Palaeomagnetic Investigations on Permo-Carboniferous Rocks in the Area of the KTB Drill Site

H. C. Soffel
F. Harzer

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Summary

In the area of the KTB drill site on the western margin of the Bohemian Massif 15 sites of Lower Permian to Upper Carboniferous rocks (quartz porphyries, granites and a siltstone) have been studied in order to obtain a reliable pole position for this time interval. While four sites (quartz porphyries) showed too weak NRM values, the results of two other sites with otherwise good rock magnetic properties had to be discarded because of unreliable tectonic positions in a shear zone. The remaining nine sites (mean geographic coordinates 12°E, 49.8°N) had all reversed polarity in agreement with a remanence age within the reversed Kiaman interval and a mean pole position at 165.9°E, 42.3°N with N=9, R=8.8776, A_{95}=6.4°, which is in good agreement with the mean Upper Carboniferous - Lower Permian European pole position of Stable Europe. Rock magnetic investigations showed that the CARM of the siltstone is due to primary magnetite, while the mostly monocomponent CARM of the magmatic rocks is carried by primary magnetite and by primary haematite produced by syngenetic high temperature oxidation of primary magnetite. Radiometric age determinations point to a remanence age of 280 Ma.

H.C. Soffel, F. Harzer
Institut für Allgemeine und Angewandte Geophysik, Universität München, Theresienstrasse 41, D 8000 München 2, FRG

1) Introduction

Earlier palaeomagnetic measurements in the western part of the Bohemian Massif carried out on mostly Devonian rocks from the Frankenwald area (KIM and SOFFEL, 1982; BACHTADSE, HELLER and KRÖNER, 1983) showed complete or partial remagnetization due to a possibly Permo - Carboniferous overprint. It is believed that the entire variscan mountain belt has been affected by remagnetization (e.g. EDEL and COULON, 1984) during the latest stage of the variscan orogeny by an increased heat flow in connection with the intrusion of granites and the extrusion of large masses of quartz porphyries. Quartz porphyries of this age (around 280 Ma) are abundant in the Alps (e.g. the Bolzano quartz porphyries), in the Black Forest, in the Rhenish Massif (e.g. in the Nahe Basin) and in the Thuringian Forest about 100 km north of our sampling sites. Quartz porphyries occur on the western margin of the Bohemian Massif only rarely. In contrast to the other regions mentioned above they form small bodies intercalated between Upper Carboniferous - Lower Permian sediments (mostly sandstones and siltstones) or occur as dykes associated with granites. Within a palaeomagnetic pilot study 15 sites of quartz porphyries and similar rocks including one site with a siltstone have been sampled for a palaeomagnetic study. It was intended to establish a reliable reference CARM direction for the detection of a Permo - Carboniferous overprint in palaeomagnetic studies of older rocks in the western part of the Bohemian Massif.

2. Sampling

Sampling was done with portable drilling equipment. The selected sites, their geographic coordinates, the rock type and the ages are listed in Table 1a. Fig. 1 shows a map with the geographical distribution of the sites and some basic geological information. Table 1b is a list of the strike and dip of the sites, the number of cores and specimens, respectively, the mean NRM intensity, the Q-ratio and the mean apparent susceptibility

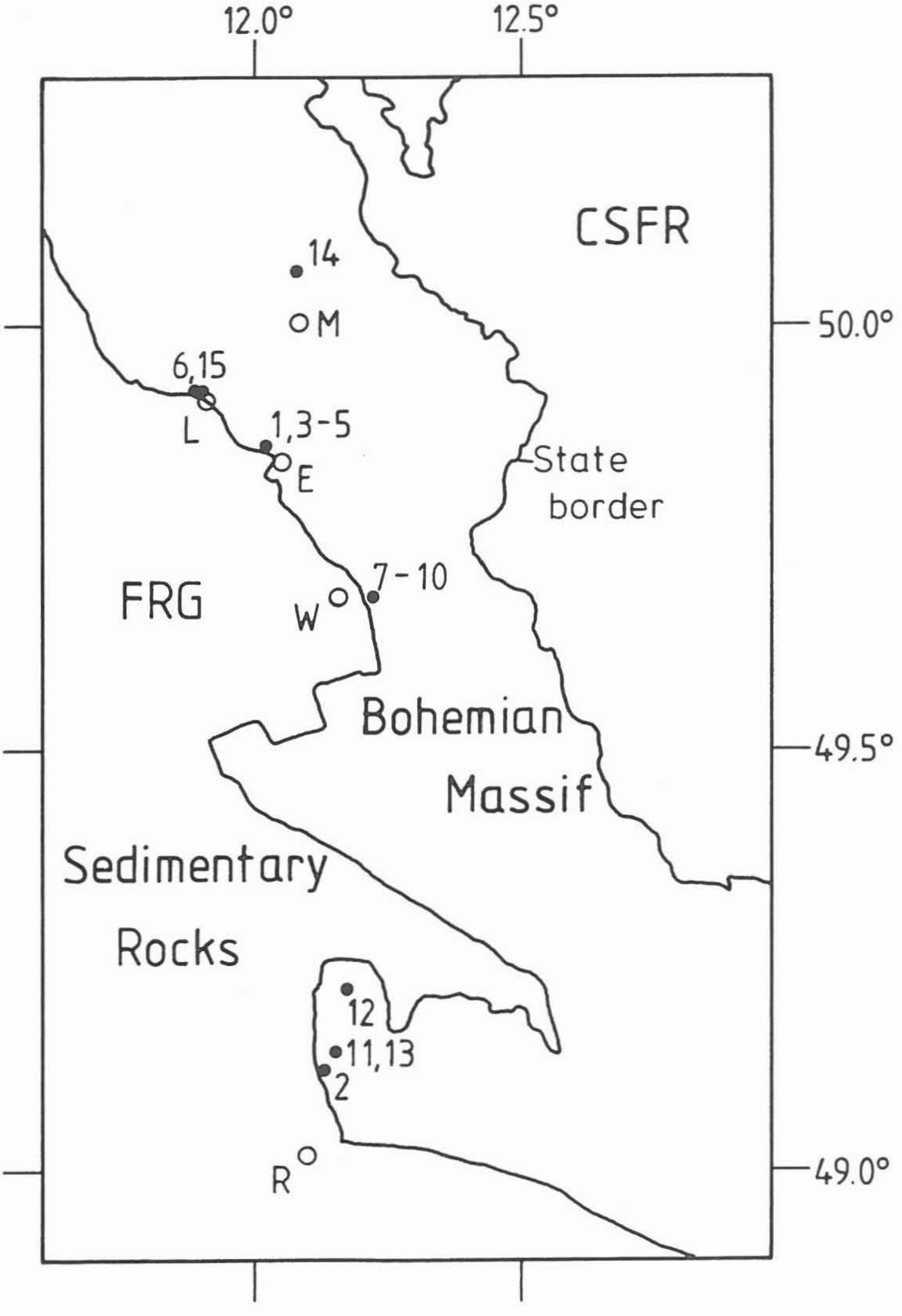

Figure 1
Map showing the sampling sites on the western margin of the Bohemian Massif. R: Regensburg; W: Weiden; E: Erbendorf; L: Lenau; M: Marktredwitz.

k_a in 10^{-6} SI units. In most cases a bedding correction was not necessary. Two sites (numbers 6 and 15) are situated in a shear zone near the Frankonian line (western border of the Bohemian Massif). Their results had to be discarded despite of very good rockmagnetic properties. For four sites (site numbers 1, 3-5) some minor tilt corrections were necessary which were unsufficiant for a tilt test.

3. Palaeomagnetic measurements

The NRM of the specimens was measured in part with a Molspin fluxgate spinner magnetometer or with a cryogenic magnetometer of type LETI (Grenoble, France). Fig. 2 shows an equal area projection of the NRM of site 1 (2a) and the site mean NRM directions together with their cones of confidence (2b).In some cases there was already excellent grouping of the NRM far away from the present field direction in the sampling area (D=0°, I=65°; star in Fig. 2b) around directions with D=180° and mostly flat inclinations. This is an indication for the presence of a significant CARM component. Similar behaviour was also found in the Bolzano and other quartz porphyries (e.g. ZIJDERVELD and VAN DER VOO, 1973). This seems to be typical for this type of extrusive rocks. Sites number 7 - 10 had very weak NRM intensities with directions in the vicinity of the present day geomagnetic field direction (see also Fig. 2b and Table 1b) which collapsed quickly during later thermal demagnetization. The mean NRM directions are distributed along a great circle connection the present geomagnetic field direction with the CARM direction. They are also listed in Table 2.

Alternating field demagnetization was not successful for the complete destruction of the NRM. Thermal demagnetization was preferred for all types of rocks using a nonmagnetic Schoenstedt furnace. Fig. 3 shows an example (Zijderveld diagram) for an orthogonal vector plot during thermal demagnetization. In most cases straight lines (like for the specimen from site 4) towards

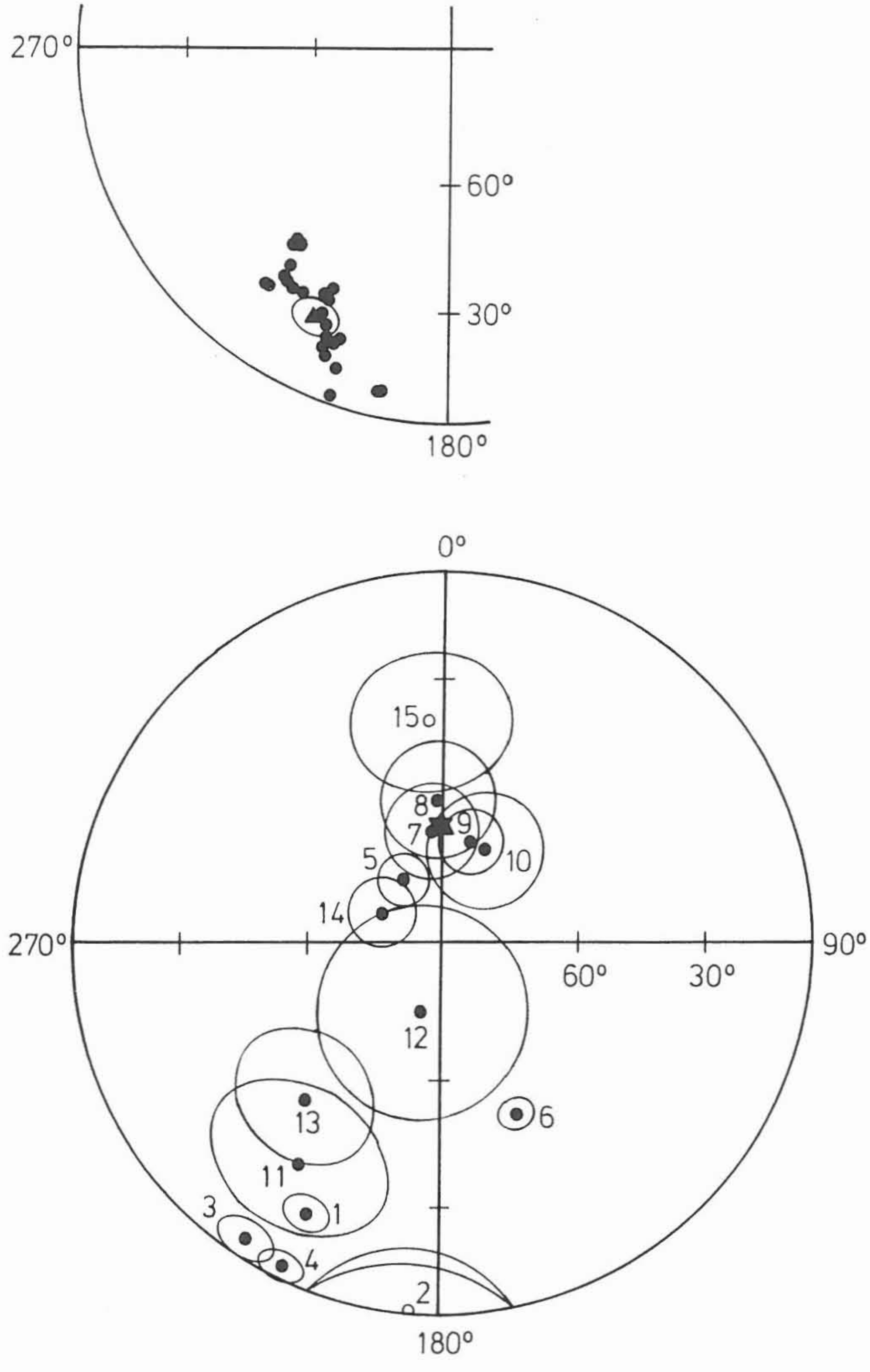

Figure 2
Equal area projection of NRM directions together with the cones of confidence. Numbers refer to site numbers (see Table 1).
2a) NRM direction for specimens from site number 1.
2b) Site mean NRM directions.

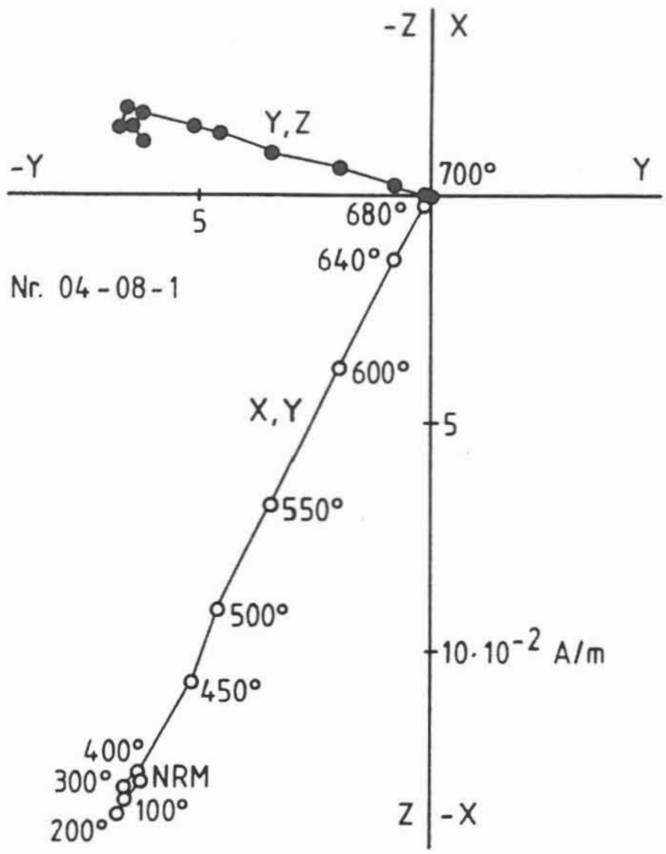

Figure 3
Zijderveld diagram for a specimen from site 4 (quartz porphyry).

the origin could be obtained after the removal of a small erratic (possibly viscous) component. A complete demagnetization was obtained in the quartz porphyries and the other magmatic rocks only at temperatures close to the Curie temperature of haematite. There was no kink when the Curie temperature of magnetite was passed at 580° C indicating that magnetite as well as haematite carry the same remanence component (see also section 4 with the discussion of the ore mineralogy and rock magnetic properties). Only site 5 (siltstone) showed blocking temperatures which did not exceed the Curie temperature of magnetite. The determination of the monocomponent CARM direction was therefore quite easy and did not require a sophisticated multicomponent analysis. The bedding corrected mean CARM data are listed in Table 2 together with the statistical parameters, the site mean pole position and the mean pole position (including statistical parameters) for nine sites.

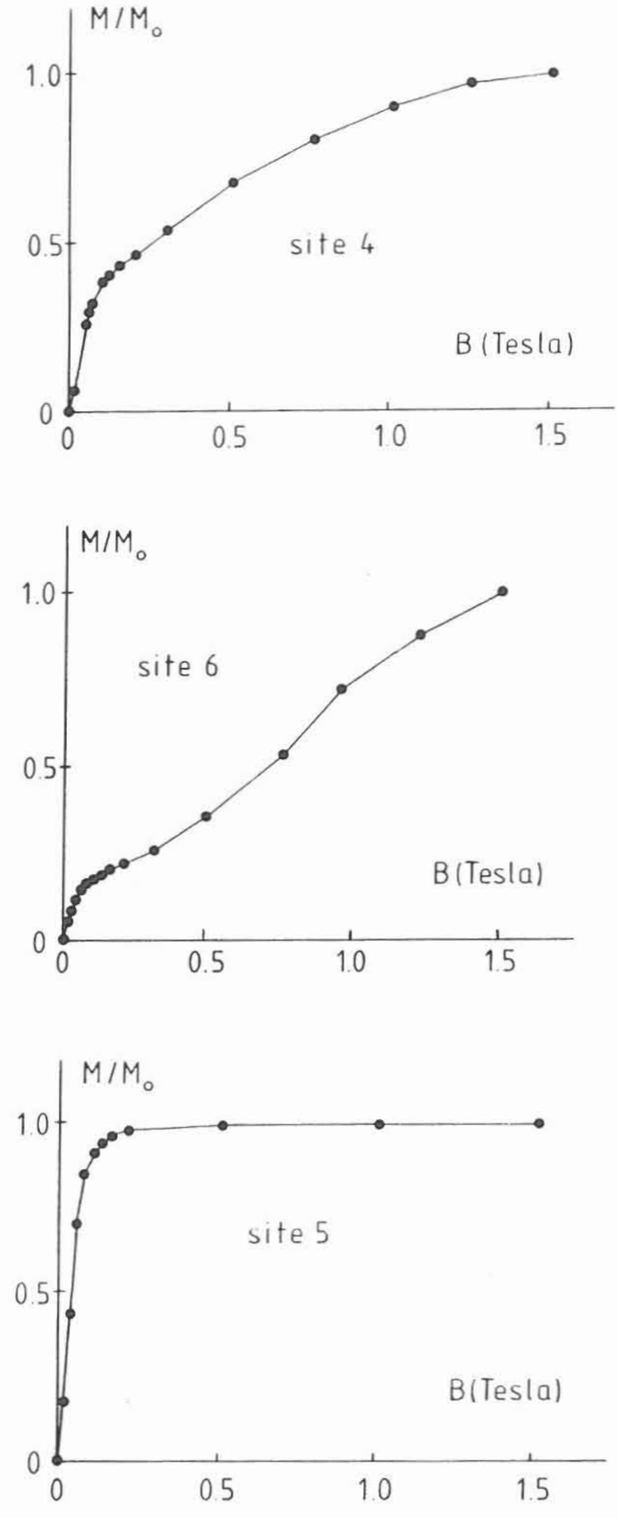

Figure 4
Saturation remanence (SRIM) acquisition curves, normalized to the final intensity obtained in a field of 1.5 T.
4a) Specimen from site 4 (quartz porphyry), indication for magnetite and haematite.
4b) Specimen for site 6 (quartz porphyry situated within a shear zone), indication for magnetite and goethite.
4c) Specimen from site 5 (silt stone), indication for exclusively magnetite.

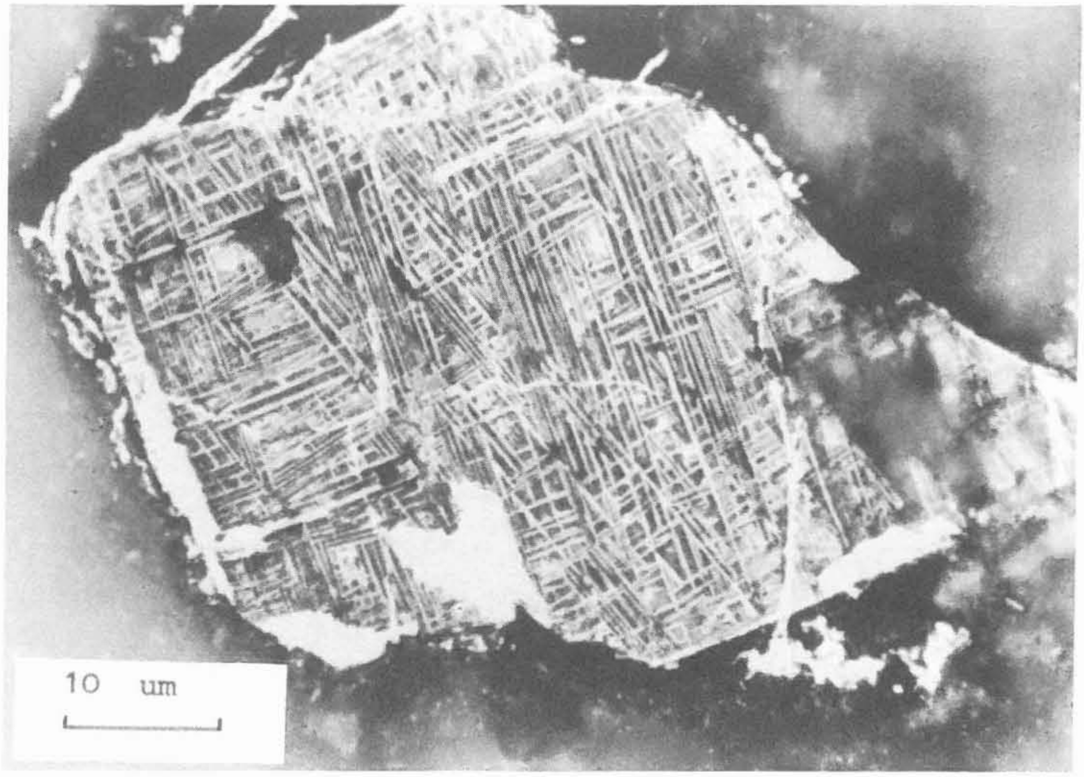

Figure 5
Polished section of a large ore grain from site number 1 under crossed Nicols with exsolution lamellae of magnetite (grey) in an ilmenite magnetite ground mass (dark grey) and haematite (light grey).

4. Rock magnetic measurements and ore microscopy

The acquisition of saturation remanence (SIRM-curves) has been determined for specimens from all sites in order to obtain information about the content of ferrimagnetic ores (DUNLOP, 1972). Three types of SIRM-curves have been observed for which examples are shown in Fig. 4. The first type was observed for the quartz porphyries (Fig. 4a, specimen from site 4). The curve shows a rapid increase in low fields between 0 and 0.1 T followed by a more gentle convex increase between 0.1 and 1.5 T. We interpret this as an indication for magnetite (with the lower coercivities) and haematite (with the higher coercivities). A combination of magnetite (low coercivity) and goethite (extremely high coercivity) is shown in Fig. 4b (site 6). The results of this site have not been used because of its uncertain tectonic position near a shear zone. The third type of curve was obtained for the siltstone of site 5 (Fig. 4c) which shows the low coercivities typical for magnetite. The specimens for which the SIRM-curves have been determined were also demagnetized thermally. The blocking temperature spectra confirmed the presence of magnetite plus haematite for site 4, magnetite and goethite for site 6 and just magnetite for site 5. Curie temperature measurements confirmed these results as well.

The nature of the ferrimagnetic mineral assemblages was also investigated by ore microscopy. Of special interest was the question whether the haematite was of secondary (e.g. due to wheathering) or of primary origin. Fig. 5 shows a polished section with a typical ore grain from site 1 under crossed Nicols. The rather large ore grain consists of grey lamellae of magnetite in a darker grey ilmenite ground mass. This is typical for a high temperature oxidation and exsolution process. The haematite (light grey) has in part replaced the magnetite syngenetically by an oxidation process which affected also the silicates leading to a red colour of the quartz porphyries. They ressemble in this respect and also in respect to their rockmagnetic and palaeomagnetic properties the Bolzano quartz porphyries (ZIJDERFELD and VAN DER VOO, 1973). The thermal demagnetization diagrams (see Fig. 3) as well as the ore microscopy indicate that the CARM carried by exsolved magnetite and by haematite are syngenetic. However, some quartz porphyry sites had so small ore grains that they could not be identfified by ore microscopy. In the siltstone, on the other hand, only very fine grained magnetite and no other ferrimagnetic mineral could be detected, which is in agreement with the conclusions from the SIRM acquisition curve of Fig. 4c. The optically observed main ferrimagnetic ores are also listed in Table 2. In conclusion we assume that the CARM of the porphyries is carried by primary magnetite and haematite, while that of the siltstone is due to primary magnetite alone.

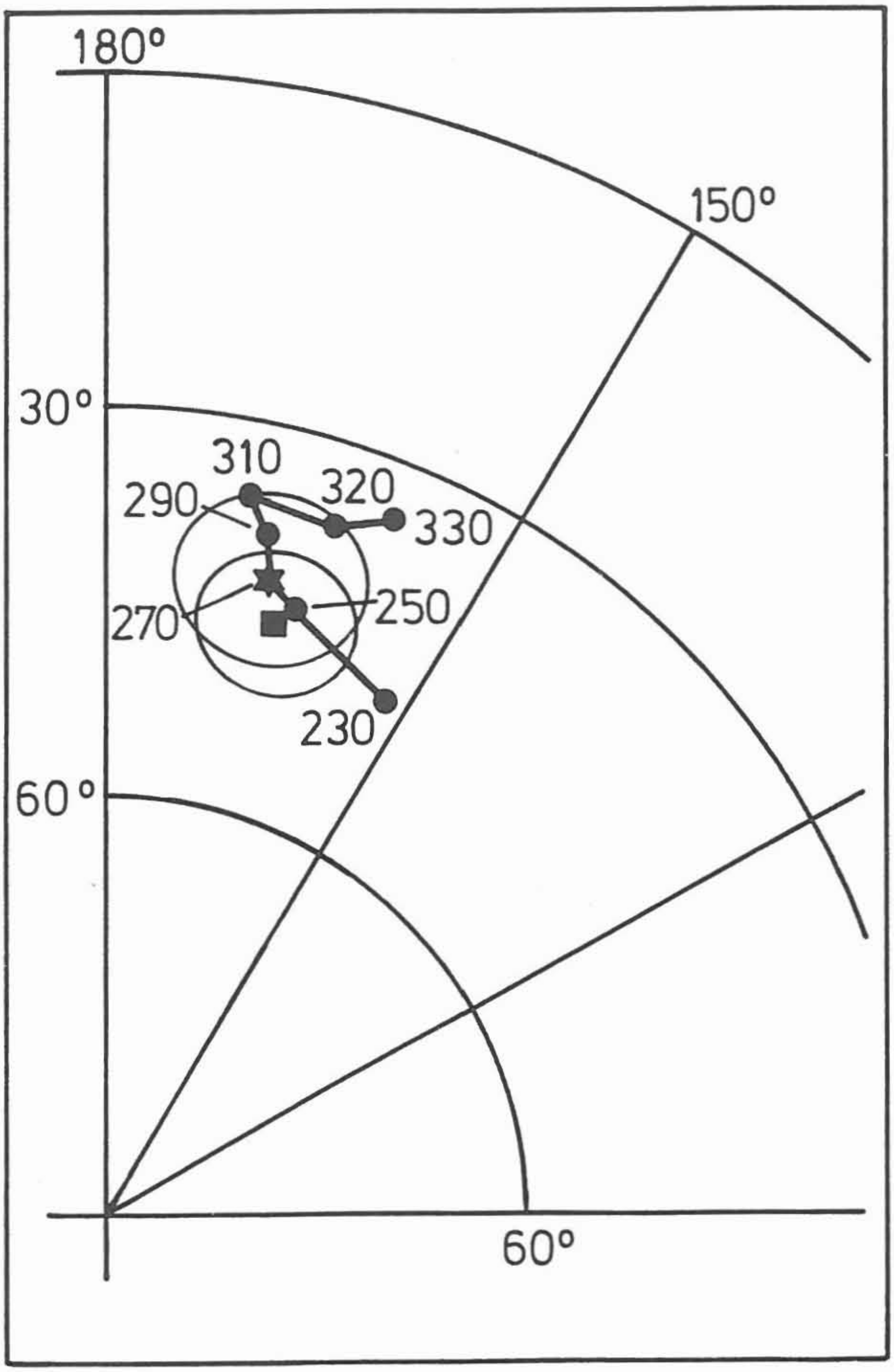

Figure 6
European apparent polar wander path for the time interval 230-330 Ma (after IRVING and IRVING, 1982) in equal area projection with the mean pole positions (together with the A_{95} cones of confidence) of this study (star) and the study by KIM and SOFFEL (1982) (square) on Devonian rocks from the Frankenwald area showing a Permo-Carboniferous overprint.

5. Palaeomagnetic pole position and conclusions

The mean pole position of the nine sites (see Table 2) is situated at 165.9°E, 42.3°N, A_{95}= 6.4° and is plotted in Fig. 6 in equal area projection together with the European apparent polar wander path (APWP) according to IRVING and Irving (1982) for the time interval 230 - 330 Ma. The result of this paper (star) agrees well with the mean Upper Carboniferous - Lower Permian pole for Stable Europe and the pole of the secondary (overprint) remanence direction (164.4°E, 45.7°N, A_{95}=5.5°) determined by KIM and SOFFEL (1982) for the Devonian rocks in the Frankenwald area about 60 km north of Erbendorf (square). Two conclusions can be drawn from this study. Firstly it gives a reliable reference direction for the Permo-Carboniferous remagnetization in the western part of the Bohemian Massif, which is useful for the palaeomagnetic study of Lower Paleozoic and older rocks in the area. The radiometric age determintations carried out on the latest granite bodies in the area point to a remanence age of about 280 Ma of the quartz porphyries and the associated sediments (BESANG et al., 1976). This is in almost perfect agreement with the remanence age concluded from the APWP. Secondly, the good agreement with the European APWP indicates that there was no relative rotation of this geological unit with respect to the other areas of Stable Europe since the Late Paleozoic.

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Table 1

a) Site names, geographic coordinates, rock type and stratigraphic ages. qp:quartzporphyry; pp:piniteporphyry; ss:siltstone; gp:graniteporphyry; cg:crystalgranite; LP:Lower Permian; UC:Upper Carboniferous.

b) Strike and dip, N:number of cores; n:number of specimens; n*:number of specimens for computation of means (see Table 2); NRM:site mean NRM intensity in mA/m; Q:Koenigsberger Q-ratio, k_a :susceptibility in 10^{-6} SI units.

a)

No.	Locality	°E	°N	Rocktype	Age
1	Erbendorf 1	12.08	49.84	qp	LP
2	Regenstauf	12.14	49.12	pp	UC
3	Erbendorf 2	12.03	49.85	qp	LP
4	Erbendorf 3	12.03	49.85	qp	LP
5	Erbendorf 4	12.02	49.84	ss	LP
6	Lenau 1	11.98	49.92	qp	LP
7	Weiden 1	12.22	49.69	qp	UC-LP
8	Weiden 2	12.22	49.69	qp	UC-LP
9	Weiden 3	12.22	49.69	qp	UC-LP
10	Weiden 4	12.22	49.69	qp	UC-LP
11	Karlstein 1	12.16	49.16	gp	UC
12	Marienthal	12.18	49.22	cg	UC
13	Karlstein 2	12.16	49.16	gp	UC
14	Göpfersgrün	12.08	50.07	qp	LP
15	Lenau 2	11.98	49.92	qp	LP

b)

No.	strike (°E)	dip	N/n	NRM	Q	k_a (10^{-6} SI)
1	33	40 NW	15/28	60.4	2.31	723.0
2	in situ		15/24	0.8	0.30	71.1
3	33	23 NW	15/21	24.3	1.19	569.8
4	33	23 NW	10/20	58.7	2.37	717.4
5	35	37 NW	19/34	1.5	0.15	306.1
6	unknown		19/33	58.2	3.97	412.9
7	in situ		18/25	0.096	0.07	41.1
8	in situ		18/30	0.111	0.04	69.5
9	in situ		17/30	0.134	0.10	36.6
10	in situ		16/19	0.138	0.09	39.8
11	in situ		11/16	0.186	0.06	82.0
12	in situ		15/18	0.251	0.07	102.4
13	in situ		14/25	0.195	0.07	80.0
14	in situ		12/30	0.525	0.14	101.8
15	unknown		7/8	134.0	17.16	215.0

Table 2
Site mean directions of natural remanent magnetization (NRM) together with statistical parameters (precision parameter k and α_{95} as the semiopening angle of the 95% cone of confidence). n: number of specimens used for the computation of the mean NRM direction.

No.	D(NRM) (°E)	I(NRM)	n	k	α_{95} (°)
1	206.5	20.3	24	50.4	4.2
2	184.8	-1.3	19	5.4	16.0
3	213.4	6.0	21	37.3	5.3
4	206.1	4.1	13	114.6	3.9
5	328.8	73.9	34	19.5	5.7
6	155.6	48.2	30	65.2	3.3
7	354.8	65.8	25	8.7	10.4
8	357.8	58.8	30	5.1	13.0
9	16.4	67.3	30	14.2	7.2
10	25.4	67.7	19	4.2	12.9
11	212.9	30.3	16	5.1	18.3
12	195.4	74.2	17	3.4	23.0
13	221.0	43.6	25	4.6	15.1
14	295.8	75.6	21	19.5	7.4
15	356.2	-40.5	7	14.1	16.7

Table 3

a)
Directions of bedding corrected characteristic remanent magnetization (CARM) together with the range of maximum blocking temperature used for the determination of the CARM and the statistical parameters (n: number of specimens used for the computation of the mean; k,K:precision parameter; α_{95},A_{95}: semiopening angle of the 95% cone of confidence). For sites number 7-10 no consistent CARM component could be determined.

No.	D(CARM) (°E)	I(CARM) (°)	TH (°)	n	k	α_{95} (°)
1	197.1	+ 8.5	580-600	23	107.0	2.9
2	204.8	- 23.1	600	18	30.5	6.4
3	206.6	- 2.1	580-600	16	250.0	2.3
4	202.6	- 6.5	580-600	11	355.0	2.4
5	192.7	+ 13.6	480-500	15	48.1	5.6
6	162.1	+ 34.9	540-550	26	82.1	3.1
11	203.2	- 26.7	500	9	65.3	6.4
12	196.5	- 16.9	400	9	53.2	7.1
13	203.2	- 18.2	450	13	106.0	4.0
14	185.6	- 9.8	500	13	207.0	2.9
15	84.0	+ 41.8	550	6	43.6	10.3

b)
Site mean palaeomagnetic pole positions as well as the mean pole positions of all sites giving unit weight to each site together with their statistical parameters defined as above. For sites number 6, 7-10 and 15 no pole position could be determined. The principal carriers of remanence are also given. pH:primary haematite; pM:primary magnetite. H: haematite; M: magnetite; G: goethite; TM: titanomagnetite; Il: ilmenite.

No.	VGP-LONG. (°E)	VGP-LAT. (°N)	Ores
1	171.4	33.9	pH, TM, Il
2	154.7	47.6	pH, TM, Il
3	158.3	36.2	pH, TM, Il
4	162.2	39.6	pH, TM, Il
5	177.1	32.2	pM
11	155.6	50.1	pH
12	167.8	47.1	pH
13	158.3	45.7	pH
14	184.2	44.6	pM, G

Mean pole position: λ = 165.9°E φ = 42.3°N ;

N = 9 ; R = 8.8776 ; K = 65.4 ; A_{95} = 6.4°