1**, 90–105.

Johnsen, S. J., Dansgaard, W. & Clausen, H. B. (1972). Oxygen isotope profiles through the Antarctic and Greenland ice sheets. *Nature* **235**, 429–434.

Klein, R. G., Wolf, C., Freeman, L. G. & Allwarden, K. (1981). The use of dental crown heights for constructing age profile of Red deer and similar species in archaeological samples. *Journal of Archaeological Science* **8**, 1–31.

Kukla, G. J. (1975). Loess stratigraphy of Central Europe. In (K. W. Butzer & G. L. Isaac, Eds) *After the Australopithecines*. The Hague: Mouton, pp. 99–188.

Laville, H. (1973). Mousterian industries in the climatic chronology of the early Würm in the Perigord. *World Archaeology* **4**, 324–329.

Laville, H. (1975). *Climatologie et chronologie du Paléolithique en Perigord. Etudes Quaternaires*, **4**. Marseille: Université de Provence.

Leroi-Gourhan, Arlette (1971). Análysis polínico de Cueva Morín. In (J. G. Echegaray & L. G. Freeman, Eds) Cueva Morín: Excavaciones 1966–1968. Santander: Patronato de las Cuevas, pp. 357–365.

Leroi-Gourhan, Arlette & Renault-Miskovsky, J. (1977). La palynologie appliqué à l'archéologie. *Bulletin, Association française pour l'Etude du Quaternaire, Supplement*, 35–49.

Lumley, H. de, (Ed.) (1976). *La Préhistoire Française*. Paris: Centre National de la Recherche scientifique, vol. I, part 2.

Mary, G. (1971). Les formations quaternaires de la côte asturienne (Espagne) entre Ribadesella et Comillas. *Bulletin, Association française pour l'Etude du Quaternaire* **7** 111–118.

Mary, G., Médus, J. & Délibrias, G. (1975). Le quaternaire de la cote asturienne (Espagne). *Bulletin, Association française pour l'Etude du Quaternaire* **11** (42), 13–24.

Mellars, P. (1965). Sequence and development of Mousterian traditions in south-western France. *Nature* **205**, 626–627.

Mellars, P. (1970). Some comments on the notion of 'functional variability' in stone-tool assemblages. *World Archaeology* **2**, 74–89.

McIntyre, A. *et al.* (1976). Glacial North Atlantic 18,000 year ago: A CLIMAP reconstruction. *Geological Society of America Memoir* **145**, 43–76.

Moure-Romanillo, J. A. (1968). La Cueva de Cobalejos en Puente Arce, Santander, y su industria paleolítica. *Ampurias* **30**, 181–193.

Moure-Romanillo, J. A. & Cano-Herrera, M. (1976). *Excavaciones en la Cueva de "Tito Bustillo" (Asturias)*. Oviedo: Institutio de Estudios Asturianos.

Obermaier, H. (1924). *Fossil Man in Spain*. New Haven: Yale University Press.

Rat, P. (1959). *Les pays crétacés basco-cantabriques (Espagne). Publications, Université de Dijon* **18,** 1–525.
Ruddiman, W. F. & McIntyre, A. (1973). Time-transgressive deglacial retreat of polar waters. *Quaternary Research* **3,** 117–130.
Shackleton, N. J. & Opdyke, N. (1973). Oxygen isotope and paleomagnetic stratigraphy of Equatorial Pacific core V28–238. *Quaternary Research* **31,** 39–55.
Sieveking, A. & Sieveking, G. (1962). *The Caves of France and Northern Spain: a Guide.* London: Vista Books.
Sivertsen, B. (1980). A site activity model for kill and butchering activities at hunter-gatherer sites. *Journal of Field Archaeology* **7,** 423–441.
Sonneville-Bordes, D. de (1966). L'évolution du Paléolithique superiéur en Europe occidental et sa signification. *Bulletin Societé préhistorique française* **63,** 3–34.
Sterud, E. L. (1977). Analytical techniques to answer new theoretical questions. Paper, *Conference on Contemporary Theory and Paleolithic Data,* Department of Anthropology, State University of New York at Binghamton, March 1977.
Straus, L. G. (1975). El Solutrense de las cuevas del Castillo y Hornos de la Peña (Santander). *Trabajos de Prehistorica* (Madrid) **32,** 9–19.
Straus, L. G. (1977). Of deerslayers and mountain men: Paleolithic faunal exploitation in Cantabrian Spain. In (L. R. Binford, Ed.) *For Theory Building in Archaeology.* London: Academic Press, pp. 41–76.
Straus, L. G. & Clark, G. A. (1978). Prehistoric investigations in Cantabrian Spain. *Journal of Field Archaeology* **5,** 289–317.
Straus, L. G., Altuna, J., Clark, G. A., González, M., Laville, H., Leroi-Gourhan, A., Menéndez de la Hoz, M. & Ortea, J. A. (n.d.). *Paleo-ecology at La Riera* (Asturias, Spain). *Current Anthropology* **22.** (In press).
Swineford, A. & Frye, J. C. (1945). A mechanical analysis of windblown dust compared with analyses of loess. *American Journal of Science* **243,** 249–255.
Tresguerres, J. Fernández (1976). Azilian burial from Los Azules I, Asturias, Spain. *Current Anthropology* **17,** 769–770.
Tricart, J. (1956). *Le Modelé des Régions Périglaciaires.* Paris: SEDES.
Tuffreau, A. (1979). Les débuts du paléolithique moyen dans la France septentrionale. *Bulletin, Societé préhistorique française* **76,** 140–142.
Wijmstra, T. A. (1969). Palynology of the first 30 m of a 120 m deep section in northern Macedonia. *Acta Botanica Neerlandica* **18,** 511–527.
Woillard, G. M. (1978). Grande Pile peat bog: a continuous pollen record for the last 140,000 years. *Quaternary Research* **9l,** 1–21.
Woldstedt, P. (1929). *Das Eiszeitalter.* Stuttgart: Enke, 2nd Edn, 3 vol., 1954–1965.
Zeuner, F. E. (1945). *The Pleistocene Period: its Climate, Chronology and Faunal Successions.* London: Ray Society (2nd Edn, Hutchinson, 1959).
Zeuner, F. E. (1946). *Dating the Past: an Introduction to Geochronology.* London: Methuen (4th Edn 1958).