Lower Permian to Miocene Apparent Polar Wander Path for Iberia and its bearings on kinematic evolution

J. J. SCHOTT
Institut de Physique du Globe, 5 rue Descartes, 67084 Strasbourg cedex. (France)

ABSTRACT

A review of the reliable paleomagnetic poles for the Iberian plate is given in the range Permian to Miocene. After rejection of data belonging to displaced of deformed areas, or representing remagnetizations, 11 poles are selected. Using this data base, an Apparent Polar Wander Path (APW) is constructed. Two methods are used. The first one is a refined sliding window method. The second one is the small circle fitting recently developped in APW modelling. This method is appropiate for the lower Permian-lower Jurassic track only. Finally, the consistency of the APW with known kinematic models for Iberia is tested. There are, roughly speaking, two kinds of models describing the evolution of Iberia relative to Europe: single rotation models and left-lateral shift models. As a result, both models lead to statistically equivalent fits between the European and Iberian APW's, for the lower Permian-lower Jurassic track. Thus, it is clearly shown that the current lack of paleomagnetic data prevents us from giving close constraints to the kinematic evolution of Iberia.

INTRODUCTION

It is well known that paleomagnetism provided crucial quantitative evidence about the past location of lithospheric plates. This is also true for the Iberian plate for which the work undertaken in the 1960s, especially by Van der Voo (1969) demonstrated that the plate has undergone a counterclockwise rotation relative to Europe of about 35° since the Permian. Apparent polar wandering (APW), that is, plate motion relative to the Earth spin axis, is depicted by the path traced out by the paleomagnetic poles of various ages belonging to a given plate. McElhinny (1973) showed how matching the paths of continents which were previously part of the same plate, enables the initial relative positions of the blocks to be determined in a unique fashion. The European and Iberian plate which were once rigidly fixed in a position different from the present day configuration seem at first sight to provide a good example of application. The purpose of this report is to propose an APW for Iberia, using the data available since the upper Carboniferous-lower Permian period and then to check the consistency of the paleomagnetic data with two models of evolution of the peninsula representing two radically different concepts. This examination will show the limits of matching APWs for geodynamic purposes and try to set out the reasons why we are unable to do so in the case studied here.

LOWER PERMIAN TO MIOCENE APW FOR IBERIA

In this section, we will apply two methods suggested during the last ten years in order to construct APWs for various lithospheric plates. As pointed out by Harrinson and Lindh (1982), whatever the smoothing or fitting method used, the data upon which the model is based, plays the most prominent role. The paleomagnetic poles (Fig. 1), which seem reliable for our purpose, are listed in Tabla 1. Some of them deserve a few lines of comment:

— Several poles come from areas whose stability is questionable: the lower Triassic poles from the Cantabric Chain, the upper Jurassic and lower Createceous poles from the Iberic Chain. So far, we have no reason to suspect them of being disturbed by local movements and hence to be unrepresentative for the Iberian plate. Their incorporation yields an APW which is similar to the European one, after returning Iberia to its initial position (section 2). But, of course, the number of poles available is too low to allow a fairly safe conclusion.

— The lower Triassic pole obtained by Van der Voo (1969) on a red bed sequence in the vicinity of Alcazar de San Juan was discarded owing to its deviation from other contemporaneous poles. In our opinion, its location near the lower Tertiary poles shows that a remagnetization has to be suspected.

— The basalts of Lisbon, earlier considered as Eocene in age, give upper Cretaceous radiometric ages, around 70 Ma. Thus, the only genuine Tertiary result is the Miocene data given by Dikjsman (1977).

Other poles have been discarded because recent studies have shown that they represent remagnetizations. This is the case for the results published by Stauffer and Tarling (1971) and Vandenberg (1979) on the Tera

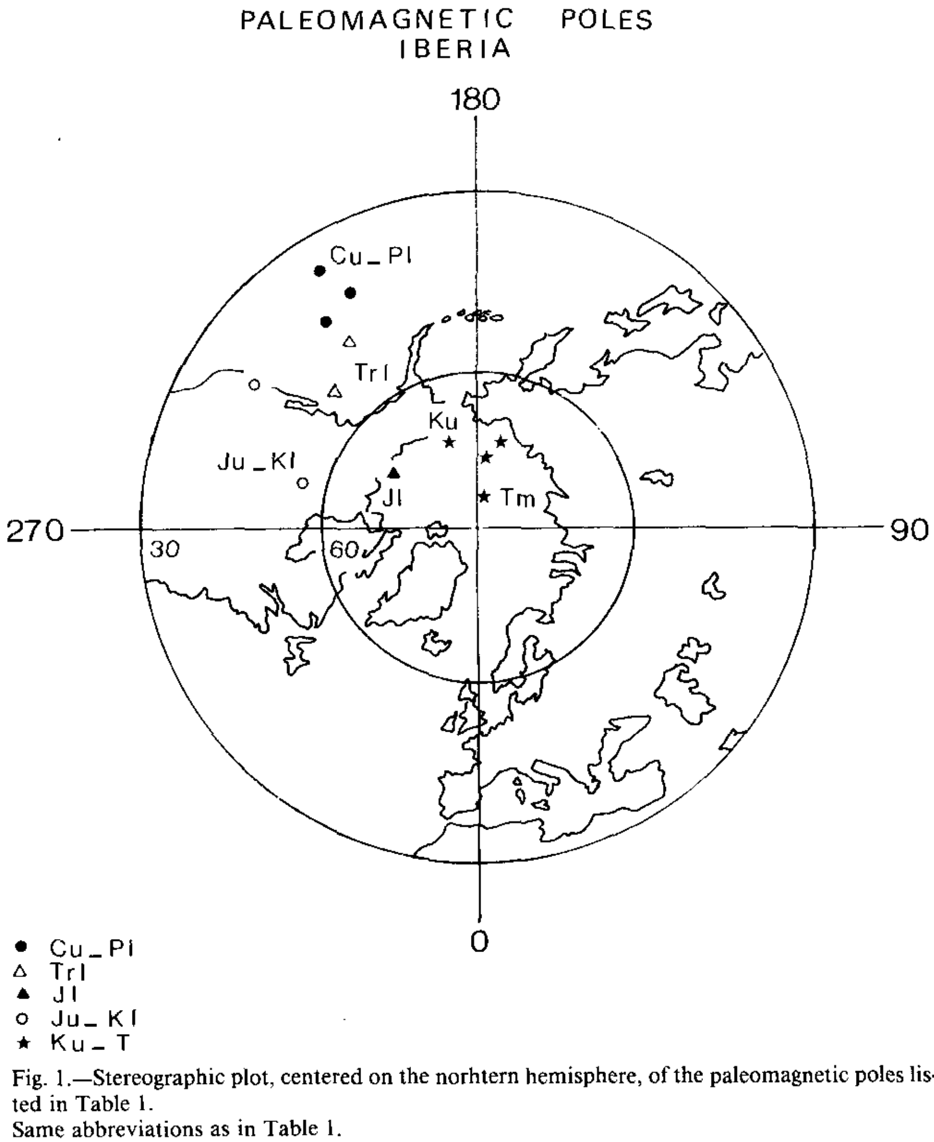

Fig. 1.—Stereographic plot, centered on the norhtern hemisphere, of the paleomagnetic poles listed in Table 1.
Same abbreviations as in Table 1.

group (Sierra de los Cameros). These results havè been discussed by Schott and Peres (1987).

TABLE 1

Age	Reference Location, formation, author	N	Lat. N	Long. E	K
Cu-Pl (293-268 Ma)	Buçaco-Red beds	4	35.5	211.5	332
	Viar-Red (VAN DER VOO, 1969)	3	42.5	216	845
	Viar-Dykes and sills	3	41	208	174
Pu-Trl (255-243 Ma)	Cantabric Chain-Red beds (VAN DER BERG, 1979)	3	52.5	226	405
	(SCHOTT and PERES, 1987)	8	47.5	214.5	216
Jl (179.4 ± 6.2 Ma)	Alentejo dykes (SCHOTT et al. 1981)	14	71	236.5	41
	Dykes South Portugal (SCHOTT, unpublished)				
Ju (159 ± 4 Ma)	Iberian Cordillera-Pelagic limestones (STEINER et al., 1986)	4	55.5	255.5	240
Kl (156-138 Ma)	Sierra de los Cameros Wealdien red beds (SCHOTT and PERES, 1987)	6	41	237	186
KU (87.5 ± 5 Ma)	Granite Sintra (VAN DER VOO, 1969)	8	76.5	174	50
KU (72.0 ± 2.0 Ma)	Syenite Monchique (VAN DER VOO, 1969)	2	73	165.5	(397)
KU 72.6 ± 3.1 Ma)	Basalts Lisbonne (VAN DER VOO and ZIJDERVELD, 1971)	33	72.5	197	21
TM (15 ± 1 Ma)	Teruel Basin-Red beds	3	84	162	639

Paleomagnetic poles used in the construction of an Iberian APW for the period upper Carboniferous-Miocene.
Cu-Pl: upper Carboniferous-lower Permian; Pu-Trl: upper Permian-lower Triassic; Jl lower Jurassic; Ju: upper Jurasic; Kl: lower Cretaceous; Ku: upper Cretaceous; TM: Miocene.
Ages are either stratigraphic or radiometric. For stratigraphic estimation, age range is given. For radiometric or magnetostratigraphic estimation, mean age and standard deviation are indicated. Time scale used is that of Harland et al. (1982).
N: number of individual poles in each study.
Lat. N, Long. E: north latitude and east longitude of the mean pole.
K: precision parameter (Fisher, 1953).

Sliding windows

This smoothing method is well known and easy to handle. Its application to the construction of APW was first made by Irving (1977). Given a time interval of width 2a, centered on the moving time T_j, a pole with an assigned age T_j is calculated as the weighted mean of all the available poles whose weights Pi (T_j) (see below) are not zero, using the formula:

$$\vec{U}(T_j) = \sum_{i=1}^{N} P_i(T_j)\,\vec{V}(t_i) / \|\sum_{i=1}^{N} P_i(T_j)\,\vec{V}(t_i)\|$$

where $\vec{U}(T_j)$ is the unit vector associated with the mean paleomagnetic pole, $\vec{V}(t_i)$ the unit vector associated with each of the N individual poles and $P_j(T_j)$ the weight calculated for each pole at time T_j. Generally, ages T_j are equally distributed in time, at 10 Ma interval or so. In the most recent applications of the sliding window, authors proposed a weighting scheme which took into account the inaccuracy in the ages of the paleomagnetic poles given by each study in the following way:

— a probability law is attributed to the estimation t_i of the true, unknown age. t_i can be obtained in various ways (radiometric, stratigraphic).
— using the assumed probability law, the probability $P_i(T_j)$ that the true, unknown age, will fall into the range (T_j–a; T_j–a) is computed for each pole of the data base. Note that if the estimated age t_i does not belong to that interval, the probability $P_i(T_j)$ is not necessarily zero, but of course $P_j(T_j)$ decreases towards zero when T_j moves away from t_i.

Harrison and Lindh (1982) merely used a uniform probability distribution over the age range of each pole, whereas Fabre (1986) tried to model the actual evaluation of the age by more realistic probability laws. We have adopted here essentially the same approach as Fabre and have introduced probability laws corresponding to three kinds of measurements of t_i radiometric, stratigraphic and magneto-stratigraphic determinations.

In the first and third cases, a Gaussian function is assumed, whereas in the second case the random variable t_i is the mean of n variables each having the same uniform density distribution. The probability law for the mean was computed by Fisher (1953). In practice, when n is greater than 5, this rather complicated function can be approximated to a Gaussian one. Having computed the quantities $P_i(T_j)$ for each of the N poles from the date base, we calculated the sums $S(T_j) = \sum_{i=1}^{N} P_i(T_j)$ which can be interpreted as the number of poles contributing to the smooth pole of age T_j. Obviously, $S(T_j)$ is a function of time which takes any value between 0 and its maximum value depending on the time-distribution of the ages assigned to the data. It is also clear that smooth poles associated with values of S (T_j) less than 1 are meaningless.The function S (t) is displayed on Fig. 2a for a 20 Ma-window. Gaps ocurring in the Triassic and Cretaceous periods are conspicuous and illustrate the rather poor definition of the Iberian APW. The corresponding smooth APW is shown on Fig. 2b.

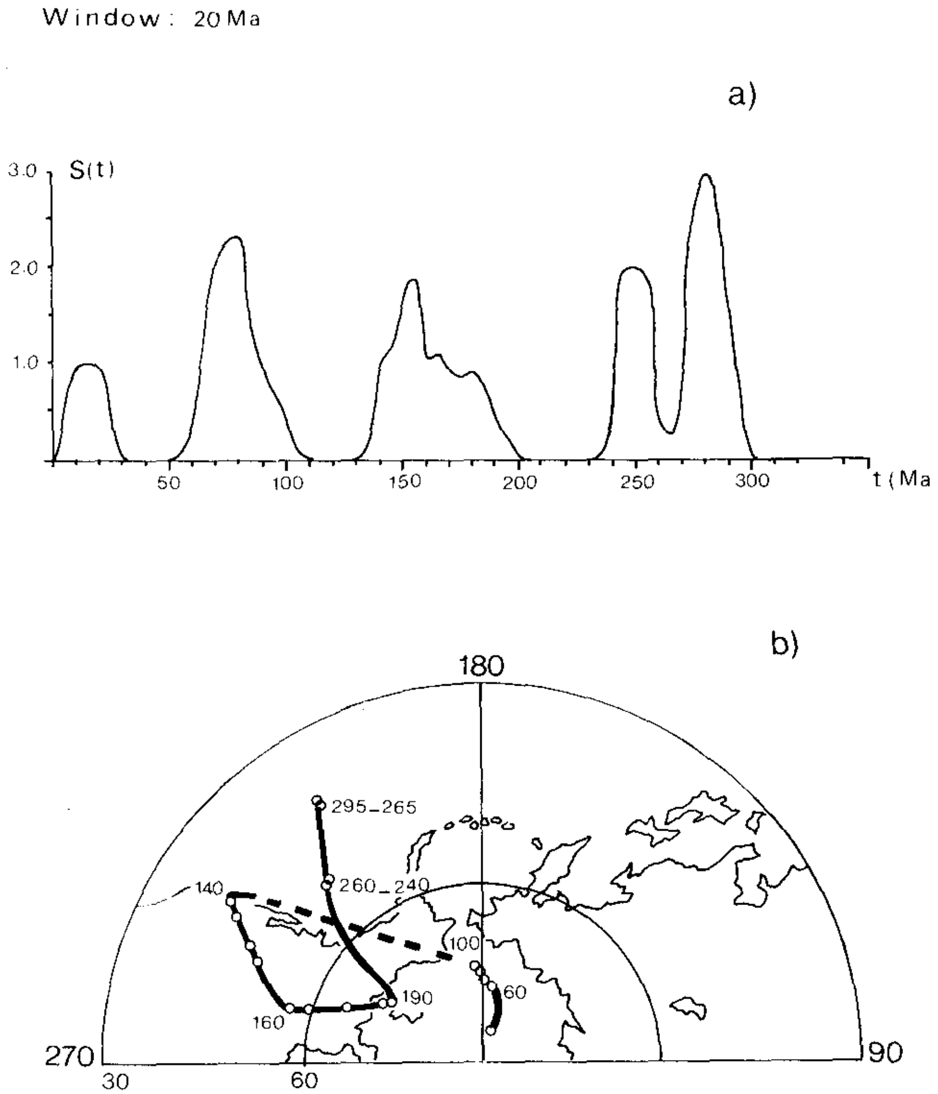

Fig. 2.—Construction of an Iberian APW using the sliding window method. a: density of poles as a function of time. For S(t) lower than 1, the calculated smooth pole is meaningless. b: «smooth» APW yielded by the 20 Ma-sliding window.

Actually, it is highly exaggerated to speak of a «smooth» curve. In fact, as can be seen on the figure, the sliding window method does not allow the construction of a smooth curve, due to the scarcity of the data.

Small circle fittings

This method was applied recently by Gordon et al., (1984) and May and Buttler (1986) to the North American APW. It is related to non-linear regression analysis, and consists in fitting a small circle to suitable portions (called tracks) of the APW. The parameters to be adjusted are the spherical coordinates of the small circle axis and the angle of the cone sustained by the small circles. We used the same maximum likelihood criterion as Gordon et al., which consists in minimizing the quantity:

$$d^2 = \sum_{i=1}^{N} K_j \, (\theta_j - \alpha)^2 \quad (2)$$

where K_j is the precision parameter, θ_j the angular distance to the axis of the small circle for each individual pole from the list, and α the angle of the cone.

In addition, we computed a 95 per 100 confidence interval for each point on the small circle. The only track which seems appropiate is the upper Carboniferous-lower Permian to lower Jurassic portion. The best-fitting small circle and strip of confidence are displayed in Fig. 3.

GEODYNAMIC IMPLICATIONS

We will now test the consistency of the paleomagnetic data summarized by the APW with published kinematic models for Iberia. There are, roughly speaking, two categories of models: models advocating a single rotation of Iberia relative to Europe, without significant transcurrent movement in the Pyrenees, and models assuming a left-lateral shift of the Iberian plate, inducing a strike-slip motion in the Pyrenees amounting to about 400 km. In their most recent quantitative versions, the two kinds of models are represented by those of Masson and Miles (1984) and Olivet et al. (1984), respectively.

APW for Europe

In order to perform the above-mentioned test, we have to take into consideration an APW for the European plate. The European data base

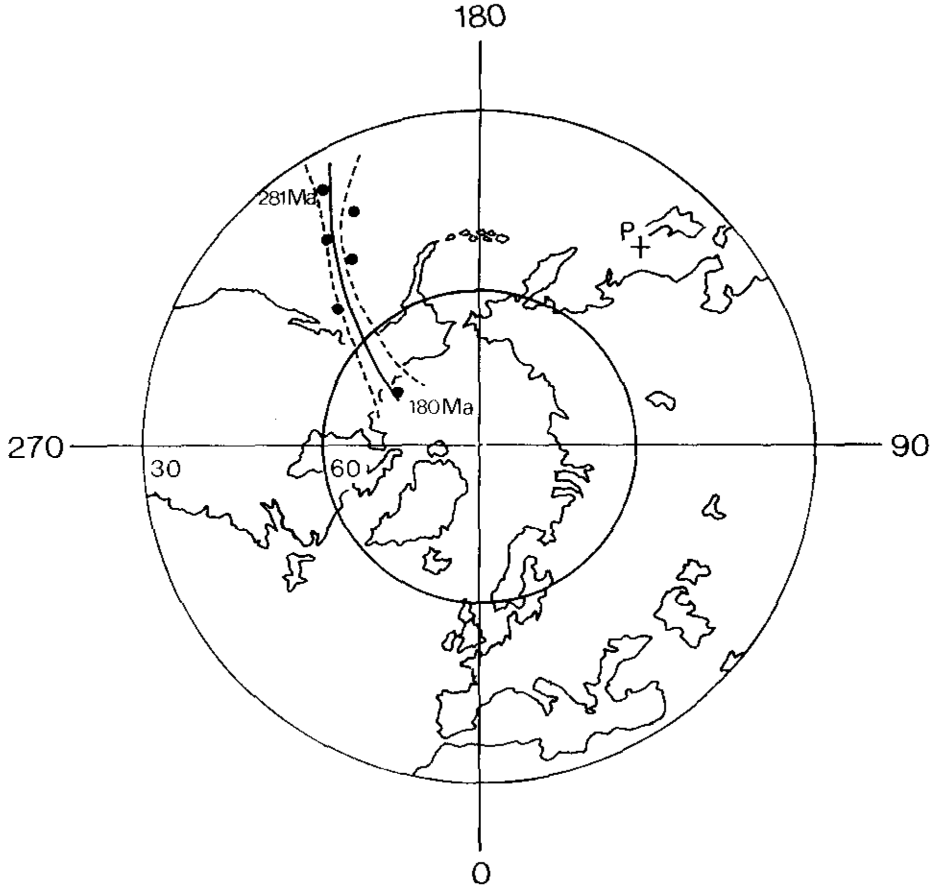

Fig. 3.—Small circle fitting to the Cu-Jl portion of the Iberian APW. The stippled lines are the confidence limits (95 % level of significance) of the angular distance from a point on the small circle to the pole P of the circle. P is the intersection of the axis with the northern hemisphere.

has been discussed by various authors (Westphal et al., 1986; Fabre, 1986; Besse, 1986). Although we believe that the available data needs a careful and critical reexamination, this discussion is beyond the scope of the present paper and we will provisionally adopt a data base corresponding to most of the results selected by the authors named above. Fig. 4 shows that the European APW can be matched by two successive small circles (Cu-Jl track and Jl-Ku track) linked by a «cusp» in the lower Jurassic. The shape obtained is very similar to the fitting of the North American APW published by Gordon et al. (1984).

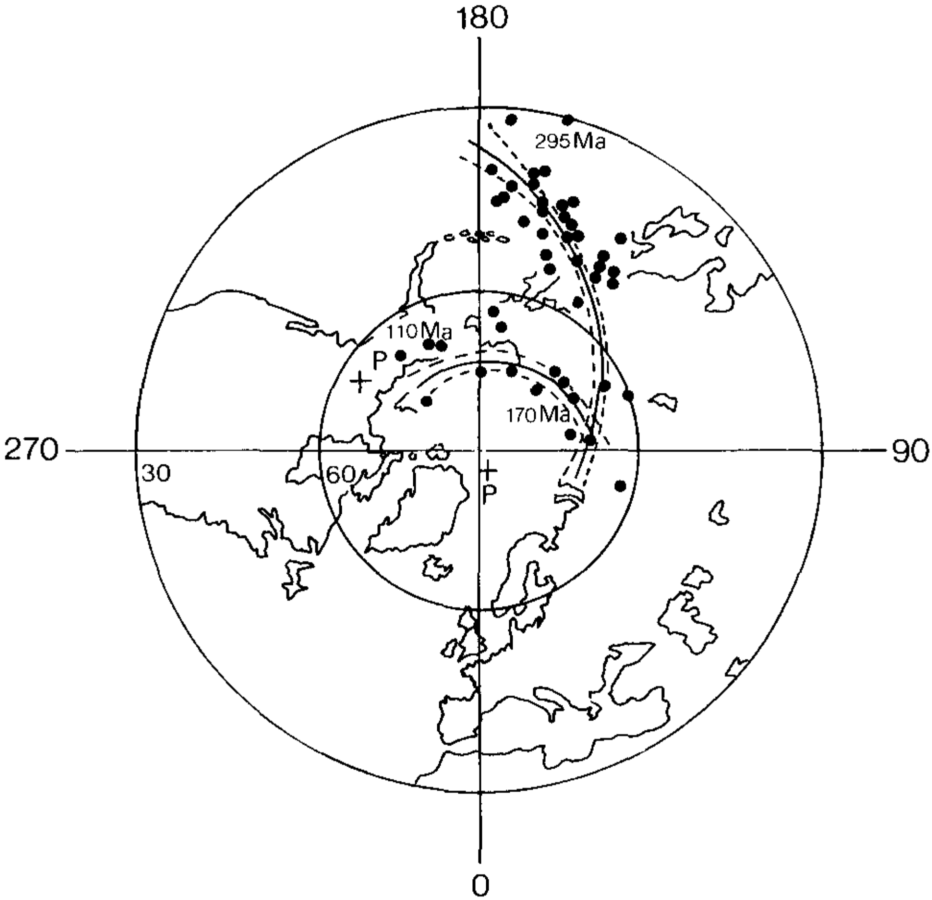

Fig. 4.—Small circle fitting to the European APW. The fit is achieved with 2 small circles: one for the Cu-Jl track and one for the Jl-Ku track. Crosses labelled P and lines have the same significance as in Fig. 3.

Model of Masson and Miles (1984)

This model describes the motion of the Iberian plate through three stages of evolution (Fig. 5b), but the authors did not mention an eulerian pole of rotation for the intermediate stage at 106 Ma. Position 1 reached at 84 Ma is practically identical to position 2 in the model of Olivet et al. (Fig. 6b). The opening of the Bay of Biscay occurs during the movement from position F (initial position) to 1, whereas the Pyrenean orogeny is a result of the convergence movement subsequent to position 1. Restoring the Iberian peninsula to its initial location using the eulerian

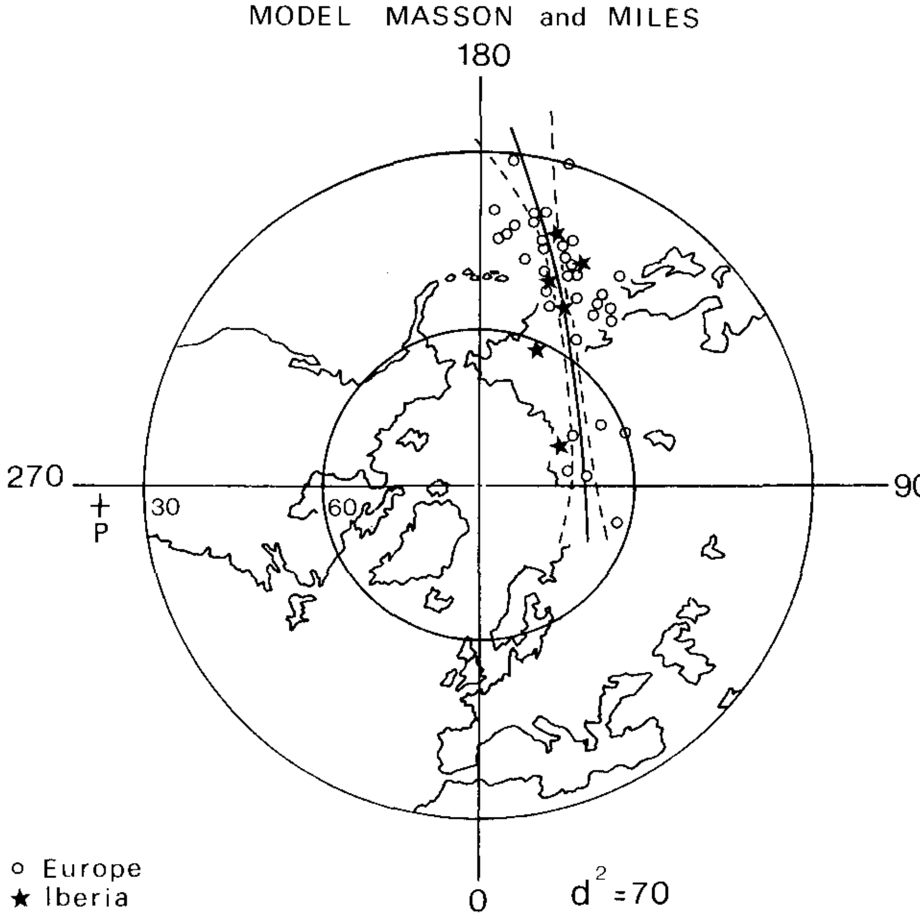

Fig. 5.—Model of Masson and Miles for the kinematics of Iberia.
a: Location of the Cu-Jl portion of the Iberian APW after returning the plate to his initial position, the European plate being in its present-day position. Te common small circle fitted to the European and Iberian Cu-Jl portions of APW, along with the confidence strip and the pole P to the small circle are show. d^2 is the sum of the square deviation of each paleomagnetic pole from the small circle (see formulae 2).

pole of rotation calculated by Masson and Miles, induces a displacement of the upper Carboniferous to lower Jurassic track of the APW which is displayed in Fig. 5a. The figure also shows the small circle fitted to the combined European-Iberian paleomagnetic poles. Owing to the dissimilarity between the number of poles defining each APW, the parameters K_i (see formulae 2) corresponding to the European poles were divided by a constant so that the sums $\sum_{j=1}^{N} K_j$ for the European and Iberian APWs

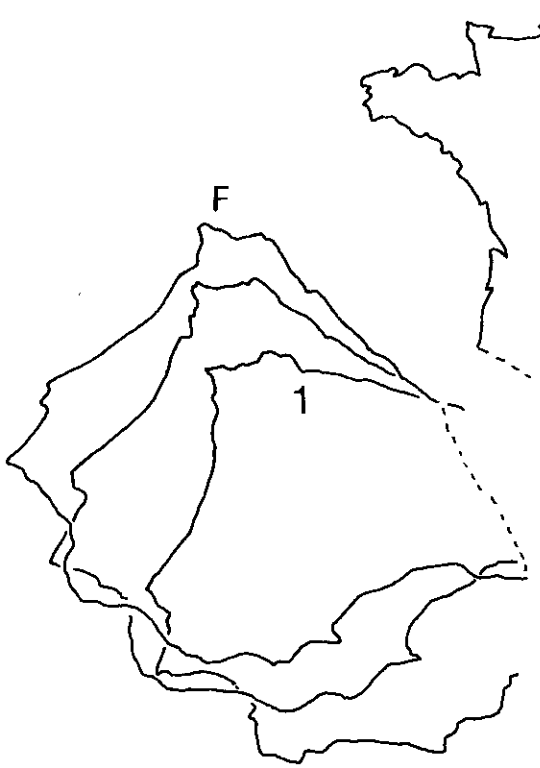

Fig. 5.—Model of Masson and Miles for the kinematics of Iberia.
b: F: initial fit; 1: position at 84 Ma.

respectively, would be equal. In this way, the quantity d ^{2} (see formulae 2) is more sensitive to the fit and hence, more conclusive as to the goodness of fit. The fit proposed by Masson and Miles leads to a value of 70 for the sum of squares d ^{2}.

Model of Olivet et al. (1984)

This model explains the opening of the Bay of Biscay by a left lateral shift documented by 4 successive positions of Iberia. Position 3, reached at 86 Ma, which is not really different from position 2, has been omitted on Fig. 6b, for the sake of clarity. After returning Iberia to position 4, the deviation between the European and Iberian APWs remains significant. In order to bring them to coincide, a further rotation, moving the plate from position 4 to F, must be assumed. The authors suggested that this initial movement could have been connected with the opening of the western part of the Tagus abyssal plain. So far the evidence supporting

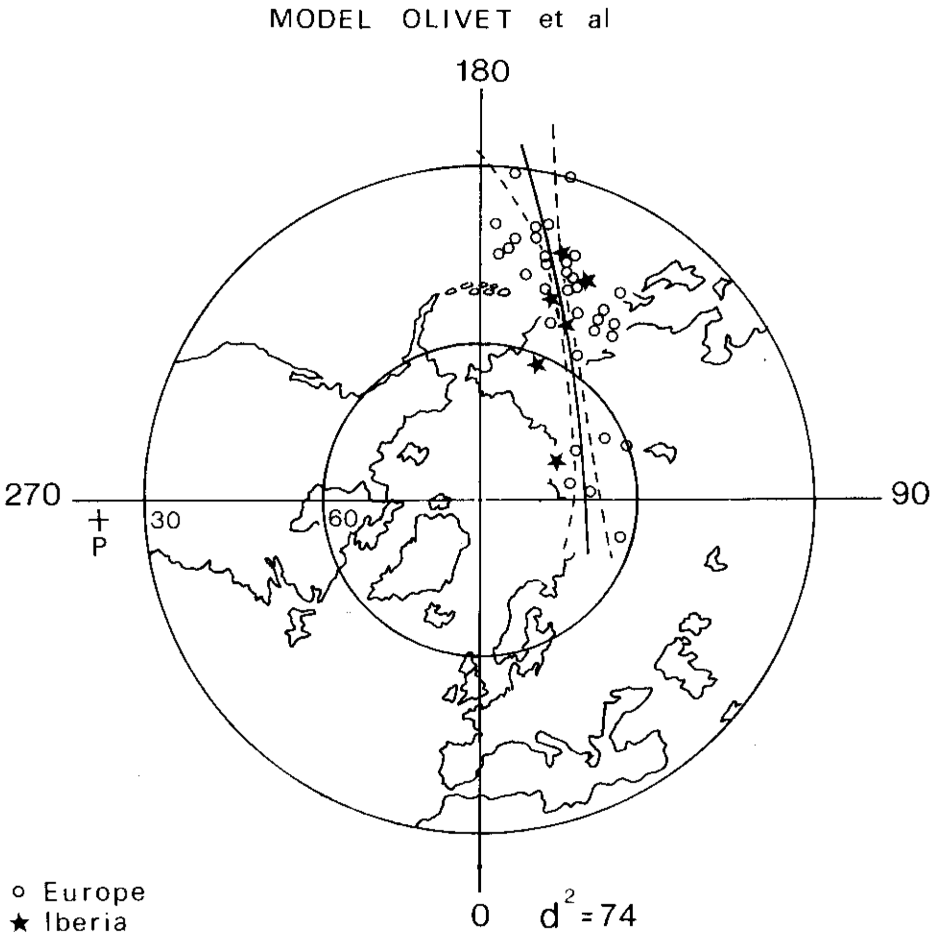

Fig. 6.—Model of Olivet et al. for the kinematics of Iberia.
a: location of the Cu-J1 track of the Iberian APW after returning the plate to its initial position. For other lines and symbols drawn, see Fig. 5a.

this hypothesis is limited, but although the kinematics of this initial opening is scarcely known, its existence is required from a paleomagnetic point of view. Assuming the initial location of the Iberian plate suggested on Fig. 6b, leads to a fit of the European and Iberian plates displayed on Fig. 6a. The calculation of the quantity d^2 (formula 2), performed in the same conditions as in section 3-2, gives a value of 74. Thus, both models lead to superpositions of APWs which are statistically equivalent, and therefore, it is impossible, on paleomagnetic grounds only, to make any difference between models as radically different as are the ones outlined here.

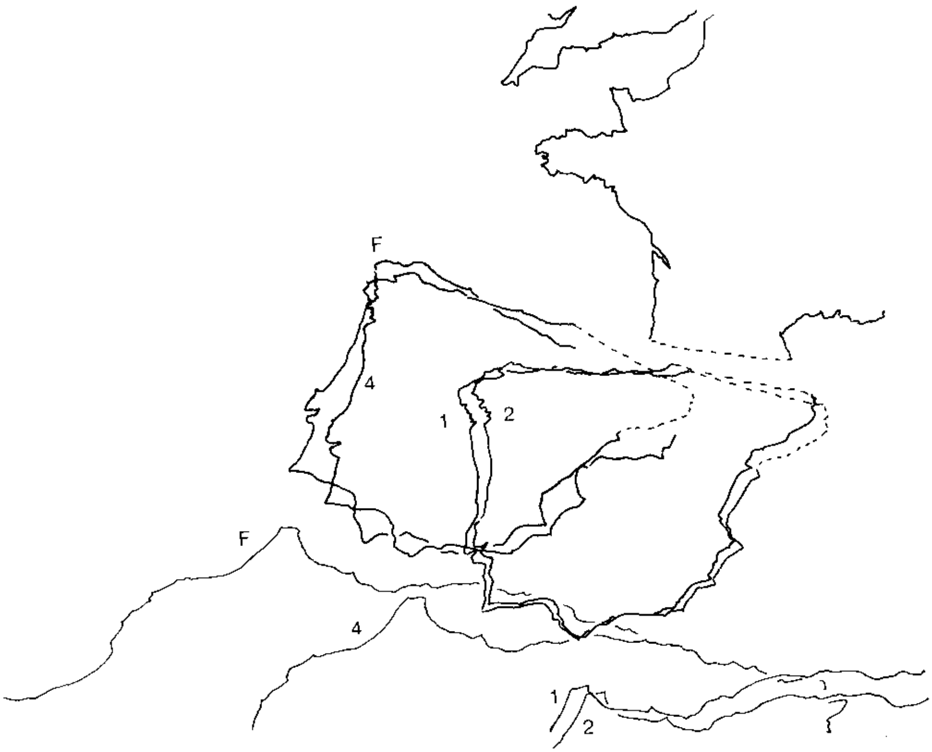

Fig. 6.—Model of Olivet et al. for the Kinematics of Iberia.
b: F; initial fit; 4: position at 110 Ma; 2: position at 76 Ma; 1: position at 53 Ma.

Best fit

Modelling APWs by parts of small circles allows the determination of an eulerian rotation pole which gives the best fit, that is the fit which renders the quantity d^2 minimum. But without further constraints, there are several solutions because any rotation whose axis lies along that of the common small circle makes no difference to the value of d^2. Therefore, in order to find only one best-fit position, we added the following further constraint: on the small circles fitting separately the two APWs (that is in their present-day locations), we chose two points of identifical age, P_1 and P_2 say. Then we looked for the eulerian pole giving the smallest d^2 under the condition that, after rotation, P_1 and P_2 must lie along the same great circle passing through the small circle axis (this condition is equivalent, given d^2, to rendering the angular distance between P_1 and P_2 minimal). We chose points corresponding to a 180 Ma age, because on both APWs, these ages are radiometrically determined. The result is shown if Fig. 7 and the eulerian pole of rotation with its associated ellip-

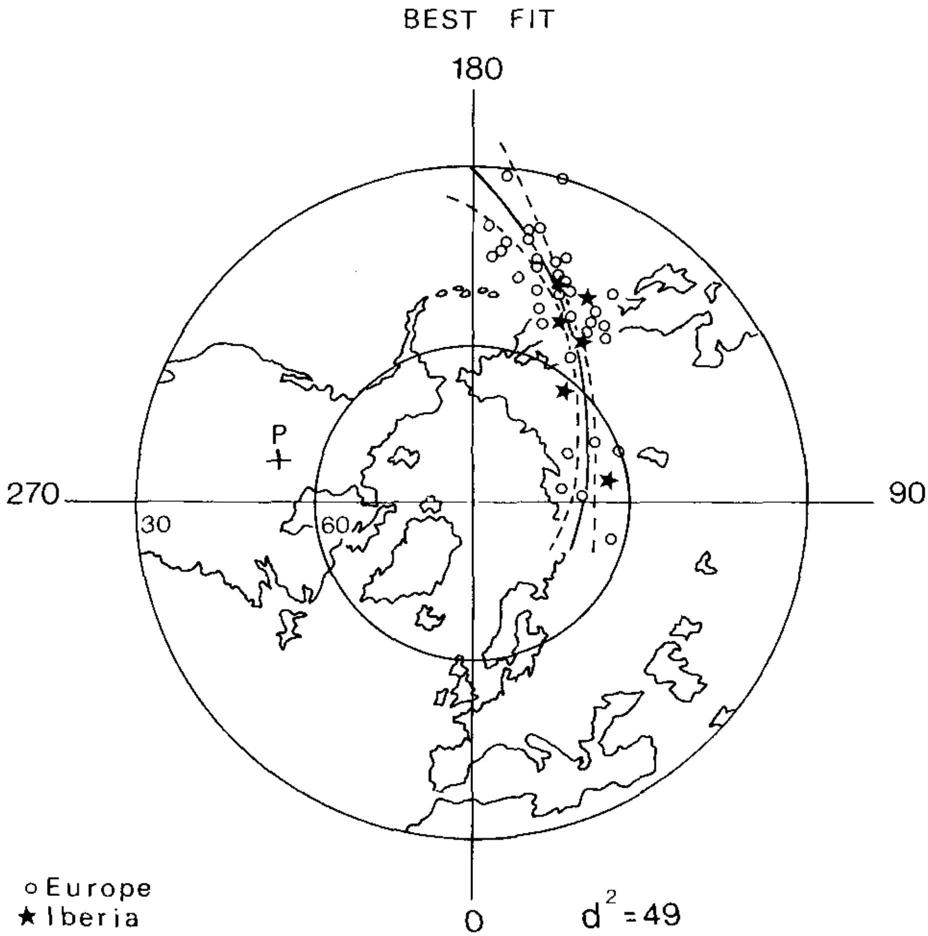

Fig. 7.—Best fit of the Cu-Jl portions of the European and Iberian APW's. For the lines and symbols drawn, see Fig. 5a.

tically shaped confidence area are represented in Fig. 8. This «ellipse» of confidence was estimated under the assumption that d^2 is a chi-squares statistic (Gordon et al., 1984). Eulerian poles whose axis are included in the confidence area give values of d^2/d^2_{min} less than the 95 by 100 level of the Fisher-Snedecor F statistics with 38,38 degrees of freedom. Fig. 8 shows that the axis of the finite rotations given by the models discussed above is located inside the 95 by 100 confidence area. Surprisingly, as can be readily deduced from Fig. 8, the best fit solution is not consistent with the generally accepted kinematics of the Iberian plate, because it involves an initial location to the East.

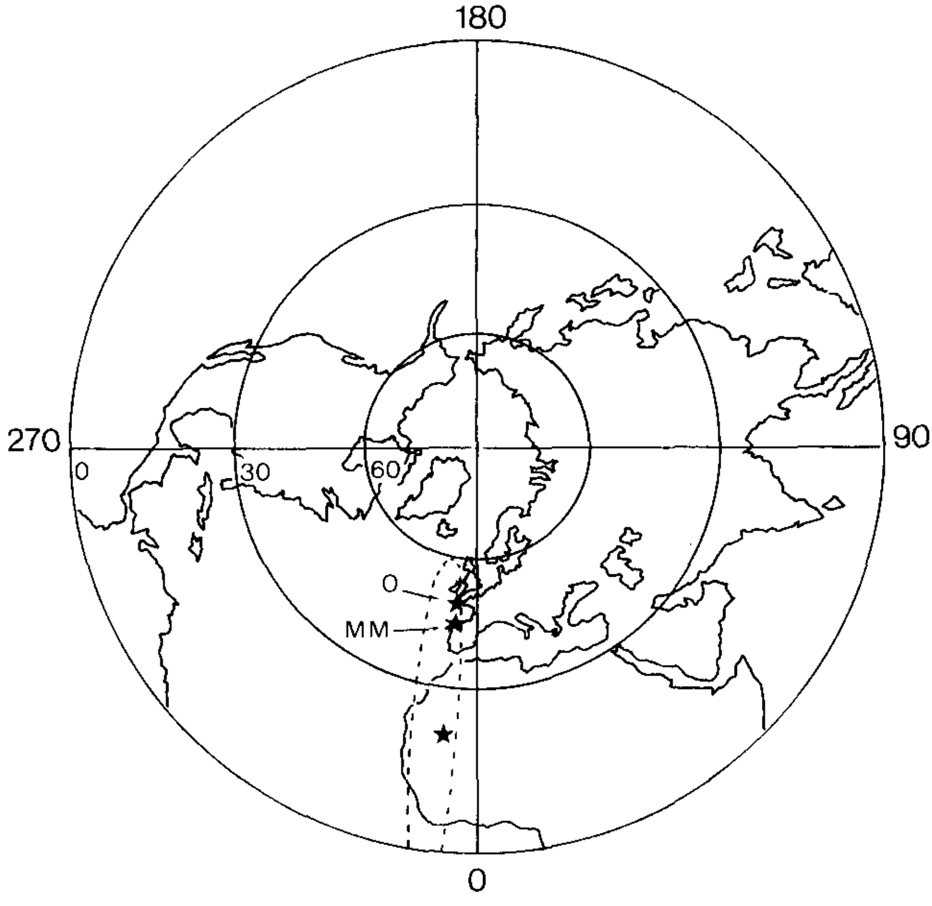

Fig. 8.—Stereographic plot centered on the northern hemisphere of the axis of the eulerian rotation giving the initial locations of the Iberian plate using the best fit, Masson and Miles (MM), Olivet et al. (0) model, respectively. Stippled curve is the boundary of the confidence area (at the 95 % level of significance) for the axis of rotation.

This observation shows that paleomagnetic data alone is unable to show the kinematic evolution of the peninsula. This is partly due to our scant knowledge of the APW. It is to be remembered that the portion of the APW suitable for the search for the fit, that is, the upper Carboniferous-lower Jurassic portion, is defined by 6 poles only. On the other hand, examination of the European APW shows that the data is unevenly distributed along the lower Permian-lower Jurassic track, with a majority of lower Permian-lower Triassic poles and a lack of data in the late Triassic period. But even with better sampling of both APWs, the inaccurracy in fitting the APWs to a single small circle probably cannot be much reduced. Taking into account the Jurassic and lower Cretaceous poles, which apparently belong to another small circle, would probably help in the search for a better constrainted fit. Unfortunately, this improvement is not possible with the current state of knowledge.

CONCLUSIONS

Using the data base listed in table 1, two methods of modelling APWs have been applied. The data are too scarce for the sliding window method to be efficient. But the age weighting outlined in section 2-1 leads to the determination of a probability function S(t) which allows a graphical representation of the density of poles available and is a pictorial call for new data. Although the lack of data is obvious in the late Triassic and the late Cretaceous, which is a crucial period in the kinematic evolution of Iberia, any new data will be valuable.

The method of fitting to small circles allows us to test the consistency of kinematic models with the paleomagnetic data available for Europe and Iberia respectively. Only the portions ranging from upper Carboniferous-lower Permian to lower Jurassic are suitable and allow the fit to a common small circle after returning the Iberian plate to its initial position. Both models tested give equivalent and undistinguishable results which lead to the conclusion that it is not possible, on paleomagnetic grounds alone, to find an unambiguous kinematic model. Calculation of the best fit and of a limit for acceptable poles of rotation merely shows that both models are consistent with the paleomagnetic data.

Once again, the lack of paleomagnetic data is responsible for the fact that the paleomagnetic method alone is unable to give close constraints to the kinematic evolution of Iberia.

REFERENCES

BESSE, J., 1986. Cinématique des plaques et dérive des pôles magnétiques. Evolution de la Téthys, collisions continentales et couplage noyau-manteau. Thesis, Paris VII, 380 pp.

DIJKSMAN, A. A., 1977. Geomagnetic reversals as recorded in the Miocene redbeds of the Calatayud-Teruel basin (Central Spain). Thesis, Utrecht, 156 pp.

FABRE A., 1986. Le temps dans la construction des courbes de dérive apparente du pôle paléomagnétique. Application à l'Europe du Permien au Jurassique. Thesis, Brest, 157 pp.

FISHER, R. A., 1953. Dispersion on a sphere. Proc. R. Soc. A., 217: 295-305.

GORDON, R. G., GOX, A., and O'HARE, S., 1984. Paleomagnetic Euler poles and the apparent polar wander and absolute motion of North America since the Carboniferous. Tectonics, 3: 499-537.

HARLAND, W. B., COX, A. V., LLEWELYN, P. G., PICKTON, C. A. G., SMITH, A. G., and WALTERS, R., 1982. A geologic time scale. Cambridge University Press, New York, 131 pp.

HARRISSON, C. G. A., and LINDH, T., 1982. A polar wandering curve for North America during the Mesozoic and Cenozoic. J. Geophys. Res., 87: 1903-1920.

IRVING, E., 1977. Drift of the major continental blocks since the Devonian, Nature, 270: 304-309.

MASSON, D. G., and MILES, P. R., 1984. Mesozoic sea-floor spreading between Iberia, Europe and North America. Marine Geology, 56: 279-287.

MAY, S. R., and BUTTLER, R. F., 1986. North American Jurassic apparent polar wander: implications for plate motion, paleogeography and Cordilleran tectonics. J. Geophys. Res., 91: 11519-11544.

MC ELHINNY, M. W., 1973. Paleomagnetism and plate tectonics. Cambridge University Press, New York, 358 pp.

OLIVET, J. L., BONNIN, J., BEUZART, P., and AUZENDE, J. M., 1984. Cinématique de l'Atlantique Nord et Central. IFREMER, Sci. Techn. Report núm. 54, 108 pp.

SCHOTT, J. J., and PERES, A., 1987. Paleomagnetism of the lower Cretaceous red beds from northern Spain: evidence for a multistage acquisition of magnetization. Tectonophysics, 139: 239-253.

SCHOTT, J. J., and PERES, A., 1987. Paleomagnetism of Permo-Triassic red beds from the Asturias and Cantabric Chain (northern Spain): evidence for strong lower Tertiary remagnetizations. Tectonophysics, 149: 179-191.

SCHOTT, J. J., MONTIGNY, R., and THUIZAT, R., 1981. Paleomagnetism and potassium-argon age of the Messejana dike (Portugal and Spain): angular limitation to the rotation of the Iberian Peninsula since the Middle Jurassic. Earth Planet. Sci. Lett., 53: 457-470.

STAUFFER, K. W. and TARLING, D. H., 1971. Age of the Bay of Biscay: new paleomagnetic evidence. In: Histoire Strucurale du Golfe de Gascogne. Technip, Paris, II (2), 1-18.

STEINER, M. B., OGG, J.G., MELENDEZ, G. and SEQUEIROS, L., 1985. Jurassic magnetostratigraphy, 2. Middle-Late Oxfordian of Aguilon, Iberian Cordillera, northern Spain. Earth Planet. Sci. Lett., 76: 151-166.

VAN DER BERG, J., 1979. Paleomagnetism and the changing configuration of the western Mediterranean area in the Mesozoic and early Cenozoic eras. Geologica Ultraiectina, 179 pp.

VAN DER VOO, R. 1969. Paleomagnetic evidence for the rotation of the Iberian Peninsula. Tectonophysics, 7: 5-56.

VAN DER VOO, R., and ZIJDERVEDL, J. D. A., 1971. Renewed paleomagnetic study of the Lisbon volcanics and implications for the rotation of the Iberian Peninsula. J. Geophys. Res., 76: 3913-3921.

WESTPHAL, M., BAZHENOV, M. L., LAUER, J. P., PECHERSKY, D. M., and SIBUET, J. C., 1986. Paleomagnetic implications of the evolution of the Tethys belt from the Atlantic Ocean to Pamir since the Triassic. Tectonophysics, 123: 37-82.

Received 21 Dec. 1987.
Accepted 4 Jul. 1988.