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Late Miocene alluvial sediments from the Teruel area: Magnetostratigraphy, magnetic susceptibility, and facies organization

Sedimentos aluviales del Mioceno Superior del área de Teruel: Magnetoestratigrafía, susceptibilidad magnética y organización de facies

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ABSTRACT

We present the paleomagnetic dating of the upper Miocene red alluvial to palustrine sequences of the area north of Teruel. The magnetostratigraphy of the Masada del Valle and Masada Ruea sections indicates a minimum age of about 11 Ma to the lowermost sediments post-dating the unconformity over the Mesozoic basement. The overall Miocene sequence represents a retrogradation of the alluvial system, grading upwards into palustrine/lacustrine sedimentation. The onset of palustrine deposition is dated in Masada Ruea at about 9.7 Ma. The late Vallesian faunas of Masía del Barbo, of which level 2B is the reference locality of biochronozone MN10, are dated to 9.3 Ma. The anisotropy of magnetic susceptibility (AMS) in the terrigenous sediments suggests that the orientation of the magnetic ellipsoids represents the paleocurrent direction. Paleocurrent interpretations based on AMS data can be used for a better comprehension of the facies arrangement in the Neogene sediments of the Teruel basin.

Keywords: Teruel Basin. Miocene. Vallesian. Turolian. Vertebrate fossils. Magnetostratigraphy. Magnetic anisotropy. Alluvial sedimentation.

RESUMEN

Se ha realizado un estudio magnetostratigráfico de las sucesiones aluviales que afloran al norte de Teruel (sector de Masada del Valle-Masada Ruea) con objeto de precisar la edad de los sedimentos y de los yacimientos de vertebrados fósiles. La correlación de las sucesiones con la escala de tiempo de polaridad geomagnética indica una edad de 11 Ma para los sedimentos más antiguos estudiados y que yacen en discordancia sobre el substrato Mesozoico. La iniciación de la expansión de la sedimentación palustre/lacustre ha sido datada en Masada Ruea en cerca de 9.7 Ma. La edad de las faunas de Masía del Barbo 2B, localidad de referencia para la biocronozona MN10, es de 9.3 Ma. La anisotropía de la susceptibilidad magnética (AMS) en las facies siliciclásticas indica que la orientación de la fábrica magnética está controlada por la dirección de paleocorrientes. Los datos de AMS pueden ser útiles para determinar la evolución de las paleocorrientes y contribuir al estudio de la distribución de facies y la evolución del relleno sedimentario de la cuenca.

Palabras clave: Cuenca de Teruel. Mioceno. Vallesiense. Turoliense. Vertebrados fósiles. Magnetoestratigrafía. Anisotropía magnética. Sedimentación aluvial.

INTRODUCTION

The Teruel basin is a preferred region among vertebrate paleontologists because of the abundance of rich fossiliferous sites, particularly of late Miocene to Pliocene age. The relatively low structural complexity combined with extensive and accessible rock outcrops allows accurate lithostratigraphic correlations between neighbouring sections. Paleontologists have succeeded on building a detailed biostratigraphic zonation based on unequivocal stratigraphic superposition of faunas (van de Weerd 1976; Adrover 1986; Mein et al., 1983; Mein et al., 1989; Daams et al., 1988; van Dam, 1997; van Dam et al., in prep.).

The biostratigraphy in the Teruel basin has recently been coupled with a series of magnetostratigraphic studies (Moissenet et al., 1990; Opdyke et al., in press; Krijgsman, 1996; Krijgsman et al., 1996). These studies have provided the continental biostratigraphy with a high-resolution absolute chronology. This is the basis for further regional and global correlations, allowing a better understanding of the significance of the events recorded in the basin.

Despite the resolution already achieved in the sequences of the Teruel basin, some aspects of the chronology of late Miocene faunas are still to be refined. In this study we present the magnetostratigraphic dating of some alluvial sequences in the Teruel area. We provide age constraints for: 1) the beginning of the subsidence and clastic sedimentation in this area, and 2) the onset of the palustrine and lacustrine conditions after a period of widespread alluvial sedimentation. This study also yields an age for the late Vallesian locality Masía del Barbo 2B, the reference site of the MN 10 zone (de Bruijn et al., 1992).

THE TERUEL AREA: GEOLOGICAL SETTING

The Teruel basin is a narrow NNE-SSW striking half-graben that cuts the megastructures of the Iberian chain along more than 100 km (Fig. 1). It can be considered as the westernmost rift basin related to the Neogene extensional structure of the eastern Iberia continental margin (Moissenet, 1984; Anadón et al., 1989a). The geometry and evolution of the Teruel basin were fundamentally controlled by tectonic extension and subsidence along its basin bounding faults.

Sedimentation in the Teruel basin took place under endorreic conditions from the early Miocene to late Pliocene (early Villafranchian) (Moissenet, 1989). Basin infill was dominated by alluvial red bed sequences alternating with lacustrine/palustrine limestones and gypsum units. As a rift basin, lateral and vertical facies distribution was primarily controlled by syndepositional tectonic activity along the basin bounding faults. Terrigenous contributions were fed into the basin through alluvial fans located on its active margins, which graded laterally into shallow lacustrine deposits in areas with more restricted clastic supply: either central areas far beyond the terrigenous influence or protected areas behind paleogeographic elevations, acting as efficient sediment traps or inducing particular directions of detrital transport (Broekman, 1983).

The Teruel area shows a complicated structure due to the concurrence of: 1) the Neogene NNE-SSW fault lineation; 2) the reactivating of the pre-Neogene NW-SE structural trend of the Iberian chain (Concud fault); and 3) the diapiric manifestations of Triassic evaporites (El Salobral, NE Teruel). The initiation of the sedimentation in the Teruel area is represented by the upper Miocene Tejares Formation, informal denomination for the red alluvial sequences near Teruel (Anadón et al., 1990; Alcalá et al., 1994), also referred to as part of the Peral Formation (van de Weerd, 1976). The Tejares Fm. lies in unconformity over the diapiric Triassic evaporites and the Jurassic limestones (Adrover et al., 1986). Biostratigraphic information for the Tejares Fm. is limited to its upper levels (upper Vallesian of la Salle, Adrover et al., 1982; Alcalá et al., 1994) and laterally equivalent palustrine/lacustrine units (e.g.: upper Vallesian-lower Turolian in Los Aguanaces, La Gloria section, Krijgsman et al., 1996; van Dam, 1997;

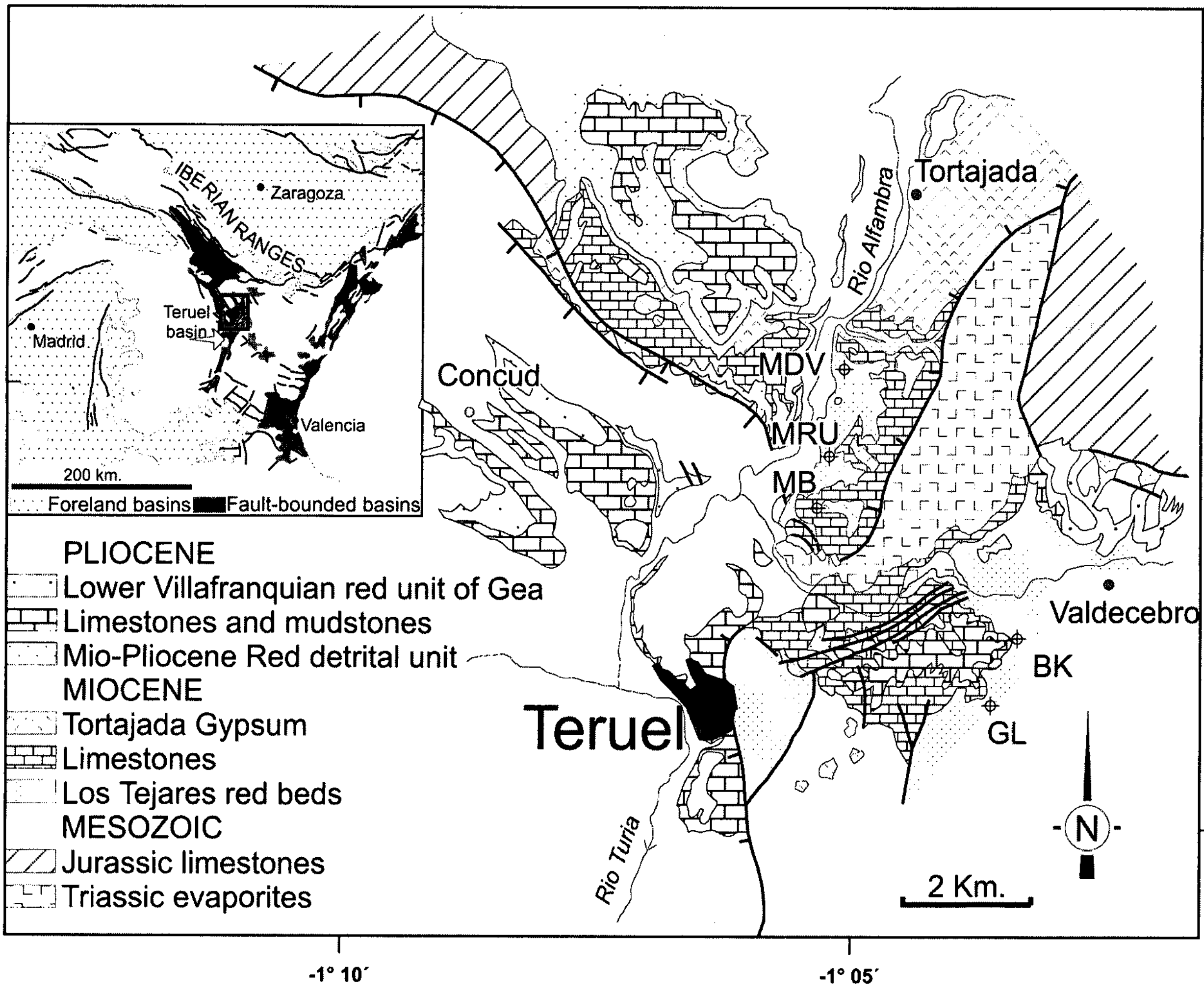

Figure 1. Geological sketch of the Teruel area (adapted from Anadón et al., 1990) and location of the sites mentioned in the text: MDV: Masada del Valle; MRU: Masada Ruea; MB: Masía del Barbo; GL: La Gloria; BK: El Bunker de Valdecebro.

Figura 1. Esquema geológico de los alrededores de Teruel (adaptado de Anadón et al., 1990) y situación de las localidades nombradas en el texto: MDV: Masada del Valle; MRU: Masada Ruea; MB: Masía del Barbo; GL: La Gloria; BK: El Bunker de Valdecebro.

van Dam et al., in prep.). The Tejares Fm. is lithostratigraphically equivalent to the lower terrigenous member of the Rio Turia Fm. (Broekman et al., 1983), that extends south of Teruel along the western side of the Teruel-Ademuz basin. The base of Rio Turia Fm. is dated as Aragonian-early Vallesian at Casas Bajas (Broekman et al., 1983), and lies unconformably over the alluvial sediments of the Umbria de la Muela and Val de la Sabina formations, which are dated as late Aragonian-early Vallesian at Casas Altas as well (Broekman et al., 1983). The terrigenous sequences represented by the lower Rio Turia and Tejares Formations have the greatest surface-extension of all units distinguished in the Teruel basin and represent a major retreat of pre-existing lacustrine systems (Libros sequence, Anadón et al., 1989b). North and East of Teruel, the Tejares Formation is overlain by the white limestones of the Alfambra Formation (van de Weerd, 1976). The distinct time-transgressive character of the transition from red beds to carbonates is demonstrated by direct field observations of lateral lithofacies transitions and by biostratigraphic information of different sites at the base of the Alfambra Fm. (van de Weerd, 1976; van Dam, 1997).

MAGNETIC STRATIGRAPHY

In this study, we present the magnetostratigraphic results from the Tejares Fm. and its transition to the over-

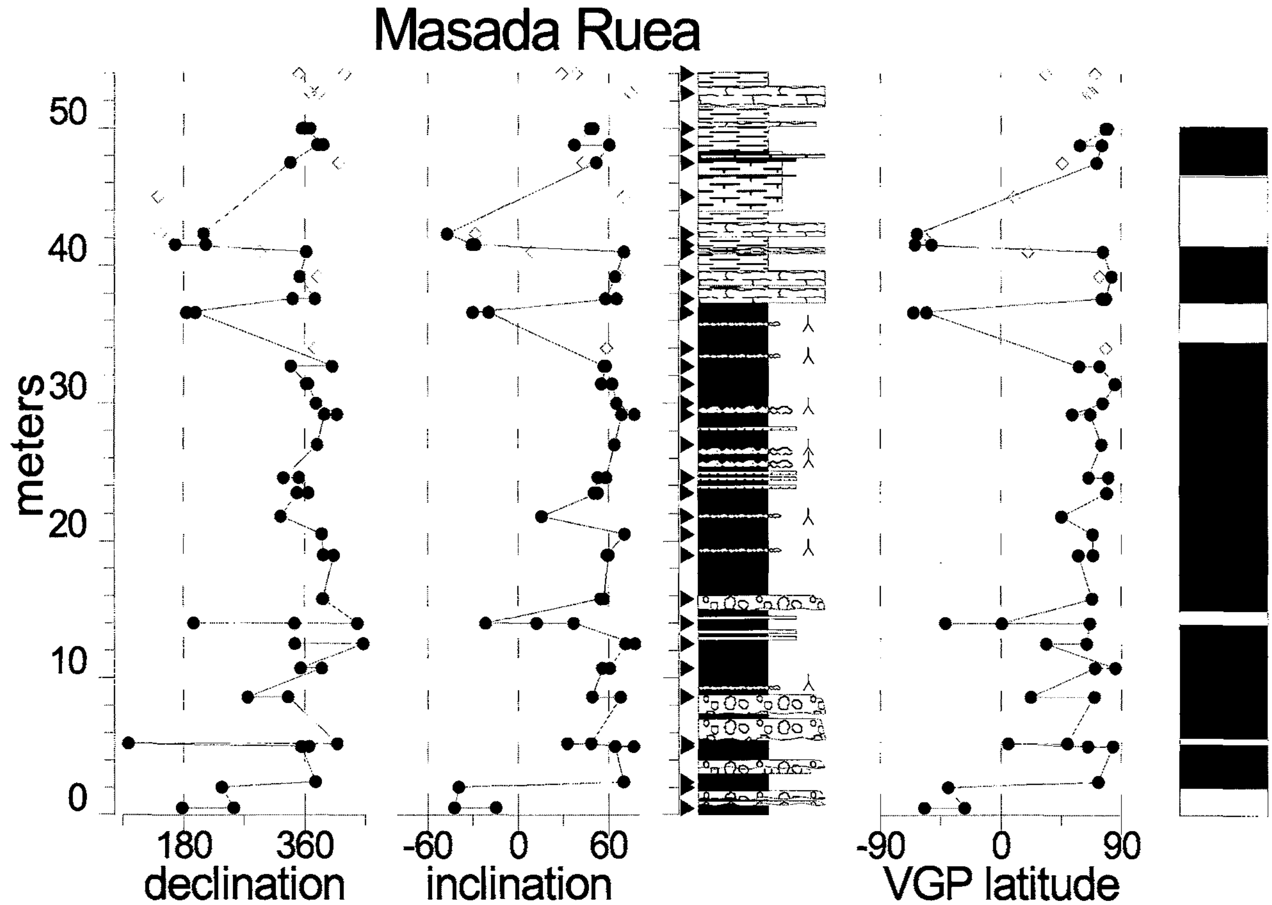

Figure 2. Magnetostratigraphy of the Masada Ruea section (see fig. 6 for legend).

Figura 2. Magnetoestratigrafía de la sucesión de Masada Ruea (ver leyenda en fig. 6).

lying Alfambra Fm. in the Masada Ruea (Fig. 2) and the Masada del Valle (Fig. 3) sections. The studied succession outcrops along the eastern slopes of the Alfambra valley, 2-3 km. north of Teruel. The classic late Vallesian faunas of Masía del Barbo are found at the transition from the red beds of the Tejares Fm. to the whitish limestones of the Alfambra Fm., some hundred meters south of Masada Ruea (Fig. 1). Beds are easily traced in the field, allowing an accurate correlation of the Masía del Barbo (MB) sites to the magnetostratigraphic sequence of Masada Ruea. The middle to late Turolian faunas of Masada del Valle (MDV) are found at six different levels in the palustrine beds of the Masada del Valle section (Fig. 3).

The sections were sampled at stratigraphic intervals of about one meter, focusing preferably on fine-grained red terrigenous lithologies. The upper levels of the Masada Ruea and Masada del Valle were not sampled because of the absence of suitable lithologies and the chances for occurrence of hiatuses in the palustrine facies of the Alfambra Fm. (as indicated in the Bunker de Valdecebro section, Krijgsman et al., 1996). The sampling was concentrated in the terrigenous Tejares Fm. and its transition towards the overlying Alfambra Fm.

Cylindrical samples were drilled and oriented in the field. Paleomagnetic analysis was based on standard techniques of stepwise demagnetization. Thermal demagnetization demonstrated to be effective in removing unstable components and isolating a characteristic remanent magnetization (ChRM) (Fig. 4). A substantial difference on the natural remanent magnetization (NRM) intensities is observed between lithologies: NRM was 10 to 100 times higher in red beds than in carbonates and interbedded light grey silts of the Alfambra Fm. (Fig. 5). On the contrary, the stability spectra during thermal demagnetization shows a similar pattern in the majority of samples: 1) a

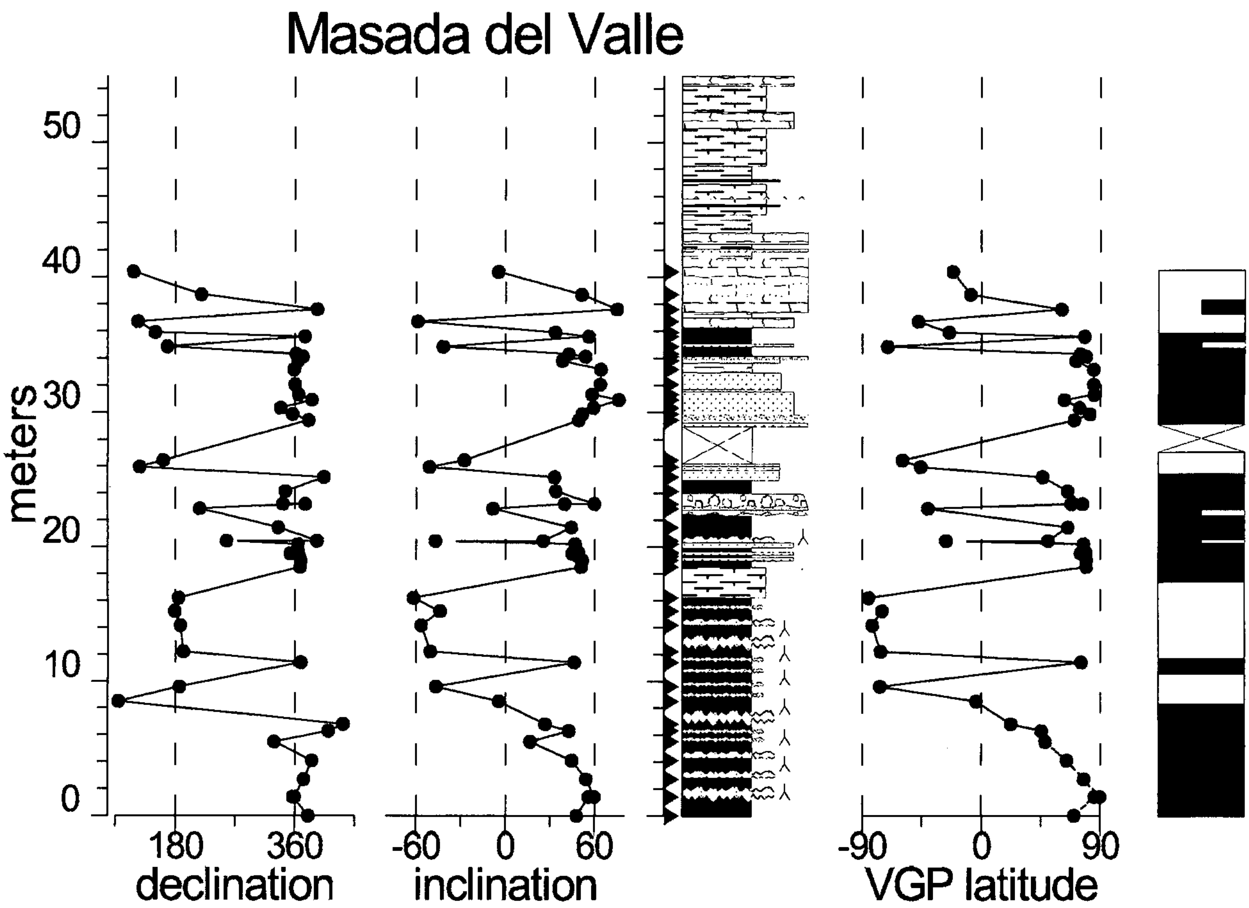

Figure 3. Magnetostratigraphy of the Masada del Valle section (see fig. 6 for legend).

Figura 3. Magnetoestratigrafía de la sucesión de Masada del Valle (ver leyenda en fig. 6)

steep decrease of magnetization (1/2 to 2/3 of the initial NRM) from room temperature to 200°-300 °C, removes a low temperature secondary component; 2) a gradual decrease of the NRM from 300° to 600 °C outlines a stable ChRM component that shows both normal and reverse polarities. Maximum unblocking temperatures near 600 °C are observed in the red bed samples, suggesting the presence of magnetite as the principal carrier of the remanence.

ChRM directions of Masada Ruea (Fig. 4 G) and Masada del Valle (Fig. 4 H) are calculated from principal components analysis of the demagnetization data. The overall mean direction (dec/inc: 009/53, Fig. 4 I) is not significantly different from present geomagnetic field, and consequently does not support any marked (latitudinal) translation nor vertical axis rotation of the studied sequences since their deposition. ChRM directions are used to calculate virtual geomagnetic pole (VGP) latitudes for each site (Fig. 2 and 3), which are interpreted as normal (VGP lat>0) and reversed (VGP lat<0) polarities. The resulting magnetic polarity sequence in Masada Ruea and Masada del Valle conforms with the visual correlation between both sections (Fig. 6), and strengthens the reliability of the magnetozones identified in this study. The composite sequence is made of 4 normal (N1 to N4) and 5 reversed (R1 to R5) magnetozones (Fig. 6).

The correlation of the composite section to the geomagnetic polarity time scale (GPTS) of Cande and Kent (1995) is based on the presence of the late Vallesian faunas of Masía del Barbo which are correlated to the top of Masada Ruea. Since the late Vallesian (MN10) is known to span from 9.7 Ma (Garcés et al., 1996) to 8.7 Ma (Krijgsman et al., 1996), the reversed magnetozones R2 and R3 just below Masía del Barbo are correlated to chron C4Ar (Fig. 7). The two sites Masía del Barbo A and B are found at the base of N3, which correlates to chron

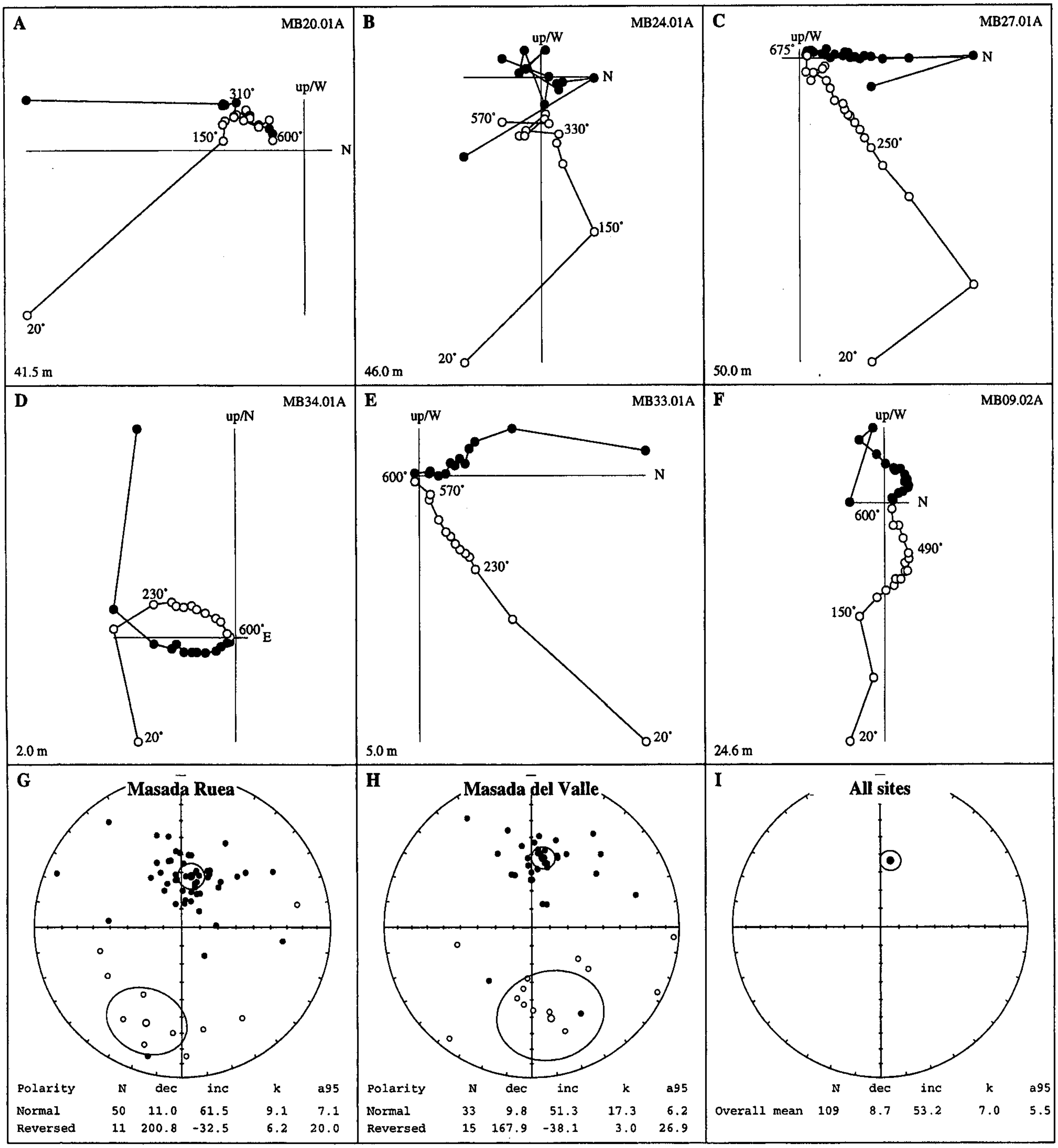

Figure 4. Stepwise demagnetization diagrams of representative samples (A, B, C: grey silts; D, E, F: red silts). Equal area projection of all characteristic directions (G,H) and overall mean paleomagnetic direction (I).

Figura 4. Diagramas de desmagnetización progresiva de la MRN de muestras representativas (A, B, C: lutitas grises; D, E, F: lutitas rojas). Proyección estereográfica de todas las direcciones características (G, H) y dirección paleomagnética media (I).

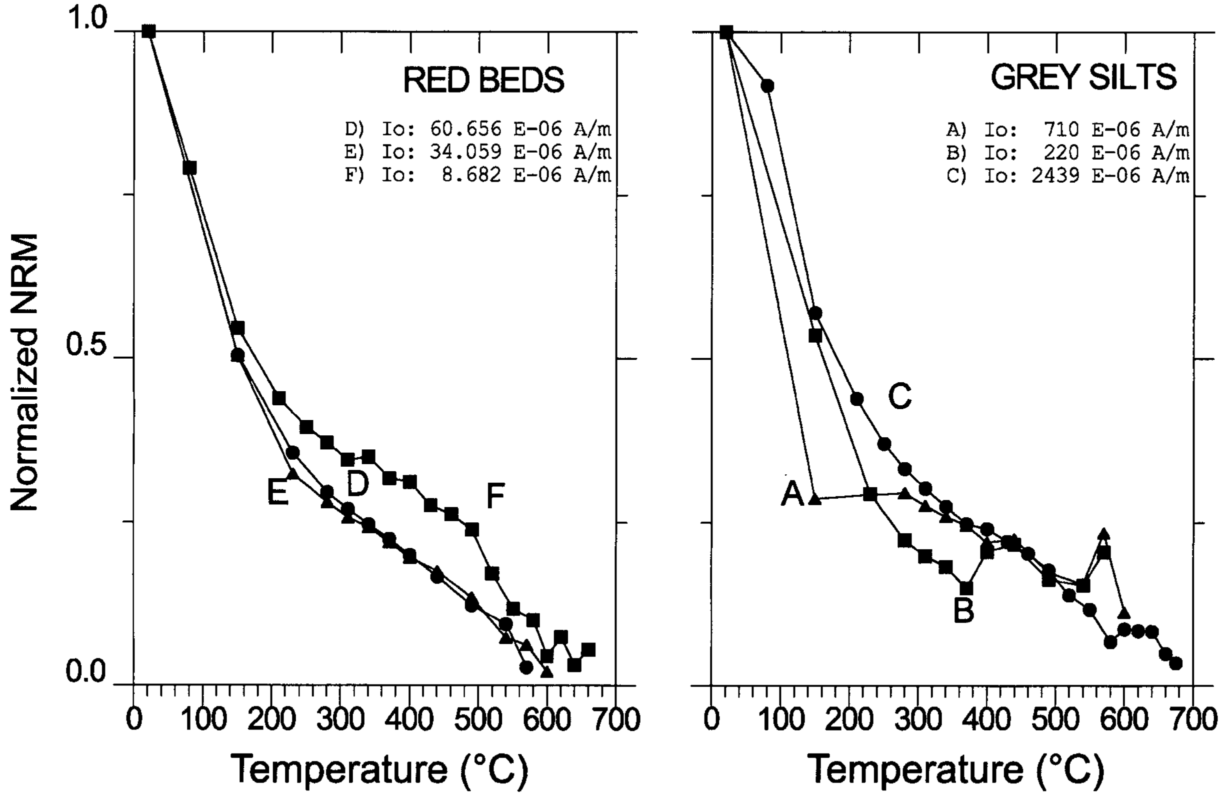

Figure 5. NRM Intensity thermal decay of samples from fig. 4.

Figura 5. Caída de la intensidad de la MRN de las muestras de la fig. 4.

C4Ar.1n, and has an age of about 9.3 Ma. The lowermost long normal magnetozone N1 correlates to the characteristic chron C5n. The reversed magnetozone R1 at the base of Masada Ruea likely represent the top of chron C5r (Fig. 7), indicating an age for the base of the succession of about 11 Ma. Because R1 is represented by only two sites (Fig. 2), an alternative correlation of R1 to one of the subchrons in chron C5n is possible, although rather unlikely since these are very short events lasting only a few thousand years.

The pattern of reversals of the upper half of the sequence does not easily match with the GPTS (Fig. 7), and an independent correlation based only on the polarity sequence is not strong for magnetozones N3 to R5. Chances of having hiatus and/or condensed sections in these sequences are not unrealistic since: 1) the average sediment accumulation rates are typically low (less than 3 cm/kyr, Fig. 9); and 2) the observed upward trend towards decreasing terrigenous input is compatible with the occurrence of periods of no sedimentation. New biostratigraphic information from site MRU, at the levels above the Masada Ruea section and equivalent to magnetozone N4 in Masada del Valle (Fig. 7), indicates a late Vallesian age (van Dam, 1997). This supports a correlation of N4 to chron C4An. The approximate field correlation of the early Turolian faunas in the El Regajo (Adrover et al., 1984) and Alfambra sections (van Dam et al., in prep.) to the levels below MDV supports the correlation of R5 to the chron C4r. In addition to this, the identification of late Vallesian fossils in MRU rules out the alternate correlation of N4 to C4n and the possibility of hiatus in the Masada Ruea-Masada del Valle area corresponding to most part of chron C4r. The chron C4r was recognized in the area East of Teruel (in La Gloria and El Bunker de Valdecebro sections, Krijgsman et al., 1996; van Dam et al., in prep.) in a sequence of 25 meters of alluvial deposits (Fig. 7), which are bounded above and below by palustrine carbonates with early Turolian fossils. The occurrence of middle to late Turolian faunas only a few meters above R5 (Fig. 7) may indicate low sedimentation rates and hiatuses in the upper levels of the Masada del Valle section, as occurs in the El Bunker de Valdecebro section.

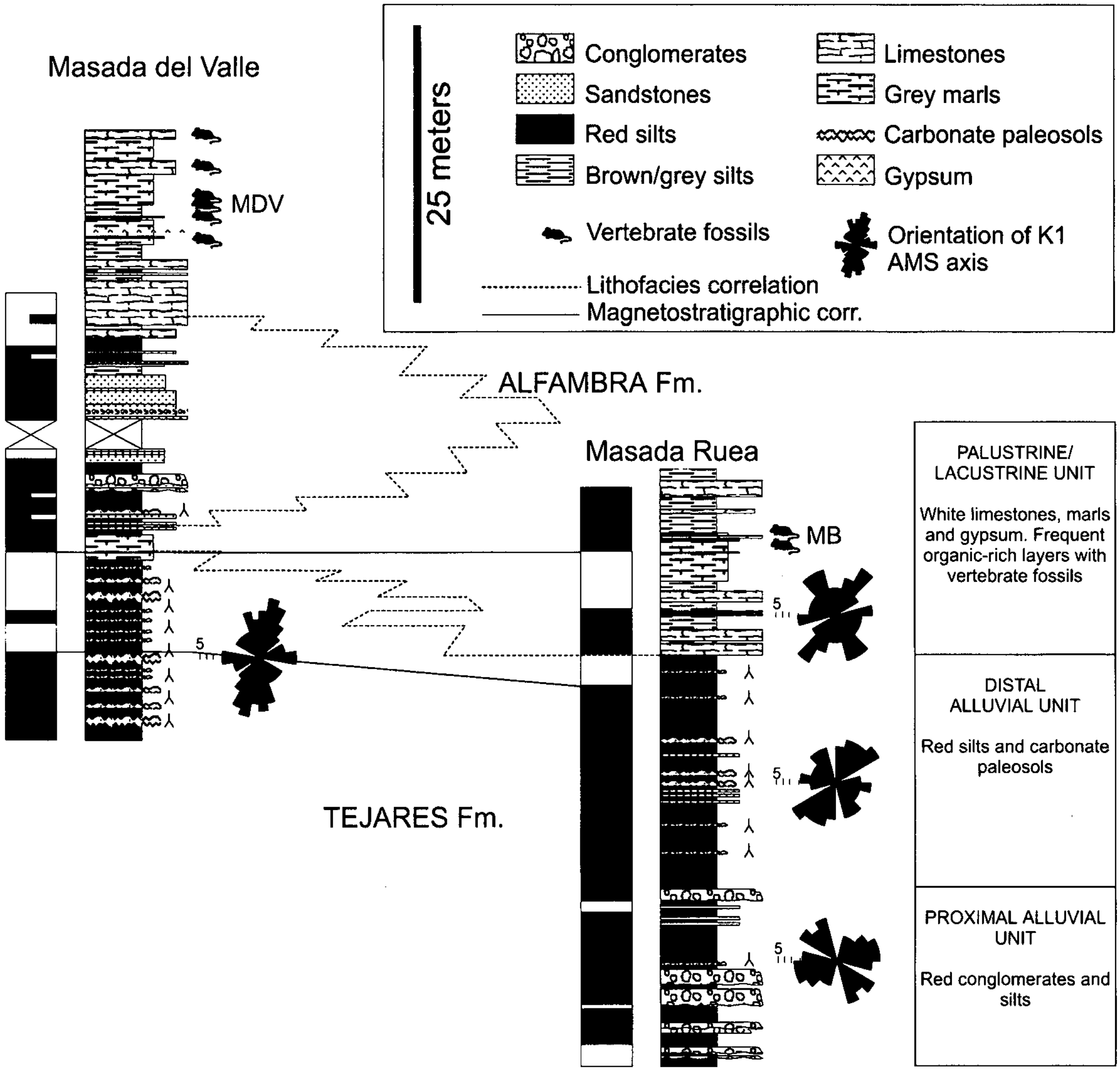

Figure 6: Magnetostratigraphic correlation of Masada del Valle to Masada Ruea. Rose diagrams of orientation of K1 principal axis of the AMS ellipsoid.

Figura 6. Correlación magnetoestratigráfica entre Masada del Valle y Masada Ruea. Histograma circular de las orientaciones de los ejes principales K1 del elipsoide de la Anisotropía de la Susceptibilidad Magnética.

AMS FABRICS AND PALEOCURRENT INTERPRETATION

The anisotropy of magnetic susceptibility (AMS) was measured in all specimens before they were subjected to thermal demagnetization. The fifteen positions measurement routine in the low field susceptibility bridge provides an accurate estimate of the magnetic anisotropy, which can be represented by a second order tensor (Jelinek, 1981). The AMS tensor is represented by three orthogonal principal axis: $K1 \geq K2 \geq K3$.

The overall mean AMS ellipsoid (Fig. 8A) agrees with a planar (disc shaped) depositional fabric: magnetic foliation (K1-K2) contained in the bedding plane and minimum principal axis (K3) parallel to the bedding pole. However, some differences both in the orientations of the principal susceptibility axis (Fig. 8A) and in the anisotropy parameters (Fig. 8B) are observed among facies: 1) Undisturbed red bed samples show well preserved flat-lying foliated AMS ellipsoids ($T>0$ in Fig. 8B) with low to intermediate values of degree of anisotropy ($P'<1.04$, Fig. 8B) and tight clustering of K3 along a sub-

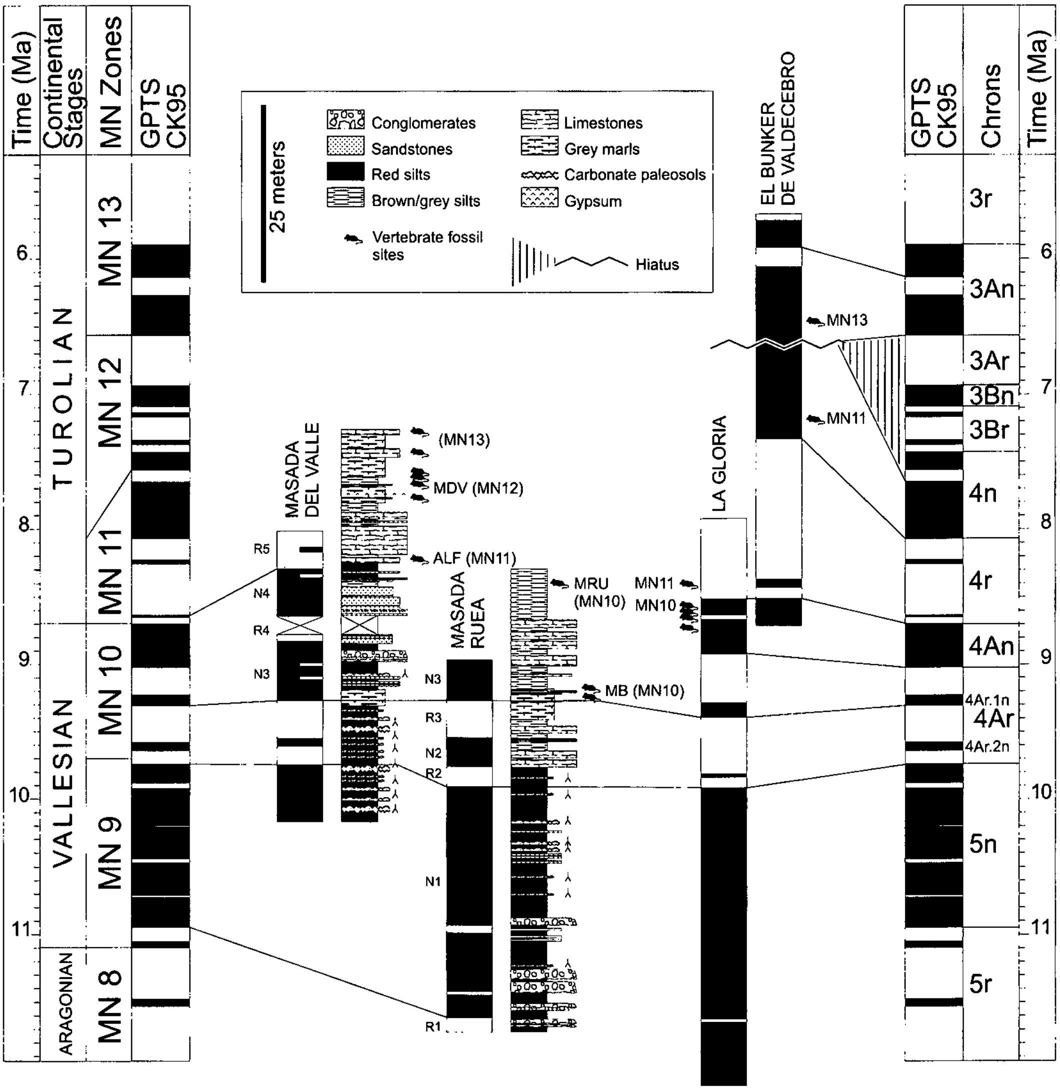

Figure 7: Proposed correlation of the studied sections to geomagnetic polarity time scale of Cande and Kent (1995).

Figura 7: Correlación de las sucesiones estudiadas con la escala de tiempo de polaridad geomagnética de Cande y Kent (1995).

vertical axis; 2) palustrine grey silts present a weak anisotropy (P'<1.02, Fig. 8B), as a result of the decreased amounts of detrital phyllosilicates and clay minerals, but still show foliated depositional fabrics; 3) samples from carbonate paleosols have weak anisotropy, no signs of depositional fabric, and prolate ellipsoids (cigar shaped, T<0, Fig. 8) with K1 subvertical. The change from oblate depositional fabric to prolate subvertical ellipsoid in these facies is likely the result of mechanical activity of roots during paleosol formation.

Orientation of K1 in red beds appears to present a broad clustering along a preferred orientation. The overall distribution in Masada del Valle presents a clear NNE-SSW dominant orientation of K1, while in Masada Ruea preferred orientations vary vertically through the section (Fig. 6): broadly E-W in the lower alluvial part, NNE-SSW in the upper alluvial unit, and with no clear orientation in the upper palustrine beds.

The orientation of AMS ellipsoid in the majority of sedimentary rocks is determined by the particle shape anisotropy, the maximum principal axis K1 being parallel to the direction of maximum grain elongation. Assuming that directions of K1 correspond to the preferred orientations of elongated grains in the sediments, it is possible to

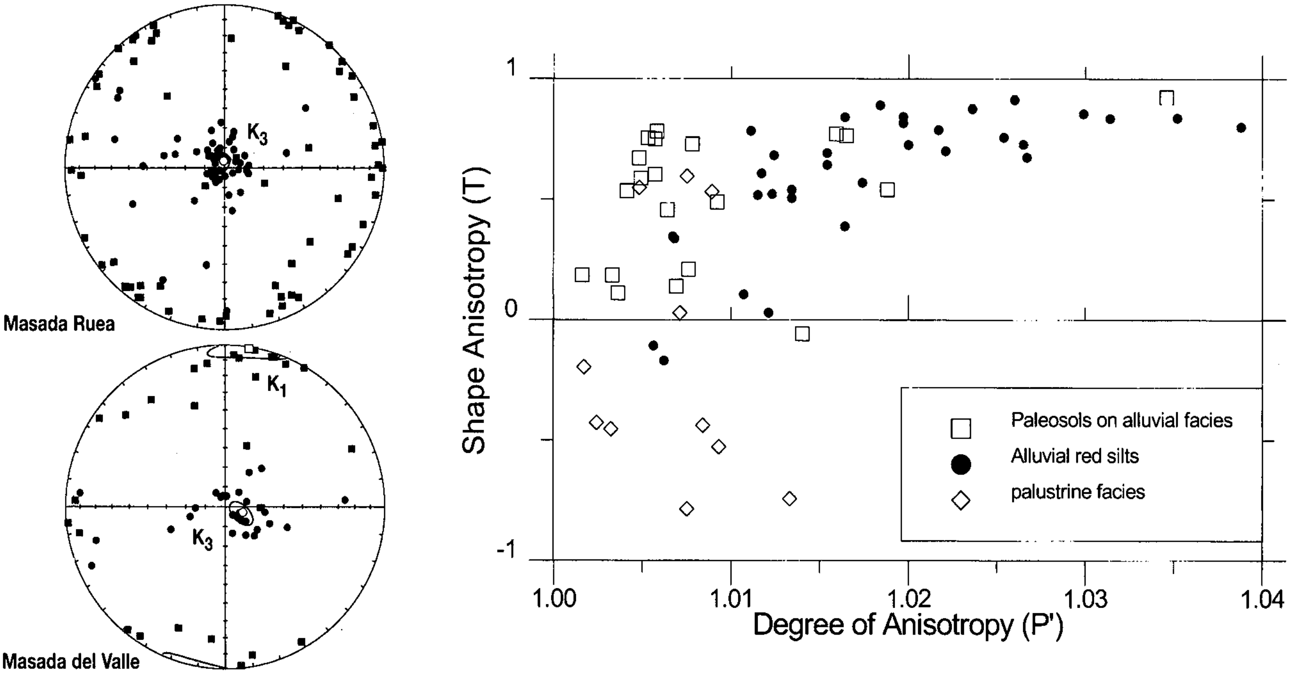

Figure 8. Equal area projection of the principal susceptibility axis of samples from Masada del Valle (A) and Hrouda diagram showing the contrasting anisotropy of the different lithofacies (B).

Figura 8. Proyección estereográfica de las direcciones de los ejes principales de la ASM de las muestras de Masada del Valle (A) y diagrama de Hrouda, mostrando el contraste en los parámetros de anisotropía de las diferentes litofacies estudiadas (B).

interpret the observed grouping of K1 in depositional fabrics as a result of the dominant paleocurrents during deposition. In the terrigenous sequences of the Teruel area, the preferred orientation of K1 is most likely driven by paleocurrents, since a post-depositional tectonic cause is likely to be ruled out since: 1) extensional regimes have dominated the region since the deposition of the sediments, 2) the direction of K1 orientation shows a vertical variation through the section (Fig. 6).

The paleocurrents interpreted from AMS data show two consecutive stages: a first one, represented by the coarse terrigenous deposits of the lower Masada Ruea, in which paleocurrents appear to be dominated by a lateral E-W component; and a second one, represented by the red clay-paleosol cyclic alternations of the intermediate unit, in which axial distributing NNE-SSW paleocurrents are far more important. The first is coincident with the flow directions interpreted from the gravel beds of the lower unit in Masada Ruea (N 105°) and Alfambra (N 110°) The second is in agreement with the alluvial to palustrine lateral facies transition observed in the area (Fig. 6), that evidences a north-south polarity of the alluvial contributions.

Although the distribution of K1 in Masada del Valle shows a reasonably good grouping, the directions of the sites from Masada Ruea are more scattered, and may question the significance of the mentioned preferred orientations. However, more precise results can be achieved with a separate sampling strategy, specially oriented for paleocurrent analysis; that is, selecting postdepositionally undisturbed layers and skipping paleosol horizons, performing extensive lateral sampling of selected beds, and increasing substantially the number of samples per site.

FACIES ORGANIZATION AND SEDIMENTARY EVOLUTION

The overall sequence in the Teruel area represents a fining upwards retrogradation of the alluvial system (Tejares Fm.), and the progressive and punctuated expansion of the palustrine-shallow lacustrine domain (Alfambra Fm.). Both laterally and vertically the sequence is made of three fundamental lithofacies units: 1) proximal alluvial conglomerates and silts; 2) distal alluvial fine-grained flood plain facies with carbonate paleosoils; and

3) palustrine-lacustrine carbonates and evaporites. The lower alluvial unit unconformably overlies Mesozoic basement rocks, which outcrop at several spots near the base of the Masada Ruea section. The base of Masada Ruea approximately dates the beginning of the tectonic subsidence and sedimentation in this area at older than 11.0 Ma, near the Aragonian-Vallesian boundary. This age is close to that suggested for the expansion of the red alluvial sedimentation of the Rio Turia Fm. in the Teruel-Ademuz basin, which is related to the renewed activity of the NNE-SSW basin-bounding faults. Evidence for the tectonic control on the basin-wide expansion of the terrigenous sedimentation during the early Vallesian are the unconformable contact of this unit over both Miocene sediments and Mesozoic basement in the area near Ademuz (Broekman et al., 1983).

The dominant lateral E-W paleocurrents in the lowermost coarse alluvial unit from Masada Ruea (Fig. 10a) are consistent with the initiation of sedimentation as a result of tectonic activation of basin-bounding faults and the uplift of the basement blocks located to the East. The vertical transition from coarse proximal alluvial deposits to silt-paleosol red bed alternations takes place as the lateral coarse alluvial input decreases and axial distributing currents dominate the system (Fig. 10b). The gradual decrease of the lateral alluvial contributions eventually causes terrigenous sediment starvation and favours the conditions for deposition of carbonates.

In such a setting, restriction of terrigenous sediment supply can be seen as a basic requirement for deposition of carbonates, either paleosols on distal alluvial or

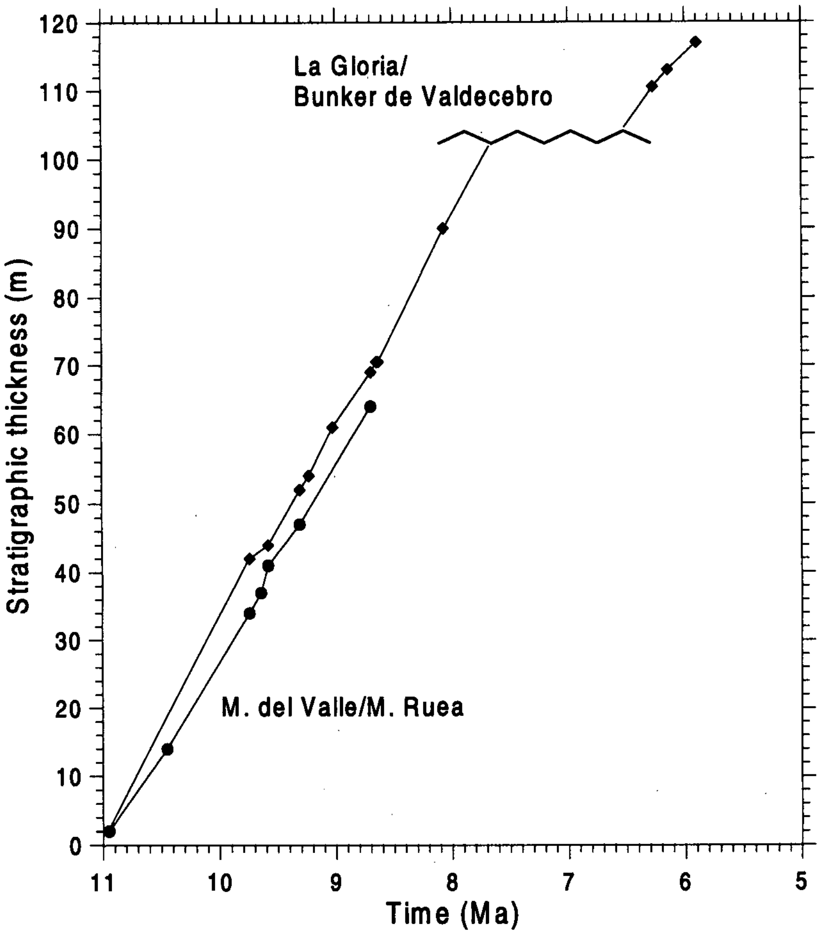

Figure 9. Sediment accumulation rates of the Masada del Valle/Masada Ruea composite section compared to those obtained in La Gloria/Bunker de Valdecebro composite section (Krijgsman et al., 1996).

Figura 9. Tasas de acumulación de sedimento en las sucesiones de Masada del Valle/Masada Ruea comparadas con las obtenidas en la sucesión de La Gloria/EL Bunker de Valdecebro (Krijgsman et al., 1996).

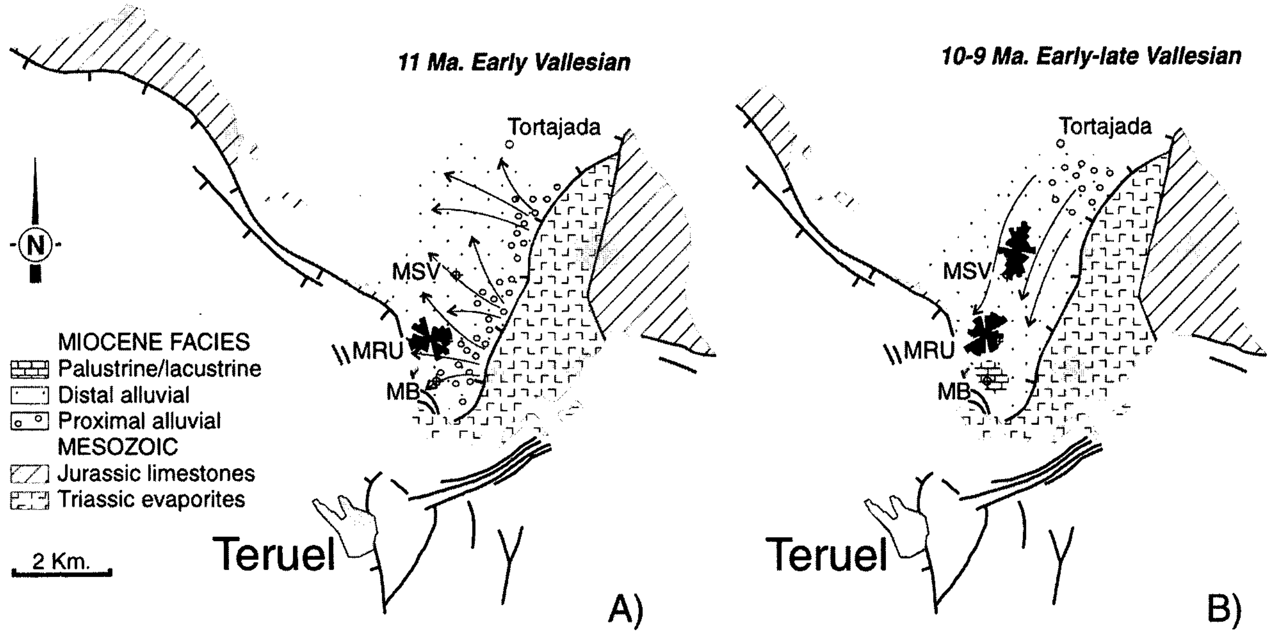

Figure 10. Paleogeographic sketch showing the evolution of the paleocurrents in the alluvial sediments North of Teruel. The dominant lateral E-W paleocurrents in the lowermost coarse alluvial unit from Masada Ruea (A) are consistent with the initiation of sedimentation as a result of tectonic uplift of the eastern basin margin. The vertical transition from coarse proximal alluvial deposits to silt-paleosol red bed alternations takes place as the lateral coarse alluvial input decreases and axial NNE-SSW distributing currents dominate the system (B).

Figura 10. Esquema paleogeográfico mostrando la evolución de las paleocorrientes en los sedimentos aluviales miocenos situados al Norte de Teruel. Las direcciones de transporte en sentido E-W en el tramo inferior de Masada Ruea (A) pueden relacionarse con la iniciación de la sedimentación en este sector de la cuenca como consecuencia del levantamiento de su margen oriental. La transición vertical desde sedimentos aluviales proximales de grano grueso a una alternancia de limos rojos y paleosuelos carbonatados tiene lugar a medida que el aporte de terrígenos desde el margen de cuenca disminuye, y las corrientes axiales de dirección NNE-SSE de redistribución del sedimento dominan el sistema (B).

palustrine facies, or shallow water lacustrine marls and limestones. The necessary clastic "starvation" may occur in particular areas in the basin as: a) the continuous erosion of the margins is not being balanced by tectonic rejuvenation (uplift) of the source areas, or b) there is a change of precipitation regime as a result of climate change. Understanding the influence of climate on sedimentation is difficult to asses because there is a large number of variables which are dependent on climate. An increase on the average precipitation during wet periods might help highstand phreatic levels and development of ponded areas and palustrine/lacustrine carbonate deposition. Such correlation of palustrine/lacustrine units to wetter periods is suggested by paleoecological analysis of rodent fossil faunas in the basin (van Dam and Weltje, submitted). In an alternate scenario, increasing precipitation during wet periods may activate sediment transport from the basin margins, favouring the progradation of alluvial fans towards the center of the basin, and diminishing the extend of carbonate deposition. In such model, a decrease of runoff during arid periods, for example, may prevent terrigenous input and, consequently, prompt condensed palustrine/lacustrine deposition in the more distal parts of the basin. In addition to that, climate also influences very directly the vegetation cover, which is a primary factor controlling erosion rates in the source area and, consequently, terrigenous sediment supply.

In the study area, the transition from alluvial to palustrine deposition has indeed a strong time-transgressive character. Also, rapid lateral migrations of basin depocenters are evidenced when correlating the sequences North of Teruel (Masada Ruea-Masada del Valle) to those East of Teruel (La Gloria-Bunker de Valdecebro) (Fig. 7). These features obviously illustrate the prevalence of local (tectonic and paleogeographic) controls on the sedimentary evolution of the area. These factors are likely to determine the geographic extend and the long-term evolution of the alluvial fan deposition, while other climatic variables (precipitation regime) would be responsible for higher frequency variations.

In tectonically controlled settings such as rift basins, any supposedly climatic signal is necessarily modulated by the polarity of the depositional systems, that is, the (rapid) lateral transition from basin bounding fanglomeratic wedges to central basin shallow carbonate lakes. Because of the high diachrony of the lithofacies boundaries, the stratigraphic position of a particular lithological transition in a section may not have significance. Nevertheless, the onset of a facies expansion (or retraction) can have true climatic significance, and the local character of carbonate deposition do not rule out a climate forcing in the transition from alluvial to palustrine/lacustrine deposition. Because precipitation of carbonates need to match certain climatic requirements, the time of initiation of carbonate deposition in the Teruel area after a long period of extensive alluvial sedimentation, may represent a climate shift. In the time slice this study involves, the rodent fossil successions in Spain record important faunal turnovers at the early/late Vallesian transition (Agustí and Moyà-Solà, 1990) at 9.7 Ma (Garcés et al., 1996), in the late Vallesian (~9.1 Ma), and the Vallesian-Turolian boundary (van Dam, 1997) at 8.7 Ma (Krijgsman et al., 1996). The first boundary coincides with the expansion of Muridae at the cost of Cricetidae, Gliridae and Eomyidae, the second with the final extinction of various species of Gliridae, Cricetidae and Soricidae, and the third with the immigration of a number of rodent species, among which are Zapodidae and the murid Parapodemus. The disappearance of various Cricetidae and expansion of Muridae at the beginning of the late Vallesian has been interpreted as a shift towards dryer conditions (van de Weerd and Daams, 1978: Daams et al., 1988; Agustí and Moyà-Solà, 1990). A new paleoecological analysis (Van Dam and Weltje, submitted) indicates that the main shift towards dryer conditions occurred later, around the Vallesian-Turolian transition. The diversification of Muridae at this time corresponds to a transition towards a warmer, drier, more wet-dry seasonal and more unpredictable climate in Spain.

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