Hercynian palaeomagnetism of Europe: arguments for large scale complex thin-skinned and thick-skinned rotations

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ABSTRACT

Palaeomagnetic data for the Devonian and Carboniferous of the European Hercynides and from their stable foreland (northern Europe and the British Isles) display a very coherent pattern in inclination, pointing towards consolidation of Hercynian Europe during the mid to late Devonian. Declination data however, show a significant dispersion and can be used in order to unravel the deformation history of the mountain belt. Differences between the observed palaeomagnetic declinations and those expected for the specific areas and the age of magnetization can be correlated to the changes in regional strike. Linear regression analysis of the declination deviations, shows a very strong correlation (close to unity) for those areas, where thin-skinned nappe emplacement has been most prevalent. This suggests the predominantly primary character of the structural curvature. Data from presumably autochthonous parts of the orogen are more scattered but nevertheless yield a significant, but shallower regression line. A t-test of the slope against zero slope is significant at the 95 % confidence level, indicating secondary (oroclinal) bending of an originally deformed fold system for the autochtohonous parts of the mountain belt. It can be inferred, that the present shape of the Hercynian mountain belt is the result of combined recurrent deep-reaching deformation of the lithosphere and the superimposed effects of thin-skinned thrust rotations, compatible with geodynamic models involving the indentation of Hercynian Europe by a microplate or an African promontory during the Hercynian orogeny.

INTRODUCTION

The geodynamic evolution of the European Hercynides has been the subject of intense research during the last two decades and rather antagonistic scenarios for the Palaeozoic crustal consolidation of Europe have been proposed by numerous authors (e.g. Lorenz and Nicholls, 1984, Behr et al.., 1984, Matte, 1986, Ziegler, 1986 and references therein). However, a unifying model for Hercynian geodynamics, which integrates geophysical data and geological observations has not been brought forward yet.

The Hercynian fold belt of Europe is generally characterized by a central polymetamorphic crystalline belt, bordered on both sides by outward facing fold and thrust belts, consisting of unmetamorphosed or low grade sedimentary and volcanic assemblages. Although there is evidence for a localized tectonic event during the Devonian (Acadian), the main orogenic pulse has been shown to be Carboniferous (i.e. Late Visean to Namurian) in age (Behr et al., 1984 and references therein). The most prominent feature of the European Hercynides is the well pronounced curvature of the mountain belt as defined by the change in the structural trend (Fig. 1). This is most spectacular around the Bay of Biscay, where the total bending of the Ibero-Armorican arc in a pre-Mesozoic reconstruction

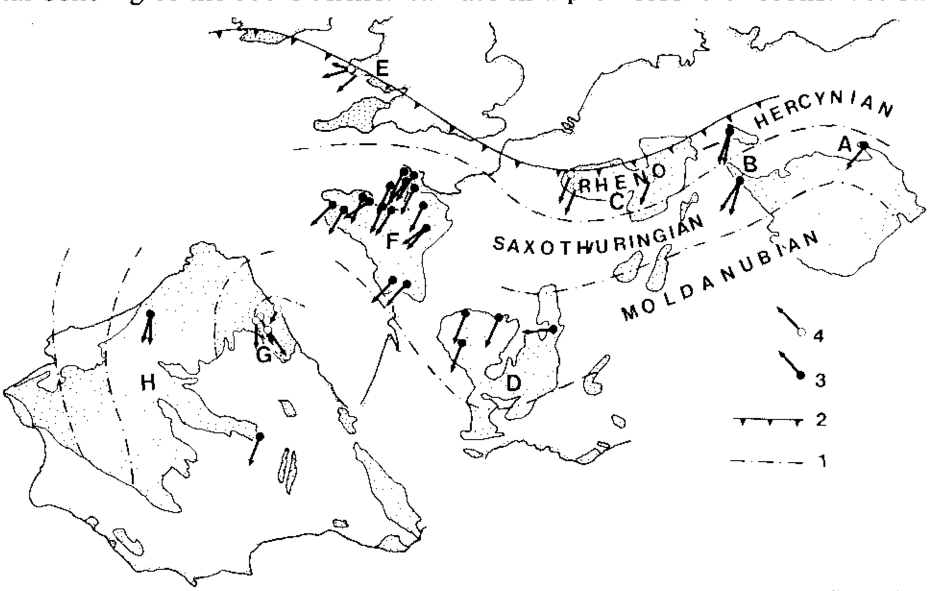

Fig. 1. Geological sketch map of the European Hercynides in pre-Mesozoic configuration (Van der Voo, 1969). Shown are the directions of the structural trend (1), the northern overthrust (2), and the directions of Devonian and Carboniferous paleomagnetic declinations from autochthonous (3) and allochthonous (4) areas. A: Carpathians; B: Central Europe (Harz Mountains and Franconian Forest); C: Ardenne-Eifel; D: Massif Central; E: Wales; F: Armorica; G: Cantabria; H: Galicia-Castilla.

(Van der Voo, 1969) approximates 165° (Ries and Shackleton, 1976). In Central Europe, the change from the Hercynian (NW-SE) to the Variscan (SW-NE) striking structural trend is less dramatic but still amounts to about 40°. Finally a change in the structural trend of about 80° can be observed in the Carpathians.

Based on palaeomagnetic (Van der Voo, 1979) and general geological evidence (e.g. Ziegler, 1986 and references therein), it is now widely accepted, that the Palaeozoic consolidation of Western Europe was controlled by the convergence of three major plates (Laurentia, Baltica and Gondwana) as well as by the amalgamation and deformation of smaller, Gondwana-derived, crustal elements such as the Armorica microplate (Van der Voo, 1979) and the Iberian and Austro-alpine allochthonous terranes (Ziegler, 1983). In this paper a brief review of the Devonian to Carboniferous palaeomagnetic data from Central Europe will be given and an attempt will be made to elucidate a structural and geodynamic interpretation.

THE PALAEOMAGNETIC REFERENCE FRAMEWORK

The structural significance of palaeomagnetic data from deformed areas hinges crucially on the quality of the reference data base from a stable foreland or craton. It is now widely accepted, that Laurentia, Baltica, the British Isles south of the Iapetus and the Central European pre-Variscan basement (stable Europe), have been assembled during the Caledonian orogeny (e.g. Soper and Hutton, 1984). Devonian and Carboniferous palaeomagnetic data from the Baltic shield and the British Isles can therefore be used as reference for the geodynamic and structural interpretation of palaeomagnetic data from the European Hercynides.

The various proposed apparent polar wander (APW) paths for stable Europe (Briden et al., 1973, McElhinny, 1973, French, 1976, Duff, 1980) agree rather well for the Silurian to early Carboniferous period. Differences of up to 10° in the longitudinal position of the Carboniferous poles between various proposed models (Duff, 1980; Briden, 1973, McElhinny, 1973) are however conspicuous, and point towards unresolved problems in age calibration (Perroud, 1986). Following a different line of argument, Edel (1987a) postulated that notably the Devonian and Carboniferous parts of the APW path of stable Europe have been severely affected by Permo-Carboniferous remagnetizations and therefore cannot be used as a reference for the interpretation of pre-Variscan directions. Consequently, he proposed to use the APW path for the Russian platform instead. The rather tight cluster of Devonian to Permian poles from European Russia (Khramov et al., 1981) however, which are not significantly different from western European Permian palaeopoles, indicates unresolved pervasive Kiaman (Permo-Carboniferous) remagnetization of the Russian Palaeozoic rocks. Lacks fo accessibility of the original publications withdraws those data from any further serious evaluation. The more vigorous use of modern statistical methods and reliability criteria resulted in several published mean palaeopole positions for stable Europe (Table 1) considered to be more credible and used as reference for this paper.

PALAEOMAGNETIC FRAMEWORK OF THE EUROPEAN HERCYNIDES

Widespread Kiaman remagnetization is a predominant feature of the European Palaeozic palaeomagnetic record (Creer, 1968). Although we are still far from understanding the dynamics of this continent, it becomes more and more obvious, that the remagnetization process is controlled by chemical rather than thermal conditions (Courtillot et al., 1986). Fluid migration related to Hercynian thrusting can potentially provide the chemical conditions for such a large scale event (McCabe et al., 1983). It comes therefore not as a surprise, that only a minority of the reliable palaeomagnetic pole positions tabulated (Table 2) are thought to reflect primary (e.g. prefolding) directions.

Only five primary palaeomagnetic palaeopoles have been reported for the Devonian so far, namely from the Iberian Meseta (Perroud and Bonhommet, 1984), the Harz mountains and Franconian Forest (Bachtadse, 1984), Wales (McClelland Brown, 1983) and more recently from the Holy Cross Mountains, Poland (Lewandowski et al., 1987). Except for the Po-

TABLE 1

Siluro-Devonian to Permian reference poles for stable Europe

Age	Pole		A95	N	Reference
	Lat. °S	Long. °E			
Siluro-Devonian	−2	321			Duff, 1980
Mid-Devonian	18	332	5	11	Pesonen et al., 1987
Late Devonian-Early Carboniferous	30	333	8	8	Duff, 1980
Mid to late Carboniferous	37	341	7	6	Frey and Cox, 1987
Late Carboniferous	40	344	3	21	Frey and Cox, 1987

Lat. and Long. are latitude and longitude of the palaeopole position in degrees South and East, respectively. N is the number of data entries and A95 is the radius of the cone of confidence at the 95% probability level.

TABLE 2

Devonian and Carboniferous palaeomagnetic directions and pole positions for Hercynian Europe

Locality	N	Mean	k	α_{95} °S	Pole Lat °E	Long.	Age		Reference
	dec.	inc.							
Galicia-Castilla									
Bucaco 'C'	(6)	144	36	45	9	19	25	Cm	Perroud and Bonhommet, 1981
Bucaco 'D'	(3)	153	5	212	6	38	24	Cm-u	Perroud and Bonhommet, 1981
Atienza	6	159	19	—	12	36	23	360	Van der Voo, 1967
Cantabria									
San Pedro	8	113	34	·	10	3	25	D	Perroud, 1984
San Emiliano	6	102	13	—	2	4	69	Cl-m	Bonhommet *et al.*, 1981
Alba	3	155	40	78		19	17	Cl	Hirt *et al.*, 1987
Cabo de Penas	8	178	19	—	9	35	355	Cl-m	Perroud, 1983
Armorican Massif									
M. de Chateaupanne overprint	10	217	25	77	6	21	320	Cm-u	Perroud *et al.*, 1986a
St. Malo dykes	13	206	14	110	4	30	328	330	Perroud *et al.*, 1986b
Laval syncline	11	220	-6	15	12	33	309	Cm-u	Edel and Coulon, 1984
Cambro-Ord. red beds		207	6	14	14	33	325	Cu	Duff, 1979
Cap Frehel	2	195	2	11	12	39	338	Cm-u	Jones *et al.*, 1979
Zone Bocaine	7	203	8	22	13	33	332	Cm-u	Jones *et al.*, 1979
Montmartin	7	206	-3	27	12	38	325	Cm-u	Perroud *et al.*, 1984
Carteret 'B'		216	28					Cm-u	Perroud *et al.*, 1982
Rozel 'B'	3	203	00	145	7	37	341	Cm-u	Perroud *et al.*, 1982
Crozon 'B'	11	217	29	21	10	23	322	Cm-u	Perroud *et al.*, 1983
Thouars 'ovp'	6	219	20	15	18	23	316	Cm-u	Perroud and Van der Voo, 1984
Flamanville	(8)	203	14	—	15	30	332	320	Van der Voo and Klootwijk, 1972
Plourivo	7	213	17		12	26	320	Cm-u	Jones *et al.*, 1979
Tregastel-Ploumanac'h granite	5	200	9	121	7	34	320	300	Duff, 1979
Jersey dolerites	5	199	16	71	9	31	336	Cm-u	Duff, 1980
N. Britanny	3	212	10	40	—	30	332	330	De Bouvier *et al.*, 1979
Wales									
Mill Haven sediments 'P-C'	(11)	251	10	33	8	8	283	P-C	McClelland Brown, 1983
Freshwater 'C'	(29)	222	-11	14	7.3	32	303	Cu	McClelland Brown, 1983
Freshwater 'D'	(15)	278	20	8	15	13	85	Dm	McClelland Brown, 1983
Central Massif									
Aigurande	4	247	4	53	13	14	290	Cm	Edel, 1984
Limousin	5	249	7		6	111	291	Cm	Edel, 1987
Montmarault	5	205	20	25	16	29	334	C	Edel, 1984
Morvan	9	78	-2	19	12	8	284	Cl-u	Edel, 1984
Ardenne/Eifel									
Hohes Venn	4	191	-12	29	6	45	351	Cu	Nowaczyk and Bleil, 1985
Ardenne	13	236	2	16	11	20	303	Cm	Edel and Coulon, 1984
Brabant	5	204	-7	67	9	39	333	Cm-P	Edel and Coulon, 1984
Central Europe									
Franconian Forest 'C'	3	203	-2	242	8	35	343	Cm-u	Bachtadse, 1984
Franconian Forest 'D'	11	186	30	33	8	22	5	Dm-u	Bachtadse, 1984
Harz mts 'C'	3	183	-4	46	18	40	7	Cm-u	Bachtadse, 1984
Harz mts 'D'	3	189	24	51	18	25	1	Dm-u	Bachtadse, 1984
Carpathians									
Holy Cross	9	231	0	39	6	24	322	Dm-u	Lewandowski *et al.*, 1987

N is the number of sites (samples). Dec. and Inc. are declination and inclination of the paleomagnetic mean direction reported in degrees. α95 is the radius of the cone of confidence at the 95% probability level. k is the precision parameter. Lat. nad Long. are latitude and longitude of the paleopole position in degrees South and East, respectively.

lish result, the primary character of those magnetizations has been supported by positive fold tests.

The Devonian palaeomagnetic inclinations (Table 2) show a rather good agreement with the inclinations derived from the mid to late Devonian reference pole for stable Europe (Table 1), putting Armorica next to Laurentia to the East and Baltica to the North. Any wide Palaeozoic ocean (e.g. mid to late Devonian - early Carboniferous, see Johnson, 1974) must therefore be indentified South of the Central Crystalline belt (Moldanubian) of the Hercynian orogen.

Althought a detailed review of the Palaeozoic palaeomagnetism of Gondwana is beyond the scope of this account, several recent studies of Palaeozoic rocks from Gondwana will be discussed briefly since their interpretation has a direct bearing on the understanding of the tectonic evolution of Hercynian Europe. Unfortunately, Palaeozoic data from Gondwana published during the last years is rather controversial. Earlier reconstructions of the palaeo-geodynamics of the circum-Atlantic continents for the late Devonian (Van der Voo, 1982, Van der Voo, 1983), position the leading edge of Africa at about 37° South, allowing for an ocean of maximal 3,700 km in width between Africa and sothern Europe. The position of Africa was exclusively based on the result for the Msissi norite (Hailwood, 1974), which has been cited as late Devonian in age. A re-investigation of the Msissi key pole by Salmon and co-workers (1987) however, demontrated a Jurassic age of the Msissi norite. Furtheremore Kent et al. (1984) reported a pole position for the early to mid Devonian Gneiguira Formation in Mauritania, which plots off southern Africa, and which would imply, that any ocean separating Africa and Europe must have been vanished below palaeomagnetic resolution in the Devonian, e.g. before the main pulse of the Hercynian orogeny. Saradeth et al. (1987) further more reported a palaeopole position from the Devonian Sabaloka ring complex, Sudan, very similar to the one from the Gneiguira Formation.

Conflicting palaeomagnetic results have also been reported from Australia. A very well defined palaeopole for the late Devonian from the cratonic Canning Basin (Hurley and Van der Voo, 1986), puts the pole into Central Africa (very close to the original Msissi position), while Schmidt et al. (1987), on the basis of palaeomagnetic data from the eastern Australian Lachlan fold belt, proposed a Devonian pole position east of the southern tip of Africa.

There is however reason for the suspicion that the Gneiguira pole is based on a Carboniferous remagnetization of the sediments studied (May and Kent, 1987) and that the palaeomagnetic direction from the Australian Lachlan fold belt has been deflected by tectonic rotations of eastern Australia (Hurley and Van der Voo, 1987). Studies on Palaeozoic sediments from South Africa (Bachtadse et al., 1987) as well as from southern Iberia (Perroud and Bonhommet, 1984) yielded further support for a Central African position of the palaeopole during Devonian times and are in support of Van der Voo's (1983) reconstruction. However much more high quality palaeomagnetic data for the Devonian of Africa is urgently needed before the pre-Hercynian palaeogeography of Europe and Africa and Hercynian geodynamics can be finally assessed.

PALAEOMAGNETIC DECLINATIONS

While observed palaeomagnetic inclinations from a wide variety of rocks and areas within the Hercynian mountain chain show a remarkably good agreement with the inclinations expected for the particular area and the given age of magnetization (Table 2), there exists a rather large variation in palaeomagnetic declinations along the belt (Eldredge et al., 1985). Those changes in declination appear to be systematic anomalies are in following the trend of the northern Hercynian front (Fig. 1). As declination anomalies are indicative for tectonic rotations about vertical axis, a detailed analysis of palaeomagnetic data can reveal further insight into the structural evolution of the mountain belt (Van der Voo and Channel, 1980). Any correlation between the change of strike along the Hercynian Front and the change in declination can be tested rather straightforwardly using graphic (Fig. 2) and mathematical (linear regression) methods (Schwartz and Van der Voo, 1983). The deviation of the locally observed structural trend (S_o) can be determined by subtraction from an arbitrarily chosen reference value (S_5). Accordingly, changes in declination will be revealed by comparing the locally determined observed palaeomagnetic declination (D_o) to the reference declination (D_r), which has been computed for the locality and the age assigned to the observed declination using the relevant palaeopole position (Table 2) as reference. Linear regression on those two variables (S_r–S_o, D_r–D_o) reveals the nature of the data set. High correlation coefficients and regression slopes near unity ($m = 1$) suggest, that the palaeomagnetic declinations have seen the same amount of rotation as the structural grain (Fig. 2). Significant deviation from unity points either towards secondary tightening ($m<$) or secondary opening of an originally bent mountain belt ($m>$). Regression slopes, which are not significantly different from the abscissa ($m=0$), suggest that tectonic deformation is likely to pre-date the acquisition of the magnetization.

Using the data set for the mid-Devonian to late Carboniferous from the European Hercynides, Eldredge et al. (1985), concluded that there is a good correlation between changes in regional strike and anomalies in declination. The intermediate slope of the reported regression line strongly suggested that the curvature of the Hercynian belt is in fact a secondary feature, an orocline in the sense of Carey (1958). A more detailed inspec-

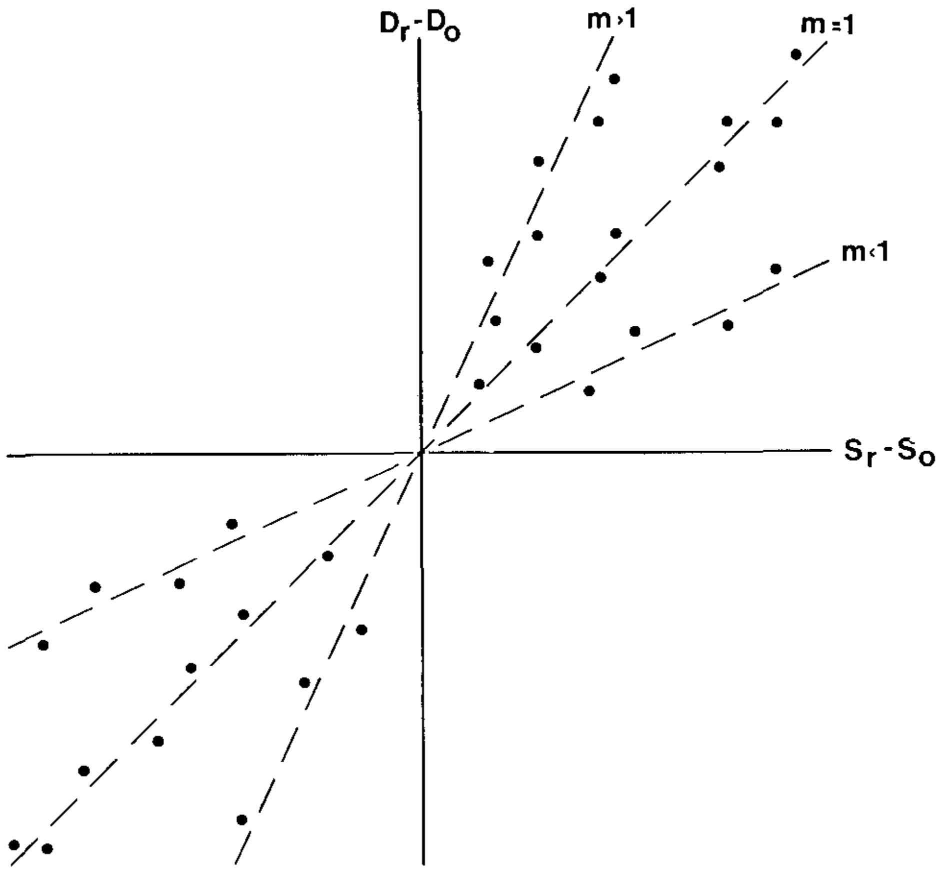

Fig. 2. Plot of declination anomalies as a function of strike anomalies. Slopes of the regression line near unity (m=1) indicate a primary origin of the curvature. Slopes significantly different from unity are indicative for secondary tightening (m<1) or opening (m>1) of an originally curved structure.

tion of the same data and of the tectonic setting of the individual directions in particular (Bachtadse and Van der Voo, 1986) however revealed that about 20 % of the data points originally analyzed, originated from thin-skinned data set into allochthonous areas such as the Cantabrian Arc and Wales. Dividing the data set into allochthonous and autochthonous groups and performing linear regression on both sets independently, yielded two significantly different regression lines. While the data from thin-skinned areas such as Cantabria and Wales showed an extremely good correlation between changes in strike and declination (close to unity), this was much less pronounced for data from presumably autochthonous parts of the mountain belt, yielding a rather shallow slope of the regression line. Consequently, Bachtadse and Van der Voo (1986) arrived at the conclusion, that the bulk of Hercynian deformation had been taken up by thin-skinned thrusting in the outer part of the mountain belt, while the final collision of Africa and Europe during the Carboniferous led to further tightening of the already bent inner (autochthonous) regions of the mountain belt.

Additional data, which has emerged during the last couple of years such as from the allochtchonous Ardenne-Eifel Massif (Nowaczyk and Bleil, 1985, Edel and Coulon, 1985), and the Cantabrian arc (Hirt *et al.*, 1987) as well as from the presumably autochthonous Massif Central, France (Edel, 1984, Edel, 1987b), The Armorican Massif (Perroud *et al.*, 1976a,b) and the holy Cross Mountains, Poland (Lewandowski et al., 1987), resulted in wider geographic coverage of the palaeomagnetic data and allows a more stringent evaluation of the large scale structural setting of the Hercynides.

In order to minimize the deviations in declination, normal directions tabulated (Table 3), have been reversed.

Palaeomagnetic and structural data from the Iberian Peninsula have been adjusted for the Mesozoic opening of the Bay of Biscay by adding 35° (Van der Voo, 1969) to strike and declination. The reference declination for each study has been computed using the reference palaeopole positions given in Table 1, and the age of (re-) magnetization as assigned by the authors of the original publications (Table 2). A strike of 210° has been used for reference (S_r). Variations in declination (D_r-D_o) have been plotted as a function of the change in general strike (S_r-S_o; Fig. 3) The errors associated with the observed declinations (Table 3 and error bars in Fig. 3) have been calculated according to Beck (1980). Following Bachtadse and Van der Voo (1987) the structural setting of each palaeomagnetic datum had been determined and a statistical analysis had been carried out on the autochthonous (28 entries) and allochthonous (11 entries) sub sets independently.

Linear regression of the data from the allochthonous outer zones of the Hercynides, namely the Ardenne, South Wales and, most pronounced, Cantabria (see review by Matte, 1987), yield a very well defined regression line (correlation coefficient $r = 0.933$, line «A» in Fig. 3). A t-test (e.g. Lowrie and Hirt, 1986) of the slope ($m = 0.695$) of the regression line against zero slope results in $t = 7.785$ which is significant at the 95 % confidence level. The same test against unit slope (pure primary curvature) gives $t = 1.918$, which is marginally greater than the reference value (1.833) at the 95 % level, and therefore indicates, that the slope of the regression line is significantly different from unity. The rather steep slope of line «A» nevertheless points towards the predominantly primary curvature of the structural trend observed in the thin-skinned zones of the orogen. Linear regression of the «autochthonous» data set (line «B» in Fig. 3), re-

TABLE 3

Deviation of observed declinations and strike from reference directions and reference strike

Locality	regional struct. trend	Decl/Inc		S_r-S_o	D_r-D_o	I_r-I_o	dD
		observed	expected				
Bucaco 'C'[1]	180	179/+36	191/+10	+30	+12	−26	11
Bucaco 'D'[1]	180	188/+05	198/+03	+30	+10	− 8	6
San Pedro[1,2]	135	148/+34	203/+38	+75	+55	+ 4	9
San Emiliano[1,2]	125	137/+13	191/+09	+85	+56	− 4	2
Alba[1,2]	180	190/+40	199/+20	+30	+ 9	−20	—
Atienza[1,2]	160	194/+19	199/+20	+50	− 5	+ 1	12
Cabo de Penas[1,2]	265	178/+19	199/+19	−55	−18	—	
Moulin de Chateaupanne ovp	270	217/+25	194/+08	−60	−23	−17	7
St. Malo dykes	270	206/+14	194/+07	−60	−12	− 7	4
Laval syncline	307	220/−06	190/+02	−97	−30	+ 8	12
Cambro-Ord. red beds	259	207/+06	191/+06	−49	−16	—	14
Cap Frehel	272	195/+02	190/+01	−62	− 5	− 1	12
Zone Bocaine	290	203/+08	191/ 00	−80	−12	− 8	13
Montmartin	270	206/−03	191/ 00	−60	−15	+ 3	12
Carteret 'B'	272	216/+28	190/+02	−62	−26	−26	14
Rozel 'B'	255	203/ 00	191/+01	−45	−12	− 1	7
Crozon 'B'	240	217/+29	189/+03	−30	−28	−26	10
Thouars overprint	270	219/+20	192/+04	−60	−27	−16	18
Flamanville granite	270	203/+14	193/+04	−60	−10	−10	15
Plourivo	275	213/+17	191/−01	−65	−22	−16	12
Tregastel-Ploumanac'h granite	275	200/+09	194/−04	−65	− 6	+13	7
Jersey dolerites	275	199/+16	198/ 00	−65	− 1	−16	9
N. Britanny	275	212/+10	193/+05	−65	−19	− 5	—
Mill Haven sediments 'P-C'[2]	280	251/+10	188/−05	−70	−63	+15	8
Freshwater 'C'[2]	280	222/−11	188/−04	−70	−34	− 7	7
Freshwater 'D'[2]	280	278/+20	203/+32	−70	−75	12	16
Aigurande Plateau	300	247/+04	197/+09	−90	−50	+ 5	13
Limousin	300	249/+07	196/+1-	−90	−5-	+ 3	6
Montmarault	300	205/+20	197/+09	−90	− 8	−11	17
Morvan	250	258/+02	195/+08	−40	−63	+ 6	12
Hohes Venn[2]	220	191/−12	197/−06	−10	+ 6	+ 6	6
Ardennes[2]	230	236/+02	197/−06	−20	−36	− 8	11
Brabant[2]	220	204/−07	196/−	−10	− 8	− 2	9
Franconian Forest 'C'	240	203/−02	200/−07	−30	− 3	− 5	8
Franconian Forest 'D'	240	186/+30	217/+28	−30	+31	− 2	9
Harz mts 'C'	240	183/−04	200/−08	−30	+17	− 4	18
Harz mts 'D'	240	189/+24	218/+24	−30	+29	—	20
Holy Cross	290	231/ 00	210/−02	−80	−12	− 2	6

Devonian and Carboniferous paleomagnetic directions (Dec. and Inc.) for Hercynian Europe. S_r is the reference strike (210°), S_o is the regional strike. D_r (I_r) is the reference declination (inclination), D_o (I_o) the observed magnetic declination. dD is the radius of the circle of confidence about the observed declination at the 95% probability level (Beck, 1980).

1 Magnetic and structural data corrected for the opening of the Bay of Biscay.

2 Data from presumably allochthonous areas of the orogen.

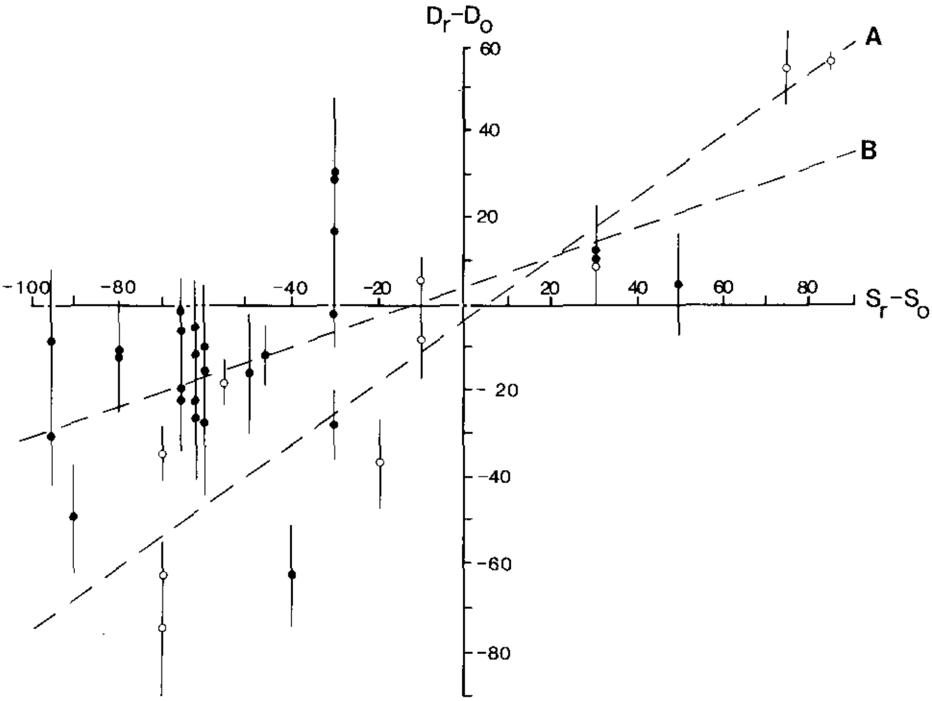

Fig. 3. Declination deviations (D_r-D_0 plotted as a function of strike deviation (S_r-S_0) for the European Hercynides. Open (closed) symbols: data from allochthonous (autochthonous) parts of the orogen. S_r: reference strike; S_0: observed (regional) strike; D_r: reference paleomagnetic declination; D_0: observed paleomagnetic declination. Error bars on the declination anomalies calculated according to Beck (1980). Lines «A» and «B» are the best fit for the data sets from allochthonous an autochthonous regions of the mountain belt, respectively.

sults in a correlation coefficient $r = 0.551$, which again is significant at the 95 % confidence level. Testing the slope of «B» against the slope of «A» gives $t = 3.617$, which exceeds the reference value and shows, that both data sub-sets are independent and justifies the original decision to evaluate both data sets individually. Furthermore a t-test for the rather shallow slope ($m = 0.334$) of line «B» against zero slope (no oroclinal bending at all) results in $t = 2.477$, which is greater than the reference value ($t = 1.708$) underlining the significance of the regression line and therefore being indicative for the secondary character of the structural curvature associated with the autochthonous areas of the orogen (see also Fig. 2). Thus the analysis of palaeomagnetic directional data from the presumably autochthonous areas of the Hercynides suggest, that the bending of the orogen is only in part a secondary feature. Furthermore the rather steep slope of the regression line for the «allochthonous» data set strongly indicates, that the pronunced curvature of the thin-skinned zones of the Hercynides is a predominantly primary feature.

CONCLUSION

The allochthony of a substantial number of areas within the Hercynides reduces the value of the Hercynian palaeomagnetic data base, for reconstruction of the predeformational palaeogeography of the Central European crust. The analysis of directional data can nevertheless provide insights into the structural evolution of a mountain belt.

Combined primary (thin-skinned) and secondary (thick-skinned) structural bending along the European Hercynides, as reported in this paper, is compatible with several geodynamic models (Bachtadse and Van der Voo, 1986). Structural data from the Ibero-Armorican arc (Matte, 1986 and references therein) as well as palaeogeographical reconstructions (Ziegler, 1986) seem to support a Himalaya— type (Molnar and Tapponier, 1978) setting of the geodynamic evolution of the Hercynides during the Carboniferous (Lefort and Van der Voo, 1981). Although more palaeomagnetic data from areas south of the mountain belt is needed in order to substantiate this geodynamic model, northwestward impingement of the hypothetical Ebro-Pyrenean microplate (Ziegler, 1983, 1986) or an African promontory (Matte and Ribeiro, 1975) into Europe during the Carboniferous provides a viable setting to explain intensive thin-skinned thrusting in the Cantrabrian zone as well as along the northern edge of the Hercynides. Parallel to thrusting in the external parts of the orogen, the internal zones were subjected to further tightening of an already existing fold system. Thus deep reaching crustal deformation in combination with extensive thin-skinned thrust development caused by continental indentation is a rather simplistic but nevertheless plausible model for the Carboniferous evolution of the Hercynides.

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