

NEW PALAEOMAGNETIC DATA FROM THE IBERIAN PENINSULA¹J. VANDENBERG²

ABSTRACT

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The results of a palaeomagnetic investigation of Mesozoic sediments from the Betic Cordillera, the Iberic Chain and Cantabria in general confirm earlier conclusions about the rotation of the Iberian peninsula. The start of the rotational movement could be specified as post-Barremian/Aptian. Palaeomagnetic results from the Bilbao synclinorium show that the Iberia-Europe plate boundary has to be situated south of the synclinorium. Along the coast of Cantabria near Gijon Mesozoic European-like poles have been found probably indicating a complicated fault system along which the rotational movement of the Iberian peninsula was achieved. A model for the development of the Iberia-Europe plate boundary in its final stage is presented. A magneto-stratigraphic correlation of a Santonian-Campanian section from the Betic Cordillera with the Italian 'Gubbio' section is discussed.

INTRODUCTION

The rotation of the Iberian peninsula has become a well established and documented phenomenon from studies on the magnetic anomaly pattern in the Bay of Biscay (MATTHEWS & WILLIAMS, 1968; WILLIAMS, 1975), the palaeomagnetism of Palaeozoic, Mesozoic and Tertiary rocks (ZIJDERVELD & VAN DER VOO, 1973) and the pattern of Hercynian trends in Spain with respect to adjacent Europe (COGNÉ, 1971; BARD ET AL., 1971).

Palaeomagnetic data show that most of the rotation occurred between the Kimmeridgian and Maastrichtian (STAUFFER & TARLING, 1971; ZIJDERVELD & VAN DER VOO, 1973). Studies on the magnetic anomaly pattern of the Bay of Biscay have contributed additional information. Anomalies 34-31 could be recognized, implying that spreading was still active in Campanian and Maastrichtian times (WILLIAMS, 1975). Spreading ceased between anomaly 32 and 31 (Early Maastrichtian). If a constant spreading rate is assumed, the onset of the rotational

opening of the Bay of Biscay can be extrapolated to Mid-Cretaceous. The calibration of the Mesozoic and Tertiary reversal scale with the relative and absolute timescale proposed by LABRECQUE ET AL. (1977) slightly changes the timing of the various stages of opening as suggested by WILLIAMS (1975). Accordingly, from 130 Ma until 110 Ma the Bay of Biscay was the location of a sinistral strike-slip faultzone, with Iberia moving in a southeasterly direction away from its 'best fit' position against France and North America. After about 110 Ma the Mid-Atlantic ridge curved eastwards into the Bay of Biscay and the rotational opening of the Bay of Biscay took place. This movement ceased at about 68 Ma and the Iberian peninsula stayed attached to Europe.

The paroxysmal phase in the Pyrenean orogeny was at about 40 Ma, and therefore postdates the rotational opening of the Bay of Biscay. Compressional phases of Mesozoic age have not been reported and it was therefore argued that the rotation of the Iberian peninsula took place along an east-west striking faultzone in the Pyrenean region (LEPICHON ET AL., 1970, 1971; LEPICHON & SIBUET, 1971; LE BORGNE ET AL., 1971; CHOUKROUNE ET AL., 1973).

The North Pyrenean faultzone is generally considered as a remnant of that original faultzone. The Pyrenean orogeny and the associated extensive flysch deposits obliterated major

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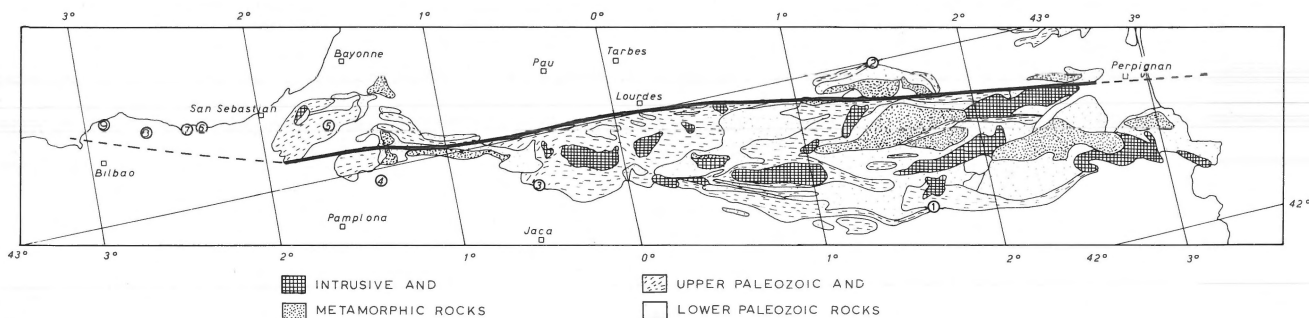


Fig. 1

Rough delineation of the North Pyrenean fault zone. Numbers refer to palaeomagnetic studies that have been carried out. 1: Van Dongen, 1967; 2: Girdler, 1968; 3: Van der Lingen, 1960; 4: Van der Voo, 1969; 5: Van der Voo & Boesenkool, 1973; 7-9: present study.

parts of the fault zone and caused its present course. Palaeomagnetic studies are very appropriate to delineate the plate boundary between stable Europe and the Iberian continent, and were successful in the Pyrenean region (see Fig. 1). VAN DER VOO & BOESENKOO (1973) could show that the Permian of the Cinco-Vilas Massif (Western Pyrenees) revealed European palaeomagnetic directions and therefore most probably belonged to the European continent. GIRDLER (1968) showed this for the Satellite Massif in the North-East Pyrenees. Several studies on the southern side of the Pyrenees (Fig. 1) showed counterclockwise rotated palaeomagnetic directions, confirming that this part belonged to the rotated Iberian continent.

The aim of this study was to make the timing of the rotation more specific.

GEOLOGICAL SETTING AND DESCRIPTION OF THE SAMPLING LOCALITIES

Betic Cordillera

Two localities were visited in the Betic Cordillera to collect Late Cretaceous pelagic limestones (see Fig. 2). The limestones belong to the Sub- and Prebetic zones (miogeosynclinal) and are strongly folded and faulted.

El Burruenco (SEB) — This is a small village east of Cordoba (see Fig. 2). Northwest of the village a continuous section of Late Santonian and Campanian limestones is exposed. The tectonic position of the rocks is allochthonous, on the N.W. flank of a diapiric structure. Sedimentologically, the El Burruenco upper Cretaceous is a good example of a hardly altered, friable pelagic foraminiferal nanno-ooze. The facies is comparable with that of the Scaglia Rossa formation in the Northern Apennines, but the rocks are hardly affected by diagenesis. Foraminifera and calcareous nannofossils can easily be isolated and are well preserved. All the samples had to be taken from the relatively hard layers in the lower part of the section.

Agost (SAG) — Agost (prov. Alicante) is situated in an area

with Mesozoic and Tertiary rocks of the Prebetics, which form a coherent chain of N.W. vergent folds. The area was described in detail by LECLERC (1971). Sampling was restricted to the upper Cretaceous part of the series, the reddish Campanian limestones, the 'couches rouges' facies comparable to that of El Burruenco. These are fine grained, possibly (hemi)pelagic, and contain abundant planktonic foraminifera and *Inoceramus* fragments; other fossils are rare.

Iberic Chain

Soria (SPI/STE) — This city is situated in the northwestern part of the NW-SE trending Iberian mountain chain, an intracratonic fold belt. Here a series of Mesozoic and Early Tertiary continental and shallow-marine sediments unconformably overlies the Hercynian basement. We sampled the Late Cretaceous limestones in the southern flank of Picofrentes (close to Soria), in a section described in detail by WIEDMANN (1975).

The Upper Jurassic (Kimmeridgian) North of Soria was subject of an earlier palaeomagnetic study by STAUFFER & TARLING (1971). It consists of continental deposits, mainly conglomerates, sandstones and red siltstones. For the present study at 4 localities samples were taken from homogeneous siltstones, known as the Tera group.

Bilbao synclinorium

In the Bilbao synclinorium (Fig. 3) predominantly Cretaceous rocks crop out. Black Jurassic limestones are only exposed at a few places around diapiric dome structures, covered by massive sandstones and coarse-grained conglomerates of the Early Cretaceous Wealden facies. The Barremian to Aptian contains black shales with sparse sandstone intercalations. Locally these shales are substituted by reef limestones of Aptian age. In the Albian and Cenomanian turbiditic sandstones are intercalated in the still predominantly black shales. During the late Cretaceous the turbiditic sandstones became dominant and the shales were substituted by grey marls. In the Middle Maastrichtian the turbiditic sandstones disappeared completely and a more open marine sedimentation occurred

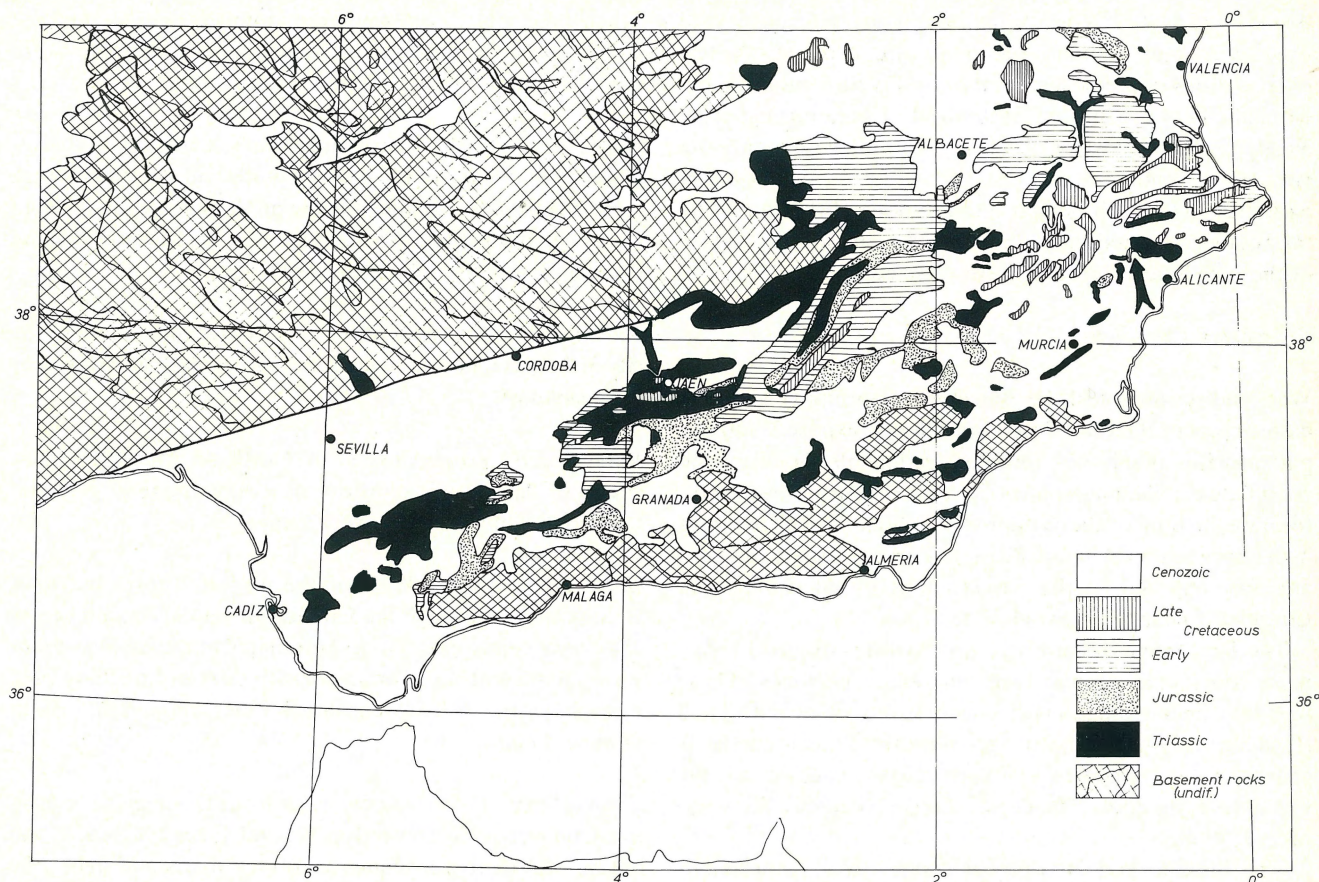


Fig. 2
Geological map of the Betic Cordillera. Two arrows point to sampling localities, West of Alicante and East of Cordoba.

with pelagic carbonates and marls often red and pink in colour. The Late Palaeocene and Early Tertiary once again contained an alternation of turbiditic sandstones and marls. At several places a succession of pillow lavas is exposed. Deformation of the Bilbao synclinorium becomes more intense towards the southwest, where tight folds with sub-vertical axial planar schistosity occur. This abruptly changes south of the line Bilbao-Pamplona (Fig. 3), where the Mesozoic sediments crop out in a monoclinial sequence slightly dipping towards the southwest.

Deva (SDE) — At the coast from Deva to Zumaya a continuous section of late Cretaceous to Early Tertiary sediments is exposed in the northern flank of the Bilbao synclinorium. This section was previously described by HERM (1965). ROGGENTHEN (1976) sampled the top of the section in detail for a palaeomagnetic study. We sampled the Late Albian flysch sequence at five levels, 10 m apart. Sampling was restricted to the topmost layers of the turbiditic sandstones that have a red colour, when weathered.

Guernica (SQU/SIM) — Northeast of Guernica an Aptian reef limestone is exposed, intercalated in black shales with

rare sandstones. The reef is quarried and fresh outcrops are easily accessible. The reefal limestone and the reef debris are red and the bedding planes are tilted into a vertical position. Southwest of the quarry black fetid limestones and shales of Triassic/Jurassic age crop out in a 100 m section along the Ria de Mundaca. The section dips gently northwards. At several levels samples were taken from the limestones.

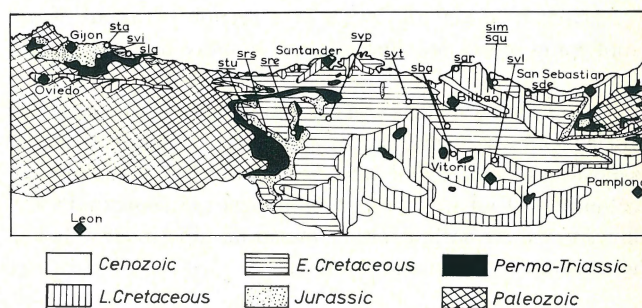


Fig. 3
Geological map of Northern Spain (Cantabria). Sampling localities have been indicated.

Arminza (SAR) — North of Bilbao, along the coast, Late Cretaceous and Tertiary sediments are exposed. A few intercalations of pillow lavas can be observed. Unfortunately the sediments are heavily tectonized in general and have mostly vertical bedding tilts. Close to the village Arminza the late Albian sediments in a distal flysch facies, composed of dark grey marls with regular intercalations of thin turbiditic sandstones, dip moderately northwards. The topmost layers of the turbiditic sandstones were sampled.

Cantabrian Cordillera

West and southwest of the Bilbao synclinorium (Fig. 3) the eastern part of the Cantabrian Cordillera is exposed, and this part consists mainly of Cretaceous sediments. South of the coast between Santander and Gijón the Palaeozoic basement, forming the bulk of the Western Cantabrian Cordillera, rises high above sea level in the 'Picos de Europa'. Mesozoic rocks are only exposed in the western part of the Cantabrian Cordillera, near the coast close to Gijón.

The Palaeozoic basement is discordantly covered by Permian conglomerates and conglomeratic sandstones. These pass into finer-grained clastics such as red-violet shales and siltstones of Permo-Triassic age. Here the Triassic shows its characteristic variegated evaporite facies, overlain by the Carniolas Formation. The Permo-Triassic reaches a thickness of ± 1500 m.

The Jurassic and Neocomian consist of a monotonous sequence of dark grey shales with limestone intercalations and has a thickness of about 600 m. The upper Early Cretaceous is developed in Wealden facies: an alternation of sandstones, conglomerates and red-violet siltstones, more than 1000 m thick. Black shales cover the Wealden facies and sometimes reef limestones of Aptian age are intercalated. In Albian times an alternation of black shales and sandstones developed, which passed into grey marls and pelagic limestones during the late Cretaceous. The Upper Cretaceous has an enormous thickness (about 5000 m) around Vitoria. The Tertiary contains continental clastics.

Villaviciosa (SVI) — The Permo-Triassic close to the village of Villaviciosa along the road to Infiesto is well exposed. Here we sampled at several levels in a section of about 50 m, containing red-violet siltstones and massive marls.

Lastres/Tazonas (SLA/STA) — Along the coast near the villages of Lastres and Tazonas the Upper Jurassic consists of sandstones, shales and mudstones, which are mainly red coloured. At Lastres these directly overlie Liassic marls and limestones. At both localities the strata dip moderately and were sampled at several levels.

Tudanca (STU) — Opposite this village a sequence is exposed that contains Permo-Triassic to Jurassic sediments, dipping moderately northwards. At several localities Permo-

Triassic red-violet siltstones were sampled, close to the base and higher in the section. Black Liassic limestones were sampled at 3 different localities.

Vega de Pas (SVP) — Stratigraphically high in the subhorizontal Wealden facies red massive marls and sandstones were sampled at two levels. The Barremian/Aptian age, assigned to the upper part of the Wealden here, is based on *Orbitulina* found in limestone intercalations at the top.

Rio Saja/Reinosa (SRS/SRE) — At two localities close to the city of Reinosa, Permo-Triassic red-violet marls and siltstones were sampled.

Villaverde de Trucios (SVT) — North of this village dark shales of Aptian age crop out in a subhorizontal position. Carbonatic intercalations were sampled.

Barambio (SBA) — West of the city of Vitoria the river Barambio cuts through the Cretaceous sequence, and causes very nice exposures. Grey Turonian/Coniacian limestones were sampled at three localities with different bedding tilts. Also dark grey Albian sandstones were sampled in a north dipping section.

Villareal (SVL) — Along the road from Durango to Vitoria the Cretaceous is exposed at several places. Close to the village of Villareal a sequence of grey marls and light grey limestones is exposed, which range from Albian to Coniacian age. This sequence was sampled at 4 localities.

MAGNETIC PROPERTIES AND LABORATORY TREATMENT

In the field samples were cored with an electric drill and the cores were sliced into cylinders (specimens) of 2.2 x 2.5 cm at the Fort Hoofddijk Laboratory. All measurements were carried out with a spinner magnetometer (JR3) and/or with a ScT cryogenic magnetometer.

The initial Natural Remanent Magnetization (N.R.M.) intensities of such different rock types varied noticeably, as can be seen in table I. The N.R.M. of almost all the sampled rock types could be measured. Only most of the white limestones from Picofrentes (Soria-SPI) had marginal intensities of the N.R.M.

Several pilot specimens per locality were progressively demagnetized in 10 to 15 steps in alternating fields up to the maximum obtainable value of 3000 Oe. From those localities where red beds were sampled several pilot specimens per locality were also thermally demagnetized in 8 steps up to 700 °C.

The vector path of the total remanent magnetization was analysed in orthogonal projection diagrams. All specimens from carbonatic rock types could be properly demagnetized in

Table I

Locality	Initial N.R.M. x 10 ⁻⁶ Gauss	Rock Type
SEB	0.08-33.0	pelagic limestone
SAG	0.3 - 2.4	pelagic limestone
SPI	0.05- 0.4	white limestone
STE	5.0 -22.0	red siltstone
SDE	0.4 - 0.88	turbiditic sandstone
SQU	1.9 - 3.7	reef limestone
SIM	5.5 -82.0	black limestone
SAR	0.04- 9.6	turbiditic sandstone
SVI	2.2 -17.0	red siltstone
SLA	5.9 -19.4	red mudstone
STA	1.3 -11.3	red mudstone
STU-PT	4.7 -13.9	red siltstone
STU-J	3.9 -20.4	black limestone
SVP	4.5 -38.4	red marl
SRS	1.6 - 9.6	red siltstone
SRE	5.0 -16.3	red sandstone
SVT	2.5 - 6.9	black limestone
SBA	0.09- 3.7	black limestone and sandstone
SVL	2.4 - 7.5	grey limestone

alternating fields, whereas for the red beds better results were obtained by thermal demagnetization. In figure 4 characteristic examples of demagnetization curves are given for different rock types. All remaining specimens were demagnetized in at

least 5 steps in that range where the characteristic magnetization component was removed.

Evaluation of some palaeomagnetic results proved to be difficult because of the spread (geographically as well as in age) of the sampling localities and rocks. Common palaeomagnetic reliability tests, such as the fold test, reversal test, etc., could not in most cases be applied. Some indication of the reliability of palaeomagnetic results is given by the consideration that palaeomagnetic directions close to the present geomagnetic field might be of recent origin.

The results have been divided into two groups. In table IIa the site mean directions have been compiled, which are regarded as being palaeomagnetic results that can be used for reconstruction purposes. The pole positions, corresponding to these palaeomagnetic directions have been added. In table IIb the palaeomagnetic directions of questionable reliability or with uncertain reference are given. This table IIb includes palaeomagnetic directions which either before or after bedding-tilt correction are close to the present field direction, those giving a negative fold test, and those coming from a known allochthonous sequence in the Betic Cordillera. Since these results might become of interest in future research, the mean directions are given before and after bedding-tilt correction. Pole positions, however, have been omitted to emphasize the uncertain character of most of these palaeomagnetic directions.

Table IIa
Remanent magnetization parameters

Locality	N	n	Mean Direction	a ₉₅	Pole position	dp	dm	Age
SAG	7	40	330.3 +53.9	4.8	65.8 N 90.9 W	4.7	6.7	Campanian
STE	4	24	352.2 +44.9	3.6	70.4 N 156.3 W	4.4	7.3	Kimmeridgian 1)
SDE	5	27	359.6 +45.1	3.4	73.3 N 178.9 E	2.7	4.3	Late Albian
SIM	2	13	44.0 +18.0	1.6	38.7 N 115.6 E	0.9	1.6	Triassic-Juras.?
SVI	5	28	13.0 +20.3	4.3	55.1 N 151.6 E	2.3	4.5	Permo-Triassic
STA	3	20	6.0 +62.5	2.9	85.6 N 78.4 E	3.5	4.5	Late Jurassic
STU-PT	5	30	333.3 +26.6	5.8	52.9 N 138.1 W	3.4	6.3	Permo-Triassic
SVP	7	45	349.4 +38.2	0.9	66.5 N 158.3 W	0.6	1.0	Barremian-Aptian
SRS	2	12	333.1 +32.2	9.5	55.7 N 134.3 W	9.6	16.	Permo-Triassic
SRE	1	8	327.0 +26.5	25.5	49.4 N 130.0 W	14.	27.	Permo-Triassic

Table IIb
Remanent magnetization parameters for unusable rock samples

Locality	N	n	Mean Direction Before tect.	a ₉₅	Mean Direction After tect.	a ₉₅	Age
SEB	1	24	40.5 — 3.2	13.5	12.4 +52.3	10.7	Sant.-Camp.
SPI	1	15	— —	—	— —	—	Late Cretaceous
SQU	1	10	272.0 +72.5	2.0	243.3 + 6.4	2.0	Aptian
SAR	5	36	350.1 +26.0	9.4	345.1 +58.8	8.9	Albian
SLA	3	22	283.6 +69.2	3.2	332.2 +52.0	2.0	Late Jurassic
STU-J	7	38	345.1 +62.5	2.3	1.3 +43.7	1.7	Liassic
SVT	2	15	358.0 +61.7	4.0	347.0 +67.7	4.0	Aptian
SBA	6	36	354.4 +60.9	4.0	14.4 +49.9	3.7	Late Cretaceous
SVL	10	67	359.0 +47.0	2.8	321.0 +66.9	2.6	Late Cretaceous

N: Number of sites; n: Number of samples; 1) Mean direction for present study; Pole position was calculated from present data combined with data from Stauffer & Tarling (1971), giving unit weight to each site. Mean directions in both parts were calculated only from cleaned samples.

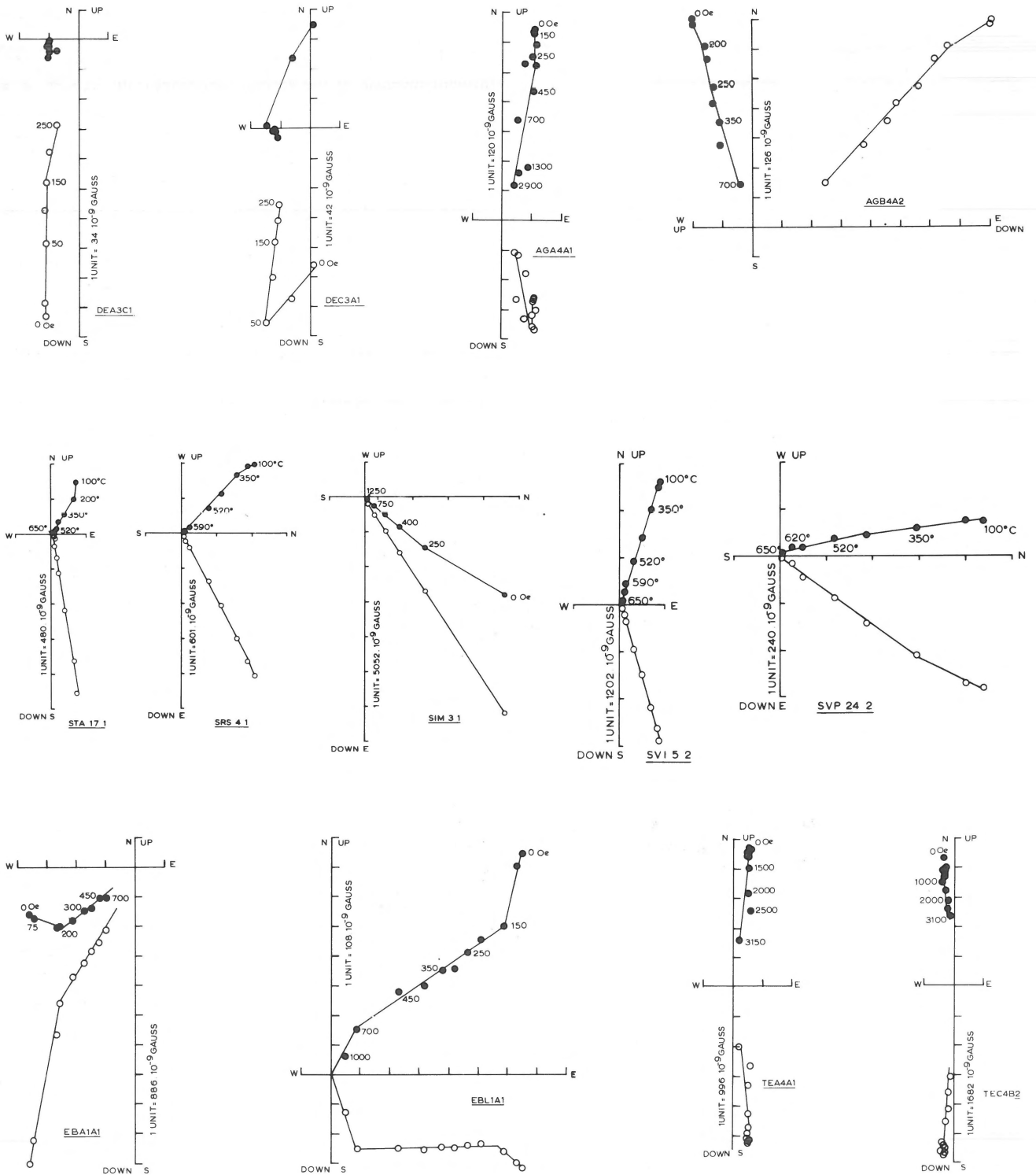


Fig. 4
 Orthogonal projection figures of the remanent magnetization vector path during demagnetization. Solid dots denote projections on the horizontal plane and open circles on the vertical E-W or N-S planes. Numbers are Oersted values of the applied field or values of the furnace temperature during thermal cleaning in °C. Specimen code is given underlined.

INTERPRETATION OF THE RESULTS

Betic Cordillera

Since the rocks sampled near El Burrueco (SEB) are situated in an allochthonous block (Wonders, in prep.) their palaeomagnetic results can only be used for magnetostratigraphy. In figure 5 the declination and inclination of the primary magnetization components from the short El Burrueco section are plotted versus stratigraphic position. The study of the planktonic foraminifera of this section (Wonders, in prep.), as given in column II of figure 5, enables direct comparison with the results from the Gubbio section (LOWRIE & ALVAREZ, 1977; PREMOLI SILVA, 1977) as represented in column III. Although there are no palaeomagnetic data between level C and level D, simply due to the absence of suitable sampling possibilities, the Gubbio 'A' reversal can be recognized in the El Burrueco section. A discrepancy exists on the timing of the lower polarity change. PREMOLI SILVA (1977) places the concurrent range of Elevata and Carinata on the lower boundary of the Gubbio 'A' reversed interval, while in the El Burrueco section this zone falls entirely within the lowermost part of the reversed interval. The discrepancy in timing covers about 1 million years. Whether a short event or just an excursion of the geomagnetic field is recorded in the normal interval above the Gubbio 'A' reversal cannot be decided from the deviating result of level H.

The pelagic sediments sampled close to Agost have yielded only normal polarities and an excellent grouping of the primary magnetization components (see SAG in Table II). A very accurate age could be assigned on the basis of planktonic foraminifera: Middle Campanian. The westerly deviating result from Agost (Prebeticum) is tentatively interpreted as a consequence of the allochthonous position of the Prebetics in this part of the Betic Cordillera.

Iberic chain

The Late Cretaceous samples (SPI) from the section close to Soria (Picofrentes) revealed very low intensities of the N.R.M. and widely scattered directions. The secondary magnetizations could not be removed sufficiently because of the low intensities.

The Kimmeridgian siltstones from the Tera group (STE in Table II) could be cleaned satisfactorily and the minor tectonic corrections improved the result. The newly obtained result is in excellent agreement with the earlier results of STAUFFER & TARLING (1971). Their conclusion that the Iberian peninsula rotated after the Late Jurassic with respect to Europe is therefore supported, as can be ascertained from figure 8.

Bilbao synclinorium

The northern flank of the Bilbao Synclinorium was sampled at

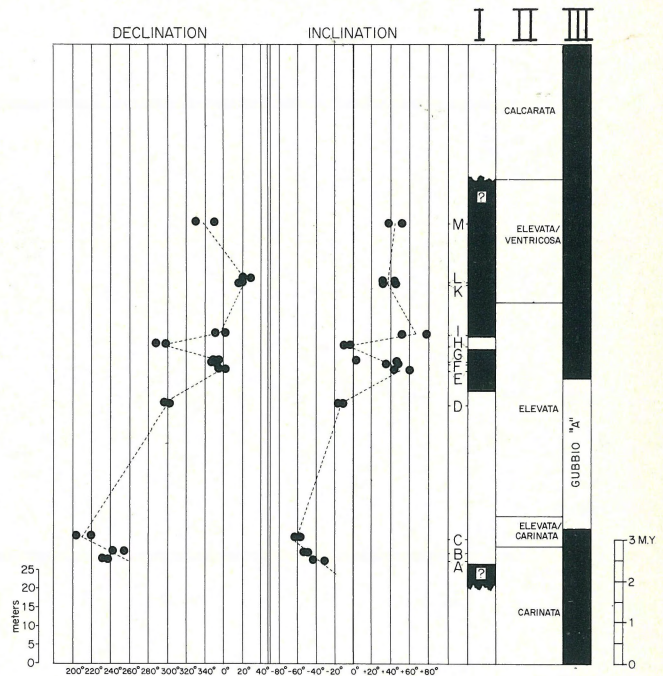


Fig. 5 Palaeomagnetic directions versus stratigraphic position of the El Burrueco section (Betic Cordillera). Sampled levels are indicated with letters. Column I gives interpretation of the palaeomagnetic data. Column II gives planktonic foraminifera distribution through the section (Wonders, in prep.). Column III gives magnetostratigraphy from the Gubbio section (Alvarez et al., 1977). Shaded regions normal polarity and unshaded reversed polarity.

4 localities (see Fig. 3), but only the palaeomagnetic results of 2 localities appeared to be usable for reconstruction purposes. The directions which have been found in the reef limestones (SQU-Guernica) are very close to the present field before bedding-tilt correction and were therefore rejected. This was also the case with the majority of the magnetic directions from the turbiditic sandstone samples, which were collected at Arminza (SAR).

The sandstone samples collected near Deva (SDE) have yielded good grouping magnetic directions (see Fig. 6a), which were far off the present field direction before and after bedding-tilt correction. The mean result differs only slightly from the mean direction found by ROGGENTHEN (1971) for the Palaeocene limestones that belong to the very same section. Both results have been plotted in figure 7, and fall within the range of European poles.

The result from locality SIM (Guernica) can also be taken into consideration, since a.f. cleaning improved the grouping of the characteristic magnetic directions and because their mean direction was quite different from the present field direction even before the minor tilt correction. Unfortunately the age is uncertain (Carniolas Formation) and cannot be established more precisely than Late Triassic to Early Jurassic. The mean result is plotted in figure 8. Its position is somewhat aside Late Triassic European poles.

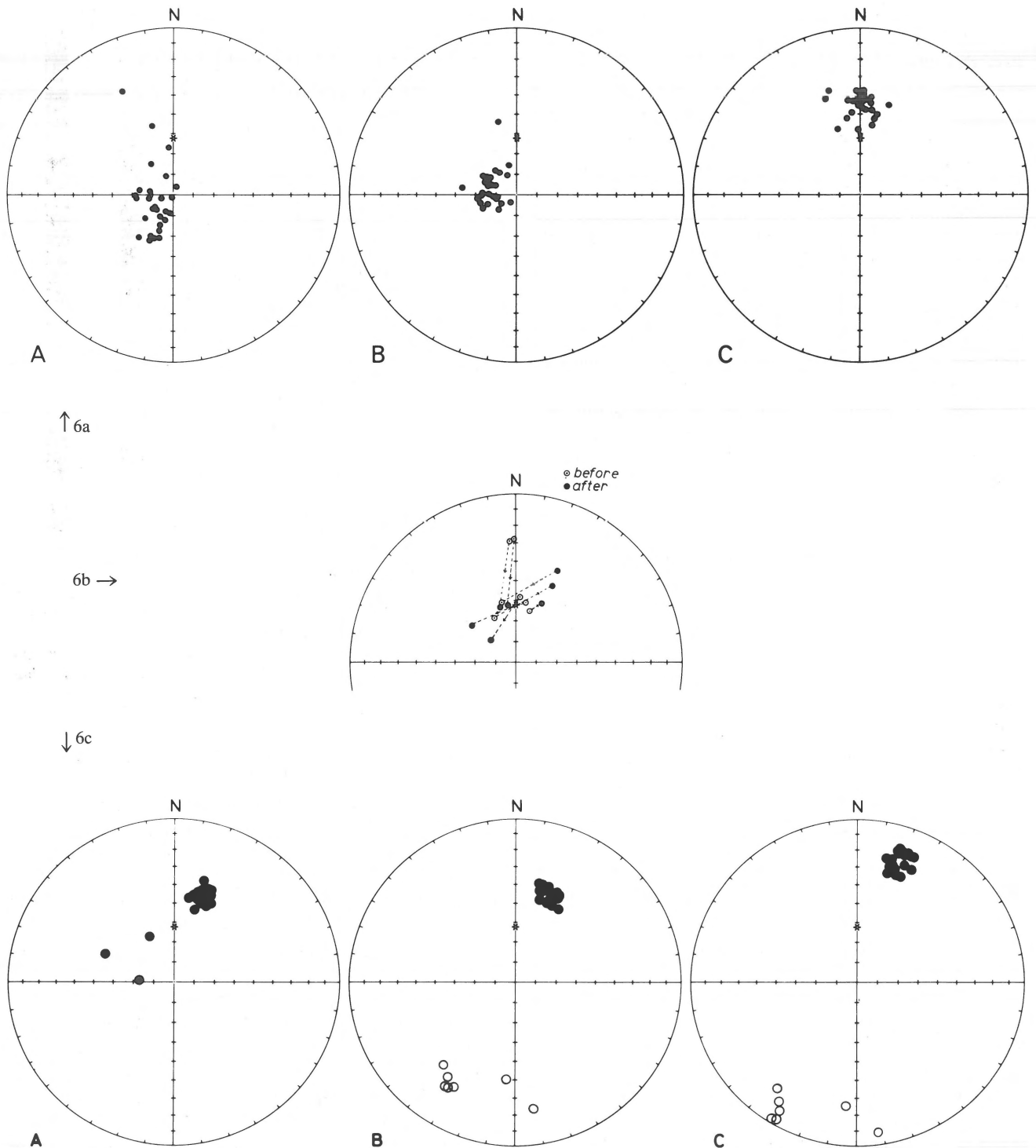


Fig. 6
Stereographic projection figures (lower hemisphere) of palaeomagnetic directions. Asterisk denotes the direction of the present local magnetic field.

6a: palaeomagnetic directions from samples collected near Deva (SDE). A: initial remanent magnetization directions; B: characteristic magnetization directions before tilt correction; C: idem after correction for the bedding tilt.

6b: distribution of characteristic sample directions of localities SVL and SBA, before (open circles) and after (full dots) tectonic correction, showing negative fold test.

6c: as 6a but now for samples from locality SVI; notice that normal as well as reversed polarity samples are found.

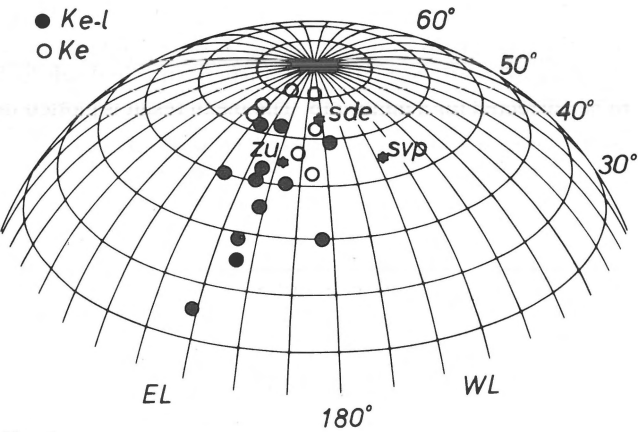


Fig. 7 Distribution of Cretaceous Eurasian palaeomagnetic poles in orthographic projection. Open circles denote Neocomian poles and full dots represent Barremian to Maastrichtian poles (Khramov, 1977). Results from Iberia indicated by full stars. ZU = Zumaya (Palaeocene), Roggenthen, 1976; SDE = Deva (Upper Albian), and SVP = Vega de Pas (Barremian-Aptian), all present paper.

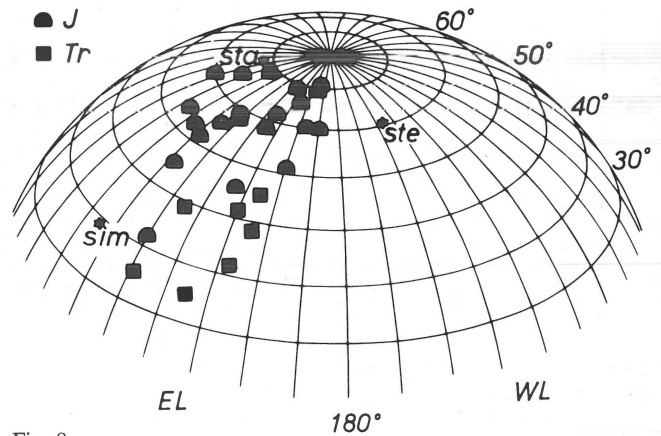


Fig. 8 Distribution of Late Triassic and Jurassic Eurasian palaeomagnetic poles in orthographic projection (Khramov, 1977). Half full dots represent Jurassic data, full squares Late Triassic data. Results of present study plotted as full stars. STA = Tazonos (Upper Jurassic); STE = Tera group (Kimmeridgian); SIM = Guernica (Triassic-Jurassic?).

In fact the Permian pole from the Cinco-Vilas massif (VAN DER VOO & BOESENKOOL, 1971) is equally aside the European Permian poles, as can be seen in figure 9.

The palaeomagnetic directions from the Deva-Zumaya section show that the crustal block, which they belong to, did not rotate during the Albian-Palaeocene timespan. The palaeomagnetic data at present available from the Cinco-Vilas massif and from the northern flank of the Bilbao synclinorium seem to justify the conclusion that the major Iberia-Europe plate boundary is situated south of these areas.

Cantabrian Cordillera (East)

Unfortunately the palaeomagnetic results from several localities had to be rejected. In the area around Vitoria grey limestones and sandstones of Cretaceous age (Albian-Coniacian) have been sampled (SVL and SBA). Although a very stable magnetization component was removed during a.f. cleaning, this characteristic magnetization is not of primary origin, since the mean directions from all the different localities very clearly showed a negative fold test (see Fig. 6b). The Aptian black limestones sampled near Villaverde de Trucios (SVT) revealed magnetization directions closely aligned with the present magnetic field, and this was also the case with the black limestones (Jurassic) from Tudanca (STU-J).

On the other hand the magnetic directions obtained from (Permo-) Triassic red siltstones (SRS/SRE/STU-PT) are very similar and revealed even a better grouping after dip corrections. Thermal cleaning showed the absence of important secondary magnetization components and the characteristic magnetization directions are different from the present geomagnetic direction, both *in situ* and with respect to the

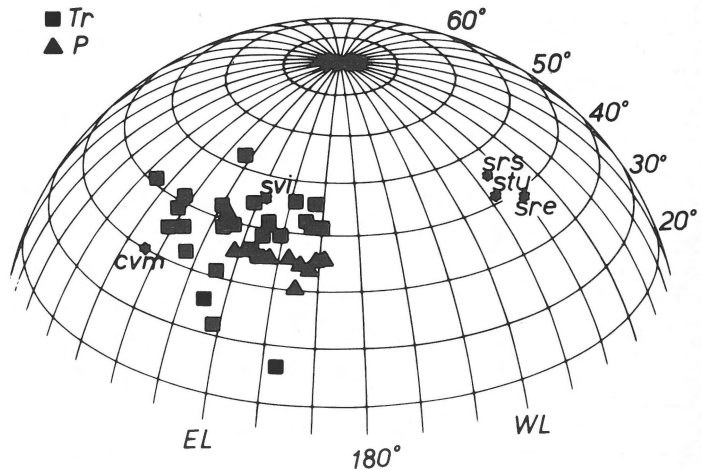


Fig. 9 Distribution of Permo-Triassic Eurasian palaeomagnetic poles in orthographic projection. Full squares represent Early Triassic data and full triangles Permian data (Khramov, 1977). Results from Iberia denoted by full stars, CVM = Cinco-Vilas Massif (Permian, Van der Voo & Boesenkool, 1973); SVI = Villaviciosa (Permo-Triassic); SRS = Rio Saja (Permo-Triassic); STU = Tudanca (Permo-Triassic); SRE = Reinosa (Permo-Triassic). All present study.

bedding. Since, moreover, the inclinations are typical for the Triassic palaeomagnetic field, it is most likely that the characteristic remanences found are of primary origin.

The pole positions have been plotted in figure 9, depicting that these new palaeomagnetic poles deviate appreciably from the European poles.

At Vega de Pas marls and sandstones have been sampled (SVP) that are intercalated in the Wealden facies and could not be better dated than Barremian-Aptian. These

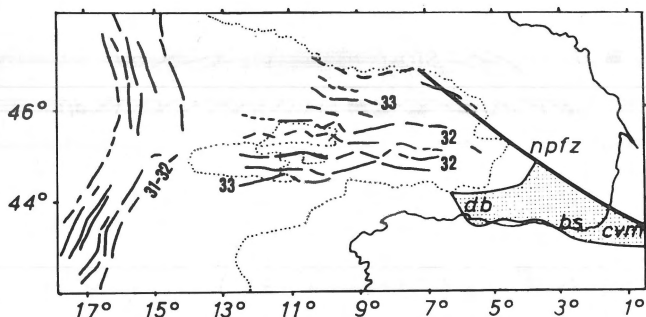


Fig. 10
Magnetic anomalies in the Bay of Biscay, after Williams (1975). Also the extension of the North Pyrenean fault zone (NPFZ), according to LePichon et al., (1970) is indicated. DB = Danois Block; BS = Bilbao synclinorium; CVM = Cinco-Vilas Massif.

samples have yielded a good palaeomagnetic result. After thermal and a.f. cleaning the grouping of the characteristic magnetization directions was excellent and they are quite different from the present field direction before as well as after bedding-tilt correction. It is likely that these characteristic magnetizations are of primary origin. The mean result is plotted in figure 7 and it is clearly deviating from the Cretaceous poles of stable Europe. This Barremian-Aptian direction is only differing in inclination from the Kimmeridgian result STE (see Table II). This implies that no major rotations with respect to Europe have occurred yet in the Early Cretaceous. This new Barremian-Aptian palaeomagnetic result probably just predates the anti-clockwise rotation of the Iberian peninsula with respect to Europe.

Cantabrian Cordillera (Northwest)

In the Western Cantabrian Cordillera Late Jurassic and Permo-Triassic rocks were sampled (SLA/STA/SVI), which belong to a crustal block that extends off shore and is known as the Danois block. On land this block is separated from the remaining Cantabrian Cordillera by major faults. The city of Villaviciosa (SVI) lies on this block surrounded by Permo-Triassic sediments, which have yielded very interesting palaeomagnetic results. All samples were thermally demagnetized and showed very stable magnetization components (see Fig. 6c). The presence of two polarities in the sampled section indicates an Early Triassic age (McELHINNY & BUREK, 1971). Also because of the presence of a level with reversed polarities little doubt can exist about the primary origin of the magnetization. The inclinations of the characteristic magnetization components have values that are characteristic for the Triassic. An interesting feature is the position of the palaeomagnetic pole (see Fig. 9), which shows no major offset relative to the European Triassic poles.

The samples from Late Jurassic mudstones collected along the beach of Lastres (SLA) have yielded palaeomagnetic directions deviating from European as well as from other

Iberian palaeomagnetic data and were rejected. The samples from the Late Jurassic sandy marls of Tazonés (STA) could be cleaned sufficiently by thermal demagnetization and only had to be corrected for a minor dip. The mean result is plotted in figure 8 and is close to the corresponding European Jurassic poles. This result confirms the absence of major rotations of the Danois block with respect to Europe.

DISCUSSION

The palaeomagnetic results from stable Iberia presented in this paper indicate a new and younger lower limit of Barremian-Aptian, for the timing of the rotation and corroborate the results of earlier studies. The results from the Bilbao synclinorium and from northwestern Cantabria, however, are puzzling. LEPICHON ET AL. (1970) have proposed a rather simple movement scheme for the Iberian peninsula around the 'Paris-pole of rotation'. They supposed the North Pyrenean fault to be the fundamental boundary between Iberia and Europe. Accordingly its western extension should pass Biarritz and follow the North Gascony ridge (see Fig. 10, solid line marked N.P.F.Z.). Seismic studies have shown the presence of oceanic basement directly west of it, at 5° EL 45° NL (LIMOND ET AL., 1974). It therefore seems very likely that a fundamental boundary is located there. One must realize, however, that the rotation started in the 'Mid-Cretaceous' and that the anomalies 33-31 only specify the very final stage.

A hypothesis for the Iberia-Europe plate-boundary configuration that reconciles all arguments can be proposed. When the Iberian peninsula moved away from Europe following the proposal of WILLIAMS (1975), the plate boundary was situated west and south of the Danois block, along the present coast of Cantabria, through the Bilbao synclinorium, south of the Cinco-Vilas massif and then eastwards following the North Pyrenean fault (as given in Fig. 1). This line is a circle of a rotation pole hardly differing from the Paris-pole of rotation. Slightly after or contemporaneous with anomaly 33 (Fig. 10) the plate boundary shifted more inland (towards Europe) and the configuration proposed by LEPICHON ET AL. (1970) became effective. So the crustal fragment (stippled area in Fig. 10) containing the present Danois block, the Bilbao synclinorium and the Cinco-Vilas massif, became part of Iberia and separated from the European continent and anomaly 32-31 came into existence. In figure 11 this is further elucidated in a schematic way. The amount of separation (100-200 km) of the Danois block from the European continent is not detectable by palaeomagnetic means; palaeomagnetic data coming from this block (stippled in Fig. 10) will therefore reveal European-like poles. The later northward compressive phase (40-45 Ma) has obscured the plate boundaries: the sediments were thrust towards the South, forming the Cantabrian Cordillera. Moreover, to the north and west of the Danois block the North Pyrenean trough developed and presumably reduced the initial amount of separation.

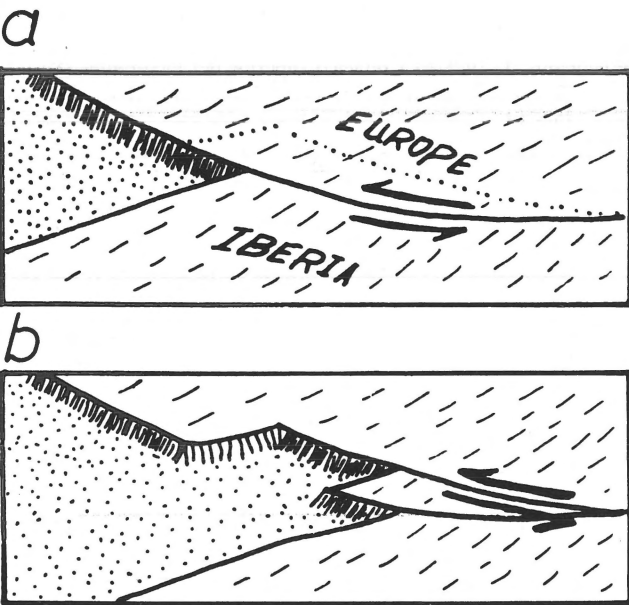


Fig. 11
Schematic block diagram showing the possible changing plate-boundary configuration and development in the Bay of Biscay during the final stage of the movement of Iberia.

CONCLUSIONS

The rotation of the Iberian peninsula had not yet started or was at a very early stage in Barremian-Aptian times.

Mesozoic palaeomagnetic data from areas along the coast of Cantabria do not show any difference with coeval data from the European plate and presumably prove the existence of a shifting fault system, along which the rotational movement of Iberia was achieved.

The magnetostratigraphic study of Late Santonian and Early Campanian limestones revealed that the concurrent range of Elevata and Carinata falls entirely within the lowermost part of the Gubbio 'A' reversed interval.

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