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Paleomagnetic study of upper carboniferous volcanics from Sudetes (Poland)

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Abstract. Upper Carboniferous and Permian volcanites from Sudetes were sampled in 11 localities (mean site coordinates: 50.8° N, 16.3° E). Thermal demagnetizations of the samples showed several magnetic components. But in one site, all high-temperature components are reversed. The interpretation of the results shows a first, primary magnetization acquired probably in the Upper Carboniferous before tilting ($N=8$, $D=192°$, $I=-2°$, $k=27$, $\alpha_{95}=11°$, pole: 39° N, 181° E) and a remagnetization acquired later, during or after tilting ($N=5$, $D=190°$, $I=-19°$, $k=18$, $\alpha_{95}=18°$, pole: 48° N, 181° E).

Key words: Paleomagnetism – Carboniferous – Permian – Sudetes – Poland – Remagnetization

Introduction

As time goes on, it is more and more evident that Carboniferous and older rocks are remagnetized and contain several magnetic components (Kim and Soffel, 1982; Perroud et al., 1984; Edel and Coulon, 1984; Tarling, 1985; Courtillot et al., 1986; Edel, 1987). Thus, many results, obtained several years ago, need to be reworked. In the scope of unravelling the deformation of the Hercynian fold belt we have resampled the Upper Carboniferous rocks from Sudetes. These were originally studied by Birkenmajer et al. (1968), but they used AC demagnetization only in a limited way and did not look for different magnetic components.

Geology

The Inner Sudetic Depression is an elongated syncline of north-west-southeast direction. It is a variscan structure accentuated by bordering faults reactivated in younger geological times. Since the Visean, the Depression was an area of deposition of mainly detritic and fresh-water sediments throughout the Upper Carboniferous to Permian and into Lower Triassic times.

The Inner Sudetic basin was initiated as a result of late Bretonic movements, but the main earth movements were the Erzgebirgian and Asturian phases. Repeated movements occurred from Westphalian B through Stephanian. Further distinctive movements during the Lower Permian are assigned to the Saalian phase.

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The more important stages in the tectonic history of the basin were accompanied by volcanic activity. The earliest one (Tournaisian-Visean) was not very marked and was not sampled. The main volcanic phases accompanied the Asturian movement and the final Saalian phase.

We sampled mainly in the Late Carboniferous magmatic formations (Fig. 1). These are mainly felsite porphyritic effusives (sites 1, 2, 4, 5, 8, 9, 10, 19) and sometimes intrusive necks and laccoliths (6, 7, 13). All the outcrops are not equally well dated, but the eruptives usually overlay or cut Westphalian B sediments dated by macrofloras in nearby coal mines (2, 4, 5, 13) or cut Namurian A levels (19). They are overlain by Westphalian C or D (8) or by Lower Permian redbeds (2, 4, 5). The other outcrops are dated by similarity with the former (1, 6, 7, 9, 10). The Permian volcanics are melaphyre sills and we sampled them only in one locality (Gluszyca, sites 11 and 12). The folding was usually not very important. It gave the sampled localities a general south-west dip of about 40°. For each locality the mean magnetic directions were corrected according to the local bedding plane, assuming that the fold axis was horizontal.

Sampling and measurements

The sampling and the measurements were always doubled by the Polish and French teams. One set of samples was taken as hand samples and another set by a portable drill. In both cases the samples were oriented with a magnetic compass and often with a sun compass. The samples were spread as widely as possible in order to cover the whole outcrop. About 110 separately orientated samples were taken in ten localities. The samples were cut into 25-mm-diameter, 22-mm-height specimens.

The measurements were done in Strasbourg with a Digico spinner magnetometer and in Warsaw with a Jelinek JR4. AC and thermal demagnetization were done in coil or screen-compensated free-field spaces in both laboratories. The demagnetization paths were analysed with Zijderveld plots. The different magnetic components were determined by least-square methods either on intervals chosen by eye or by automatic determinations (Kirschvink, 1980). Some demagnetizations were checked with the Kent et al. (1983) LINEFIND program. Several specimens from the same hand samples were measured and demagnetized in Warsaw and in Strasbourg in order to cross-check methods. The results are always very similar.

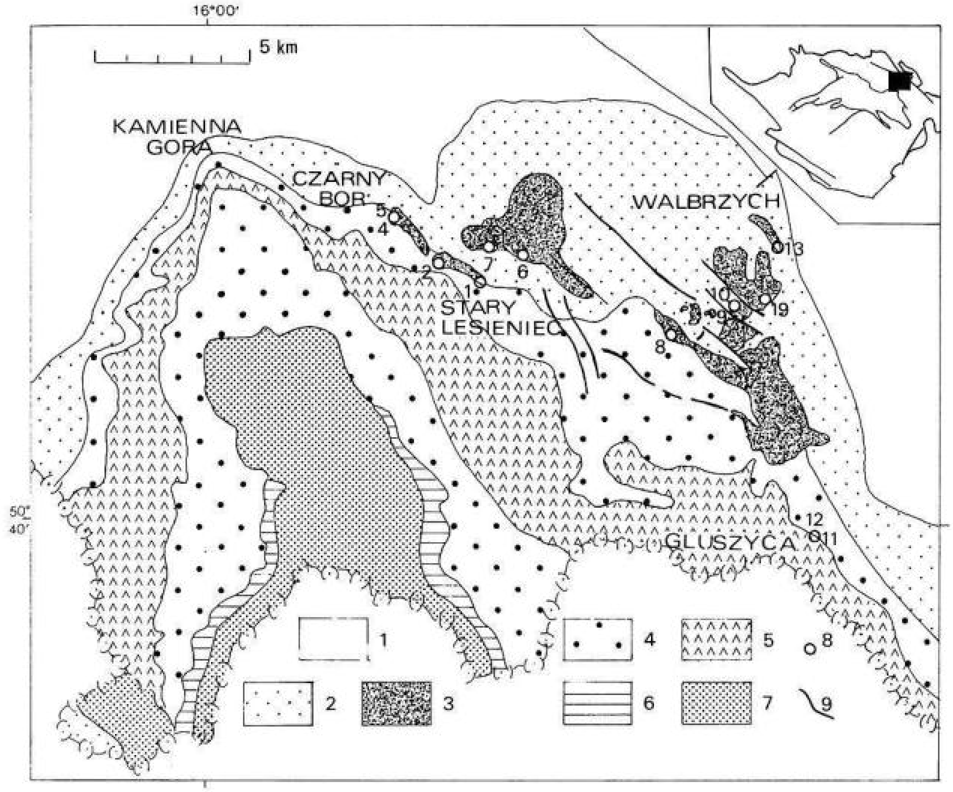


Fig. 1. Geological map and sampling sites in the Sudetes. In *the corner* is the outline of the Bohemian Massif. *1:* Lower Carboniferous sediments; *2:* Upper Carboniferous sediments; *3:* Upper Carboniferous volcanites; *4:* Lower Permian sediments; *5:* Lower Permian volcanites; *6:* Upper Permian sediments; *7:* Triassic to Cretaceous sediments; *8:* Sampling sites; *9:* Main faults

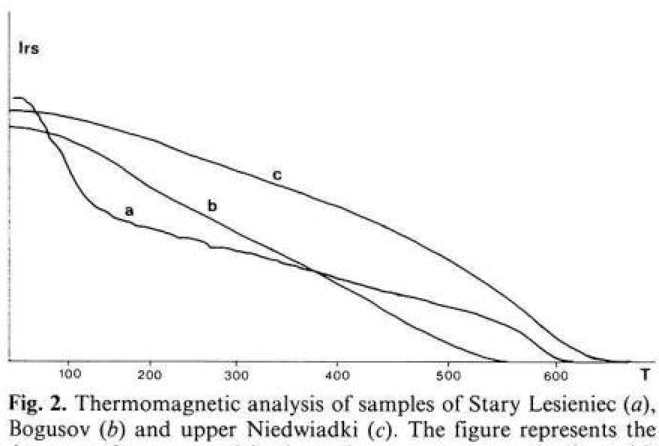


Fig. 2. Thermomagnetic analysis of samples of Stary Lesieniec (*a*), Bogusov (*b*) and upper Niedwiadki (*c*). The figure represents the decrease of a saturated isothermal remanent magnetization with temperature

Rock magnetism

Together with the classical thermal demagnetization, a continuous thermal demagnetization of a saturated isothermal remanent magnetization was done on selected samples (Fig. 2). They show mostly a single haematite (curve c) or magnetite (curve b) blocking temperature and sometimes a first phase with a lower blocking temperature (curve a). During the thermal demagnetization of the NRM, the low-field susceptibility was measured after each step. This shows two different behaviours (Fig. 3). For some samples the susceptibility decreased sharply between 300° and 400° C, showing an irreversible transformation (Fig. 3a). This is especially the case for Stary Lesieniec, where three magnetic components coexist. For other samples the susceptibility was stable up to 500° C, where it increased sharply (Fig. 3b).

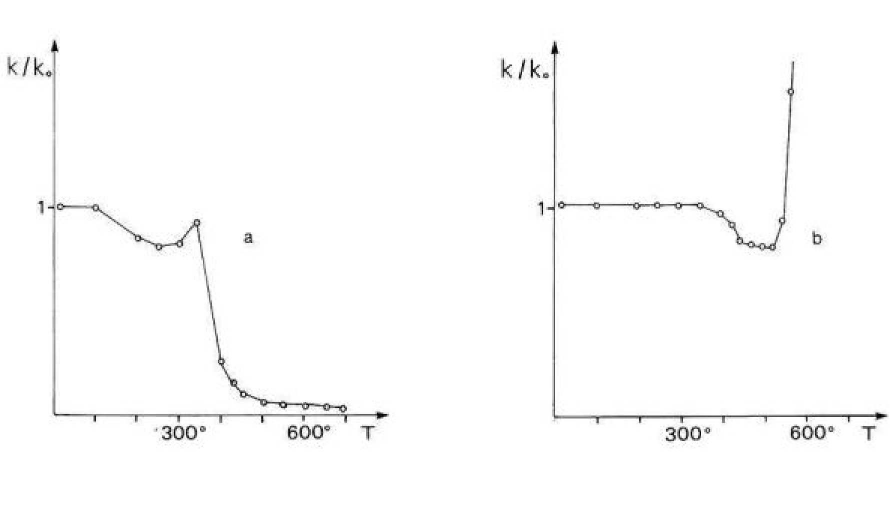
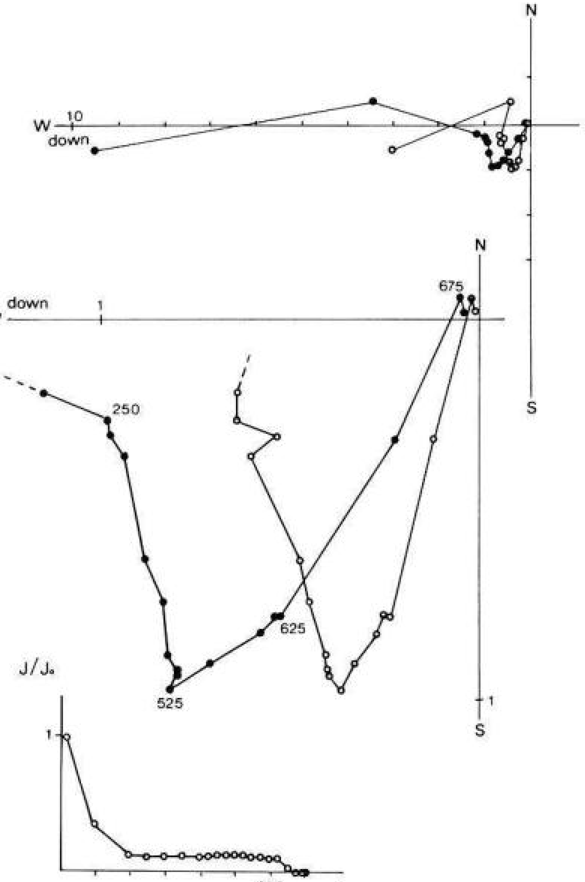


Fig. 3a and b. Susceptibility variations after each heating step of samples. **a** Stary Lesieniec; **b** Czarny Bor



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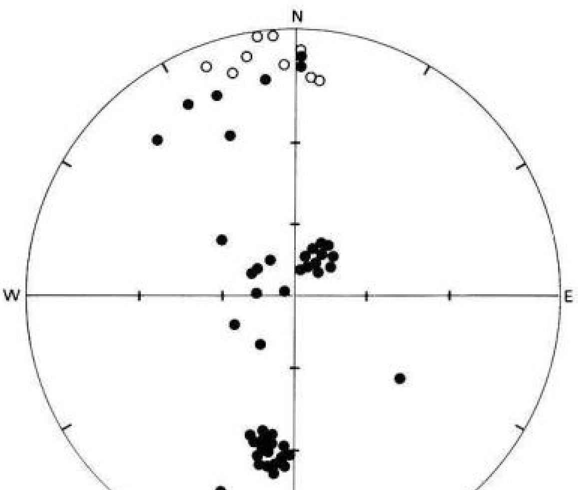

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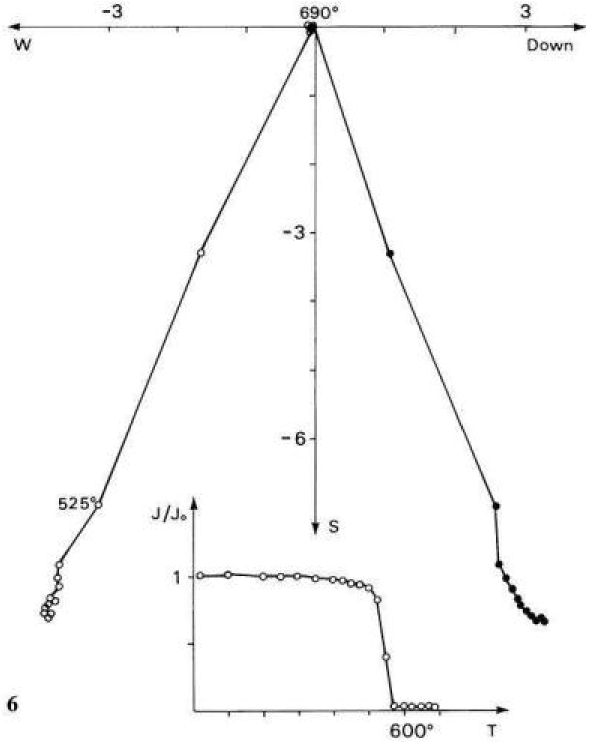

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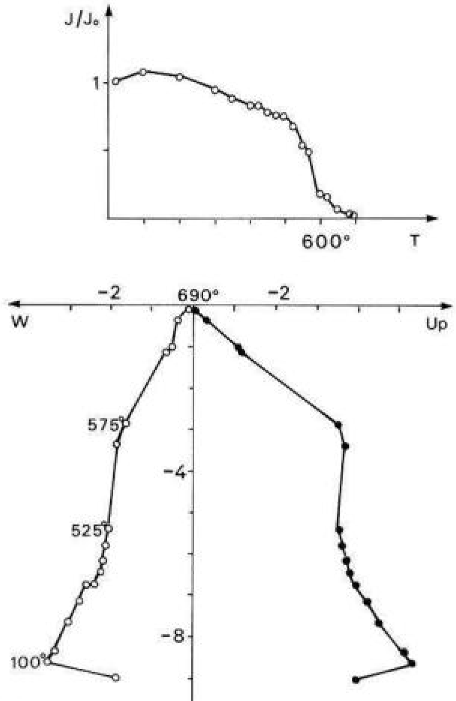

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Fig. 4. Thermal demagnetization of a sample of Stary Lesieniec (site 1). *Open dots:* horizontal plane; *black dots:* north-south vertical plane. An enlargement of the central part of the figure is shown *in the middle. At the bottom* is plotted the variation of total intensity with temperature. Note the three different components. Scale in 10^{-3} A/m

Fig. 5. Stereogram of all the magnetic components found in the samples of Stary Lesieniec. Nearly vertical directions: soft component, destroyed at 200°–250° C; northerly flat directions: components destroyed between 250° and 550° C; southerly directions with positive inclination: components destroyed above 590° C

Fig. 6. Thermal demagnetization of a sample of Czarny Bor (site 4) with almost a single magnetization

Fig. 7. Thermal demagnetization of a sample from Kamiensk (site 13). It shows two magnetic components (100°–575° C), (575°–690° C). The bends of the 100°–575° C part of the curve may show that a part of the higher-temperature component is already demagnetized at lower temperatures

Table 1. *C:* component identification number; *Ns:* number of specimens where this component was found; Dg, Ig: declination and inclination of mean before tectonic correction; *Ds, Is:* mean direction after tectonic correction; *k*, α_{95}: Fisher precision parameter; *Tb:* blocking temperature; *id:* identification in text. Numbers in brackets below the locality name: strike and dip of the bedding plane (left-hand conventions)

Site name and number	*C*	*Ns*	*Dg*(°)	*Ig*(°)	*Ds*(°)	*Is*(°)	*k*	α_{95}(°)	*Tb*(°)	*id*
Stary Lesieniec (1)	1	28	191	29	201	2	156	2	675	SL 1
(160/44)	2	22	353	0	349	9	21	7	550	SL 2
		15	356	− 5	355	7	67	5		
	3	29	359	78	267	49	20	6	300	SL 3
Gorce (2)	1	20	200	38	213	8	32	6	675	GO 1
(160/40)	2	7	151	87	245	50	33	11	500	GO 2
Czarny Bor (4,5) (160/27)	1	28	201	12	202	− 6	214	2	580	CZ 1
Boguszov (6)	1	21	188	− 2	177	−33	111	3	575	BO 1
(140/45)	2	4	339	35	304	36	20	21	250	BO 2
Boguszov Gorce (7)	1	12	175	−13	162	−48	36	7	575	BG 1
(110/40)	2	9	164	88	198	48	9	17	300	BG 2
Barbarka (8) (120/12)	1	20	193	−29	190	−40	37	5	670	BA 1
Niedwiadki (9)	1	20	184	11	182	− 5	71	4	570–630	UN 1
upper part	2	7	190	−14	203	−19	128	5	680	UN 2
(24/42)	3	5	355	25	20	38	49	11	250	UN 3
Niedwiadki (10) lower part (24/42)	1	7	184	25	173	6	98	6	585	LN 1
Kamiensk (13)	1	12	189	8	189	− 7	49	6	580–630	KA 1
(90/15)	2	6	208	−39	217	−52	101	7	680	KA 2
	3	11	5	50	7	65	66	6	250	KA 3
Rusinowa (19)	1	6	182	37	202	− 4	20	15	670	RU 1
(160/70)	2	10	192	82	243	16	11	14	630	RU 2
Gluszyca (11, 12)	1	14	108	−12	112	29	50	4	590	GL 1
(172/46)	2	6	240	60	251	15	124	6	590	GL 2
	3	4	31	84	268	47	49	13	300	GL 3

Paleomagnetic results

The magnetization intensity varies between 10^{-3} A/m and 1 A/m, the median magnetization is 10^{-2} A/m and the susceptibility varies between 3×10^{-5} and 2×10^{-2} SI. Thermal demagnetization showed one, two or three different magnetic components (Figs. 4–7): usually a soft component destroyed at about 300° C, a harder magnetization destroyed at 580° C and a still harder one demagnetized only at about 670° or 690° C. These three magnetizations are well seen in Stary Lesieniec (Figs. 4 and 5).

Table 1 gives the different magnetic components before and after tectonic correction with their average unblocking temperature. This Table shows several groups of directions.

– First: directions with a southerly declination and a shallow positive or negative inclination always characterized by high unblocking temperature magnetizations.

– Second: directions with a northerly declination and a shallow inclination (only in Stary Lesieniec). This is also a high unblocking temperature component.

– Third: directions with very steep inclinations corresponding to low unblocking temperature components, except in one case (Rusinowa), and a few other low-temperature components with shallower inclinations.

The low-temperature components

Two normal directions with rather shallow inclinations (B02 and UN3) are found. They may be Mesozoic remagnetizations. We have also one site with a slightly steeper inclination (KA3: $D = 5°$, $I = 50°$) which may be a recent magnetization.

The five remaining sites have a mean direction $D = 95°$, $I = 89°$, $N = 5$, $k = 82$, $\alpha = 8°$ before tectonic correction. After tectonic correction, the k value drops to 6.8. This direction is very clear and well defined. The fold test shows that it is clearly a post-tectonic one (Table 2). It does not look like a present field direction, neither a Mesozoic or Early Cenozoic one. We are unable to interpret it clearly now.

The high-temperature components

In three sites, two high-temperature components coexist in the same samples (Figs. 4 and 7). One with a 580°–630° C unblocking temperature and another one with a still higher unblocking temperature. This is the case of Stary Lesieniec, Niedwiadki and Kamiensk. In Stary Lesieniec, the presence of both normal and reversed components shows clearly that

Table 2. Means

	N	$D(°)$	$I(°)$	k	$\alpha_{95}(°)$	°N	°E
Low-temperature components							
SL 3, GO 2, BG 2, RU 2, GL 3							
before T.C.	5	95	89	82	8	51	19
after T.C.	5	–	–	7	–		
BO 2, UN 3, KA 3							
before T.C.	3	352	37	25	25	59	211
after T.C.	3	–	–	6	–		
High-temperature components							
SL 1, GO 1, CZ 1, UN 1, LN 1, KA 1, RU 1 and SL 2 (reversed)							
before T.C.	8	189	21	25	11		
after T.C.	8	192	− 2	27	11	39	181
BO 1, BG 1, BA 1, UN 2, KA 2							
before T.C.	5	190	−19	18	18	48	181
after T.C.	5	191	−44	16	19		
All							
before T.C.	13	184	6	9.8	13.2		
after T.C.	13	191	−16	10.3	12.9		

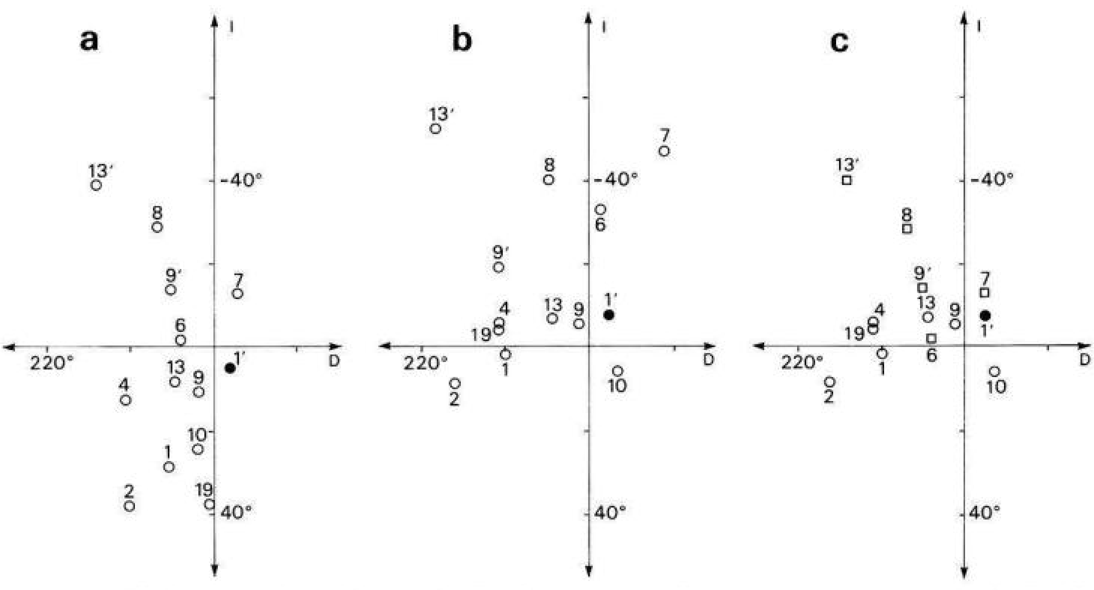

Fig. 8a–c. Cylindrical projection of mean site directions seen from the south. *Horizontal axis:* declination, left towards the west, right towards the east; *vertical axis:* inclination, positive downwards, negative upwards. Component 1 is indicated by the site number and component 2 by the site number with an′. Component SL2 (1′) is shown reversed. **a** all components before bedding corrections; **b** same components after bedding corrections; **c** interpretation: the components that have not been corrected are shown by a *square symbol*

some remagnetization process occurred after the formation of the rock.

Figure 8a shows all these directions before tectonic corrections and a clear trend of directions between positive and negative inclinations. After tectonic corrections the scatter is more random (Fig. 8b) but the overall scatter remains large: k is about 10 in both cases (Table 2).

The problem now is to separate older primary magnetizations from the younger secondary ones and to decide which should be corrected for tilting and which do not need to be corrected. The magnetizations carried by haematite (unblocking temperature of 680° C) are not necessarily the oldest.

We may have some indications of the inclinations before and after tectonic corrections. The general trend of polar wander paths in Europe (Irving and Irving, 1982; Edel, 1987) corresponds to a shift in inclinations from positive to negative (with southerly declinations, i.e. a reversed field) from Carboniferous to Jurassic through Permian and Triassic (Fig. 9). The effect of tectonic corrections is unfortunately in the same direction: it shifts these directions from positive towards negative inclinations. The older pre-tectonic directions must have very shallow inclinations, after tectonic corrections, sometimes positive. The younger, probably post tectonic ones must have negative inclinations before tectonic corrections.

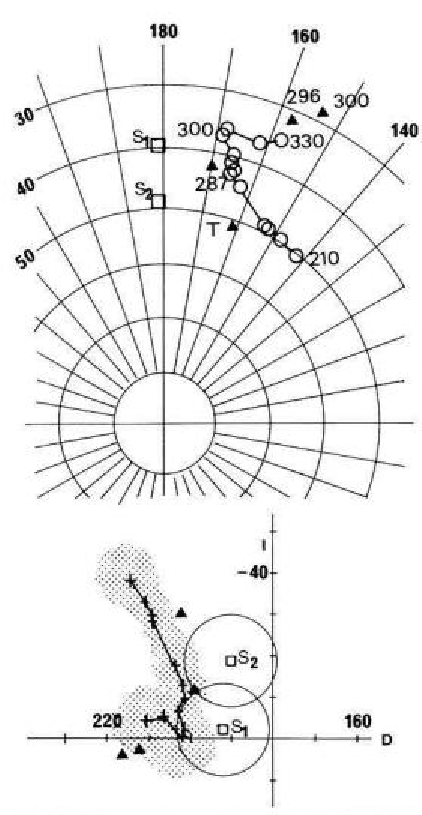

Fig. 9. *Top:* pole position for the 330–210 Ma period (after Irving and Irving, 1982). S_1 and S_2 are the two poles from Sudetes (Table 2). *Triangles* represent poles obtained on dated volcanics and plutonics from Black-Forest and Central Massif (Edel, 1987) and *T* the Thuringian pole from Maures (Merabet and Daly, 1986). *Bottom:* the same data are shown with the corresponding declination (horizontal) and inclination (vertical) recalculated for the Sudetes with averaged confidence intervals

We shall sort the components into two groups: those which can clearly be pre-tectonic and those which are clearly post tectonic. In the first group can be entered SL1, GO1, LN1, RU1 (1, 2, 10, 19). In the second group we include directions BG1, BA1, KA2 (7, 8, 13′). Then, CZ1, UN1 and KA1 (4, 9, 13) are most certainly also pre-tectonic; if this were not the case we should have a positive inclination for post-tectonic components. In the same manner BO1 and UN2 (6, 9′) are most probably also post tectonic.

The problem remains with the second component of Stary Lesieniec. It is a normal component while other components are all reversed. It has a shallow positive inclination when reversed before tectonic correction and negative after tectonic correction.

Figure 5 shows the three magnetic components found in Stary Lesieniec. The second component, with a northerly declination and a shallow inclination, shows a first group with shallow negative inclinations and a few scattered directions with higher positive inclinations. Two mean directions were calculated in Table 1: the first with all the specimens and the second with only the specimens with negative or very shallow positive inclination assuming that the directions with higher inclinations are either younger ones or badly separated from the first low-temperature component which has a high positive inclination. We have chosen to keep this second mean direction.

Until now when a locality had two high-temperature components one was considered as pre-tectonic and the other one as post tectonic (upper Niedwiadki, Kamiensk). With the Stary Lesieniec site, the two high-temperature components look as if they were both pre-tectonic. This will mean that there was a remagnetization before folding and a much younger one after folding. But we can also suppose that the folding phase provided the fluids and temperature necessary to remagnetize, partly or completely, these rocks. Thus for some sites the remagnetization process might have taken place early, and a tectonic correction should be done, completely or partly (for instance SL2); for other sites the remagnetization process might have taken place later, and the tectonic correction should not be done (UN2, KA2). The corresponding interpretation is shown in Fig. 8c.

The components BO1 and BG1 are thought to be remagnetizations. But, the corresponding formation is a laccolith which may be intruded between already tilted stratas. It is then younger than the folding phase and its magnetization may be primary. But in this case the volcanism should be almost of the same age as the folding. We would have in a short interval of time: magnetism, folding, remagnetization and a reversal of the field. We cannot exclude this possibility.

The effect of tectonic correction does not show significant increase or decrease of *k* values. This is largely due to very similar tilting. Unfortunately, we could not find sites with different bedding orientations.

The presence of a normal direction can help us to give a more precise age for the remagnetization. In Late Carboniferous and during almost all the Permian, the magnetic field was reversed. It is the well-known Kiaman interval. Normal directions are very scarce. There are the Illawara reversals in late Permian, the Paterson reversals in Westphalian-Stephanian and perhaps a single normal event at the Carboniferous-Permian boundary (McElhinny, 1973). These two last possibilities are the most probable ages for this remagnetization.

Gluszyca

The formation sampled in Gluszyca is of Lower Permian age. The quarry shows two large melaphyre sills, separated by some siltstones. The two sills gave two different characteristic high-temperature components which are 140° C apart: component GL1 for the higher one and GL2 for the lower one. Both are very different in declination and inclination with classical Permian directions. We think that it is a local problem here, probably of tectonic origin, that we cannot solve for the moment with the data already available.

Comparison with other poles

The poles of the characteristic directions are given in Table 2. The mean direction of the high-temperature components are close to the results obtained previously by Birkenmajer et al. (1968), but they did not separate the different components and did not find the normal component present in Stary Lesieniec, for instance, although they had sampled this quarry.

The overall magnetic poles calculated for Europe by Irving and Irving (1982) for the 250–330 Ma time range lie between 44° N, 163° E and 35° N, 159° E. The corresponding magnetic directions recalculated for the Sudetes range between $D=200°$ and 210° and $I=-18°$ and 0° (Fig. 9).

The inclinations obtained in this study are similar to Upper Carboniferous and Permian inclinations calculated from the Irving and Irving (1982) polar wander curve for Eurasia. The declinations are slightly different, shifted by about 10°. This is below confidence intervals.

Comparison of the mean poles with dated results from other massifs in Western Europe, for instance the Black Forest, shows that the pole corresponding to the first magmatic phase (39° N, 181° E) lies closer to the pole dated at 287 Ma (Carboniferous-Permian boundary) than to the Westphalian poles (300 Ma) (Lippolt et al., 1983; Edel, 1987). Thus, the normal event found in Stary Lesieniec may be the one which seems to be at the Carboniferous-Permian boundary, and the volcanism is then of about the same age. The second high-temperature component is then of Permian age. Unfortunately, the confidence intervals are too large and direct dating is difficult.

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