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POLYPHASED PALAEOMAGNETIC OVERPRINTING IN THE CENTRAL PART OF THE VARISCAN BELT, WITH EMPHASIS ON THE SOUTHERN VOSGES DEVONIAN - DINANTIAN BASIN. GEOTECTONIC INTERPRETATION

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Abstract: This paper aims to demonstrate that Early Carboniferous rocks from different parts of the Variscan belt display the same set of directions and reveal a common palaeomagnetic history. The mechanisms responsible for acquisition of the different directions, overprinting and geotectonics, must have been the same. Attempt is made to decipher the common palaeomagnetic record of the central part of the Variscan belt in the light of results from the southern Vosges.

Key words: magnetic overprinting, Carboniferous, Permian, rotations, Vosges, Variscan belt.

The southern Vosges (47.8°N, 7°E) are characterized by a thick sequence of volcanic and volcanic-sedimentary series emplaced in Late Devonian - Late Visean time and intruded during the same period by diorites, granites and lamprophyres. Pre-late Variscan magnetizations were obtained in volcanics from a previous study. 20 sites were resampled, 39 new sites were collected in the Late Visean volcanic and volcanic-sedimentary series, and 18 sites within Late Devonian - Visean diorites, dolerites, granites and dykes.

Thermal demagnetization demonstrates a complicated palaeomagnetic history with mostly single characteristic magnetizations in mafic plutonics and welded tuffs (ignimbrites, latites), and multicomponent magnetizations in andesites and breccias. Statistical analysis exhibits six consistent groups of normal and reversed directions. Four of them are clearly younger than the Late Visean tightening phase. The youngest A directions occur in intrusives and mostly volcanics: D = 197°, I = -22° (VGP: 51°N, 160°E), and correspond to post-tectonic Permo - Triassic overprints carried by haematite. A' directions: D = 208°, I = 27° (VGP: 23°N, 157°E) are present in volcanic and volcano-sedimentary units as post-tectonic overprints, acquired in the Late Carboniferous. The B directions: D = 65°, I = -20° (VGP: 8°N, 123°E) were found in intrusives and in volcanics. The negative fold test in volcanics indicates post-tectonic overprinting which is considered as Namurian - Westphalian in age. The most frequent C directions display an elongated distribution with quite constant northwesterly (southeasterly) declinations but variable inclinations from positive (C_p) to negative (C_n). The two mean directions of the distribution are C_P: D = 315°, I = 29°, (VGP: 41°S, 71°E) and C_n: D = 318°, I = -40° (VGP: 10°S, 46°E) and the mean C_0 corresponding to an intermediate cluster: D = 325°, I = 4° (VGP: 35°S, 52°E). The C_P components are mainly secondary and predominate in intrusives. The C_n show a positive fold test which is in favour of a Late Visean acquisition, while the C_0 are pre- or syntectonic.

Such directions exist also in other massifs of the belt. Published results from similar Early Carboniferous volcanic and plutonic rocks from Central Massif, Schwarzwald, Odenwald and Spessart show the same palaeomagnetic record as the S. Vosges. Assuming that C, B, A' and A directions correspond to the magnetic field during Carboniferous - Permian time implies two main results: 1 - overprinting has lasted from the Visean up to Trias; 2 - changes in direction of overprints can be interpreted in terms of geotectonics. The deviation from C to B implies a first rotation phase of the different massifs subsequently to the major Variscan tightening phase, i.e. in the time-range 330 - 320 Ma. The B to A' deviation results from a second clockwise rotation by 45° around 310 Ma. Due to the uncertainty concerning the inclinations of the C directions two solutions are possible for the previous motion. Taking the C_P-B-A' path implies that both rotations (C_P-B and B-A') were clockwise. When assuming the pole of rotation in the center of Baltica, the rotations are equivalent to large dextral strike-slip motions along the southwestern margin of the plate. The C_n-B-A' path is interpretable in terms of a counterclockwise rotation (C_n-B) followed by a clockwise rotation (B-A'). In both cases the motions occurred without major change in palaeolatitude. In the uppermost Carboniferous, up to Triassic the W - E motion becomes a northward drift.

Introduction

Since the Late Cretaceous, the Alpine-Himalayan area is the seat of confrontation between Eurasia and Africa. Convergence has lead to large-scale wrenching, indentation and two main phases of block rotations, respectively in the Late Cretateous and Early Miocene, during an interval of about 50 Ma (Van den Berg 1979; Edel 1980; Westphal et al. 1986). In a similar way, the Variscan belt results from the intracontinental interactions

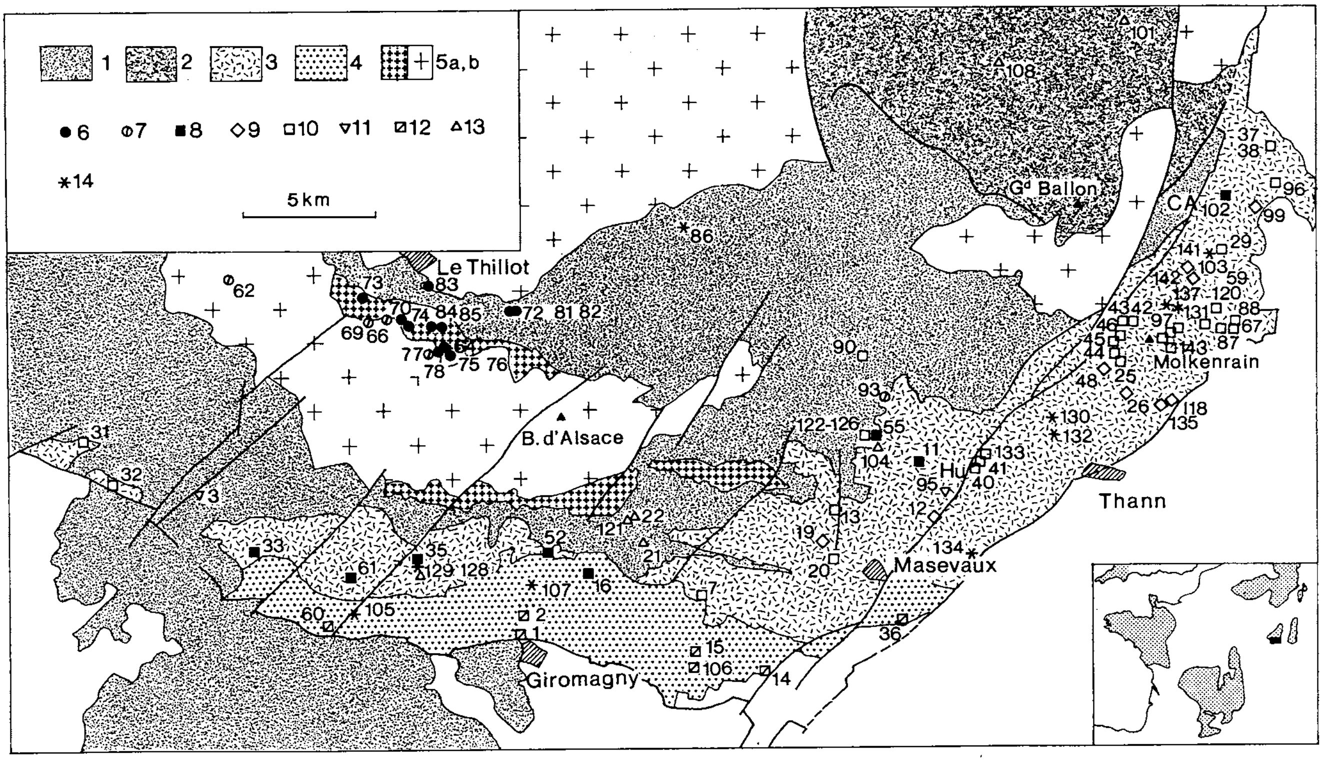

Fig. 1. Geological sketch map of the southern Vosges.
1 - Early Visean volcanic and sedimentary units; 2 - Visean undifferentiated; 3 - Late Visean volcanics and sediments; 4 - Upper Late Visean volcanics and sediments; 5a - diorites, b - granites. Location of the palaeomagnetic sites; 6 - mafic intrusives; 7 - lamprophyres; 8 - andesites; 9 - latites; 10 - rhyolitic ignimbrites; 11 - trachytes; 12 - rhyodacites; 13 - volcanic breccias; 14 - volcanic-sedimentary and sedimentary units.

of Laurussia and Gondwana during Late Devonian - Carboniferous time, i.e. during a period of about 70 Ma. Consequently, similar tectonic features are expected for the Variscan belt. Palaeomagnetic investigations have been performed on the different massifs of the Variscides in order to detect global motions, relative block rotations or bending related to the crustal tightening.

A prominent result was the large overprinting in Late Variscan time of Late Devonian - Carboniferous sediments from the Armorican Massif (Edel & Coulon 1984), Ardenne and Rhenish Massif (Edel & Coulon 1987), Central Massif (Courtillot et al. 1986), Vosges (Bachtadse et al. 1983). The consequence is that Devonian - Carboniferous sediments are largely unsuitable for palaeomagnetic investigation in the Variscan belt. Therefore we concentrate on plutonic, volcanic and metamorphic rocks which are often less sensitive for late overprinting. Unfortunately, such rocks, excepted layered volcanics, do not contain reliable palaeohorizontal indicators.

Despite of the difficulty to get optimal palaeomagnetic directions with clear ages of acquisition of the magnetization and clear tectonic setting, some order was found in the large distribution of directions and several groups of directions (A, A', B, C) apparently dependent on age could be isolated in Late Devonian - Early Carboniferous volcanic, plutonic and metamorphic rocks from the Central Massif, Vosges, Schwarzwald, Odenwald and Spessart (Edel 1987a,b; Edel & Wickert 1991). Interpretation of these directions in terms of geotectonics imply two large rotations phases in Variscan time.

As this polyphased palaeomagnetic evolution and its interpretations come from units in which tectonic control was mostly lacking, the results had to be checked in an area where such control is possible. We have focussed our attention on the Devono-Dinantian Basin of the Moldanubian S. Vosges. With its thick sequence of volcanic and volcanic-sedimentary layers and contemporaneous intrusions, the basin is the most interesting of the Variscan belt. A preliminary study undertaken in order to check different Early Carboniferous rocks, with emphasis on volcanics (Hernot 1983; Edel et al. 1984) was extended. Sampling concerns a large set of units from the Latest Devonian to the Latest Visean and spread over the whole basin in order to detect and identify the local, regional and global movements in relation with the different tectono-magmatic phases observed in the Vosges.

Geological setting and sampling

With the exception of Tertiary graben-horst tectonics at the Rhinegraben, the present structure results mainly from Visean tectono-magmatic events (Wickert & Eisbacher 1988; Fluck et al. 1989). The southern Vosges are characterized by a thick sequence of Late Devonian to Early Carboniferous sedimentary and volcanic units (Fig. 1) and by associated intrusives. The pre-Middle Visean volcanics represent a spilite keratophyre association, while the Upper Visean series include a normal volcanic association of shoshonitic tendency (Coulon et al. 1975, 1978, 1979). The oldest Late Devonian plutonic rocks, consisting mainly of diorites, were intruded by the granitic Ballons pluton (Fig. 1). In the Visean, (345 - 330 Ma, according to Montigny & Thuizat 1989; Montigny et al. 1983), numerous such granitic bodies intruded the metamorphic and volcanic-sedimentary basement of the Vosges, along major faults and thrusts. The Late Visean major N - S tightening phase (Sudetian) led to uplift of the massif.

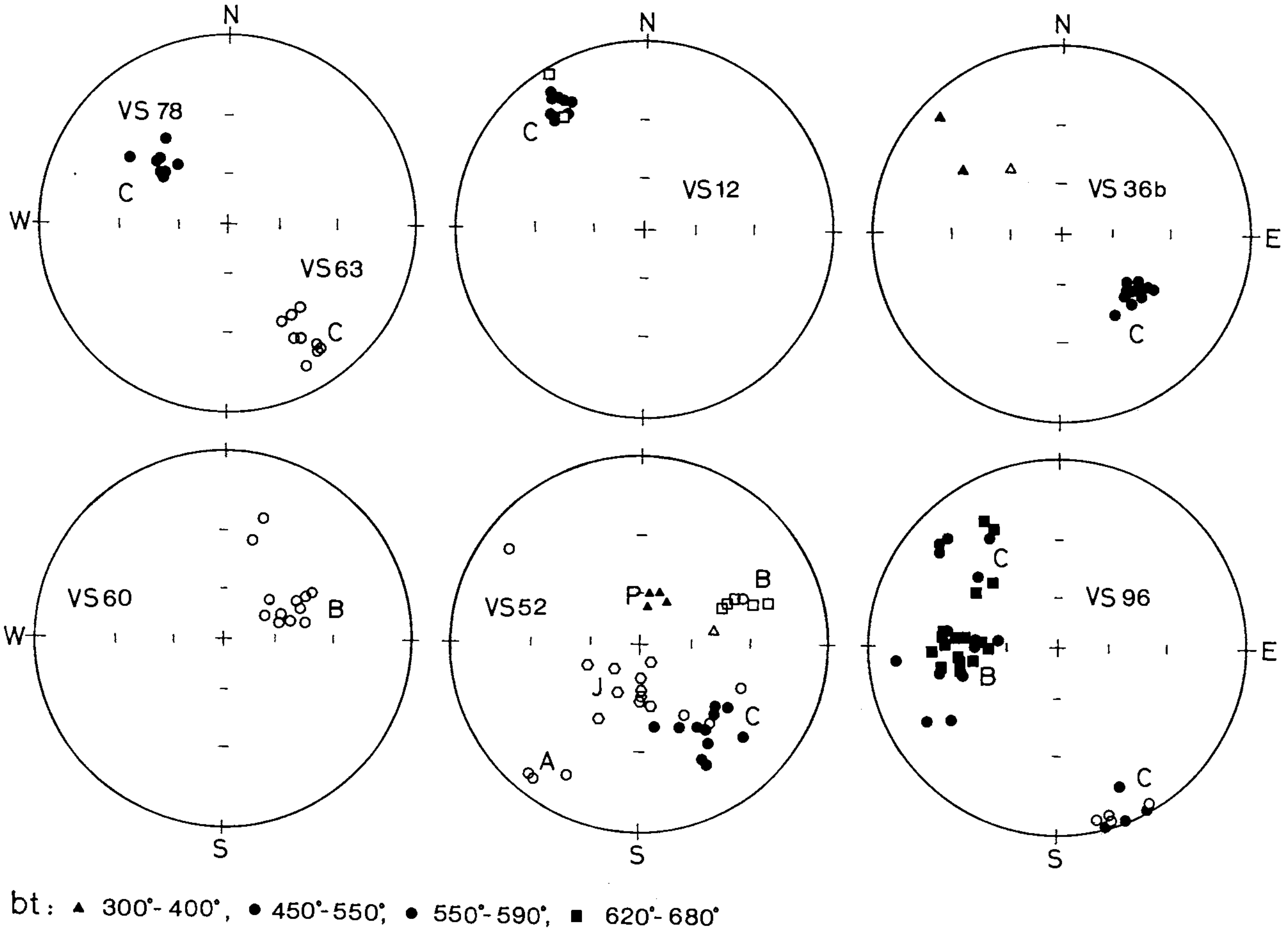

Fig. 2. Directions of remanent magnetizations measured in typical sites of diorite (VS 78), dolerite (VS 63), latite (VS 12), rhyodacite (VS 36b, VS 60), andesite (VS 52) and rhyolitic flows (VS 96) with respect to the maximum unblocking temperatures; low temperatures: 300 - 400 °C (triangles); intermediate: 500 - 550 °C (hexagones); intermediate-high: 550 - 600 °C (dots); high: 610 - 680 °C (squares). A, B, C, J, P: label of the different directions.

Sampling

The early basic intrusives consist of diorites dated at 362 ± 11 Ma (Montigny & Thuizat 1989; Boutin 1992) (VS *64, 70, 73, 74, 75, 76, 78, 82, 84*), of microdiorites (VS *85*), dolerites (VS *63, 72, 81*) and gabbros (VS 83). The N140 - 170° foliation is steep, discordant from the N100° structuration of the Ballons granite (VS *79, 80*), emplaced later (André 1983). Prior or around 330 Ma, lamprophyres intruded the pluton (Montigny & Thuizat 1989) (VS *62, 66, 77*)[1]. In the Middle Vosges, the Crete granite (VM 4) and a dyke of vaugnerites (VM 1) of the same magmatic origin were also collected.

Several sites investigated previously in the volcanic series were revisited. The existence of several magnetizations, emplaced at different time, required more extensive sampling than in the case of sites with a unique direction. Bedding was checked, and in some cases revised. 39 additional sites were collected in the Late Visean series, which are not spilitized.

The lowest investigated series consist of early volcanic breccias (VS 21, 22, *121*) and acidic flows (VS *90-91, 93, 109, 123, 124, 125, 126*), overlain by a succession of andesites (labradorites) (VS 35*, 49, 51, 52*, 55, 56, 57, 58, 61*, *102*). Subsequent to the andesites, the so-called Cremillot series were emplaced (Coulon et al. 1975, 1978). They consist of volcanic-sedimentary layers (VS 8-9, *128, 129, 130, 132, 134, 136, 137-138, 142*), trachyandesites (VS11*, 33*, 34*), latites (VS 12, 19*, 26, 28, 48*, 59, *99, 103, 118, 135*) and rhyolitic ignimbrites (7*, 13, 20, 25, 29, 31, 32*, 37*, 37b, 38*, 42*, 43*, 44*, 45, 46, *67, 87, 88, 96, 97, 97b, 97c, 120, 131, 133, 143*). Sites VS 25, 42*, 43*, 44*, 45, 46, *67, 87, 87, 88, 97, 97b, 97c, 120, 131, 143* are located in the same unit, the Molkenrain I2 layer. K-Ar dating of biotites from site VS *97* yielded an age of 337 ± 11 Ma for the ignimbrite (Montigny et al. 1984), while sedimentary interbedded layers indicate a V2b/V3a age for the beginning of the Cremillot series (Coulon et al. 1978).

The upper series consist successively of: 1 - greywackes, 2 - a third volcanic episod with trachyandesites (VS 16*) and trachytes (VS 17, *112*), 3 - greywackes again and, 4 - a last volcanic unit with rhyodacitic tuffs and ignimbrites (VS 1*, 2*, 14*, 15*, 36*, 36 b, 60*). According to macrofloras, the latest sedimentary series are still Visean (Coulon et al. 1975).

Tectonics

During emplacement of the Late Visean volcanic-sedimentary series, sinistral wrench-faulting and probably folding were

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[1] italics numbers correspond to new sites, others are from Edel et al. (1984) partly revisited and/or revised *. The results from new and revised sites are listed in tables, after elimination of post-Triassic overprints.

Table 1: Plutonic rocks and dykes.

site	formation	bt °C	N/N_0	n	D_0	I_0	D_C	I_C	k	α_{95}	dip	a	comments
VS 63	dolerite	550-580	6/9	10	145	-18			78	5		C_P	**
VS 64	diorite	550-590	6/9	10	318	26			27	9		C_P	** $N+R$
		550-590	4/9	7	309	-16			22	13		C_N	$N+R$
VS 70	diorite	580	6/7	6	142	-28			33	12		C_P	**
VS 75-76	diorite	480-580	6/16	8	296	33			26	11		C_P	**
		480-580	3/16	4	302	67			81	10		D	$C-D$ trend
VS 78	diorite	550-580	5/6	8	318	38			75.5	6		C_P	**
VS 84	diorite	580	4/4	6	307	24			37	11		C_P	**
VS 85	microdiorite	330-580	3/7	4	338	-26			31	11		C_N	**
		580	5/7	7	194	-32			31	11		A	
VS 72	dolerite	580	3/7	7	72	-7			29	11		B	**
		580	2/7	3	304	42			122	11		C_P	
VS 81-82	diorite	580	3/8	8	236	2			109	5		B	**
VS 83	gabbro	580	4/8	8	10	14			74	6		A	**
		580	1/8	2	311	26			31	46		C_P	
		580	1/8	2	236.5	44			795	9		$B-D$	
VS 71	granite, contact dyke VS 66	540-580	1/5	2	272	60.5			104	25		D	**
VS 62	lamprophyre	680	8/11	15	199	-17			115	3.5		A	
VS 66	lamprophyre	580	5/5	9	306	52			46	7.5		D	**
VS 69	lamprophyre	400-500	6/6	8	297	65			45	8		D	**
VS 77	lamprophyre	470-580	3/4	5	131	-27			431	4		C_P	**
VS 93	microgranite dyke	580	5/5	9	293	20			99	5		C_P	**
Vm 1	vaugnerite	300-400	3/4	6	241.5	30			37	11		B	**$N+R$
		300-400	3/4	5	308	28			24.5	15		C_P	
Vm 4	granite	350-580	2/10	3	76	-8			24	25		B	**
		350	5/10	8	313	-1			20	12.5		C	$N+R$

Mean directions; bt: maximum unblocking temperatures; N: number of samples containing the considered component; N_0: total number of samples; n: number of specimens containing the considered component; D_0, I_0: in situ declination, inclination; D_C, I_C: tilt corrected direction; k, α_{95}: Fisher statistic parameters; dip: inclination and azimut of maximal dip; a: direction label; *: sites from Edel et al. (1984) revisited or revised, **: new site. Underlined directions show whether the direc tions are pre- or post-tectonic.

more or less continuous. In the southeast, the Col Amic-Hunsruck fault (CA-H, Fig. 1) shifts the Early to Middle Visean series by 10 to 15 km to NE, whereas the latest rhyodacitic flows show an offset of only 3 km. After the latest Visean, all units underwent the major "Sudetian" phase. Folds generally display N90° to N100° axes, with exception for sites in the vicinity of the CA-H fault, which are characterized by N35-40° axes.

Interpretation of palaeomagnetic directions requires a good estimation of the tectonic attitude. In volcanics, reliable measurements are possible from interbedded thin layers and from ignimbrites and tuffs with fiammes. On the contrary, thick homogeneous layers, without clear contact with under/overlying layers are not suitable. In some flows, particularly in ignimbrites and tuffs, anisotropy of susceptibility measurements exhibit a foliation consistent with the fiamme planes and orthogonal to the prism axis. Systematic measurements of the magnetic anisotropy have supplemented field observations in several sites.

Results

A palaeomagnetic site represents an exposure of several tens of square meters, for instance a quarry. Samples were drilled or taken as handsamples. Usually, each sample was drilled and cut into 3 specimens of 25 mm diameter and 22 mm length; measurements were performed with a modified Digico magnetometer. Since thermal demagnetization was much more efficient in both plutonics and volcanics than alternating field, each specimen has undergone a complete stepwise demagnetization up to the maximum unblocking temperature, i.e. 11 steps up to 590°, 15 up to 660°. The resulting directions of NRM were represented on a Zijderveld plot and computed with a home-made least-square method.

Magnetic properties of the volcanics have been described in the previous study (Edel et al. 1984). In the diorites as in most volcanics, magnetite is the dominating magnetic mineral.

Table 2: Lower series and andesites.

site	formation	bt °C	N/N_0	n	D_0	I_0	D_C	I_C	k	α_{95}	dip	a	comments
VS 86	pellite	670	4/4	4	205	-28	240.5	-57.5	58	12	45 N170	A	**
VS121	lower breccias	580	3/6	6	21	17	17	-9	40	11	55 N315	A	**
		580	2/6	3	217	37	253.5	26	40	20		A'	
VS 90	tuff	>670	2/9	3	132	-28	135	-83	192	9	55 N130	C_P	**
		>670	3/9	4	192	-28	232	-37.5	92	10		A	
VS123-124-126	tuff	500,>620	3/7	6	214	36			21	14.5	37 N105	A'	**
							182	35	8.5	23	30 N115		
		530	3/7	7	318	34			27	11		C_P	
							337	67	8	20			
		530	3/7	8	152	36			21	13			
							142	8	20	13		C_0	
VS125	ignimbrite	580	4/6	10	136	56	128	27	29	9		C_N	**
VS 35	andesite	530-580	6/15	10	193	27	193	-26	25	10	55 N210	A'	*
		670	2/15	6	15	9.5	358	61	95	7		A	
		580	3/15	4	60	-32	56	17	47	13		B	
		350,580	3/15	5	312.5	-8	301	-12				C_0	
		580	3/15	10	141	-14	120	-25	37	11		C_P	
VS 52	andesite	580	6/15	10	140	28	147	-12	47	7	60 N195	C_0	*
		580	1/15	3	132	-30.5	87	-36	19.5	28		C_P	
		400,>600	5/15	7	70	-32	60	9	63	7.5		B	
VS 61	andesite	350	5/11	9	310	-32	322	23	40	8	110 N205?	C_N/C_P?	*
		580	2/11	3	53	-19	112	64	81	14		B	
		300-400	2/11	4	215	32	240	-75	118.5	8		A'	
VS102	andesite	580	2/8	4	125	-16	115	-54	169	7	40 N140	C_P	**
VS 11	trachy-andesite	500	5/6	10	322	43.5	98	73.5	20	11	60 N130	C_P	*
		550-580	5/6	9	307	-16	306	44	27	10		C_P	
VS 33	trachy-andesite	550/580	3/5	8	222	-24	222	25	22	12	50 N 30	A	*
VS 34	trachy-andesite	550-580	4/12	9	207.5	18	209	-41.5	32	8	60 N200?	A'	*
		580	4/12	10	319	22	283	35	22	20		C_P	
		500	4/12	7	93	5	106	17	104	6		E	

Explanations see Tab.1.

The mean directions of magnetizations obtained for the main geological units after thermal cleaning are listed according to the stratigraphy (Tabs. 1 - 5). In ignimbrites, latites and intrusives, a single characteristic direction of magnetization was mostly found apart from viscous magnetizations (VS *78*, *63*, 12, *36b*, 60*; Fig. 2); in other formations, particularly in andesites, the palaeomagnetic history is much more complicated. In the VS 52* andesites for instance (Fig. 2), the demagnetizing process shows five groups of directions with different unblocking temperatures (P: present day directions with unblocking temperatures up to 530°; A and C: 550 - 580°; B: mainly 610°; J: 500 - 550°). Such formations require extensive sampling, detailed demagnetization and analysis of all specimens. Each group of directions is represented by a mean direction listed in a table (Tabs. 1 - 5) and illustrated on stereographic projections (Figs. 3 - 4). Sometimes the magnetization considered as the oldest is only present in one or two samples.

Plotting all in situ directions on a same stereogram after elimination of directions consistent with Jurassic to present field directions, displays a large clustered distribution. To make easier the demarcation of different populations, Lewandowski (1992a) has proposed to use density diagrams, which enable a simple determination of bordering values of Dmin/max and Imin/ max for a given group of RM directions. In order to create density diagram, RM directions are monitoring by means of sliding, rectangular window in 3-D space. In the case of S. Vosges (Fig. 5a), a window size was set on 10°/10° of inclination and declination. The window was sliding in steps equal to the half of its size. After each step, the number of orientations has been counted and the corresponding value has been assigned to the grid nodes, which were fixed in every 3° of D and I. Kriging method, as implanted into "SURFER" plot package, has been used to create a grid and to interpolate the isolines of density. The diagrams are presented in cylindrical projection, along with original data set (Fig. 5b). Having the map created, one should to take a readings of bordering values of Dmin/max and Imin/max and then calculate the directional mean for the choosen population. The values of D and I may be set relatively free, since they do not influence Fisherian statistics as long, as a new direction is not incorporated into the population. Closer examination of diagram (Fig. 5b) reveals that populations across a meridian 180 may be transferred onto juxtaposed hemisphere (western in this example) due to opposite polarity, what enhance the sharpness of outline of each group of directions (Fig. 5c).

Table 3: Volcanic-sedimentary, volcanic breccias, latites and rhyolites.

site	formation	bt °C	N/N_0	n	D_0	I_0	D_C	I_C	k	α_{95}	dip	a	comments
VS104	breccias	540	2/2	4	197	37	174	29	68	11	35 N108	A'	**
VS108	breccias	580	3/8	6	139	-27	162	-6	20.5	15	70 N 45	C_P	**
		580	1/8	2	323.5	29	245	25	302	14		C_P	
		580	1/8	2	287	8.5	314	29	92	26		C_P	
		580	5/8	10	136	-27			25	10		C_P	$N+R$
VS128	breccias	500-580	3/5	3	318	-22	324	12	34	21	70 N205	$C_P - C_0$	**
	(Cremillot)	580-600	4/5	8	132	31	150	-3	41	9		C_P	
VS129	tuff (Cremillot)	350	3/4	4	203	8.5	196.5	-44	42	14	55 N220	A'	**
		500	4/4	8	141	-28	112	-24	17	13		C_P	
VS130	volc-sedimentary	580	4/11	9	136.5	-40	7	-57.5	33	9	77 N157	C_P	**
		580	4/11	8	199	21	208	-36.5	56	7		A'	
VS132	volc-sedimentary	350-400	3/8	3	280	35	225.5	21	131	11	82 N170	C_P	**
		580	7/8	10	195	29	202	-46	21	11		A'	
VS134	volc-sedimentary	350	6/6	7	250	27	256	20	32	11	15 N225	B	**
VS137	conglomerate	580	5/32	7	62	-20			30	11	20 N125	B	**
138	(matrix+pebbles)						54	-26	27	12			
VS142	microconglomerate	400-580	6/10	6	233	28	218.5	23	42	10	30 N120	B	**
VS 19	latite	580,670	4/4	10	326.5	5.5	328	25	44	3	20 N135?	C_P	*
VS 48	latite	500-580	3/4	6	81	-34.5	86	2	52	9	40 N200	B	*
VS 99	latite	580	6/6	9	125	-43.5	110	-45.5	43	8	15 N200	$C_P - D$	**
VS103	latite	350-550	4/7	5	335	28	332	39	29	14	12 N175	C_P	**
		550-580	4/7	6	132.5	18	134	9	18	16		C_0	
VS118	latitic tuff	580	6/14	13	217.5	28	302	83	64	5	62 N 30	A'	**
		400-580	4/14	6	335	0	318	-30	61	8.5		C_N	$N+R$
		580	5/14	5	60	-24	100	-59	40	12		B	
VS135	latitic tuff	580	5/9	9	218	36	316	74	72	6	60 N 20	A'	**
		580	1/9	2	79	-23	117	-36	2976	4		B	
		580	1/9	2	109	-47	153	-22	50	36		D	
VS 95	trachyte	590	5/5	5	169	39	156	-3	28	8	60 N120	C_P	**
VS 96	rhyolite	580,680	12/22	15	271	34	263	28	77	4	15 N200	B	**
		580	4/22	6	319	25	312	31.5	32	12		C_P	
		580	4/22	8	157	0	156	-11	105	5		$C_P - C_0$	

Explanations see Tab.1.

As shown on the density contour map (Fig. 5b), when excluding the steep southeasterly D directions which will be discussed later, the in situ directions are clustered around the normal and reversed C_P, C_n, B, A and A' directions, already defined in other areas. In intrusives and volcanics, each group of directions will be examined separately.

The intrusives (Tab. 1, Fig. 3)

In the northern part of the granitic Ballons Pluton, the earlier basic intrusives and the later lamprophyres display a cluster with north-westerly declinations and mostly positive inclinations, labelled C_P (P for positive inclination) (VS *64, 72, 75-76, 78, 84*). Three sites display opposite C_P directions (VS *63, 70, 77*). Unblocking temperatures up to 580 - 600 °C suggest magnetite as the principal remanence carrier. Lamprophyre dykes intruding the granite show two different kinds of behaviour. The dark intrusions (VS *62, 66, 69*) exhibit WNW to WSW declinations with steep inclinations and intermediate unblocking temperatures that are considered as secondary. They show a reddish pigmentation, probably due to the haematite that carries the A direction in site VS *62*. Lamprophyre VS *77*, which does not exhibit the reddish pigmentation, displays a SE declination and a negative inclination close to the C_P directions obtained in the pre-granitic diorites VS *63* and VS *70*. Unblocking temperature reveals magnetite. The acidic dyke VS *93* which is intrusive into

Table 4: Ignimbrites.

site	formation	bt °C	N/N_0	n	D_0	I_0	D_C	I_C	k	α_{95}	dip	a	comments
VS 7	ignimbrite	500	5/5	9	327	37	345	15	49	7	40 N 35	C_P	*
		670	3/5	4	21	-18	5	-53	106	9		A'	
VS 32	ignimbrite	500	2/4	4	102	-41	152	-44	74	11	50 N 40?	D	*
		580	1/4	2	82	-42	148	-59				B	
		>500	2/4	2	200	21	173	65				A'	*
VS 37	ignimbrite	580	3/3	6	118	42	145	44	117	6	28 N225	C_N	*
VS 37b	ignimbrite	580	4/4	4	120	34	130.5	37	104	9	15 N225	C_N	**
VS 38	ignimbrite	580-650	5/5	10	120	14	155	29	70	6	70 N240	C_N	*
VS 42	ignimbrite I_2	580-610	3/3	5	161	-53	117.5	-55	37	13	30 N225	D	*
VS 43	ignimbrite I_2	500	3/4	6	324	-13	330	-6	65	8	35 N225	C_N	*
	(Molkenrain)	580-610	4/4	10	166	-45	125	-52				D	convergence
VS 44	ignimbrite I_2	580-610	3/3	7	201	-41	116.5	-66.5	44	9	55 N230	D	*
VS 67	ignimbrite I_2	580-610	6/6	7	175	-49	73	-64	350	7	55 N205	D	**
VS 87	ignimbrite I_2	580-610	4/7	7	143	-43	79	-55	47	9	50 N190	D	**
		580	1/7	2	198	17	199	-32.5				A'	
VS 88	ignimbrite I_2	580-610	8/9	9	162	-35	99	-59	39	8	55 N200?	D	**
		500	1/9	2	61	-13	66	28					
VS 97	ignimbrite I_2	580-610	5/6	10	98	-63	59	-53	48	7	25 N190	D	**
VS 97b	ignimbrite I_2	590-600	5/5	8	116	-52.5	79	-48	322	3	30 N195	D	**
VS 97c	ignimbrite I_2	590-600	6/6	9	117	-57	69	-49	268	3	35 N195	D	**
VS120	ignimbrite I_2	590-600	9/12	14	184	-46	60	-52	49	5.5	70 N210	D	**
120b	volc-sedim (contact)	580	2/3	2	248	33	245	-26				B	
VS131	ignimbrite I_2	400-550	3/11	8	69.5	-27	64	16	56	7	60 N195	B	**
		590	3/11	7	115	-47	63	-25	61	8		D	
		590	4/11	6	141	23	145	-15	24	10		$C_P - C_0$	
VS143	ignimbrite I_2	500	6/6	5	218	18	218	-17	201	5	35 N210	A'	**
		580	6/6	7	188	-32	167	-62	294	3		$A - D$	
		670	6/6	10	197	-22	188	-56	163	4		A	
VS133	ignimbrite	580	3/3	6	199	-5	162	-61	157	5	70 N225	$A - A'$	**
		>640	3/3	6	196	-19	132	-63	132	6		A	

Explanations see Tab.1.

the Middle Visean volcanic-sedimentary series (Fig. 1) exhibits also a single C_P component. In vaugnerites (VM 1) and the Crete granite (VM 4) from middle Vosges C directions predominate.

Close C_P directions, normal and reversed are present in pre-granitic diorites, in granites and in post-granite dykes. It is unlikely that such an orogenic area remained stable from 362 Ma (age of diorite VS *84*) up to 330 Ma (Ar-Ar plateau from lamprophyres, Boutin 1992). The presence of C_P directions in the different rocks means that diorites and dolerite have been remagnetized during intrusion of the Ballons granite and/or of the dykes. The mean C_P direction from 9 normal and reversed directions is:

D = 313°, I = 25° k = 36, α_{95} = 9° (VGP: 38°S, 71.5°E).

Sites VS 64, 85 display NW C directions with negative inclinations labelled C_n. The stereogramm reveals also mean site directions which look like typical Stephanian - Permian A directions (VS *62*, *83*, *85*). The gabbro VS *83* has a normal direction, the other directions were probably acquired during the reversed Kiaman interval. The mean A direction is:

D = 194°, I = -21°, k = 59, α_{95} = 16° (VGP: 51°S, 345°E).

A few WSW and opposite ENE directions with shallow inclinations were isolated in a small dioritic massif and doleritic dykes (VS *72*, *81-82*) intruded into the Devonian - Dinantian volcanic-sedimentary series. According to the nomenclature adopted in previous studies, these directions are labelled B. Taking also into account B directions from Vm 1 and Vm 4, the mean B is:

D = 68°, I = -6°, k = 54, α_{95} = 17°, N = 4 (VGP: 12°N, 116°E).

Table 5: The uppermost volcanic-sedimentary series.

site	formation	bt °C	N/N_0	n	D_0	I_0	D_C	I_C	k	α_{95}	dip	a	comments
VS 16	trachyandesite	580	4/5	10	330	-38	336	16.5	14	13	60 N180	C_P	*
VS105	greywacke	280-320	3/8	5	242	8	261	-28	28	14.5	90 N180	B	** $N+R$
VS107	greywacke	300-400	3/3	7	213	24	215	-31	22	13	60 N188	A'	**
VS 1	rhyodacitic tuff	580	10/11	15	92	32	135	39	215	3	55 N215	C_N	*
VS 2	rhyodacitic tuff	550-570	4/12	10	59	-20	60	24	15	12	55 N200	B	*
VS 14	rhyodacitic tuff	500	6/6	10	68	58	161	51	63	6	55 N200	C_N	*
VS 15	rhyodacitic tuff	500-670	4/10	5	332	6.5	331	13	19.5	17	10 N200	$C_P - C_0$	*
VS 36	rhyodacitic tuff	500-580	6/6	11	137	41	129	46.5	117	6	10 N 10	C_N	*
VS 36b	rhyodacitic tuff	500-580	8/9	8	130	39	122	43	327	3	10 N 10	C_N	**
VS 60	rhyodacitic tuff	580 580	4/5 1/5	10 2	66 18	-45 -27.5	94 46	-27 -44	54 106	7 24.5	40 N325?	$D - B$ A'	**

Explanations see Tab.1.

Here also, the magnetization is carried by magnetite as shown by the 580° maximum unblocking temperature of specimens VS 82.12 and VS 72.41 (Fig. 6a).

The Late-Visean volcanic and volcanic-sedimentary units (Tabs. 2 - 5, Fig. 4)

Numerous investigated sites, and particularly andesites, exhibit a component close to the present field direction with rather high maximum unblocking temperatures of 400° to 550 °C. As a consequence of these high temperatures the late overprint remains sometimes the sole component (VS 49, 50, 51, 57). Despite of their apparent freshness, the basic volcanics are more subject to this late overprinting than acidic. In several sites was found a post-tectonic direction nearly opposite to the present field (J, Fig. 2: VS 52*). These postulated postTriassic directions are excluded from this study and not listed in tables. On the density diagramm the remaining mean in situ directions display several normal and reversed populations corresponding to the A, A', B, C_P, C_n already defined (Fig. 5b). D directions with high inclinations obtained in the Molkenrain ignimbritic layer are not plotted.

The post-tectonic A directions (Fig. 4a)

In situ A directions were mostly found in ignimbrites and tuffs with a reddish pigmentation (VS 31, 40, 41, *133*, *143*). The high unblocking temperatures (≥620 °C) reveal haematite as remanence carrier. As the tectonic correction scatters significantly the directions, the corresponding magnetizations are clearly post-tectonic overprints. The mean in situ A direction in volcanics:

D = 197°, I = -24.5°, k = 29, α_{95} = 9.5°, N = 9 (VGP: 52°N, 159°E)

is very consistent with the A mean obtained in intrusives.

The post-tectonic A' and B directions (Fig. 4b)

The A' in situ directions show declinations similar to A but positive inclinations. In andesites (VS 34*, 61*), volcanic-sedimentary layers (VS *104*, *107*, *121*, *129*, *130*, *132*), ignimbrites (VS 7*, *123-126*, *143*) and latites (VS *118*, *135*), the maximum unblocking temperature is mostly around 580 °C, indicating magnetite as carrier of the remanence (VS 118.64; Fig. 6a). Low and high temperatures were respectively found in greywackes (VS *107*) and latites (VS 26). The negative fold test (Fig. 4b) is in favour of a post-tectonic acquisition of the magnetization. The mean in situ A' direction is:

D = 208°, I = 27°, k = 44, α_{95} = 6°, N = 15 (VGP: 23°N, 157°E).

The B in situ directions are mainly normal, with ENE declinations and negative inclinations. Reversed B show inclinations comparable to A'. B directions occur in different rock types, independently of the stratigraphic position, as andesites (VS 35*, 52*, 61*), latites (VS 48*, *118*), rhyolites (VS 96), ignimbrites

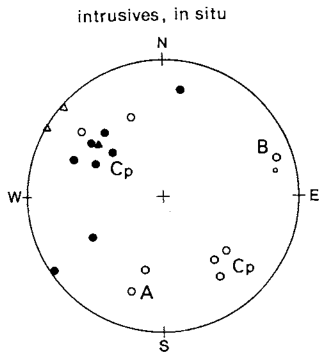

Fig. 3. Stereographic projection of the mean directions obtained in intrusives from the southern Vosges (Tab. 1, excepted D directions). Symbols are the same as in Fig. 2.

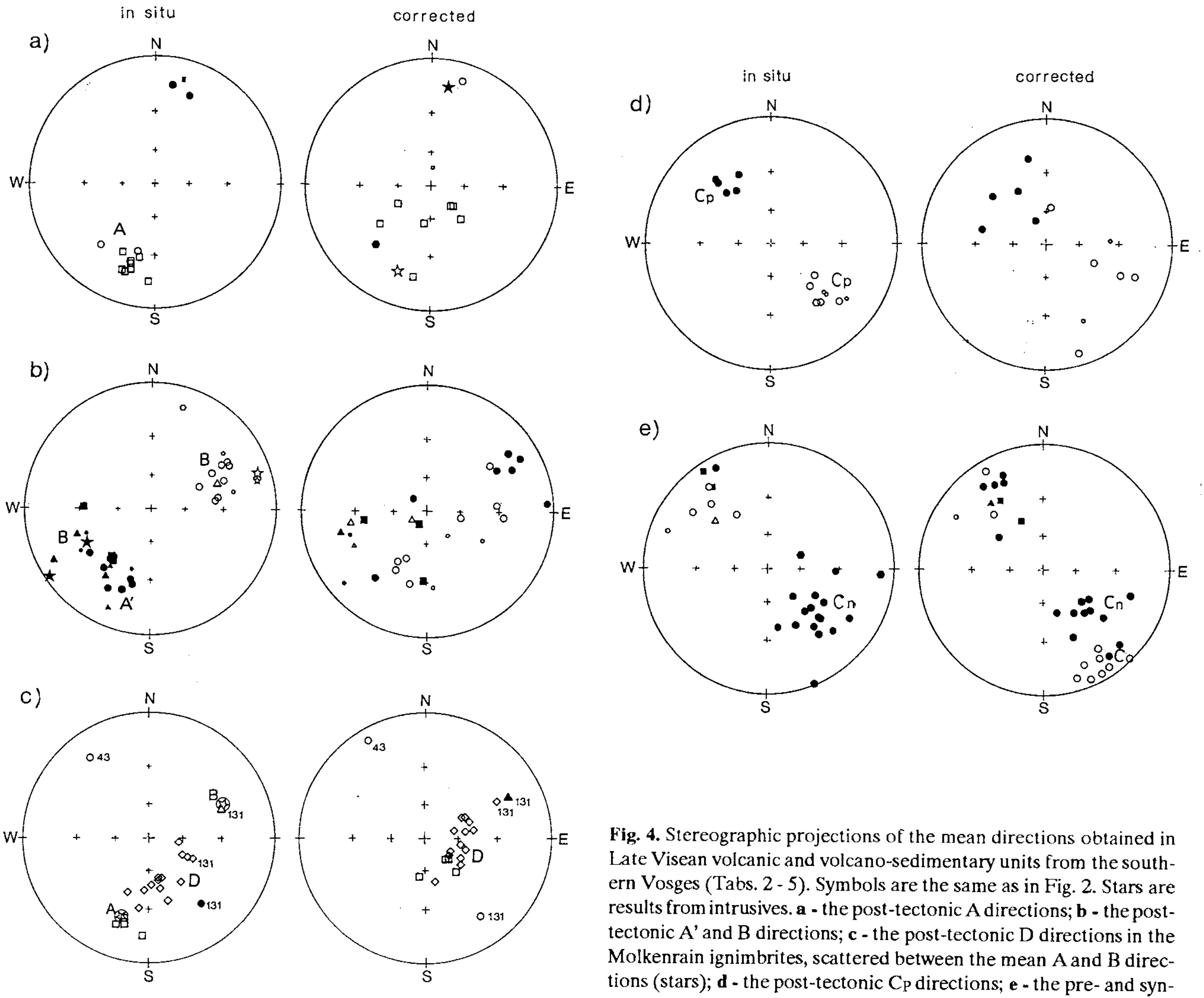

Fig. 4. Stereographic projections of the mean directions obtained in Late Visean volcanic and volcano-sedimentary units from the southern Vosges (Tabs. 2 - 5). Symbols are the same as in Fig. 2. Stars are results from intrusives. **a** - the post-tectonic A directions; **b** - the post-tectonic A' and B directions; **c** - the post-tectonic D directions in the Molkenrain ignimbrites, scattered between the mean A and B directions (stars); **d** - the post-tectonic Cp directions; **e** - the pre- and syntectonic C_n and C_0 directions.

(VS 20, *131*), volcanic-sedimentary layers (VS *134, 137-138, 142, 105*) and rhyodacites (VS 2*, 60*) (Fig. 2). In several sites, stable B directions were found in specimens from a sole sample (VS 29, 32*, *88, 141*), the other directions being later overprints generally consistent with post-Triassic directions of the same region. Unblocking temperatures are low to intermediate, mostly up to 580 °C. In rhyolites from VS *96* the high temperatures indicate haematite as carrier of the reversed B magnetization. As for the previous A and A' in situ directions, the tectonic correction splits the B cluster (Fig. 4b). The presence in conglomerates (VS *137-138*) of B directions in the fine-grained matrix and in part of the decimetric volcanic pebbles confirms the secondary acquisition of the magnetization. B overprinting was not a local effect; the whole investigated area is concerned (Fig. 6a). When excluding the site directions from a sole sample, the mean B direction is:

D = 66°, I = -28°, k = 40, α_{95} = 6°, N = 14 (VGP: 4°N, 125°E).

The D directions (Fig. 4c)

They occur in the upper ignimbritic 12 layer of the Molkenrain (Fig. 1) and are characterized by in situ declinations in the range 100 - 200 °C and high inclinations of 40 - 60 °C. Maximum unblocking temperatures of 580 - 610 °C and a reddish pigmentation restricted to fiammes in several sites suggest titano-haematite or haematite as carrier of the magnetization. Four sites (VS 40, 41, *133* and *143* display an additionnal A direction with clear high temperatures of haematite. On the other side, two sites (VS *88, 131*) show low to intermediate temperature B directions. The tectonic correction improves the cluster but the fold test is not significant (k1/k2= 16.5/14). The mean direction after tectonic correction,

D = 88°, I = -60° k = 16.5, α_{95} = 9°, N = 15

has a high inclination inconsistent with Carboniferous palaeolatitudes. Two interpretations may be proposed. 1- the D directions are B overprints acquired when the ignimbritic layer was tilted by about 40° toward NNE and tilted back toward SSW afterwards; 2 - the in situ directions are scattered along the great circle defined by the mean A and B directions. Consequently, they are interpreted as B magnetizations more or less overprinted during the period corresponding to the A magnetization (Permo - Triassic), and in the same range of blocking temperatures. Despite of the great stability of the magnetization, which explains why this layer was sampled so extensively, the D direction is a resultant of B and A directions and not a primary magnetization as expected.

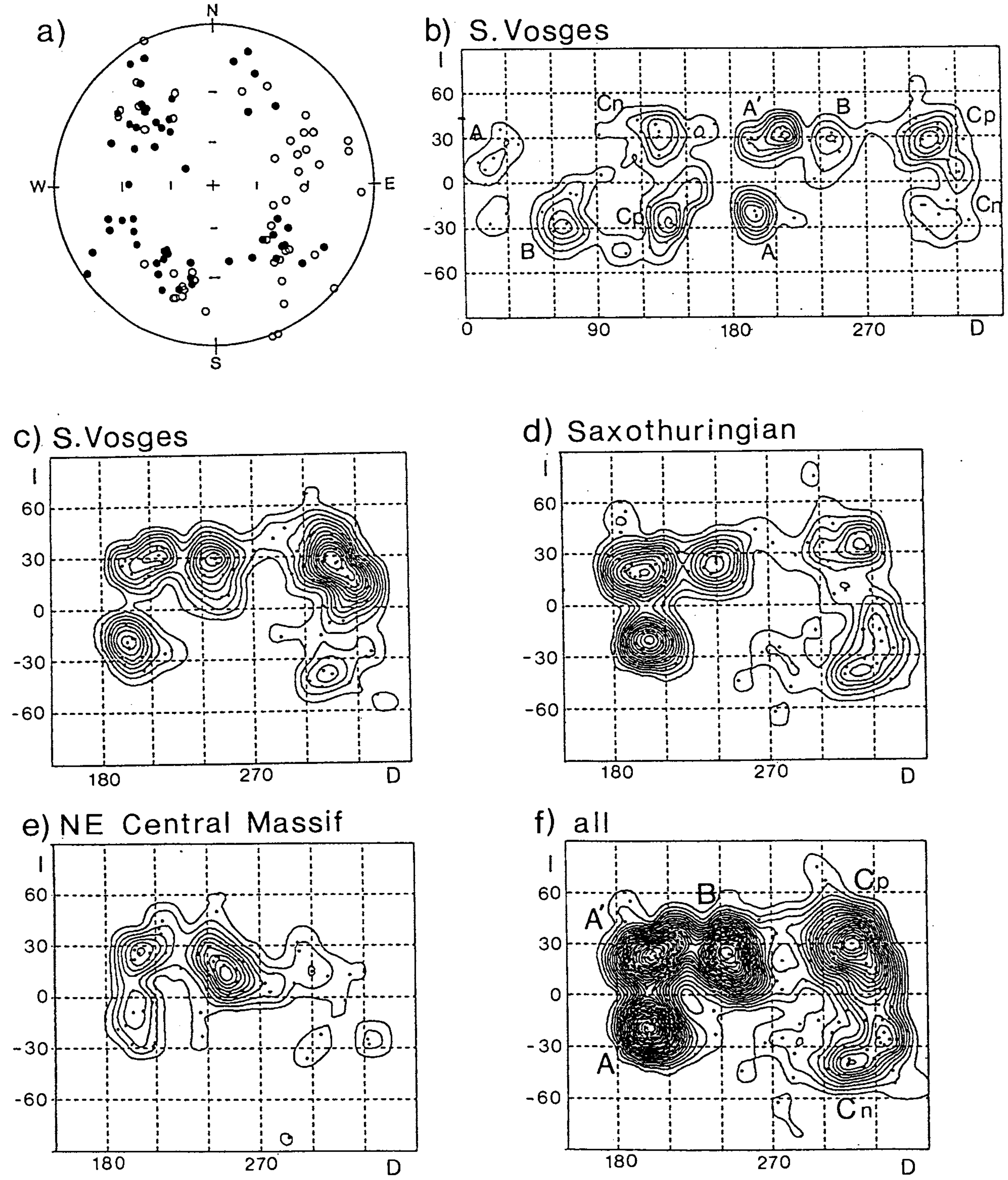

Fig. 5a. Stereographic representation of characteristic mean in situ directions from S. Vosges (excepted D directions).
Open (closed) symbols represent projections upper (lower) hemispere; **b** - density contour maps (Lewandowski 1992a) of the mean in situ directions (from 5a); **c** - density contour map of the mean in situ A, A', B, and C_P directions and the tilt corrected C_0 and C_n directions from S. Vosges, with the eastern hemisphere reversed; **d** - the Saxothuringian N. Vosges, Odenwald and Spessart (Edel & Wickert 1991); **e** - NE Central Massif (Edel et al. 1981; Edel 1987a); **f** - all directions (b, c, d), without taking into account the distances between the different areas.

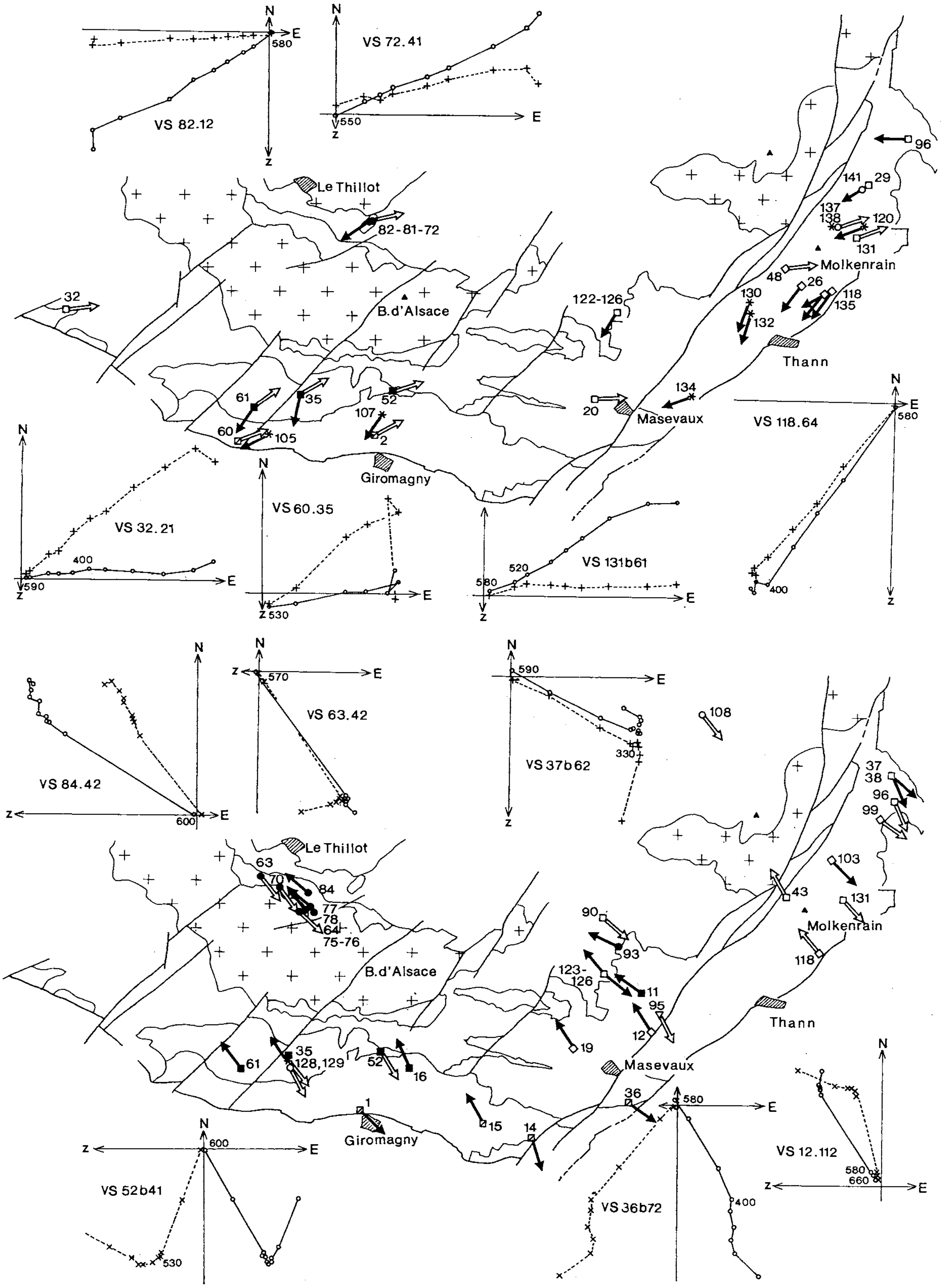

Fig. 6. Geographical distribution and typical orthogonal projections of thermal demagnetizing of:
a - A' and B directions; and **b** - C directions from the southern Vosges. See symbols and geology in Fig. 1. Open arrows show directions with negative inclinations.

In the present stage we favour the second hypothesis. In two sites (VS *97* and *120*) the stable D directions show an elongated distribution along the great circle defined by the mean A and B directions. The rocks in which the reddish pigmentation is weakly spread out show D directions closer to the mean B than to the A (Fig. 4c), while the reddish rocks display D directions closer to A, and in some cases an additionnal A component carried by haematite. In the latter case, the contribution of the B component to the D magnetization is weak while that of the A is high (VS *143*). On the contrary, in VS *88* and *131*, the oxydizing process, characteristic of the A period, has spared the sites and a low to intermediate temperature B component is still present.

The pre-, syn- and post-tectonic C directions (Fig. 4d, 4e)

The C northwesterly and southeasterly directions are widely distributed over the whole investigated area (Fig. 6) and concern as well lower as upper series. The maximum unblocking temperature of 580 °C indicate magnetite as carrier of most C directions. Three populations may be distinguished.

1 - The first group consists of normal and reversed in situ C_P directions already evidenced in intrusives (Figs. 3, 4d). These directions are dispersed after tilt correction (Fig. 4d). Consequently, the magnetizations were acquired after the Latest Visean major tectonic phase. The mean in situ C_P direction is:

$D = 318°, I = 29°, k = 46, \alpha_{95} = 7°, N = 11$.

2 - The second group is represented by southeasterly directions with positive inclinations found in two ignimbritic layers (VS *125*) and (VS 37*, *37b*, 38*), and in the uppermost rhyodacitic layer (VS 1*, 14*, 36*, 36b), labelled C_n (Fig. 4e). The positive fold test (k2/k1 = 37/15) is in favour of a pre-tectonic acquisition of the magnetization. The mean C_n is:

$D = 138°, I = 40°, k = 37, a_{95} = 9°, N = 8$.

The directions of VS *118* and VS 43* fall into the reversed C_n group after tectonic correction.

3 - The third group is a composite group consisting of C directions of both polarities from different rock types (VS 11*, 12, 15*, 19*, 16*, 43*, 52*, *96, 103, 118, 123-126, 128, 131*) and for which the fold test is unclear (Fig. 4e). Part of the in situ directions are close to the mean C_n direction (VS 52*, *103, 123-126, 128*) and its opposite direction (VS 11*, 16*, 43*, 61*, *128*). The other show flat positive and negative inclinations (VS 12, 19*, 15*, *118, 96*). After tectonic correction, the directions fall partly into the C_P group and partly into a group with flat inclinations that will be labelled C_0. The mean C_0 direction is:

$D = 325°, I = 4°, k = 30, a_{95} = 8°, N = 12$.

To explain this important variation in inclinations, a latitudinal drift of nearly 40° is excluded for a period which does not exceed 15 Ma. In the present stage of knowledge two solutions may be proposed: **1** - part of the C directions correspond to composite magnetizations as it was observed for the D directions. For instance, secondary northwesterly C_P directions may be intermediate to C_n and a post-Triassic to present directions, or a composition of normal and reversed C directions. **2** - In the Late Visean, volcanism and tectonics were contemporaneous. Part of the C_0 directions are likely syn-tectonic overprints acquired during this tectonic activity and/or during the Latest Visean (Sudetian) compression phase. Polyphased tectonics affected the units. The scenario-tilting magnetic overprinting - backtilting is possible in an area which has successively undergone distension, compression and distension again. In the present stage of knowledge we favour the explanation of syntectonic overprinting as responsible for the scatter in inclination of the C directions.

Comparison with results from neighbouring massifs

Volcanics of the same type and the same age as in the southern Vosges have been investigated in N and NE Central Massif (Edel 1987 a,b) and in the Schwarzwald (Edel 1987b). Visean intrusives as granodiorites, diorites, rhyolitic and lamprophyric dykes provided reliable results in the NE Central Massif (Edel 1987a), northern Vosges, Odenwald and Spessart (Edel et al. 1986; Edel & Wickert 1991). Initially, the objective of these investigations was to detect relative block rotations and bending due to the Variscan convergence. In fact, the results look very similar in the different massifs (Fig. 5).

A directions

They were found in Late Devonian - Early Carboniferous units from all investigated massifs but are consistent with directions obtained in Permian volcanics and Early Triassic sandstones from NE France and SE Germany (Roche et al. 1962; Konrad & Nairn 1972; Edel 1993). The overall mean VGP 50°N, 154°E corresponding to the A cluster (Fig. 5e) falls between the Late Permian pole (49°N, 159°E) and the Early - Middle Triassic pole (52°N, 150°E) computed by Van der Voo (1990) for Europe. Consequently A overprinting occurred in Late Permian - Early Triassic time, mainly during the Kiaman reversal. Predominance of high unblocking temperatures due to secondary haematite indicate low temperature hydrothermal weathering processes (Edel & Wickert 1991) which are correlated with Ar-Ar ages in the range 220 - 250 Ma evidenced for plagioclase from palaeomagnetic sites (Boutin 1992).

A' directions

They are characteristic for dykes from Spessart and Pfalz (Edel & Wickert 1991), a rhyolite dated at 296 ± 5 Ma from the Central Schwarzwald (Edel 1987 b; Lippolt et al. 1983), and a Late Carboniferous granite cooled at 300 Ma from NE Central Massif (Edel 1987 b). In the Armorican Massif, Late Carboniferous granitic plutons of Tregastel-Ploumanach and Flamanville emplaced around 300 - 308 Ma display also A' directions (Van der Voo & Klootwijk 1972; Duff 1979; Cogné 1988). Such directions were found as overprints, posterior to the Latest Visean compression phase, in Early Carboniferous plutonics and volcanics from Spessart, Odenwald, S. Vosges and NE Central Massif. The overall VGP (27°N, 163°E) derived from density diagrams is close to the mean Cm, Cl, Du/Cl pole of Europe (Van der Voo 1990; Torsvik et al. 1991). The polarities are mainly normal in intrusives from Saxothuringian Odenwald and Spessart and reversed in the volcanics from Moldanubian Vosges and intrusives from NE Central Massif.

B Directions

ENE normal B directions are characteristic of Carboniferous ignimbrites and flows from NE Central Massif (Manzat and Roannais; Edel et al. 1981; Edel 1987 b), Schwarzwald (Münstertal; Edel 1987 b), southern (this study) and northern Vosges (Edel et al. 1986) (Fig. 7). The corresponding magnetizations are clearly post-tectonic in the southern Vosges. In the monoclinal ignimbritic tuffs of Manzat (Mz, Fig. 7) and the Pouzol-Servant (PS) laccolith which are both expressions of the same magmatism, the directions are not significantly different before and after tectonic correction and the direction are B in both cases. Concerning the anthraciferous tuffs

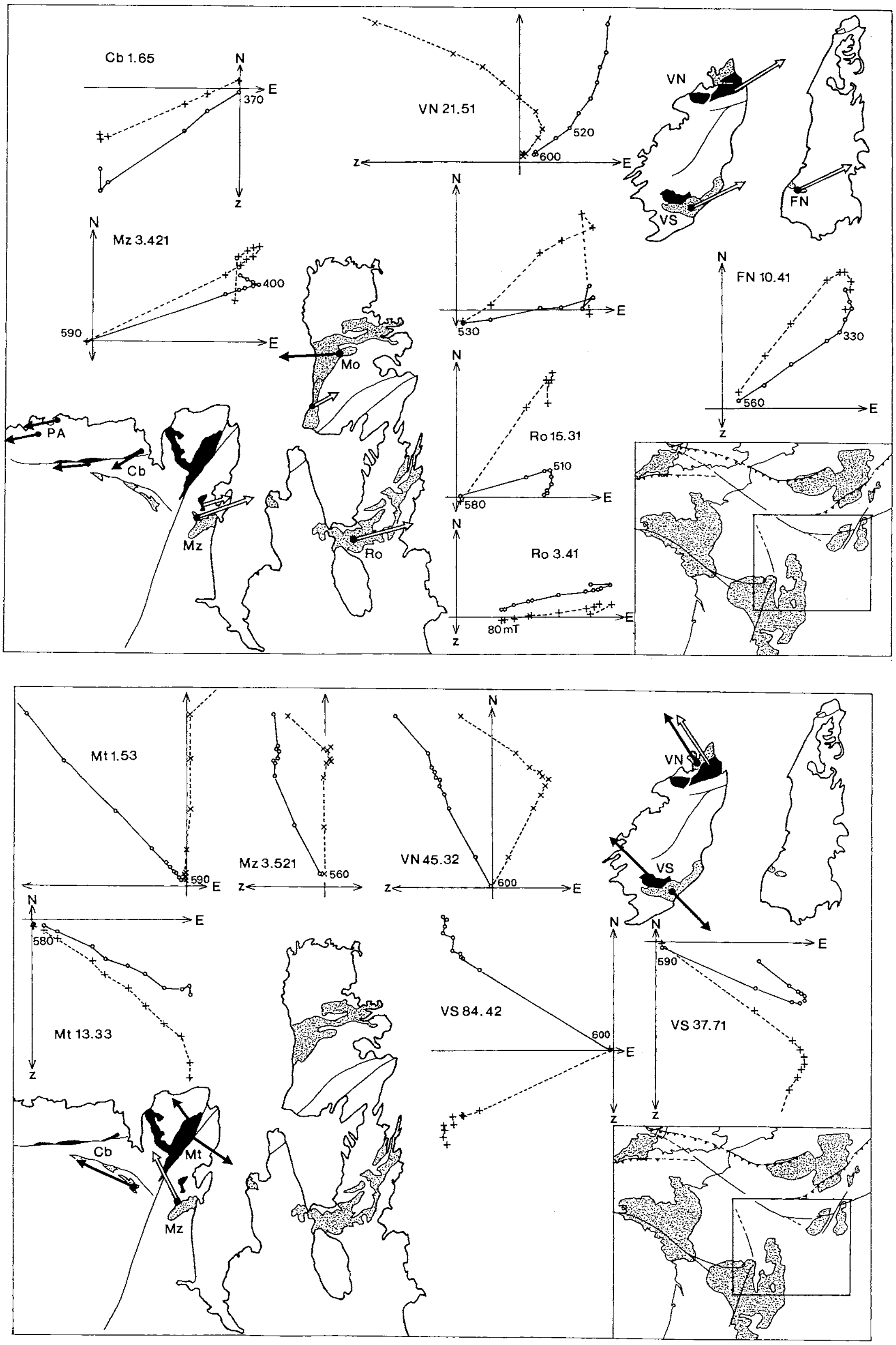

Fig. 7. Geógraphical distribution and typical orthogonal projections of thermal demagnetizing of: **a** - B directions, and **b** - C directions from the central part of the Variscan belt. Variscan intrusives are in black and Late Visean volcanics in grey.
Small arrows indicate directions from individual sites, long arrows indicate mean directions from at least 2 sites. Open arrows show directions with negative inclinations. VS: southern Vosges (this work), VN: northern Vosges (Wickert et al. 1991), FN: Schwarzwald (in Edel 1987b), Ro: Roannais, Mo: Morvan (Edel et al. 1981), Mz: Manzat, Cb: Combrailles, PA: Aigurande Plateau (Edel 1987a).

of the Roannais (Ro, Fig. 7), a tilt correction leading to B directions is only necessary for the units affected by the Tertiary graben tectonics. In sites with the Variscan strike, the fold test is not significant, but the mean direction is B, before and after tilt correction. In the Münstertal ignimbrites (FN, Fig. 7), the Rhenish strike of the bedding affects only the inclinations of the characteristic B directions, which are around -45° before and -18° after tectonic correction (Edel 1987b). Tilting being likely post-Carboniferous, the corrected B direction is considered as the good one. B normal directions are also characteristic of a rhyolitic dyke associated to a leucogranite emplaced around 328 Ma in the N. Vosges and of its host rocks (VN 21.51, Fig 7a) (Edel et al. 1986; Boutin 1992). In plutonics from Odenwald, the B normal and reversed directions correspond to post-crystallization overprinting partly carried by haematite (Edel & Wickert 1991). B overprints with a reversed polarity were also observed in amphibolites from the Aigurande Plateau (PA, Fig. 7a) intruded around 312 Ma by leucogranitic plutons, and in diorites outcropping along the Marche fault (Cb, Fig. 7a) (Edel 1987a).

In general, radiometric dating by K-Ar and Ar-Ar processing on biotites from palaeomagnetic sites with B directions has exhibited ages in the range 307 - 330 Ma (Edel 1987b; Edel & Wickert 1991; Boutin 1992). The B directions have been emplaced after the Late Visean folding phase, in the Namurian - Westphalian.

When plotting all directions from different areas together (Fig. 5e), the mean direction corresponding to the B cluster (6°N, 121°E) is not consistent with the Middle Carboniferous poles of Europe but nearly with the Silurian - Devonian poles (Van der Voo 1990; Torsvik et al. 1992).

C directions

In Central Massif these directions are less frequent than the B. Two sites from the Montmarault granite and its mafic inclusions display typical C_n directions (Mt 13.33, Fig. 7b) and a third site has opposite C_o directions with flat inclinations (Mt 1.53, Fig. 7b). The Late Visean tuffs of Manzat show also C_o in situ directions (Mz 3.521, Fig. 7b) in addition to the B (Mz 3.421, Fig. 7a) already mentionned. After tilt corrections, the C_o become C_n. In the Saxothuringian zone C_n, C_P and C_o directions coexist (Fig. 5c). In intrusive rocks and green schists from N. Vosges the C_P components are characterized by low to intermediate unblocking temperatures. The negative fold test indicates overprinting (Edel & Wickert 1991). The nice stable C_n directions from mafic and acid intrusives of the Champ du Feu batholite (VN 45.32, Fig. 7b) and of the N. Spessart metamorphics are respectively characterized by magnetite and haematite temperatures. SSE directions which may be considered as C_n were exhibited in Middle Devonian - Early Carboniferous sediments and volcanics from the Harz mountain, 500 km NE of the Vosges (Bachtadse et al. 1983).

Concerning the ages of rocks with C_n directions, Ar-Ar and K-Ar ages of biotite in the range 330 - 340 Ma were obtained in the Champ du Feu batholite (N. Vosges) (Wickert & Eisbacher 1988). A consistent age of 337 Ma was found for the Molkenrain ignimbrite (S. Vosges) (Montigny et al. 1984) which displays secondary D directions, a C_n direction in VS 43 and a C_o direction in VS 136. Similar volcanics from NE Central Massif, the tuffs of Manzat dated at 330 Ma, show also both C_o-C_n and B directions. As the B are interpreted as overprints, the age of 330 Ma may be referred to the older C directions. The secondary C_P directions which are characteristic of the S. Vosges intrusives (Fig. 3) may correspond to the numerous Ar-Ar plateaux around 330 Ma obtained on intrusives from southern and middle Vosges and which are interpreted as cooling ages related to uplift (Boutin 1992).

Discussion

The reliability of the A, A', B and C directions

The common palaeomagnetic signature in Late Devonian - Carboniferous rocks from an orogenic belt sets the problem of the significance of the different directions. Are they real or artefacts? A and A' directions clearly represent overprints. The B directions are mostly recognized as overprints in Late Visean volcanic and volcano-sedimentary layers. The C_P directions are overprints in Late Devonian - Visean intrusives from S and N Vosges. In volcanics from S.Vosges a few C_P may be primary; most are secondary. The C_n are the sole which show a positive fold test in pyroclastic layers from S. Vosges. For discussion, the corresponding pole positions are presented against the APWP for Baltica (Fig. 8), which has been constructed by means of GMAP plot package (Torsvik et al. 1990), using cubic splines to smooth the path. Pole positions selected by Torsvik et al. (1991) and suplemented by data of Smethurst & Khramov (1992) were used to the calculation of the path.

Above was shown that very stable magnetizations such as the D components of the upper ignimbrites from the S. Vosges are likely a resultant of two overprints. A confirmed pessimist could extrapolated this observation to all directions. It is clearly not the case for the nice in situ A cluster which mean pole is consistent with the Permian - Early Triassic poles of Europe (Fig. 8) and which is due to a low temperature oxydizing process (Edel & Wickert 1991; Boutin 1992). It is not more the case for the A' overprints which directions are not significantly different from A' primary magnetizations in intrusives emplaced around 300 Ma and which mean pole is consistent with the Early - Middle Carboniferous poles from Baltica (Fig. 8).

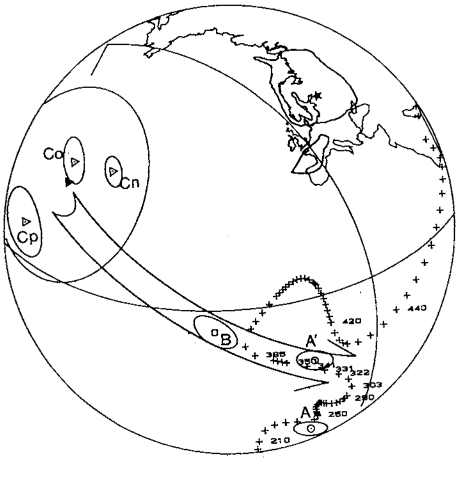

Fig. 8. Palaeomagnetic poles from S. Vosges (triangles, square and circles) against pre-Jurassic segment of APWP for Baltica (crosses) (Lewandowski 1993). Palaeopoles of Vosges are here interpreted as southern poles. Letter symbols denoting the poles are the same as in Tab. 6.
Solid triangle - mean palaeopole for C group with its α_{95} circle of confidence. Bold double arrows, drawn as a segment of circles around Eulerian pole(star), show the sense and amount of rotations of palaeopoles to match them with reference APWP. Baltica and Armorica plate are outlined by bold line. Schmidt projection.

The most frequent directions in Early Carboniferous rocks are the B and C directions. The good definition, the extension and the consistency of the B directions in rocks of the same age and the same type (the pyroclastites of Manzat, Roannais, S. Vosges and Schwarzwald cover a distance of 450 km) is remarquable (Fig. 7a). Both polarities are observed with a predominance of normal polarities. The hypothesis of a composite direction, made for instance of normal and reversed A directions, cannot be excluded but is highly unprobable. In the present stage of knowledge, these directions do likely reflect the magnetic field after the major Late Visean tectonic phase i.e. in Namurian - Westphalian time. In previous studies the B-A' deviation was interpreted as due to a global clockwise rotation of the belt (Edel 1987b).

The C_p directions could be matter of debate in the N. Vosges schists and intrusives, and in the S. Vosges volcanics where the overprints are characterized by low to intermediate temperatures. As in the case of the D directions, the eventuality of a composition of overprints, i.e. normal and reversed C directions, or normal and reversed A-A' directions, is not excluded. However, in the S. Vosges intrusives the predominance of antiparallel normal and reversed C_p components with magnetite unblocking temperatures (Fig. 3) supports the reality of these directions. The C_n and part of the C_o components show the best palaeomagnetic criterias: - very stable magnetizations; - magnetite unblocking temperatures in intrusives (Montmarault batholite in NE Central Massif, Champ du Feu batholite in N. Vosges) and volcanics (Manzat in NE Central Massif, S. Vosges); - haematite temperatures in metamorphics (Spessart); - a positive fold test in a few volcanic layers from S. Vosges.

Unfortunately, the present stage of the data precludes to draw definitive conclusions on the variable inclinations of the C directions. Syntectonic acquisition of the magnetizations and eventually composition of normal and reversed C directions seem to be the most reliable explanation. All three C directions are probably not reliable but definitive arguments leading to elimination of one or two of them are lacking. The significant result is that the declinations remain stable. This low scatter in declination allows to interprete the C-B deviation in terms of rotations.

Dating of magnetizations is not yet an exact science, particularly in an orogenic area. The carriers of magnetization and the dated minerals have different closure temperatures and variable sensitivity to secondary chemical processes (Boutin 1992). Nevertheless attempt can be made to correlate ages obtained on separate minerals from palaeomagnetic sites and characteristic directions. According to previous investigations (Edel et al. 1986; Edel & Wickert 1991) and recent dating of palaeomagnetic sites (Boutin 1992) the following sequence of directions may be proposed; C: 340 - 325 Ma, B: 325 - 307 Ma, A': 305 - 300 Ma, A: 280 - 220 Ma.

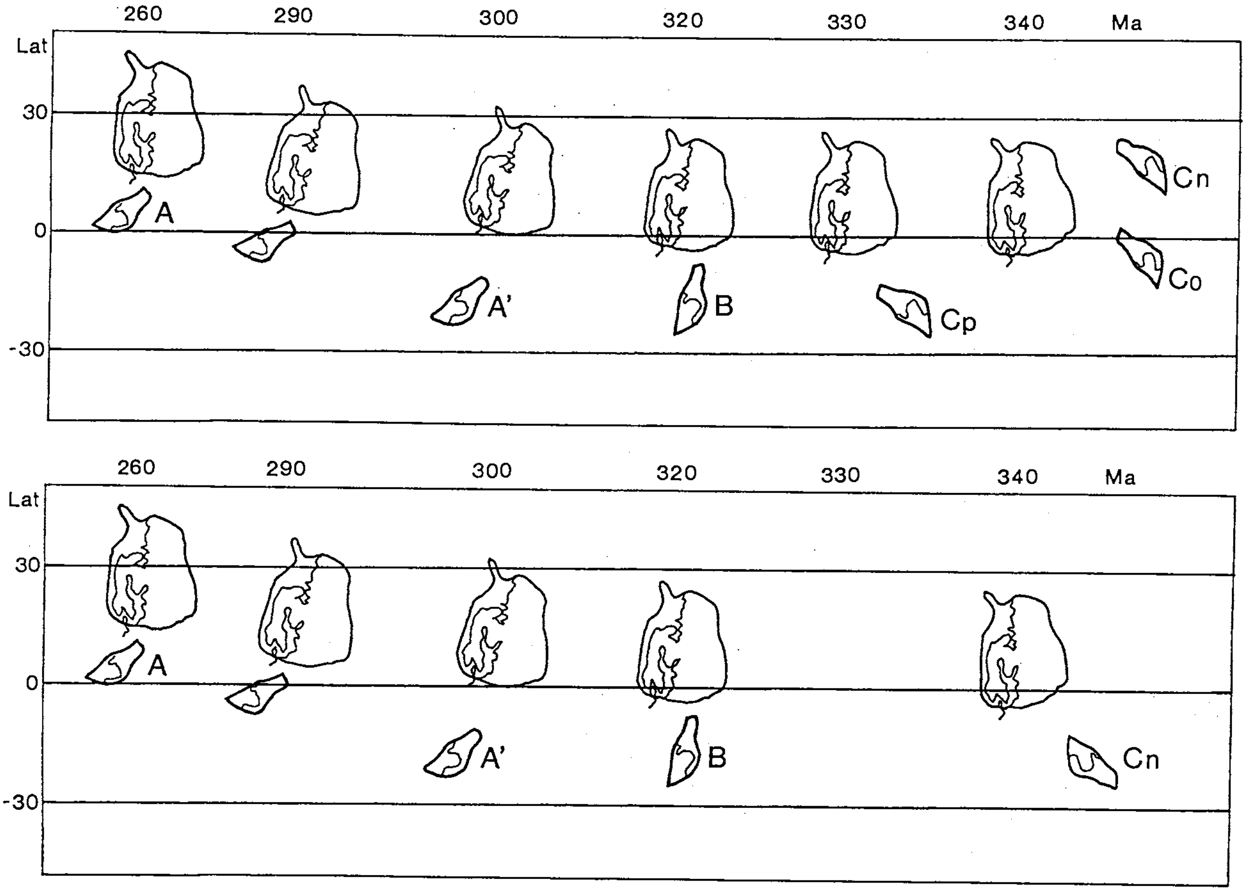

Fig. 9. Alternative palaeogeographic cartoons depicting approximate positions of Armorica and Baltica during Variscan orogeny when assuming Armorica as a uniform bloc and the APWP of Baltica as reliable. Armorica rotates clockwise around 310 Ma. Prior to 320 Ma the uncertainty concerning the inclination of the C directions leads to different possible evolutions: a clockwise rotation when taking the C_p-B deviation, and a counterclockwise with the C_n-B. Note that part of the rotations probably were accomodated by deformations inside the Variscan belt in relation with large dextral wrench-faulting. Dextral sense of general movement can be seen as Armorica is travelling toward palaeo-west. Galls projection.

Possible geotectonic interpretations of the deviated B and C directions

Generally, in order to coincide the position of poles C (taken as a mean pole for C_n, C_0 and C_P), B and A' with the corresponding time segment of APWP, they have to be rotated, respectively, by ca. 110, 45 and 20 degrees around pivot situated nearby Saint-Petersburg. Notably, such rotation is keeping in hand with the model developed for southern Holy Cross Mts. (S-HCM) by Lewandowski (1992), who have used the Eulerian pole 58°N/32°E for matching the Early Devonian palaeopoles with the APWP of Baltica. Since the Eulerian pole is laying out of the S. Vosges and other Variscan massifs, all have to be translated accordingly along small circle being drawn around the pivot of rotation, to restore their genuine, pre-Variscan position. Accepting that S. Vosges, Central Massif, Schwarzwald, Odenwald and Spessart were integral part of Armorica plate in Variscan time, the resulted "snap-shots" of palaeogeographic reconstructions for Armorica are portraited in Fig. 9. Each reconstruction of Fig. 9 has been made by precise matching of individual pole from Tab. 6 with time equivalent pole of reference APWP.

The consistency of the mean B pole with the Silurian - Devonian poles from Baltica instead with the Middle Carboniferous poles sets a problem (Fig. 8). Since the Early - Middle Carboniferous part of the N. Europe APWP is poorly documented and the age of the magnetizations is unclear, two solutions depending on the reliability of these poles may be proposed for the deviation from B to A'.

1 - The poles are not reliable. From the Silurian up to the Middle Carboniferous the N. Europe apparent poles have not moved significantly and the major drift from B poles to A' poles occurred in the Middle - Late Carboniferous. Consequently, there was no relative rotation, but a global rotation of both, the Variscan belt and northern Europe, subsequently to the collision of the Variscan belt with northern Europe, along the Variscan front .

2 - The Early - Middle Carboniferous poles of Baltica are reliable and the Variscan belt (Armorica) has undergone a clockwise rotation relative to Baltica. A 45° rotation with a vertical axis close to the Variscan front, implies the closure of a large gap that is not supported by geological data. The pole of rotation must be farther on. With a pivot in the central part of Baltica the movement becomes mainly a translation along the southerwestern margin of the plate compatible with the Late Variscan strike-slips (Artaud & Matte 1977). It is clear from Fig. 9 that from 290 Ma back in time, Armorica was situated gradually more and more to the east of Baltica and remained generally at the same palaeolatitude. The observed variations of palaeolatitude of Armorica, causing the appearence and vanishing the small oceanic domains, in between, may be either true geological events or artefacts caused by time error.

Due to the uncertainty relative to the inclination of the C directions, different models may be proposed. 1 - The deviation from C_P to B (70°) is also interpreted in terms of a clockwise rotation (Fig. 9a). The reconstruction on 330 Ma (C_P pole) is just the prior to dextral strike-slip displacement along the southern margin of Baltica (Teisseyre-Tornquist Line) and such a scenario is compatible with the strike-slip model for Variscides, as proposed by Badham (1982). The reconstruction according to C_n pole (340 Ma) has two solutions. Assuming C_n to be a north pole (Tab. 6), S. Vosges should have to be located on the palaeolatitude of 20°N, probably close to Kazachstan Plate and far away from expected position south of Baltica (Fig. 9a). On the other hand, if C_n was a south pole, S. Vosges were situated on the southern hemisphere, in a comparable palaeolatitude as B and C_P but in a position "reversed" by 180 degrees. If this reconstruction is true, then the C_P directions are not compatible and have to be omitted. The deviation from C_n to B directions then corresponds to a counterclockwise rotation.

The models of Fig. 9 show Armorica as a microplate. In fact the Variscan belt results from a large dextral shearing during Late Devonian - Carboniferous time (Badham 1982; Matte et al. 1990). Within the Variscan belt itself, a series of NW - SE dextral strike-slip faults with offsets in order of 100 to several hundred kilometers were active up to Middle Carboniferous (Edel & Weber in press). It is probable that the rotations evidenced by palaeomagnetism are partly accomodated by internal deformation of Armorica. Smaller blocks controlled by strike-slip faults may have rotated in the same way, so that the palaeomagnetic records look very similar in different parts of the belt. This may particularly be true for the early C-B rotations which occurred subsequently to the major Carboniferous tectonic phase.

Conclusions

Investigations in the S. Vosges Devonian - Dinantian Basin have exhibited a similar palaeomagnetic signature as in the Saxothuringian exposures and the NE Central Massif. Fold test applied to volcanic and volcano-sedimentary layers demonstrates that the A, A', B, D and part of the C directions are overprints acquired after the Late Visean tectonic phase (Sudetian). The common palaeomagnetic message recorded in Late Devonian - Early Carboniferous rocks from Central Massif to the Spessart has the following consequences.

Carboniferous to Early Triassic overprinting has affected at least 80 % of the investigated rocks. Carboniferous overprints (C_P, B, A') in volcanics and intrusives are mostly characterized

Table 6: Mean directions in latest Devonian - Early Carboniferous intrusives and Early Carboniferous volcanics from S. Vosges (47.8°N, 7.0°E).

magnetization	age Ma	n	D	I	k	α_{95}	N/R	VGP°N	VGP°E
A in situ	250-270	12	197	-22	75	5	2/10	-51	340
A' in situ	300-305	15	208	27	44	6	1/14	-23	337
B in situ	307-325	17	65	-20	18	8	11/6	8	123
C_P in situ	325-330	21	315	29	36	5	7/14	41	251
C_0 corrected	340-330	12	145	-4	30	8	12/3	-35	52
C_N corrected	340-330	8	138	40	37	9	8/1	-10	46
C mean		3	318	-2				29	237

n: number of within site means; N/R: normal/reversed directions. When N+R >n then part of the within site means was computed with normal and reversed directions.

by magnetite unblocking temperatures, while the Permo - Triassic overprints which are carried by secondary haematite result from a low temperature wheathering process.

Due to different rock types, magnetic minerals, grain size, chemical environment, the Visean units from S. Vosges and other massifs were differently prone to overprinting, and have acquired a stable magnetization more or less soon after emplacement. With exception of the D directions, the different groups of directions are considered as reflecting the magnetic field in Late Palaeozoic time. The S. Vosges units have recorded the apparent evolution of the field during a period of about 100 Ma (340 Ma - 240 Ma), and the C-B-A'-A sequence may be interpreted in terms of geotectonic evolution (Fig. 9). It is unclear whether overprinting was continuous or episodic. In the first case, the distinct clusters of palaeomagnetic directions would indicate rather fast motions.

The deviation from C directions to B is interpreted as due to a large rotation. The C_P-B deviation indicates a 70° clockwise rotation of the different massif, in the time range 330 - 315 Ma. When assuming a pole of rotation in the central part of Baltica the movement is mainly a dextral displacement along the southwestern margin of the plate. When taking the C_n directions instead of the C_P, the C_n-B deviation corresponds to a counterclockwise rotation of about 110°. In both cases a rotation pole within the Variscan belt implies regional bloc rotations, in relation with the large-scale dextral wrench-faulting that affected the belt in Late Palaeozoic time (Matte et al. 1990; Edel & Weber in press).

The B-A' deviation observed from the Armorican massif to the Spessart (Edel 1987b), results from a clockwise rotation by about 45° in the Westphalian, i.e. around 310 - 305 Ma. Due to the consistency of the mean B pole of the central Variscides with the Silurian - Devonian poles from Britain and to the poorly documented Early Carboniferous poles of northern Europe, two solutions are proposed: 1 - Northern Europe was stable from the Silurian up to the Late Carboniferous. Subsequently to the collision of the Variscides with northern Europe, both units rotated together, clockwise. 2 - Armorica rotated clockwise relative to Baltica and the pole of rotation was located within Baltica. The resulting motion was a large dextral strike-slip motion along the Teisseyre-Tornquist Line in continuity with the previous rotation. In both cases, the motion is correlated with the so-called Asturian phase.

The A'-A deviation. The previous motions occurred without significant change in palaeolatitude and the southern Vosges stayed at about 15°S, from the latest Visean to the Westphalian. On the contrary, the A' -A PWP indicates that from the Stephanian to the Late Permian - Early Triassic, the motion was mainly a northward drift from 15°S to 12°N. The equator was crossed around 290 Ma.

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