

Palaeomagnetic database: the effect of quality filtering for geodynamic studies

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Abstract: The Global Palaeomagnetic Database (GPMDB), now updated to 1992, contains about 7000 palaeomagnetic data, which are fundamental tools to define regional and global geodynamic models. A software developed at the Istituto Nazionale di Geofisica allows the selection of data on the basis of space, time, and quality. Six quality classes have been proposed. The African and European Apparent Polar Wander Paths (APWPs) have been computed and the role of the statistical uncertainties is discussed. Some examples from the Tethys Belt have been chosen to demonstrate the effect of the quality filtering in geodynamic studies.

In the last few years, the International Association of Geomagnetism and Aeronomy (IAGA) has officially encouraged the development of several palaeomagnetic and rock-magnetic databases, which fulfil the need of storing and easily handling the increasing amount of data coming from several palaeomagnetic disciplines: among others rock-magnetism, archaeomagnetism and magnetostratigraphy. In particular, five regional databases of directions and palaeopoles were compiled by Khramov & Pisarevsky (Russian Federation), Pesonen (Fennoscandia), Enkin (Canada), Luyendyk & Butler (USA) and Westphal (Europe). Besides the regional databases, IAGA was the sponsor of the world-wide database, the Global Palaeomagnetic Database (GPMDB), co-ordinated and published by McElhinny & Lock (McElhinny & Lock 1990a, b, 1993; Lock & McElhinny 1991). IAGA also encouraged cross checking of the regional databases with the global database, so that errors and omissions were avoided. The GPMDB synthesises all the palaeopole parameters and their quality, and its updated version contains about 7000 palaeopoles. The collection for the period 1989–1992 has been performed by Van der Voo. The GPMDB has a complex file structure, and includes data produced for completely different aims, such as magnetostratigraphy, determination of virtual geomagnetic poles (VGP), averaged palaeomagnetic poles etc. Consequently the data must be selected and weighted according to the scientific field in which the palaeopoles are to be used. The problem of quality filtering is the subject of this paper.

The tectonic framework

Data originating from the GPMDB are referred to specific areas (Fig. 1) which include Africa (excluding Madagascar), Europe to the Urals and part of Asia (Middle East, Caucasus and Arabia). Traces of various orogenic episodes can be found in Africa, Europe and Asia: the two Palaeozoic events (Caledonian, 570–370 Ma; Variscan–Hercynian, 370–220 Ma) and the Alpine Mesozoic–Cenozoic orogeny (Early Mesozoic Alpine, 220–65 Ma; Mid-Cenozoic Alpine, 65–20 Ma; Late Cenozoic Alpine, 20 Ma to present) (UNESCO 1976; Bally *et al.* 1985). The Caledonian orogeny was active in the Mauritanides (Africa) and in Scandinavia, Scotland, Wales and the Ardennes (Europe). Cratonic basins, located mainly in continental pre-Mesozoic lithosphere and shields deformed by Pre-Cambrian orogenic episodes, can be found alongside the Caledonian orogenic belts. Most of Africa has a cratonic structure, such as in western Africa, Congo, Tanzania and Kalahari, with other old deformed areas like Katanga. In Europe we can notice both old deformed zones, like the Karelian system and Fennosarmatian shield, and wide craton basins (e.g., the North Sea Basin and the Russian–Ukrainian Basin). The Variscan–Hercynian orogeny is strongly marked in Morocco, southern African Cape, in Europe in the Central Massif, the Variscides and the Urals. In Africa the Mesozoic–Cenozoic Alpine orogeny affected the Maghrebides and the Cape Range. The rift-valleys of East Africa were formed during the Neogene and are still volcanically active.

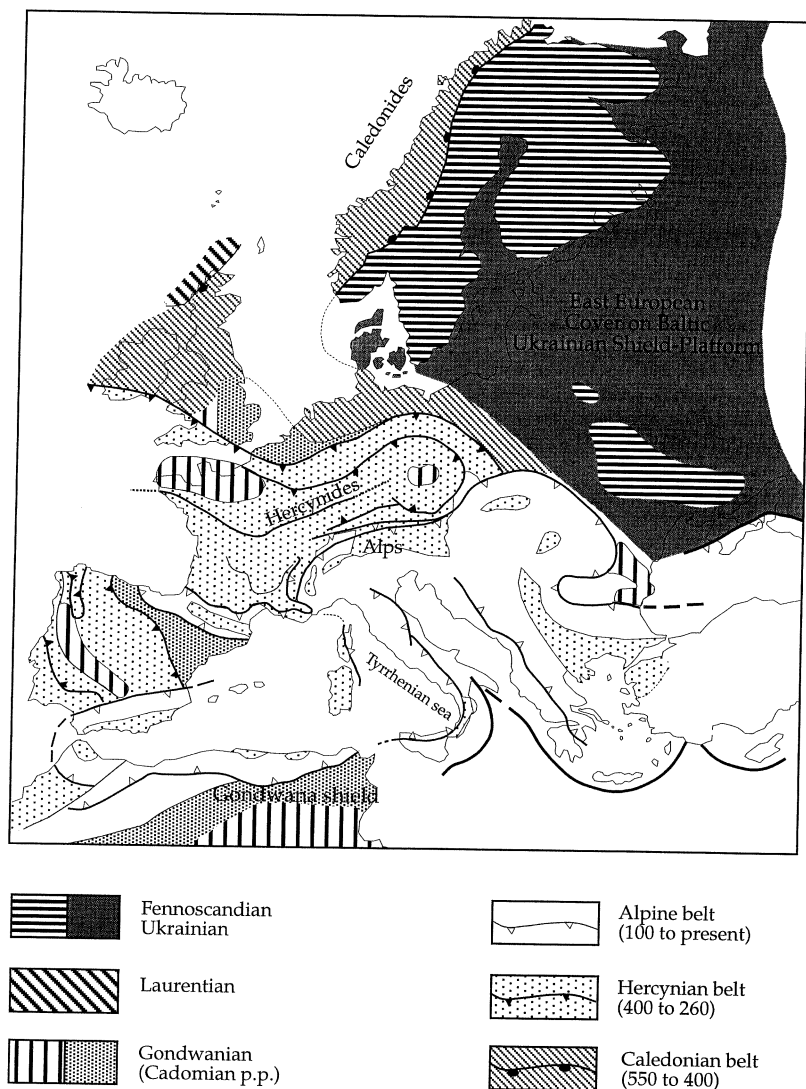


Fig. 1. Sketch of the tectonic setting of the Mediterranean area and surrounding zones (simplified from Lumsden 1992).

Further volcanic activity took place in the Ahaggar and the Tibesti during the Tertiary and Quaternary. In Europe, the Alpine orogeny deformed the mountain belts of the Betics, Pyrenees, Alps, Apennines, Dinarides, Hellenides, Carpathians, Crimean peninsula, Pontides, Taurides, Zagros, Greater and Lesser Caucasus, Elzberg and the Kopet-Dag (East of Caspian Sea). Close to these belts, some recent oceanised or relict ocean basins are recognised, like the Alboran Sea, Tyrrhenian Sea, Aegean Sea, Pannonian basin and Black Sea. In the Alpine orogenic zone (the so-called Tethys

Belt), the complex interaction between Africa and Europe caused a fragmentation into several microplates that have undergone relative movements (e.g., Kissel & Laj 1989; Şengör 1989; Stöcklin 1989; Favali *et al.* 1993a, b). It is thus necessary to separate the areas of Africa and Europe affected by older orogenies (defined stable) from those of the mobile Tethys Belt.

Data filtering

After separating the data on a regional basis, it is then necessary to select them on the basis of

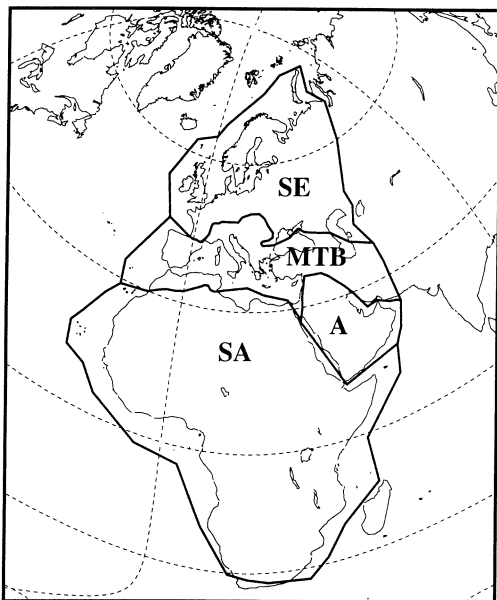


Fig. 2. Map of the polygons used in this study for extracting palaeopoles, separating data in stable areas from data in mobile ones (SE, Stable Europe; MTB, Mobile Tethys Belt; SA, Stable Africa; A, Arabia). These polygons have been drawn on the basis of the following maps and papers: Merla *et al.* (1973); Stöcklin & Nabavi (1973); UNESCO (1976); Martin *et al.* (1978); Bartov (1979); BRGM (1980); AA.VV. (1981); Nairn *et al.* (1981); Boccaletti & Dainelli (1982); Boccaletti *et al.* (1985); Salmon *et al.* (1988); Condie (1989); Kampunzu & Lubala (1991); Kruczyk *et al.* (1992); Lumsden (1992).

several different parameters linked to their palaeomagnetic quality. For both of these purposes, software has been developed by the Istituto Nazionale di Geofisica (Florindo *et al.* 1994), based on the ACCESS version of the GPMDB. This software uses 20 criteria in space, time and quality, enabling immediate evaluation of the pole distributions by means of a mapping program.

Geography–chronology

Within each geological–tectonic framework, the palaeopoles are grouped on the basis of the geographical co-ordinates of the sites. Three main polygons have been drawn to include Stable Africa (SA), Stable Europe (SE) and the Mobile Tethys Belt (MTB) (Fig. 2), based on several tectonic maps and publications (references in Fig. 2 legend). A fourth polygon, the Arabian plate (A in Fig. 2), was also considered as the geodynamics of this region are of great

Table 1. Time windows in Ma used to subdivide the data, together with approximate corresponding positions in the epochs of the Geological Time Scale

Time windows (Ma)	Epochs	Uncertainty (Ma)
0–5	Pliocene–Quaternary	5
5–15	Mid–Late Miocene	10
15–25	Early Miocene	10
25–35	Oligocene	10
35–45	Mid–Late Eocene	10
45–55	Early–Mid–Eocene	10
55–65	Palaeocene	10
65–100	Late Cretaceous	30
100–145	Early Cretaceous	30
145–180	Mid–Late Jurassic	30
180–210	Early Jurassic	30
210–245	Triassic	30
245–290	Permian	35
290–325	Late Carboniferous	35
325–360	Early Carboniferous	35
360–410	Devonian	35

The uncertainties in Ma are those required for the better quality data falling in each time window. See text for discussion.

interest, but the shortage of available data prevented further consideration. The palaeopoles were then selected on the basis of their rock magnetization ages using non-superimposed time windows (first column of Table 1). The width of the time windows has been calibrated using the epochs and periods in the Geological Time Table (Harland *et al.* 1990), as used by the compilers of the GPMDB. The first time window (5 Ma wide) includes the Pliocene and Quaternary, the six following windows (each 10 Ma wide) cover from Miocene to Palaeocene time, the next eight windows (30–45 Ma wide) extend from the Cretaceous to the Early Carboniferous. Finally the last window (50 Ma wide) represents the Devonian. Each datum was assigned to a time window on the basis of the mean of its maximum and minimum magnetization ages. The assignation of a datum was unequivocal; if the mean value fell at a window boundary, then it was assigned to the younger window.

Quality filtering

Clearly, laboratory and analytical procedures (Bazhenov & Shipunov 1991) are vital, as are the number of sites and number of samples per site, as these affect the statistical results (Tarling 1983). Multiple sites within a given rock unit are needed to provide an adequate time sampling of

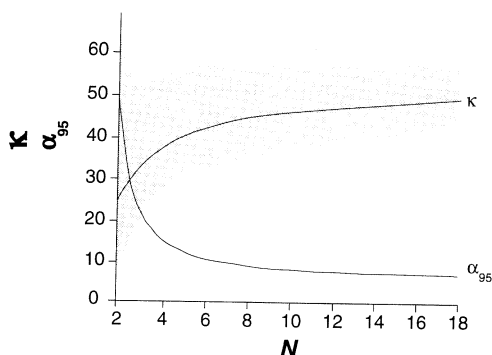


Fig. 3. Precision parameter (K) and α_{95} versus the number of observations N (redrawn from Tarling 1983). These parameters are important to define the quality of the data. It can be seen from the figure that the values of K and α_{95} tend to stabilize and become acceptable for number N of observations above 6–8. These limits have been assumed in fixing the criteria for the two higher quality classes (see text).

the geomagnetic field, and at least six to eight observations are required per site for an acceptable estimate of precision (K) and α_{95} in Fisherian statistics (Fisher 1953) (Fig. 3). Many authors have attempted to define quality criteria, using for example: the number of sites and samples per site; the lack of remagnetization; the age determination method; and the structural control.

Van der Voo & French (1974) considered reliable only those data characterised by successful removal of all possible secondary components of magnetization and based on a considerable number of samples. Moreover, they consider adequate structural control and a well-determined age to be essential, assuming that the magnetization has about the same age as the rock. Briden & Duff (1981) suggested that palaeomagnetic data could be divided into four quality classes of increasing severity. Their main criterion was that A class key-poles had known magnetization ages. May & Butler (1986) suggested that reliable poles should have at least 10 sites per pole, with Virtual Geomagnetic Pole (VGP) precision parameters (K) between 20 and 150 and α_{95} radii less than 15° . Their maximum accepted age uncertainty was 10 Ma and an appropriate understanding of the structural corrections was also a prerequisite. Van der Voo (1990) proposed a set of seven reliability criteria: (1) a well-determined age of the rocks and the presumption that the magnetization has the same age; (2) sufficient samples ($N \geq 24$), $K \geq$

10 and $\alpha_{95} \leq 16^\circ$; (3) adequate demagnetization, including demonstrable vector subtraction; (4) field tests limiting the age of magnetization; (5) structural control and tectonic coherence; (6) the presence of reversals; (7) no resemblance of the palaeopole position to that of a pole of younger age by more than a Period. The quality index (Q from 0 to 7) is assigned according to the number of criteria that have been satisfied. Besse & Courtillot (1991) assumed the following minimum reliability criteria: at least 6 sites per pole and 6 samples per site, $\alpha_{95} < 15^\circ$, evidence for successful alternating field (AF) and/or thermal demagnetization and maximum date uncertainty of 15 Ma. They have tried to identify signs of remagnetization, to check quality of the age determination and to assess the tectonic structure, including fold tests. Li & Powell (1993), following and developing the approach of Briden & Duff (1981), assigned data to five quality classes (A to E). They considered 'key-poles' as those of A and B classes, which had a well-determined magnetization age (less than 30 and 60 Ma uncertainty) and with palaeohorizontal control. The C class poles must have palaeohorizontal control but lack tight age control. The D and E class poles were considered unreliable.

In view of the need for a careful selection of palaeopoles, six different quality classes (A, B, C, D, M and U; see Table 2) are suggested here. The uncertainty of the magnetization age plays a special role. For geodynamic purposes, it is possible to describe the evolution through time of a pre-determined area by using only data with a degree of limited uncertainty, otherwise the approach would be unreliable. On the other hand, the real uncertainty of the limits among the epochs and of the age determined by isotopic methods both increase further back through time, as shown in Fig. 4, based on data given by Harland *et al.* (1990). For higher quality data, the uncertainty values should never be greater than the width of the time windows (first column of Table 1); on the other hand too strict a time uncertainty criterion can lead to an unjustified rejection. This choice is subjective and, in this study, the acceptable age uncertainties are equal or slightly smaller than the width of the time windows (5 Ma for Pliocene-Quaternary, 10 Ma for Tertiary, 30 Ma for Mesozoic, and 35 Ma for Palaeozoic; column 3, Table 1).

We define six quality classes using the following criteria.

A *quality* is characterized by: an uncertainty of magnetization age not greater than the width of time windows; at least eight sites per pole and eight samples per site; an α_{95} confidence interval

Table 2. The six quality classes (A, B, C, D, M and U) proposed in this study

	Sites	Samples	α_{95}	Laboratory and analytical procedures*	Conclusive field test
A	≥ 8	≥ 8	≤ 15	≥ 3	Yes
B	≥ 6	≥ 6	≤ 15	≥ 2	Yes
C	≥ 4	≥ 4	≤ 20	≥ 2	No
D	< 4	< 4	> 20	< 2	No
M	Magnetostatigraphy (?); samples/sites > 30				
U	Undefined number of sites and/or samples				

Although the uncertainty of magnetization ages does not appear in this table, its role for the definition of the quality of the data is important, as discussed in the text.

* Codes of the laboratory and analytical procedures (Lock & McElhinny 1991); 0, No demagnetization; 1, demagnetization only on some pilot samples; 2, all samples treated, with blanket treatment only; 3, all samples demagnetized step by step, stereonet with J/J_0 or vector plots provided (Zijderveld 1967); 4, principal component analysis (PCA) (Kirschvink 1980) and stereonet with J/J_0 or vector plots; 5, PCA and vector plots and multiple demagnetization treatments which are successfully isolating different vectors (e.g., AF and thermal, or thermal and chemical)

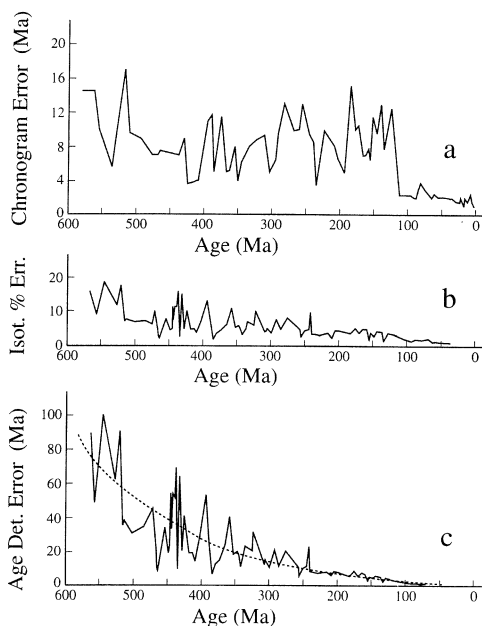


Fig. 4. The uncertainties of quantities against geological time. (a) the error (Ma) in defining the age limit between two stages in the Geological Time Scale; (b) the percentage error in measuring specimen age by isotopic methods; and (c) the uncertainty in Ma in measuring specimen age by isotopic methods.

less than or equal to 15° ; a laboratory and analytical procedure code (Lock & McElhinny 1991) greater than or equal to 3; and at least a conclusive field test. Such A class palaeopoles are considered as 'key-poles'.

B quality is characterized by: an uncertainty of

magnetization age not greater than the width of the time windows; at least six sites per pole and six samples per site; the same α_{95} as for the A class; laboratory and analytical procedure codes greater or equal to 2; and at least a conclusive field test.

C quality data have: an uncertainty of magnetization age 50% greater than B class; at least four sites per pole and four samples per site; α_{95} less than or equal to 20° ; laboratory and analytical procedure codes greater or equal to 2; but a field test is not required. Poles in this intermediate class are not suitable for the computation of APWPs. When no higher quality data are available, C palaeopoles can only be used to indicate possible trends.

D quality includes data with: less than four sites per pole and four samples per site; α_{95} greater than 20° ; and laboratory and analytical procedure codes less than 2. These data are of limited use in geodynamic studies. In this class, the uncertainty in magnetization age is irrelevant.

M quality includes all those studies with samples/sites ratios greater than 30. This class could be suitable for magnetostratigraphic studies.

U quality includes all studies with an undefined number of samples and sites.

Where the GPMDB does not have the α_{95} , this was derived from the polar semi-axis errors, i.e. $(\delta_p \cdot \delta_m)^{1/2}$ (Khranov 1987).

It should be stressed that a different choice of time window widths and of the associated uncertainties in magnetization age strongly influences the quality class assigned to each datum by the extraction program. For example, an uncertainty of 30 Ma is required to resolve the

Table 3. The lithology of the European and African sites which have been selected to construct APWPs

Time windows (Ma)	Stable Europe APWP lithology		Stable Africa APWP lithology	
	Quality A	Quality B	Quality A	Quality B
0–5	2e	1s, 2e	1e	2e
5–15		2e		3e
15–25				
25–35				
35–45			1s	
45–55				
55–65		3i, 1e		
65–100	1s		2s, 1i	1i, 1e
100–145				1e
145–180		4s		
180–210		2s		2i
210–245		4s		
245–290	2i, 1e	4s		
290–325	1s, 2i, 1e	1s		1s
325–360	1e	1e		
360–410	1s, 1e	3s, 2e		1e

The subdivision follows the time windows of Table 1, and is further divided into the two higher quality classes, A and B, which have been used in the APWPs of Fig. 5. *s*, sedimentary; *i*, intrusive; *e*, extrusive.

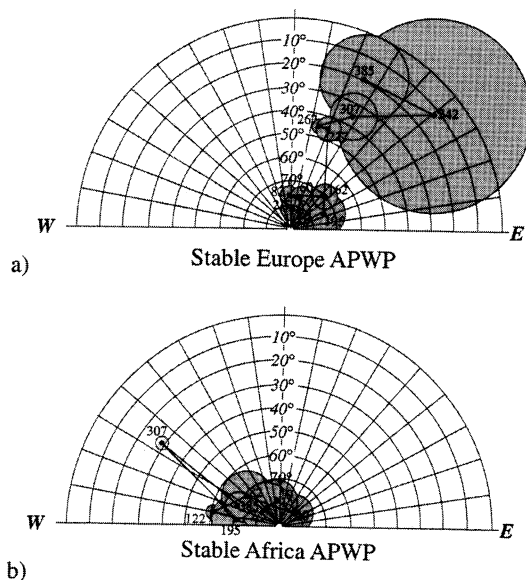


Fig. 5. Apparent Polar Wander Paths: (a) Stable Europe; (b) Stable Africa. The circles filled in grey represent the uncertainties in degrees. The numbers indicate the mid-point of the time windows.

Early Jurassic (180–210 Ma) palaeolatitudes whereas an uncertainty of about 10 Ma is required for the Sinemurian (194.5–203.5 Ma) data. It is recommended that the width of a time window (*W*) is never less than the chronogram

error (E_c ; Harland *et al.* 1990) of the geological period or stage under consideration.

African and European APWPs

The APWPs of Africa and Europe have been computed using the non-superimposing time windows defined in Table 1, and using only A and B quality data (Table 4). The lithologies involved are shown in Table 3. A 'key-pole' was selected in only one time window (325–360 Ma, Stable Europe) in which the A and B class poles had very different azimuths (*c.* 50°). In many cases the low number of data did not allow the computation of a statistically well-defined mean pole. In other cases the density of averaged poles was particularly high, for instance from 0 to 200 Ma for Stable Europe (Fig. 5a) and Stable Africa (Fig. 5b), but the circles of uncertainty (based on very few reliable palaeomagnetic poles) were very large, and did not permit definitive conclusions. The European APWP (Fig. 5a) shows a regular progression between 2.5 and 82 Ma, with two cusps at 82 and 195 Ma. There was a fast, clear displacement from high to the middle latitudes from the Jurassic to Triassic, linked to some important tectonic events, which can be interpreted in terms of plate tectonics, expanding Earth theory (Scalera 1988, 1990) or other frameworks (Chatterjee & Hotton 1992). The African APWP (Fig. 5b) shows a recent small loop between 2.5 and

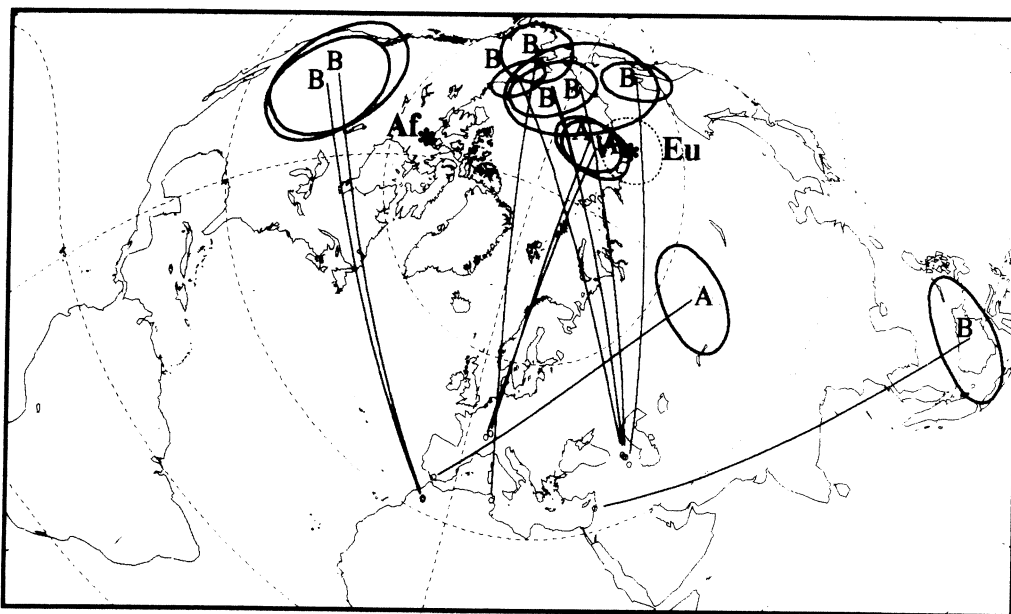


Fig. 6. Mobile Tethys Belt: sampling sites and their poles with confidence ellipses for the Mid-Late Jurassic (145–180 Ma). The stars represent the coeval African (Af) and European (Eu) reference poles and their confidence ellipse (dotted). In this time window it was possible to compute only the European confidence ellipse (see text for the explanation).

40 Ma, and a southwards trend which ends in a cusp near 122 Ma. Subsequently the path comes back towards the present higher latitudes. The next mean pole (307 Ma) is very far away from the other mean poles, and is based only on one B quality pole. Finally the APWP comes back again towards the present latitudes, giving rise to a sharp cusp.

Examples from the Tethys Belt

The poles constituting the APWPs of the major plates are used as 'reference poles' to detect motions (vertical-axis rotations and latitudinal movements) of crustal blocks. The latitudinal transport (Beck 1976, 1980; Demarest 1983; Beck *et al.* 1986; Butler 1992) is given by $L = l_o - l_r$, where l_o represents the great-circle distance in degrees between the sampling site and the observed pole and l_r is the great-circle distance in degrees between the site and the reference pole. L is positive if the block has moved towards the reference pole. The vertical-axis rotation in degrees (Beck 1976, 1980; Demarest 1983; Beck *et al.* 1986; Butler 1992) is more complex:

$$R = \cos^{-1} \left(\frac{\cos s - \cos l_o \cos l_r}{\sin l_o \sin l_r} \right)$$

where s is the great circle distance in degrees between the observed and reference pole.

A total of 1047 palaeopoles come from the Mobile Tethys Belt (MTB in Fig. 2), but only 77 (7.6 %) fall in A and B quality classes (Table 4). Two time windows (Mid-Late Jurassic and Late Cretaceous) were chosen as examples for the entire Mobile Tethys Belt as they are rich in high quality data (Figs 6 and 7). For the Mid-Late Jurassic window, the African pole is derived from the mean between the poles of the two adjacent windows (Early Jurassic and Early Cretaceous; 195 and 120 Ma in Fig. 5b) because they are close to each other. The European subset of Mid-Late Jurassic palaeopoles (two A and four B quality data, excluding the data from Lebanon, Tunisia, Morocco and Southern Spain) has a low dispersion distribution compared to the European reference pole (Fig. 6). The palaeopoles from the Caucasus show an elongated, arcuate distribution indicative of rotations among small-scale blocks of different widths (MacDonald 1980). The Tunisian pole (Nairn *et al.* 1981) has a clockwise rotation relative to the African pole and is on the edge of the European palaeopoles. This fact could be a clue to understanding its evolution as being linked to the European plate. Another anomalous result in this time window is

Table 4. Number of data subdivided for quality and extracted on the basis of the time windows and the uncertainties of Table 2

Quality classes	Age (Ma)															
	0-5	5-15	15-25	25-35	35-45	45-55	55-65	65-100	100-145	145-180	180-210	210-245	245-290	290-325	325-360	360-410
<i>Stable Europe</i>																
A	2	0	0	0	0	0	0	1	0	0	0	0	3	4	1	2
B	3	2	0	0	0	0	4	0	0	4	2	4	4	1	1	5
C	7	3	1	1	0	3	4	2	0	1	2	2	16	13	11	16
D	56	7	4	7	2	7	5	6	5	7	4	42	166	53	48	105
M	7	3	0	1	0	0	1	0	0	0	0	5	19	8	9	
U	8	4	4	2	0	3	3	2	4	3	5	15	79	25	11	38
<i>Stable Africa</i>																
A	1	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0
B	2	3	0	0	0	0	0	2	1	0	2	0	0	1	0	1
C	7	2	0	1	1	0	0	8	2	3	5	2	6	1	0	3
D	21	10	7	3	1	3	1	3	6	9	5	4	8	2	2	2
M	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
U	2	7	1	1	1	1	0	4	1	1	0	1	3	1	1	0
<i>Mobile Tethys Belt</i>																
A	4	3	3	0	1	0	0	1	0	3	3	0	3	0	0	1
B	11	7	0	1	4	0	0	10	4	8	3	1	5	0	0	1
C	18	16	3	5	4	4	2	41	18	15	5	13	27	2	5	2
D	112	38	12	15	13	18	15	73	48	71	24	33	43	5	12	10
M	15	6	3	0	4	2	1	2	23	10	1	1	1	0	0	6
U	11	9	2	4	2	6	4	38	12	28	11	11	21	2	1	11

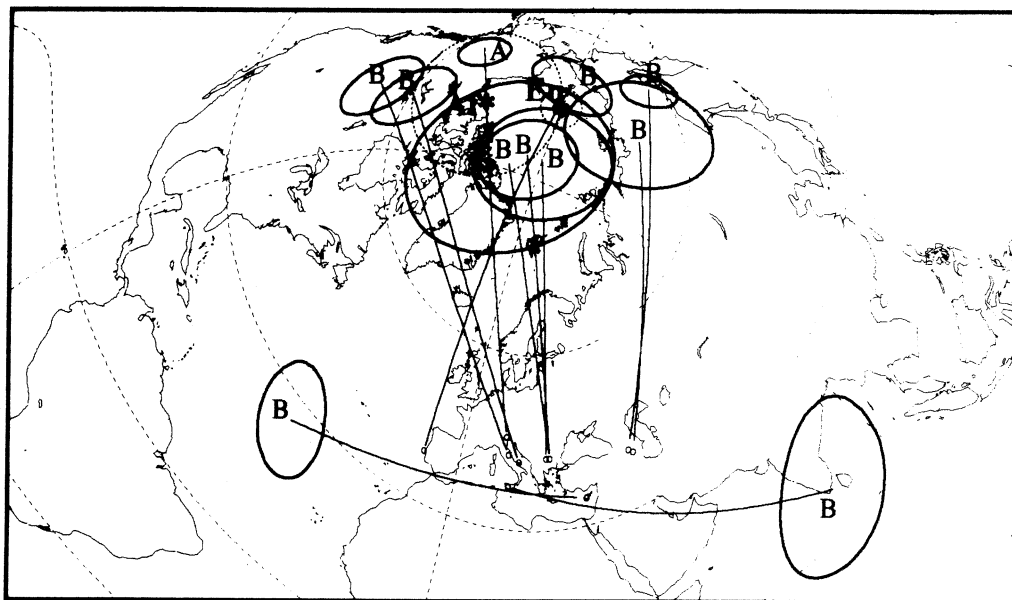


Fig. 7. Mobile Tethys Belt: sampling sites and their poles with confidence ellipses for the Late Cretaceous (65–100 Ma). The stars represent the coeval African (Af) and European (Eu) reference poles and their confidence ellipses (dotted).

from the Late Jurassic volcanic rocks from Lebanon, near the Jordan–Dead Sea (Gregor *et al.* 1974), which shows important rotations with respect to both the European ($R_{\text{Europe}}^{\text{Lebanon}} \pm \Delta R = 72.3^\circ \pm 10^\circ$) and the African reference poles ($R_{\text{Africa}}^{\text{Lebanon}} = 112^\circ$). This can be interpreted as a result of block rotations associated with the evolution of the Jordan–Dead Sea left-lateral transform fault. Its evolution is recent, starting about 30 Ma ago (Westphal *et al.* 1986), and it is possible to estimate from geophysical and geological field studies a total left-lateral movement of about 100 km after the Cretaceous (Jaradat 1990). Only one pole of A quality (Platzman & Lowrie 1992) belongs to the Iberian mobile southern belt (Betic Cordillera) and this shows a very strong clockwise rotation relative to both the European and African reference poles (Fig. 6). This rotation, which is opposite to the well known anticlockwise rotation of the Iberian microplate, could be explained by right-lateral transcurrent movement along the boundary between Africa and Iberia (e.g., Udias 1982; Grimison & Chen 1986).

The Late Cretaceous MTB palaeopoles show large rotations of $R_{\text{Troodos}}^{\text{Europe}} \pm \Delta R = -85.1^\circ \pm 8.3^\circ$ and $R_{\text{Africa}}^{\text{Troodos}} \pm \Delta R = -71.3^\circ \pm 14.0^\circ$ of the Troodos microplate (Cyprus; Fig. 7; see Morris, this volume). The Sicilian pole shows a large

clockwise rotation with respect to both European and African coeval reference poles, $R_{\text{Europe}}^{\text{Sicily}} \pm \Delta R = 96.0^\circ \pm 12.0^\circ$ and $R_{\text{Africa}}^{\text{Sicily}} \pm \Delta R = 110.9^\circ \pm 16.5^\circ$. These data come from structural stratigraphic units derived from the Sicani basin (Western Central Sicily). This large tectonic rotation has been interpreted as the probable result of the emplacement of the Calabrian–Peloritani structure onto the Sicilian continental margin.

Italy

Several palaeomagnetic studies have been carried out in the last 15 years on the Italian Peninsula (e.g. Vandenberg *et al.* 1978; Channell *et al.* 1978, 1980; Horner & Lowrie 1981; Tauxe *et al.* 1983; Besse *et al.* 1984; Mattei *et al.* 1992; Sagnotti 1992; Sagnotti *et al.* 1994; other papers in this volume). Many authors have also published critical reviews of the existing data (e.g., Vandenberg & Zijdeveld 1982; Lowrie 1986; Van der Voo 1993; Channell, this volume). In these papers anticlockwise rotations have been determined for Italy since the Early Cretaceous, but the data are concentrated in space and time and some windows of Tertiary and Quaternary age contain no high class data (Table 5). The northern Apennines, central Italy up to Campania, Puglia and the Messina

Table 5. Number of data subdivided for quality and extracted on the basis of the time windows and the uncertainties of Table 2

Quality classes	Age (Ma)														
	0-5	5-15	15-25	25-35	35-45	45-55	55-65	65-100	100-145	145-180	180-210	210-245	245-290	290-325	325-360
<i>Italy</i>															
A	3	0	0	0	0	0	0	1	0	0	1	0	1	0	0
B	3	1	0	1	4	0	0	3	1	0	0	0	0	0	0
C	4	1	1	2	1	0	0	18	5	1	0	3	10	1	0
D	7	4	3	1	2	1	3	21	7	6	1	3	8	1	0
M	0	0	0	0	0	0	0	1	3	2	0	0	0	2	0
U	2	0	1	4	1	2	2	4	3	4	2	1	3	0	0
<i>Sardinia-Corsica block</i>															
A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0
D	2	2	2	1	0	1	0	0	0	1	0	1	7	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
U	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0

Strait are particularly lacking in sampling sites. More data are present in the central-eastern Alps, Umbrian-Marche Apennines, Sardinia and Sicily, but few high quality data are present (Table 5). This uneven distribution of data prevents the definition of the main deformation phases of these Italian units.

One of the more evident effects of quality filtering can be seen in the Late Cretaceous window (65–100 Ma), in which all the A, B and C data (except three palaeopoles from Sicily) show anticlockwise rotations of up to 40° with respect to the European reference pole (Figs 7 and 8, and Table 5). The dispersion of the A and B (and more markedly C) data can be a consequence of two main concomitant causes: intrinsic uncertainties (Bazhenov & Shipunov 1991) and differential amounts of tectonic rotation (MacDonald 1980). This last cause could be explained by the location of the sites in completely different structural-geologic domains along the entire peninsula. On the other hand, the wide time span of the window (35 Ma) has to be considered. The palaeopole positions are so distant in time at the edges of the time window that they are representative of different geological ages. Consequently, no 'absolute' rotation of the peninsula should be computed, only the magnitude of the anticlockwise rotations of each A and B pole (Channell & Tarling 1975; Channell 1977; Channell *et al.* 1992) with respect to the European reference poles:

$$R_{\text{Gargano}} \pm \Delta R = -29.1^\circ \pm 7.4^\circ,$$

$$R_{\text{Umbria}} \pm \Delta R = -34.3^\circ \pm 7.1^\circ,$$

$$R_{\text{Venetian Alps}} \pm \Delta R = -16.3^\circ \pm 5.3^\circ.$$

With respect to the African reference pole, this group of poles show no significant rotation (Fig. 7) suggesting a connection between the kinematics of the African plate and the Italian crustal fragments (see Channell this volume). Such small rotations prevent palaeogeographic reconstructions of the closure of the Tyrrhenian and Alboran Seas which require nearly 90° of rotation in some models. Notwithstanding these limitations many authors have assumed an anticlockwise rotation of the entire peninsula from Cretaceous to present (e.g. Vandenberg *et al.* 1978).

Conclusions

The GPMDB has allowed a methodological, objective approach to using palaeomagnetic data in geodynamic studies, although it does not exclude the necessity for reading the original papers. The quality of a datum is dependent on the length of the period of geological time under

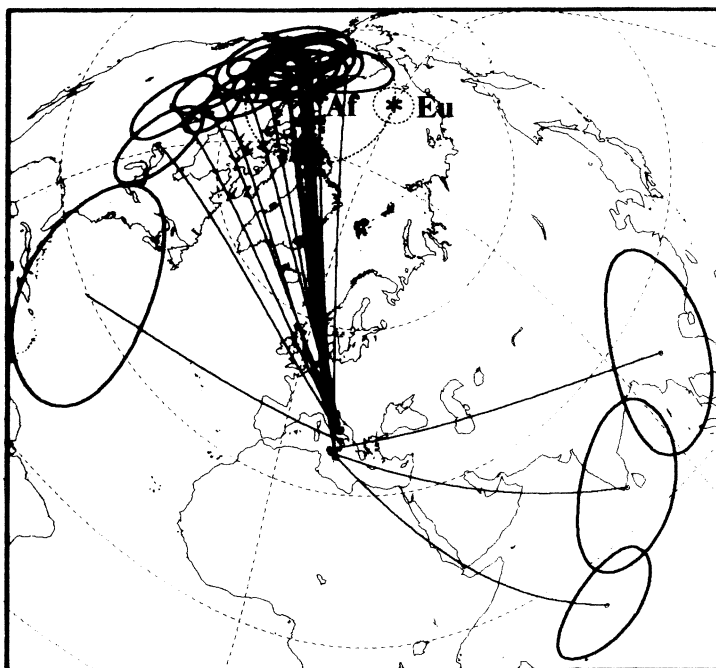


Fig. 8. Late Cretaceous (65–100 Ma) Italian palaeopoles (A, B and C quality classes). The stars represent the coeval African (Af) and European (Eu) reference poles and their confidence ellipses (dotted).

study. A lower limit for time window amplitudes has been proposed. The trend of the African and European APWPs presented here show similar patterns to previously published results, although the imprecision impedes any definitive interpretations, particularly in the narrowest loops of the paths. The firmest conclusion is the existence of a large jump in the European APWP during the Jurassic and Triassic. In the Mid–Late Jurassic and Late Cretaceous time windows there are several examples of very marked block rotations (e.g., Lebanon and Betics for Jurassic; Troodos, Cyprus for Cretaceous).

In recent years, higher quality palaeomagnetic results have been obtained following improvements in data acquisition and analysis methods. Most studies are now aimed at understanding the geodynamics of terranes in mobile zones. The contents of the database suggest that there is also a need to obtain additional data from stable areas. APWPs are in need of improvement, by provision of data for empty time windows and increasing the number of observations in others. We suggest that some tectonic models now need to be reconsidered to take new, well-constrained palaeomagnetic data into account.

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