Magnetostratigraphy of the Zobzit and Koudiat Zarga sections (Taza-Guercif basin, Morocco): implications for the evolution of the Rifian Corridor

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Abstract

Magnetostratigraphic analyses for two Neogene 'post-nappes' successions of the Taza-Guercif basin enable a reliable correlation of the sedimentary sequence to the astronomical polarity time scale. Rock magnetic analyses indicate that hematite is the dominant carrier of the magnetisation in the marine marls of the Melloulou Formation, whereas both magnetite and hematite contribute to the NRM of the near-shore and continental sediments of the Kef Ed Deba and Bou Irhardaiene Formations. Anisotropy of magnetic susceptibility (AMS) measurements indicate that the maximum axes of the magnetic fabric are aligned in a direction SW–NE. This suggests that the AMS is tectonically induced, related to SE–NW compression, in agreement with the major fold and fault systems in the basin. Our magnetostratigraphic correlation shows that the oldest marine sediments in the basin, which are related to the development of the Rifian Corridor, are dated at approximately 8 Ma. Between 7.2 and 7.1 Ma, just after the Tortonian/Messinian boundary, an important shallowing of the Taza-Guercif basin takes place. This shallowing phase is primarily related to active tectonics, although a small glacio-eustatic sea level lowering also took place. Our results indicate that at least the Taza-Guercif basin, and perhaps the entire Rifian Corridor, became emerged at an age between 6.7 and 6.0 Ma. Continental deposits, separated from the underlying deposits by a considerable hiatus of 700 kyr, extend into the Pliocene (up to 4.7 Ma). © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

The Taza-Guercif basin of northeastern Morocco represents a remnant part of the Rifian Corridor, a marine passage which connected the paleo-Mediterranean with the Atlantic during the late Miocene. It developed in the external foredeep basin of the Rif Orogen, northeast of where the present-day Rifian front is in contact with the northern part of the Middle Atlas (Fig. 1). The eastern part of the Taza-Guercif basin is bordered by the Moulouya Belt shear zone, a SW–NE striking alignment which is also found in the Moroccan Atlas and can be followed through the Alboran basin into the Betic Cordilleras of Spain

(De Larouzieres et al., 1988; Meghraoui, Morel, Andrieux & Dahmani, 1996). The Taza-Guercif basin is regarded as a 'post-Nappes' basin and existed at least since the late Tortonian. It consists of marine and continental sediments, exceeding 1500 m in thickness in the depocenter (Coletta, 1977; Michard, 1976; Wernli, 1988). The folding of the whole Mio-Plio-Quaternary sequence, with structures directed NE–SW, demonstrates that compressive tectonic activity has taken place, which was suggested to be caused by transpressive movements along the Moulouya Belt shear zone (Bernini et al., 1994; Boccaletti et al., 1990).

The Taza-Guercif basin was selected to clarify the relationships between tectonic activity and sedimentation in the Rifian foredeep basin, and to investigate the effects of the interaction between the Moulouya

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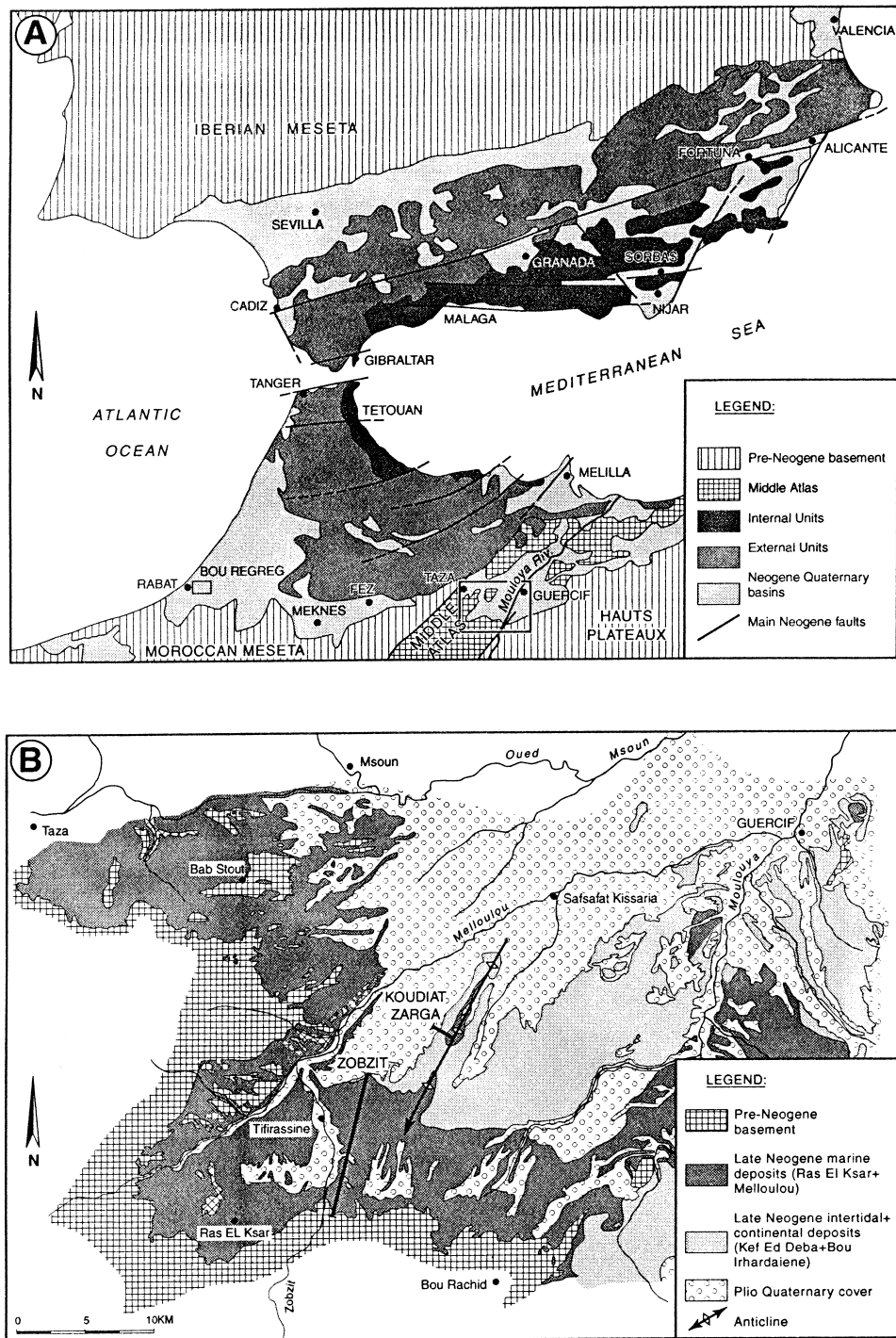 E-mail address: krijgsma@geo.uu.nl (W. Krijgsman).

Fig. 1. Simplified structural sketch-map of the Gibraltar Arc (A), modified after Boccaletti et al. (1990), showing the locations of the Taza-Guercif Basin, the Bou Regreg area, and the Fortuna, Sorbas and Nijar Basins. (B) Stratigraphic map of the Taza-Guercif Basin (modified after Bernini et al., 1994) indicating the sample trajectories of the Zobzit and Koudiat Zarga sections.

Belt shear zone and the eastern termination of the Rifian external front on its Neogene-Quaternary sedimentary evolution. The investigation was part of the program of the Regional Committee on Mediterranean Neogene Stratigraphy (RCMNS) working group 'Basin Evolution and Tectonics' which was directed to

the evolution of the Neogene-Quaternary basins in the internal and external zones of the Gibraltar Arc. The study has provided a new lithostratigraphic subdivision and a detailed geological map of the sediments in the Taza-Guercif area (Bernini et al., 1992; 1994).

A detailed time-stratigraphic framework for these

sediment, however, was still lacking. An accurate time-frame for the lithological units of the Taza-Guercif basin must aim at assigning accurate ages to: (1) the onset of marine sedimentation in the Rifian Corridor; (2) the closure of the marine connection through the Taza-Guercif Basin; and (3) the recognised tectonic events in the basin. These events have likely caused important paleoceanographic changes in the Mediterranean which have (eventually) led to the Messinian 'salinity crisis' and the total dessication of the Mediterranean (Benson, Rakic-El Bied & Bonaduce, 1991; Hsü, Ryan & Cita, 1973). Therefore, we have conducted a magnetostratigraphic and biostratigraphic research which includes most of the stratigraphic units of the Taza-Guercif basin (after Bernini et al., 1994). Our composite section can be compared with the results from drillholes GRF1 (Guercif) and Taourint PG3 of Wernli (1988). The section, along the Zobzit river (Fig. 1), consists of marine sediments which are found directly overlying the Mesozoic basement. Hence, they represent the first marine Neogene sediments of the Rifian Corridor. Another section is located in the Safsafat anticline (Fig. 1) and consists of near-shore and continental sediments. In this paper, we present the magnetostratigraphic and rockmagnetic results of the two sections in the Taza-Guercif basin and the correlation to the astronomical polarity time scale (APTS).

2. Sections and magnetostratigraphy

For our paleomagnetic study, the two sampled sections include four units of Bernini et al. (1992, 1994), the Ras El Ksar, Melloulou, Kef Ed Deba and Bou Irhardaiene Formations. The oldest unit, the Draa Sidi Saada Formation, consists of continental conglomerates and breccias which are not suitable for magneto- or biostratigraphy; this unit was not sampled.

We took standard paleomagnetic cores with an electric drill and a generator as power supply. As a routine procedure, the weathered surface (∼ 1 m) was removed to drill in fresher sediments. To carry all the equipment through the extensive badlands of the Moroccan desert, we gratefully made use of a donkey. In the Melloulou Formation, additional oriented handsamples were taken which were drilled with compressed air at the paleomagnetic laboratory, Fort Hoofddijk. In the exposures along the Zobzit river, we sampled 6 levels in the Ras El Ksar Formation and 93 levels in the Melloulou Formation. We aimed to take at least 3 levels in the marls of each sedimentary cycle that we recognised as a regular alternation of blue-grey marine marls and yellowish sandy turbidites; we did not sample the turbidites. At the Safsafat anticline, we took 20 levels in the Kef Ed Deba Formation and 43

in the Bou Irhadaiene Formation in the marly and clayey lithologies; sands and conglomerates were avoided. Here, sedimentary cycles are occasionally recognised as alternations of clayey and sandy lithology, but they lack a clear and regular expression and cannot be unambiguously identified. The natural remanent magnetisation (NRM) of the samples was measured on a 2G Enterprises cryogenic magnetometer. All samples were progressively demagnetised by stepwise demagnetisation with temperature increments of 30–50°C, using a magnetically shielded, laboratory-built furnace.

2.1. The Zobzit section

The base of the Zobzit section consists of shallow marine sandstones and mudstones of the Ras El Ksar Formation, which are found transgressively overlying the Jurassic basement of the Middle Atlas. The Ras El Ksar Formation gradually passes into the blue-grey marls of the Melloulou Formation. These classical 'Blue Marls' of Morocco can be traced through the entire Rifian Corridor from Rabat in the west (Benson and Rakic El Bied, 1991; Benson et al., 1991; Cita and Ryan, 1978) to Mellilla in the east (Arias et al, 1976). The Melloulou Formation of the Taza-Guercif basin shows a cyclic alternation of blue marls and sandy turbidites. The turbidites have irregular thicknesses, changing from 10 to 0 metres and current marks point out that their transport has been to the north (Bernini et al., 1994). As the turbidite bodies pinch out, a yellow sand layer can be traced laterally for several hundred metres. Higher in the Melloulou Formation, the turbidites disappear, but yellow sandy marls are still intercalated in the blue marls. From that level upward the blue marls contain secondary gypsum crystals. These gypsiferous marls pass gradually via a number of Ostrea-bearing beds into near-shore sediments of the Kef Ed Deba Formation. The contact between the two formations is badly exposed.

Thermal demagnetisation of the marine marls from the Ras El Ksar and Melloulou Formations shows that in most samples a viscous component is removed at 100°C. A present-day field component is removed at temperatures between 100–200°C and is characterised by a relatively rapid decrease of intensity. A characteristic remanent magnetisation (ChRM) is usually removed at temperatures between 240–500°C. Further heating mainly shows an increase of viscous behaviour leading to unreliable results. For the samples with a relatively high NRM intensity (up to 1 mA/m), the ChRM direction can reliably be determined (Fig. 2). Samples with low ChRM intensity (0.1 mA/m or lower) often show a cluster with temperatures ranging from 200 to 460°C (Fig. 2). Occasionally, multiple samples from the same level did not result in reliable
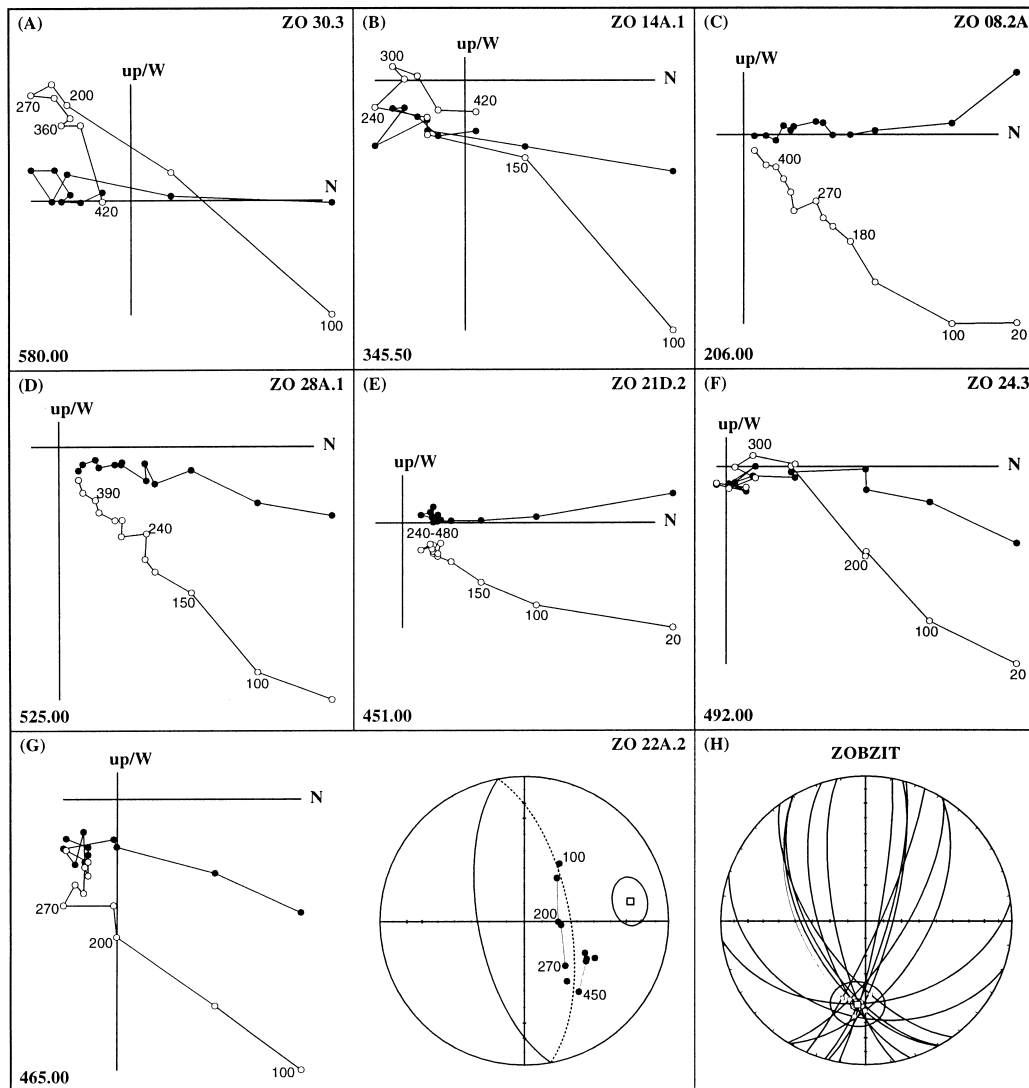
Fig. 2. Demagnetisation diagrams of samples from the Zobzit section. Solid (open) symbols represent the projection of the NRM vector end-point on the horizontal (vertical) plane. Values represent temperatures in °C; stratigraphic levels are in the lower left corner. Occasionally, great-circle analysis has been used to derive a reversed polarity if the vector clearly migrates to a reversed direction.

ChRM directions because they showed no linear decay to the origin. Instead, they seemed to 'move' to the reversed quadrant of the demagnetisation diagram. Plotted on an equal-area diagram, remanence vectors progressed along a great circle toward a southerly direction, indicating removal of a normal phase from a reversed primary component. In these cases, a best-fitting great circle plane was determined (Fig. 2g).

The paleomagnetic results show that the magnetostratigraphy of the Zobzit section consists of a long normal interval which includes a single level of reversed polarity, followed by a succession of 7 polarity zones of varying thickness. The reversed interval 550–720 m may be exaggerated in thickness, however, because of 2 very thick turbidites (Fig. 3).

The biostratigraphy of the Zobzit section is derived from planktonic foraminifera and calcareous nanno-

plankton (Krijgsman et al., 1999). The planktonic foraminiferal record contains 4 bioevents which are widely used for intra-Mediterranean correlations: (1) the last common occurrence (LCO) of *Globorotalia menardii* 4 at 290 m; (2) the last occurrence (LO) of *Catapsydrax parvulus* at 350 m; (3) the first occurrence (FO) of *Globorotalia menardii* 5 at 430 m; and (4) the first regular occurrence (FRO) of the *Globorotalia conomiozea* group at 650 m. Paleodepth reconstructions are made, based on the ratio planktonic to benthic foraminifera, and using the paleodepth equation of Van der Zwaan, Jorissen and De Stigter (1990).

2.2. The Koudiat Zarga section

The sediments of the Kef Ed Deba Formation consist of alternations of yellowish to reddish sands and

ZOBZIT
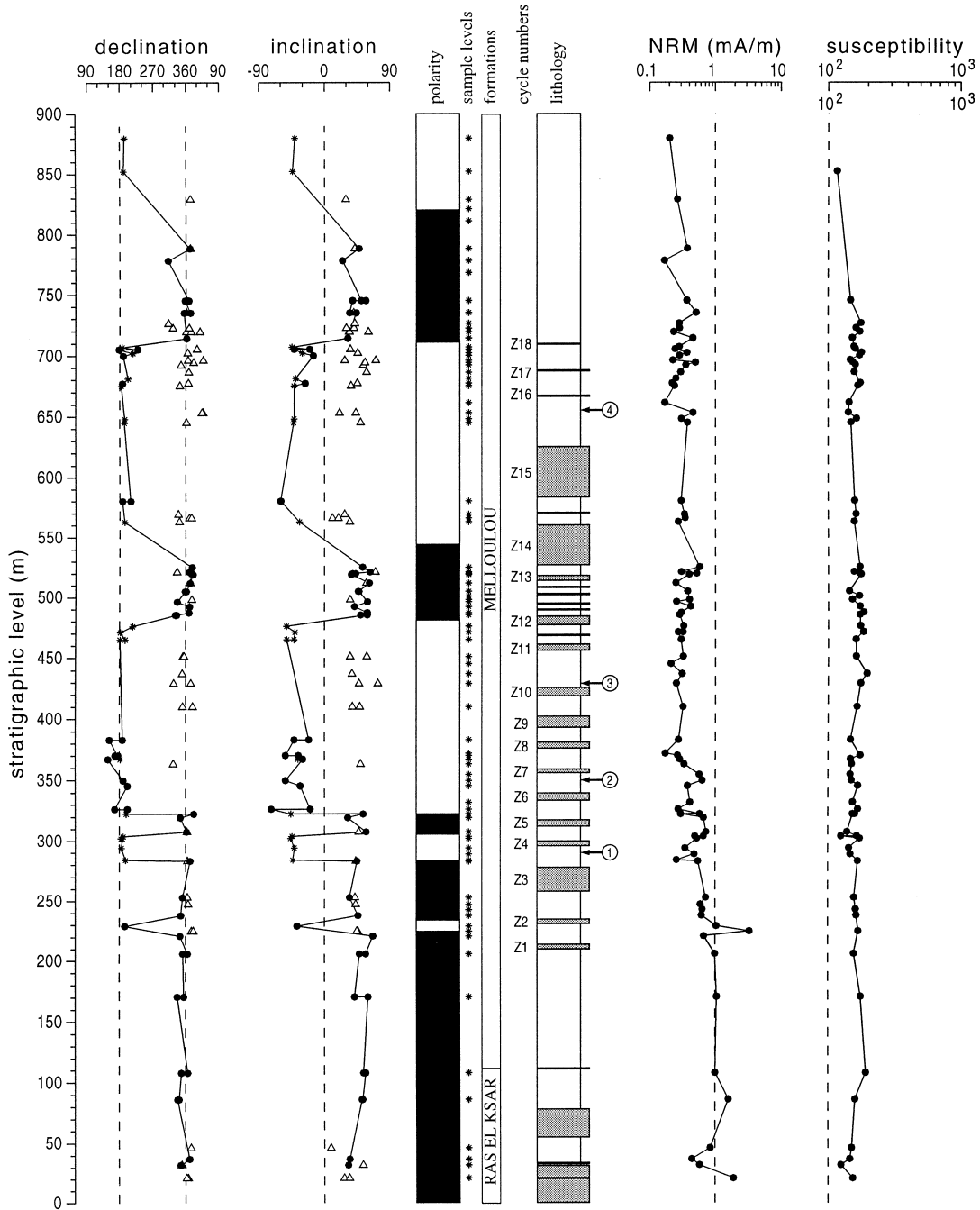

Fig. 3. Magnetostratigraphic and biostratigraphic data, lithology, sample positions, NRM intensities and magnetic suceptibility of the Zobzit section. Magnetostratigraphy is given by declination and inclination of the ChRM; black (white) denotes normal (reversed) polarity. Closed circles represent reliable directions, asterisks represent directions obtained by applying the great circle method (McFadden & McElhinny, 1988), open triangles represent secondary directions showing a clustering. Lithology consits of blue-grey marine marls (white) and yellowish sandy turbiditic layers (grey), numbered Z1–Z18. Planktonic foraminifera bioevents are: (1) Last Common Occurrence (LCO) of *G. menardii 4*, (2) Last Occurrence (LO) of *C. parvulus*, (3) First occurrence (FO) of *G. menardii 5*, (4) First Regular Occurrence (FRO) of the *G. conomiozea* group (see Krijgsman et al., 1999).
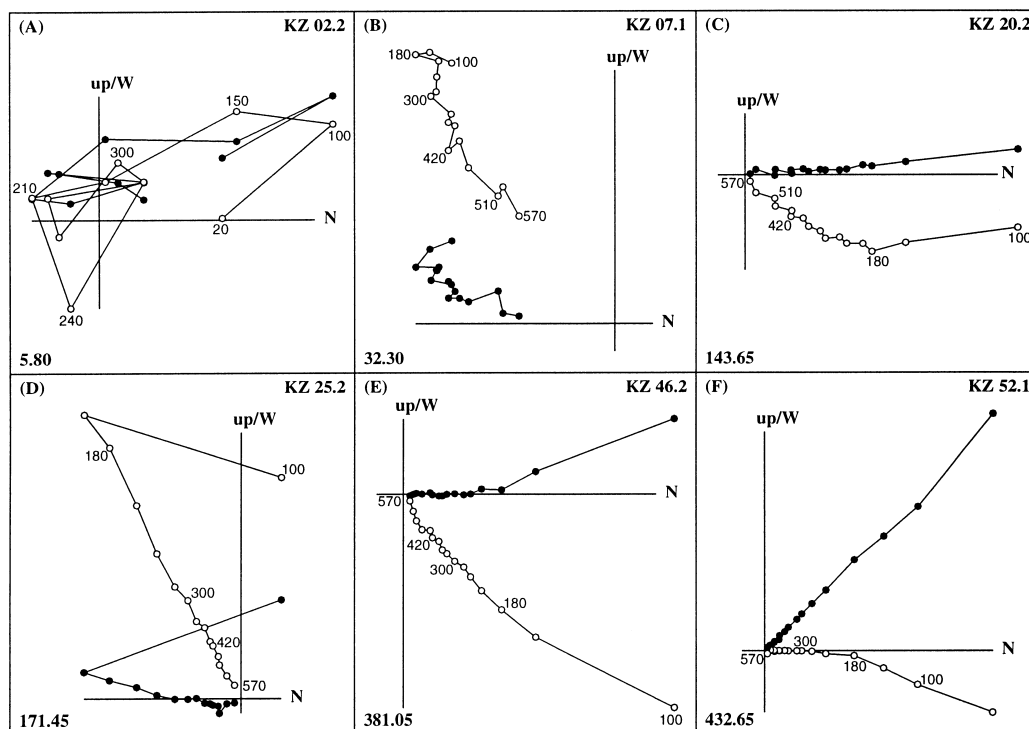
Fig. 4. Demagnetisation diagrams of samples from the Koudiat Zarga section. See also caption to Fig. 2.

marls. Biostratigraphic analysis from the basal part of the formation shows ostrea and other shallow marine fauna and suggests that a connection to marine waters still existed. Upwards, conditions change and are indicative of an alluvial tidal flat or an inner delta front (Bernini et al., 1994). An erosional unconformity, characterised by a thick fluviatile conglomerate unit with an erosive base, separates this succession from the overlying Bou Irhardaiene Formation. The latter formation consists of reddish fluvial conglomerates, sands, marls/clays and lacustrine limestones, indicative of a continental environment.

The clays and marls of the Kef Ed Deba and Bou Irhadaiene Formations are generally characterised by higher (>2 mA/m) initial NRM intensity. Thermal demagnetisation of these samples shows that the ChRM component is usually removed between 200 and 700°C; this component shows both normal and reversed polarities (Fig. 4). The high unblocking temperatures suggest that some hematite is present. Only the samples from the lowermost part are characterised by relatively low intensities (<0.1 mA/m) and no reliable ChRM could be determined, although polarities seem to be reversed (Fig. 4a).

The magnetostratigraphy of the Koudia Zarga section shows mainly reversed polarities. Above the erosional unconformity several levels of normal polarity are found (Fig. 5). Two normal polarity intervals are found in the upper half of the section; a single level of normal polarity occurs between the two intervals.

3. Rock magnetic results

3.1. IRM experiments

Acquisition of an isothermal remanent magnetisation (IRM) is indicative for the type of magnetic carrier. Low coercivity minerals like magnetite and maghemite are usually completely saturated at magnetic field well below 300 mT, high coercivity minerals like hematite and goethite usually saturate at much higher fields. Subsequent thermal demagnetisation of the (saturation) IRM reveals the characteristic unblocking temperatures of the magnetic carriers. The IRM was acquired on selected samples from the Melloulou, Kef Ed Deba and Bou Irhardaiene Formations using a PM 4 pulse magnetiser. Subsequent thermal demagnetision was measured on a 2G cryogenic magnetometer, up to a temperature of 700°C.

In the samples of the Melloulou Formation, the acquisition of the IRM shows an initial steep rise until 100/200 mT, denoting the presence of a low-coercivity mineral like magnetite or maghemite. At higher fields the IRM gradually increases, but saturation is not reached in the highest field of 2000 mT (Fig. 6A). This indicates the additional presence of a high-coercivity mineral like goethite or hematite. Thermal demagnetisation of the IRM shows that the contribution of goethite can be neglected because there is no signifi-
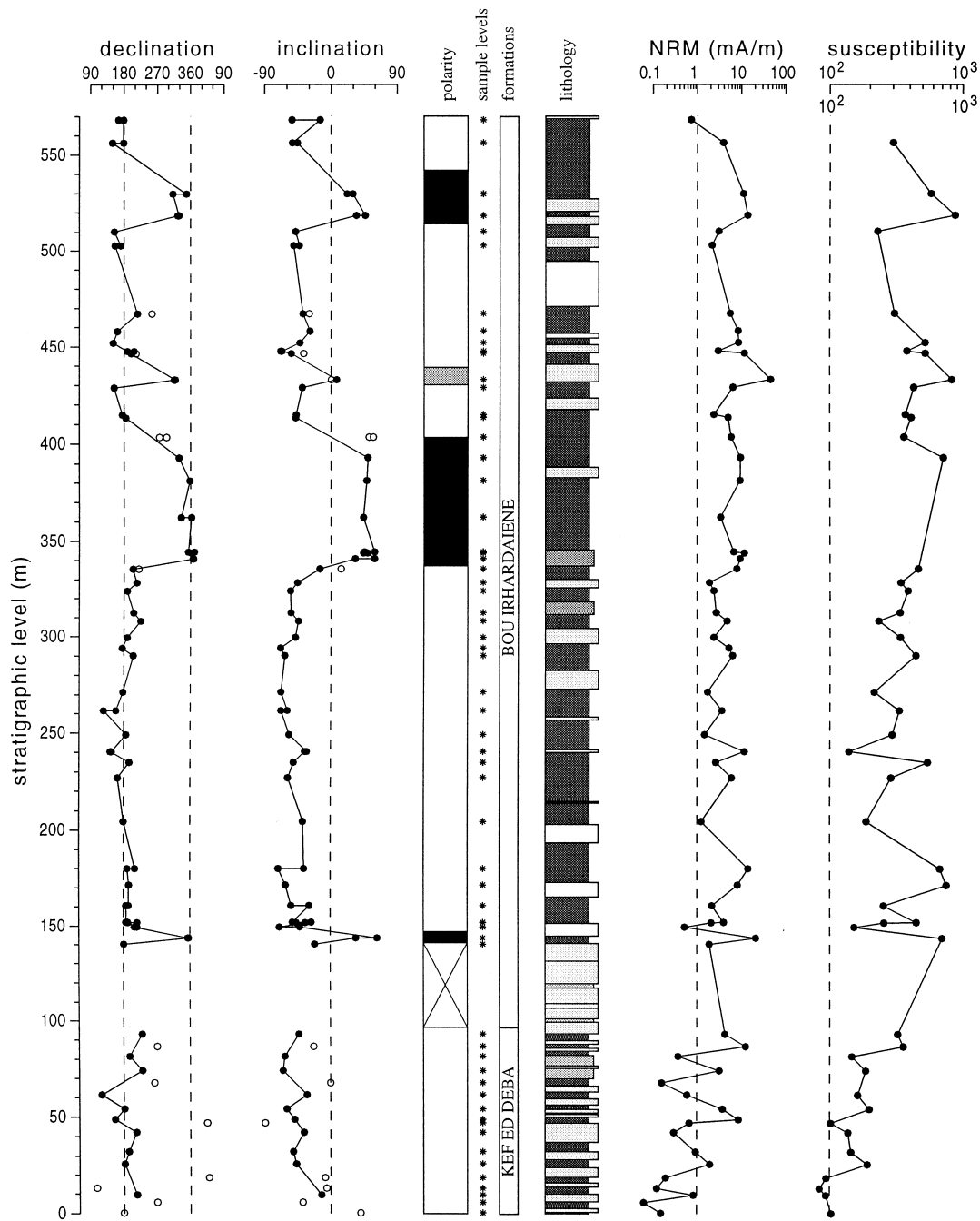
KOUDIAT ZARGA

Fig. 5. Magnetostratigraphy, sample positions, lithology, NRM intensity and magnetic susceptibility of the Koudiat Zarga section. Black (white), denotes normal (reversed) polarity interval. Closed circles represent reliable directions, open circles represent unreliable directions of low-intensity samples. Lithology consists of lacustrine limestones (white), sandy layers (light grey), reddish/brownish clays and marls (dark grey).

cant decrease below 100°C, but the high unblocking temperatures (660°C) indicate that hematite is an important carrier of the magnetisation.

The IRM of the samples from the Kef Ed Deba and Bou Irhadaiene Formations is an order of magnitude higher than in the Melloulou Formation (Fig. 6B).

The initial steep rise is more pronounced but complete saturation is also not reached at the highest fields. The unblocking temperatures, revealed by thermal demagnetisation, clearly shows the presence of magnetite (580°C) and hematite (680°C) in these sediments (Fig. 6B).
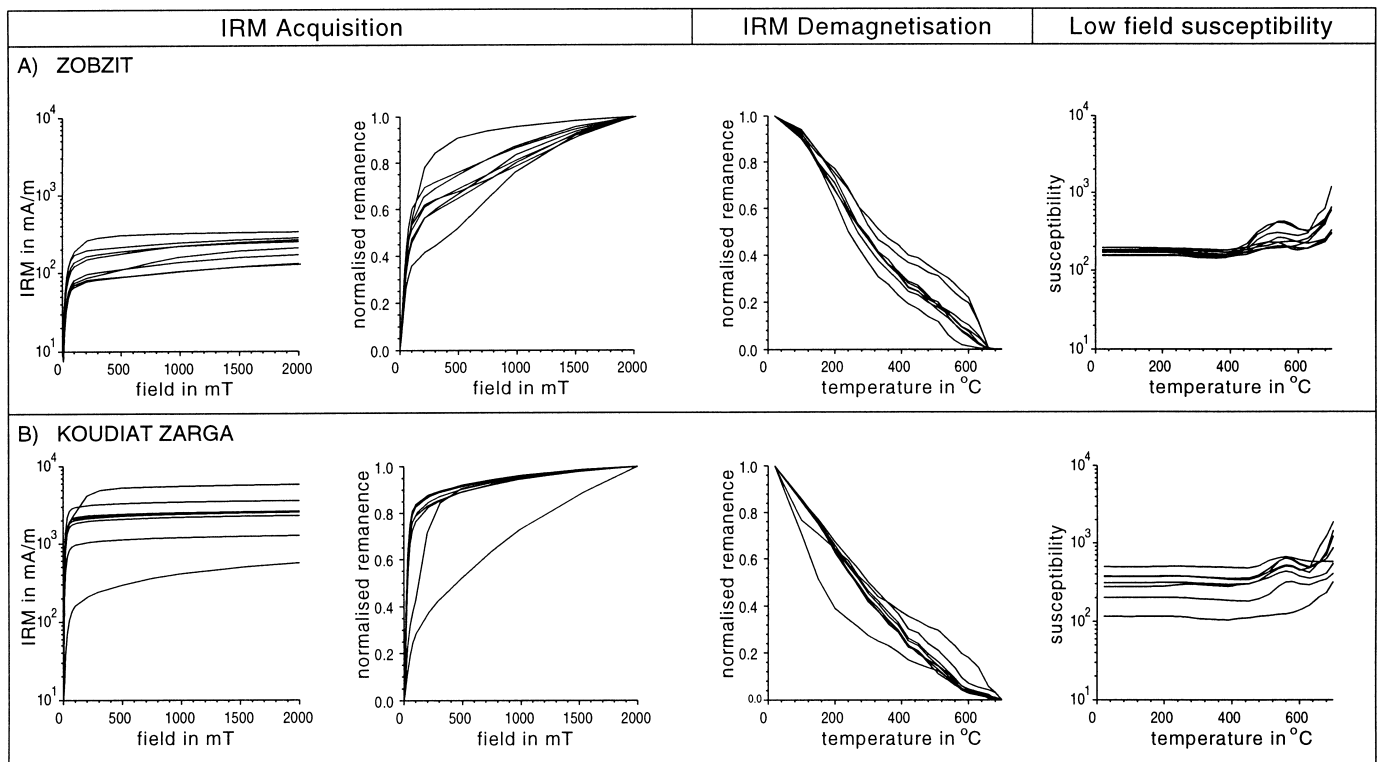
Fig. 6. IRM acquisition of selected samples from the Zobzit and Koudiat Zaraga sections; the IRM intensities of the Koudiat Zarga section are typically one order of magnitude higher. For comparison, acquisition curves have been normalised. The initial steep acquisition is typical for magnetite, but saturation does not occur in the highest fields, indicating the presence of hematite. This is confirmed by the maximum unblocking temperatures upon thermal demagnetisation of the IRM of ∼680°C. Magnetic susceptibility is rather constant upon heating, but an increase is seen at temperatures higher than 400–450°C, suggesting that some new magnetite is formed. A second increase is found at ∼600°C, probably because of formation of magnetite from clay minerals.

3.2. AMS and initial susceptibility

The anisotropy of magnetic susceptibility (AMS) in weakly deformed and unmetamorphosed rocks can be used to provide information on the sedimentary and/or tectonic history of the rock (see Kissel, Barrier, Laj & Lee, 1986; Scheepers and Langereis, 1993). There is often a relation between the AMS of rock samples and the regional stress field of the area. The AMS measurements were carried out on a Kappabridge KLY-2. The AMS is described by a tensor (Jelínek, 1977) which can be visualised by an ellipsoid having three principal axes k_{max}, k_{int} and k_{min}. Typical parameters that characterise the shape of the AMS ellipsoid are lineation ($L = k_{max}/k_{int}$) and foliation ($F = k_{int}/k_{min}$). Plots of L against F are analogous to the strain plots that are commonly used in structural geology. On these diagrams, flattened shapes (oblate) plot below, and constricted shapes (prolate) plot above the line of unit gradient (Fig. 7).

The L/F plot of the Zobzit section shows that there are clear differences in AMS between the various formations. The AMS of the Melloulou samples shows a strong oblateness of the magnetic fabric: the k_{min} axes are subvertical and the k_{max} axes are well clustered and aligned SW–NE (Fig. 7A). The AMS of the Ras El Ksar, Kef Ed Deba and Bou Irhadaiene Formations shows a much weaker foliation and shows both prolate and oblate anisotropies; the k_{max} axes are also aligned SW–NE but the mean k_{min} axis makes an angle of 45° with the vertical, while k_{min} and k_{int} axes are distributed along a great circle girdle (Fig. 7B). The alignment of the maximum axes is usually caused by tectonic deformation after deposition, causing k_{max} to be oriented perpendicular to compression or, equivalently, parallel to extension. In the Zobzit section, the k_{min} axis is perpendicular to the bedding plane, while the Safsafat Anticline shows a considerable dip of the k_{min} axes. In both sections, k_{max} is aligned SW–NE which agrees well with the SW–NE strike of the axial plane of the Safsafat anticline, implying SE–NW compression. This is also in line with the directions of the Melloulou Belt shear zone and other strike slip faults in the Taza-Guercif basin. Hence, the AMS of the sections is most likely affected by the same tectonic deformation.

4. Discussion and conclusions
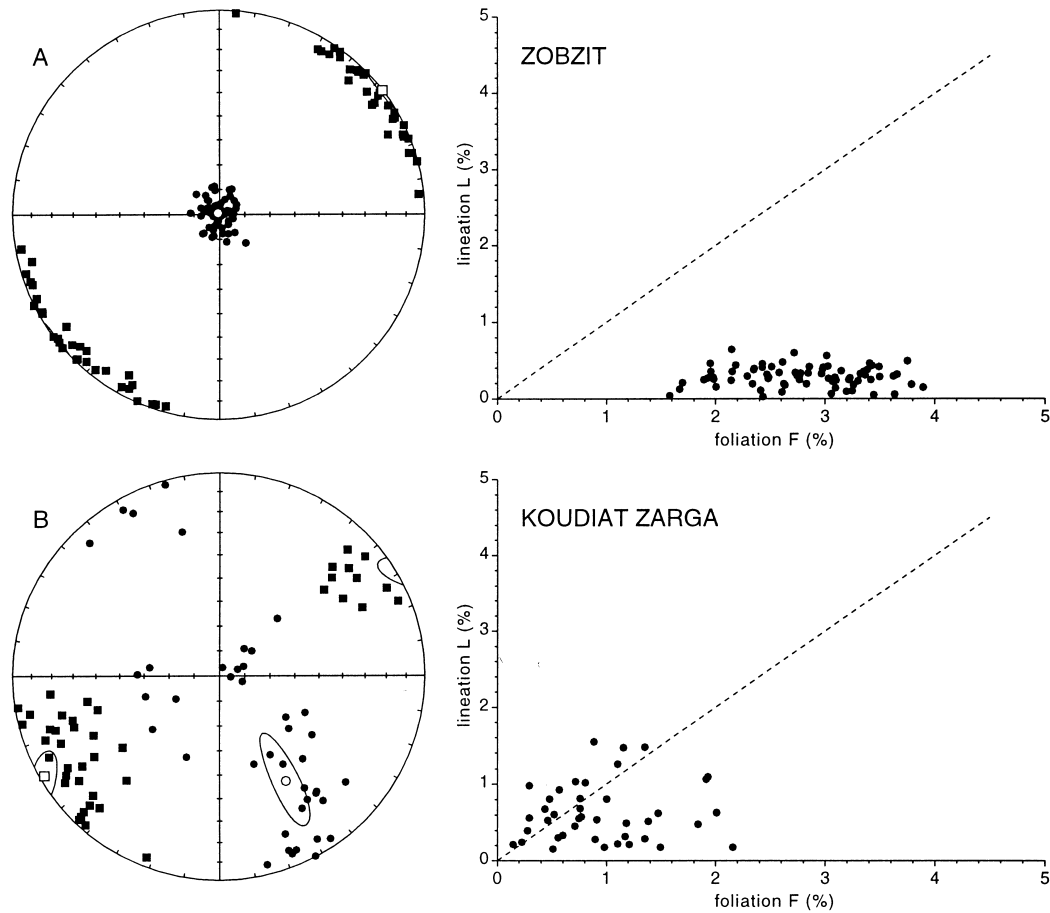
Based on the magnetostratigraphic results, with ad-

Fig. 7. Anisotropy of magnetic susceptibility of the Zobzit (A) and Koudiat Zarga (B) sections. Squares denote k_{max} directions, circles are k_{min} axes; open symbols mark the mean directions. The lineations in both sections are very similar, directed along NE–SW. This is perpendicular to the general NW–SE compressional setting of the major tectonic structures (Fig. 1). In the Zobzit sections, lineations are well clustered and k_{min} axes are perpendicular to the bedding plane, while in Koudiat Zarga the mean k_{min} axis makes an angle of 45° with the horizontal, either indicating considerable transport on a slope or significant tectonic strain.

ditional constraints provided by the planktonic foraminifera biostratigraphy, a straightforward correlation of the Zobzit section to the astronomically calibrated geomagnetic polarity time scale (APTS) can be made. The Zobzit section contains four distinctive bioevents, occurring in three successive periods of reversed polarity (Krijgsman et al., 1999). The same succession of events is recorded elsewhere in the Mediterranean (Krijgsman, Hilgen, Langereis, Santarelli & Zachariasse, 1995; Krijgsman, Hilgen, Negri, Wijbrans & Zachariasse, 1997). These events are astronomically dated (Hilgen et al., 1995) and are, from old to young, the LCO of *G. menardii* 4 (chron C3Br.3r; 7.512 Ma), the LO of *C. parvulus* (C3Br.2r; 7.456 Ma), the FO of *G. menardii* 5 (C3Br.2r; 7.355 Ma), and the FRO of the *G. conomiozea* group (C3Br.1r; 7.240 Ma), the latter being by definition the Tortonian/Messinian boundary. These results are furthermore in agreement with the magnetobiostratigraphy of the Bou Regreg area from the Atlantic margin of Morocco (Sale drillhole; Hodell, Benson, Kent, Boersma & Rakic-El Bied,

1994). It follows that the bio-events in the Taza-Guercif basin are synchronous with those in the Mediterranean and supports the correlation of the magnetostratigraphy of the Zobzit section to be correlated to the APTS (Fig. 8).

The normal zone in the basal part of the Zobzit section is correlated to chron C4n.2n. The interpolated age for the onset of marine sediments in the Taza-Guercif basin is approximately 8 Ma. The Taza-Guercif basin developed in the external foreland of the Rif Orogen, and is strongly related to the development of the Rifian Corridor. Hence, it may be assumed that the opening of this marine passage through Morocco has an age close to 8 Ma. From this age onward, a deep marine basin (±500 m) developed in the Taza-Guercif area, characterised by the deposition of the turbidite marls alternations of the Melloulou Formation. The average sedimentation rate of these deposits is approximately 40 cm/kyr (Fig. 9).

Paleodepth reconstructions clearly show the onset of a rapid shallowing of the Taza-Guercif basin to a
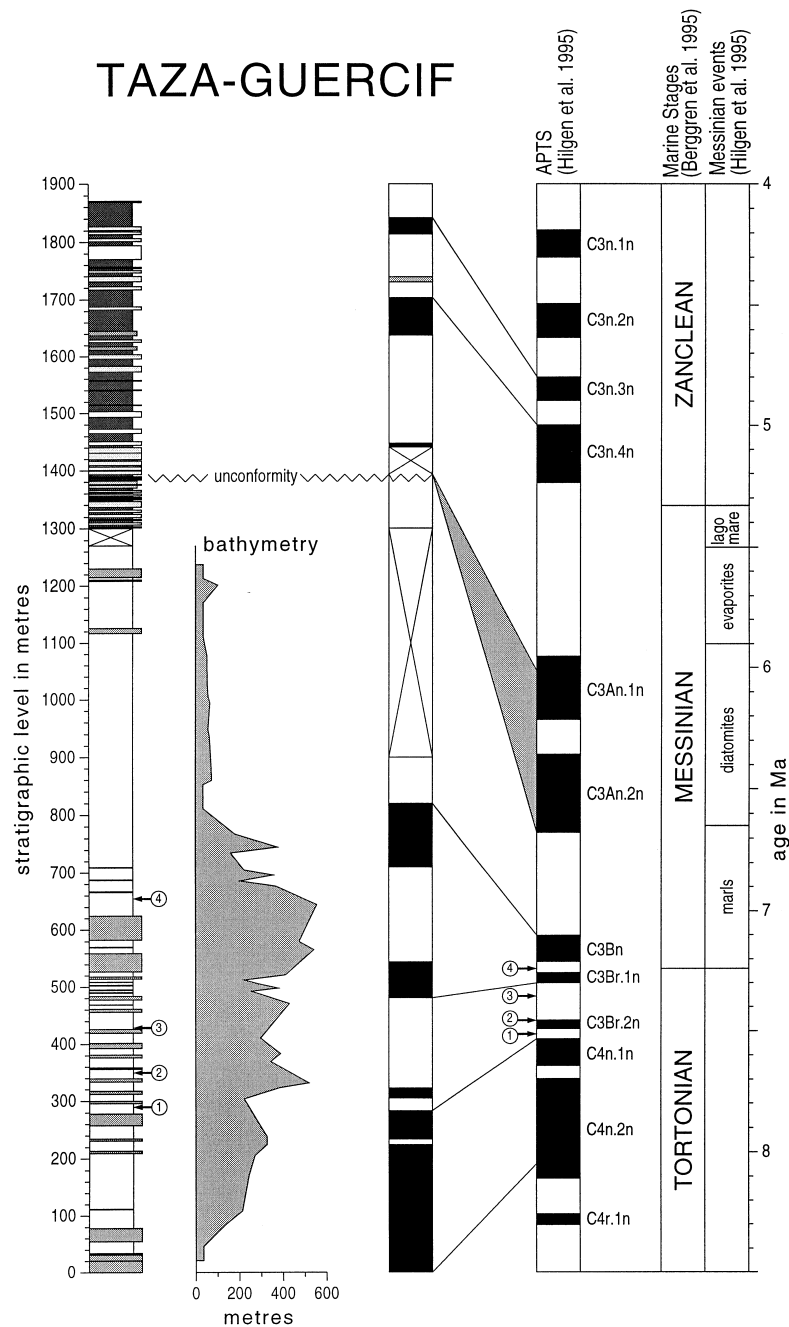
Fig. 8. Lithology, bathymetry and polarity pattern of the Taza-Guercif composite section and correlation to the APTS (Hilgen et al., 1995), marine stages (Berggren, Kent, Swisher & Aubry, 1995) and the chronology of Messinian facies types (Hilgen et al., 1995). Chron nomenclature after Cande and Kent (1992). Bathymetry is based on the P/B ratio using the paleodepth equation of Van der Zwaan et al., (1990). Encircled numbers refer to planktonic foraminiferal bioevents (see caption to Fig. 3). Their position along the APTS follows from tuning late Miocene sections to the astronomical solutions and summer insolation at 65°N (Hilgen et al., 1995).

near-shore environment between 7.2 and 7.1 Ma (Fig. 8), coinciding with an increase in sedimentation rate to 170 cm/kyr (Fig. 9). This regressive trend in the Taza-Guercif basin is dominantly related to tectonic uplift (Krijgsman et al., 1999), although a glacio-eustatic sea level lowering may have contributed. Stable oxygen isotope records at the Atlantic side of the Rifian Corridor show a distinct increase in mean $\delta^{18}O$ values

across the Tortonian-Messinian (T/M) boundary (Hodell, Benson, Kennett & Rakic-El Bied, 1989; Hodell et al., 1994). This increase is interpreted in terms of decreased sea surface temperature and/or increased global ice volume which agrees with the plankton record showing the replacement of the warm-water menardine-globorotaliids by the cooler-water *G. conomiozea* group in the T/M boundary interval. The
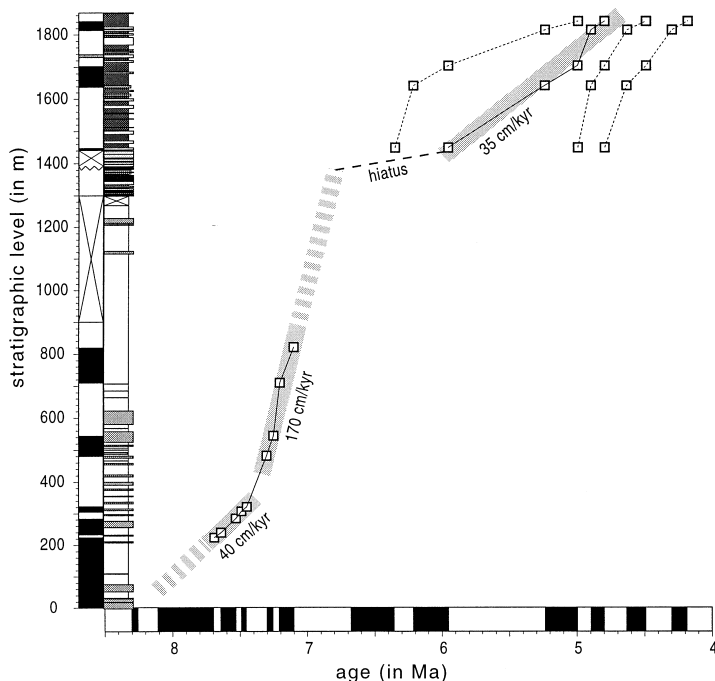
Fig. 9. Age versus thickness plot of the Taza-Guercif composite. The polarity time scale is of Hilgen et al. (1995). Note the increase in sedimentation rate from 40 cm/kyr to 170 cm/kyr in the marine sequence. The magnetostratigraphic correlation of the continental sequence (1400–1850 m) is less unambiguous. Four possible correlations are given. Our preferred correlation implies an average sedimentation rate of 35 cm/kyr.

same trend is recorded in the calcareous nannofossil association; slightly above the T/M boundary, warm taxa (Sphenoliths) show a decrease and are replaced by cool taxa (Reticulofenestrids). The reconstructed sea-level fall corresponding with this cooling episode is approximately 40 m (Krijgsman et al., 1999).

We conclude that tectonic uplift must have occurred during the earliest Messinian, probably in concert with increased sedimentation rates. At the Atlantic margin of Morocco, both Hodell et al. (1989) and Benson et al. (1991) documented a current reversal in the Rifian Corridor whereby cold Atlantic waters flow eastward and replace the warm Mediterranean outflow waters. According to Benson et al. (1991), this current reversal took place when tectonic movements reduced the bathymetry of the Rifian Corridor. This scenario is in good agreement with the timing of the rapid shallowing in the Taza-Guercif basin between 7.2 and 7.1 Ma.

The nearshore to intertidal deposits of the Kef Ed Deba Formation are entirely of reversed polarity. Stratigraphic continuity between the Kef Ed Deba Formation and the underlying shallow marine marls of the Melloulou Formation suggests that these polarities correlate with the reversed chron C3Ar (Fig. 8). Hence, the base of the unconformity is dated at approximately 6.7 Ma. The correlation of the polarity zones in the Bou Irhardaiene Formation, above the unconformity, is less unambiguous. The absence of additional age constraints in the Bou Irhardaiene Formation allows only a tentative magnetostratigraphic

correlation, assuming a more or less constant sedimentation rate and no major hiatuses. The most conspicuous characteristic of the observed polarity column is the relatively long reversed interval in the lower part of the measured sequence, which is almost three times longer than the next younger (normal) interval. A first option in which the three normal zones correlate with C3An.2n, C3An.1n, and C3n.4n would imply a drastic decrease in sedimentation rate which is not supported by the lithology and field observations. The second option, in which the upper two normal zones correlate with C3An.1n, C3n.4n and C3n.4n agrees much better with the lengths of the polarity zones. Correlations to younger parts of the APTS imply very high sedimentation rates for the continental deposits (Fig. 9). We believe that these correlations are less convincing, because the observed sedimentary cyclity suggests much lower rates. Our preferred option implies that the unconformity at ca. 1400 m represents a hiatus of some 700 kyr (Fig. 8).

It is a commonly accepted scenario that the final closure of the Rifian Corridor and Betic Strait isolated the Mediterranean from the open ocean during the latest Messinian. Our results indicate that the emergence of the Taza-Guercif basin occurred at 6.7 Ma. Whether the entire Rifian Corridor became emerged during this phase is still uncertain. The first documented mammal exchange between Europe and Africa started at the latest at 6.1 Ma (Benammi, Calvo, Prévot & Jaeger, 1996; Garcés, Krijgsman & Agustí,

1998) which indicates the existence of a passage way in the western Mediterranean well before the desiccation phase. At least from 6.0 Ma onwards, but perhaps as early as 6.7 Ma, continental sedimentation started in the Taza-Guercif basin, suggesting that no marine connection to the Mediterranean existed. However, repeated influxes of extra-Mediterranean waters must still have occurred (Krijgsman et al., 1999).

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