GEOLOGICA CARPATHICA, 47, 1, BRATISLAVA, FEBRUARY 1996
5–12

MIOCENE OVERPRINT IN THE PALEOZOIC OF GRAZ, EASTERN ALPS, AUSTRIA

ERNST BURGSCHWAIGER, HERMANN JOHANN MAURITSCH, MICHAEL BIERBAUMER and ROBERT SCHOLGER

Institute of Geophysics, Mining University Leoben, Franz-Josefstrasse 18, A-8700 Leoben, Austria

(Manuscript received March 16, 1995; accepted June 14, 1995)

Abstract: Four localities comprising 59 samples of moderately metamorphosed basalts and tuffs of Silurian age were collected from the "Paleozoic of Graz", Eastern Alps, Austria. During AF and thermal demagnetization samples from basalts, green coloured lapilli tuffs and ochre coloured pyroclastic breccias show two or three components of remanence and in some cases an overlap of blocking temperatures. The mean direction obtained is D = 47.6°, I = 61.5° with α_{95} = 5.5°. This direction yields a virtual geomagnetic pole of 57.6° N and 88.5° E. The magnetization of these rocks is considered to be secondary, which is supported by SEM examinations, and appears to have been acquired during the Miocene. The paleomagnetic data suggest that the investigated area of the "Paleozoic of Graz" has undergone a large clockwise rotation of about 45° since the Miocene.

Key words: Graz-Paleozoic, paleomagnetism, volcanics, pyroclastic sediments, tertiary overprint.

Introduction

The reconstruction of the paleogeographic and tectonic history of Paleozoic rocks in the Eastern Alps by paleomagnetic means is often hindered by the destruction of the primary magnetic rock properties during the Alpine orogeny. Hence objects for paleomagnetic studies have to be chosen with respect to low-grade Alpine metamorphism.

Our study focused on Paleozoic rocks which belong to the "Paleozoic of Graz" (PG). The aim of the study was the extent of the overprint during the Alpine metamorphism and their suitability for tectonic interpretations. In this respect, this paper is a continuation of earlier investigations in other parts of the Paleozoic of Graz as well as the Pennic windows of Rechnitz, Bernstein and Hanersdorf (Marton et al. 1987; Mauritsch et al. 1991).

The rocks of the PG, which is part of the Upper Austroalpine nappe system in the Eastern Alps, are predominantly low-grade metamorphosed sediments of Silurian to Carboniferous age. In general, the sedimentary column comprises Silurian metavolcanics, Late Silurian to Early Devonian carbonates with intercalations of clastic sediments and carbonates of up to Middle Devonian age. Intense Alpine tectogenesis created a nappe pile with the Schoeckel Nappe at the base, the Laufnitzdorf Group in an intermediate position and the Rannach and Hochlantsch Nappes in the highest position (Fritz & Neubauer 1988; Ebner 1994; Neubauer 1989). The rocks sampled for our study belong exclusively to a volcanic series at the base of the Rannach Nappe and are best exposed in the area of Haritzgraben and Eggenfeld north of Graz (Fig. 1). In the study area the investigated volcanic series basically comprises sequences of basaltic lava flows with intercalations of pyroclastic breccias and different varieties of lapilli and ash tuffs of distinct colours.

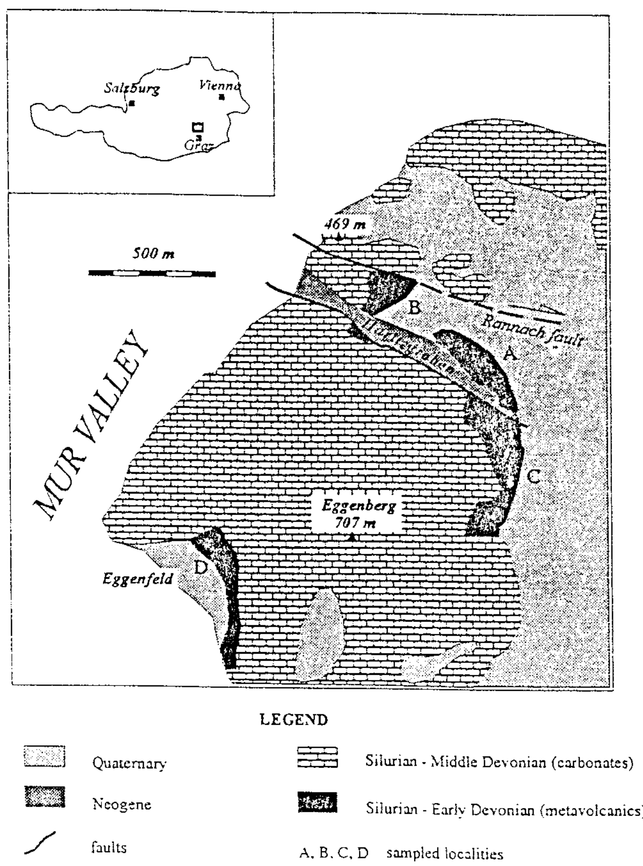


Fig. 1. Simplified geologic map of the study area (after Neubauer 1989).

Basalts, green coloured and often hard to distinguish from lapilli tuffs, ochre coloured pyroclastic breccias, ash tuffs and violet coloured lapilli tuffs were sampled. 59 samples were collected from four localities (A, B, C, D — Fig. 1). Sampling was carried out by using a field drill and orientations were taken with a magnetic compass. The deviation caused by the local field, was found to be insignificant. All measurements were carried out on standard sized specimens (i.e. 2.5 cm diameter, 2.1 cm high cylinders) with the 2G cryogenic magnetometer (at the Palaeomagnetic Laboratory in Gams, Mining University Leoben). Alternating magnetic field demagnetization was applied with a 2G600 automative sample degaussing system within a field free space provided by a three-axes Helmholtz coil system and a Mu-metal shielding.

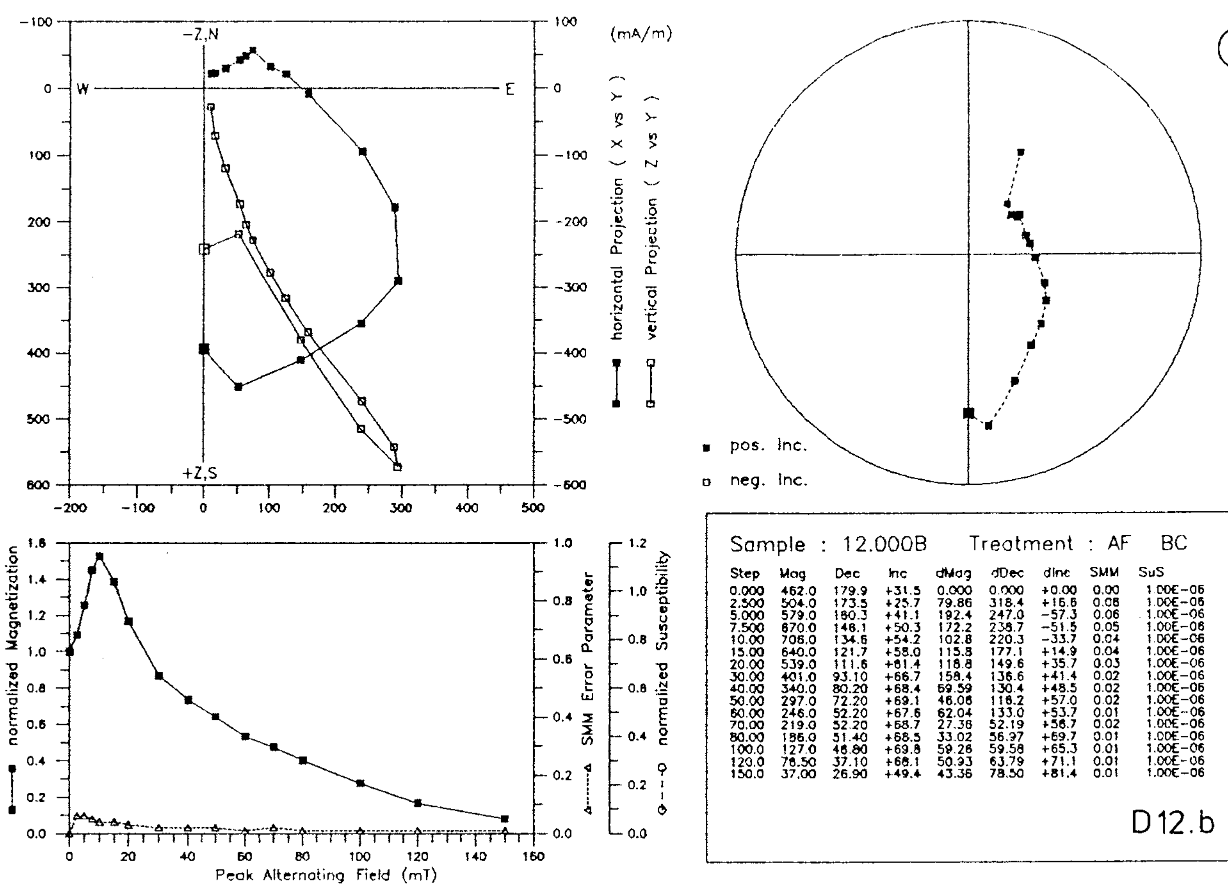
Locality mean directions and paleomagnetic poles were computed using Fishers statistics (1953).

Rockmagnetic results and analysis

Ten pilot samples from all four localities and all rock types were selected to identify the principal components present and their stability in alternating magnetic fields (AF). In general, the samples showed a steady decay in remanence with almost complete destruction of their magnetization after applying an alternating field of 150 mT. The direction of remanence showed two significant changes with the first one already at 2.5 mT and the second one between 10 and 60 mT. In single cases the Zijderveld diagram displayed curved trajectories due to overlapping coercitivity spectra (Fig. 2a). The pilot sample taken from a violet coloured lapilli tuff showed high stability of its intensity with no significant directional changes throughout the treatment. AF treatment of this sample was largely ineffective and it was concluded that the remanence was dominated by high-coercitivity minerals, probably hematite or goethite.

Therefore a second set of specimens taken from the same samples was subjected to progessive stepwise thermal demagnetization at 100, 200, 300, 400, 450, 500, 550, 575, 600, 625, and 650 °C. Bulk susceptibility values were measured at each step so that thermally induced mineralogical changes could be detected. Thermal demagnetization had distinct effects on the remanence of the violet coloured lapilli tuff (Fig. 2b). Intensity of magnetization rose slightly until 300 °C with susceptibility fluctuating and peaking at 200 °C. This behaviour is attributed to the presence of goethite. After applying higher temperatures intensities and susceptibilities decreased with susceptibility reaching its lowest value at 550 °C and intensity reaching its initial value. Above 550 °C susceptibility increased whereas intensity decreased rapidly. The direction of remanence changed at 450 °C and varied randomly above 600 °C. Isothermal remanent magnetization curves (Fig. 2d, A11.b) acquired at room temperature and after heating the sample to 150 °C confirmed titanohematite being the main carrier mineral of the characteristic remanent magnetization with a minor influence of goethite.

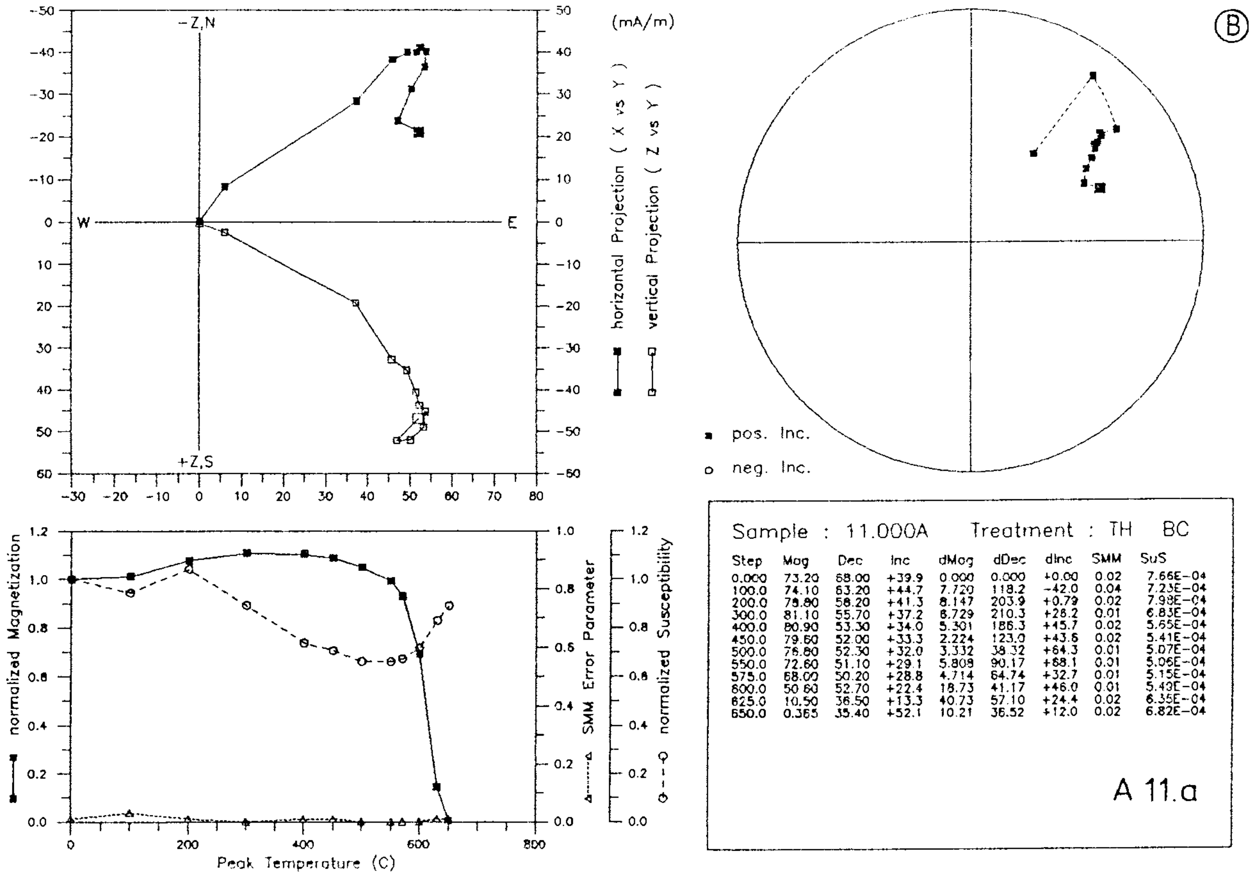
The basaltic samples all behaved similarly. Their intensity decayed steadily as heating continued and dropped below 10 per-



Sample : 12.000B Treatment : AF BC

Step	Mag	Dec	Inc	dMag	dDec	dInc	SMM	SuS
0.000	462.0	179.9	+31.5	0.000	0.000	+0.00	0.00	1.00E-06
2.500	504.0	173.5	+25.7	79.86	318.4	+16.6	0.08	1.00E-06
5.000	579.0	180.3	+41.1	192.4	247.0	-57.3	0.06	1.00E-06
7.500	670.0	146.1	+50.3	172.2	238.7	-51.5	0.05	1.00E-06
10.00	706.0	134.6	+54.2	102.8	220.3	-33.7	0.04	1.00E-06
15.00	640.0	121.7	+58.0	115.8	177.1	+14.9	0.04	1.00E-06
20.00	539.0	111.6	+61.4	118.8	149.6	+35.7	0.03	1.00E-06
30.00	401.0	93.10	+66.7	158.4	136.6	+41.4	0.02	1.00E-06
40.00	340.0	80.20	+68.4	69.59	130.4	+48.5	0.02	1.00E-06
50.00	297.0	72.20	+69.1	46.06	118.2	+57.0	0.02	1.00E-06
60.00	246.0	52.20	+67.6	62.04	133.0	+53.7	0.01	1.00E-06
70.00	219.0	52.20	+68.7	27.36	52.19	+56.7	0.02	1.00E-06
80.00	186.0	51.40	+68.5	33.02	56.97	+69.7	0.01	1.00E-06
100.0	127.0	46.80	+69.8	59.26	59.58	+65.3	0.01	1.00E-06
120.0	76.50	37.10	+68.1	50.93	63.79	+71.1	0.01	1.00E-06
150.0	37.00	26.90	+49.4	43.36	78.50	+81.4	0.01	1.00E-06

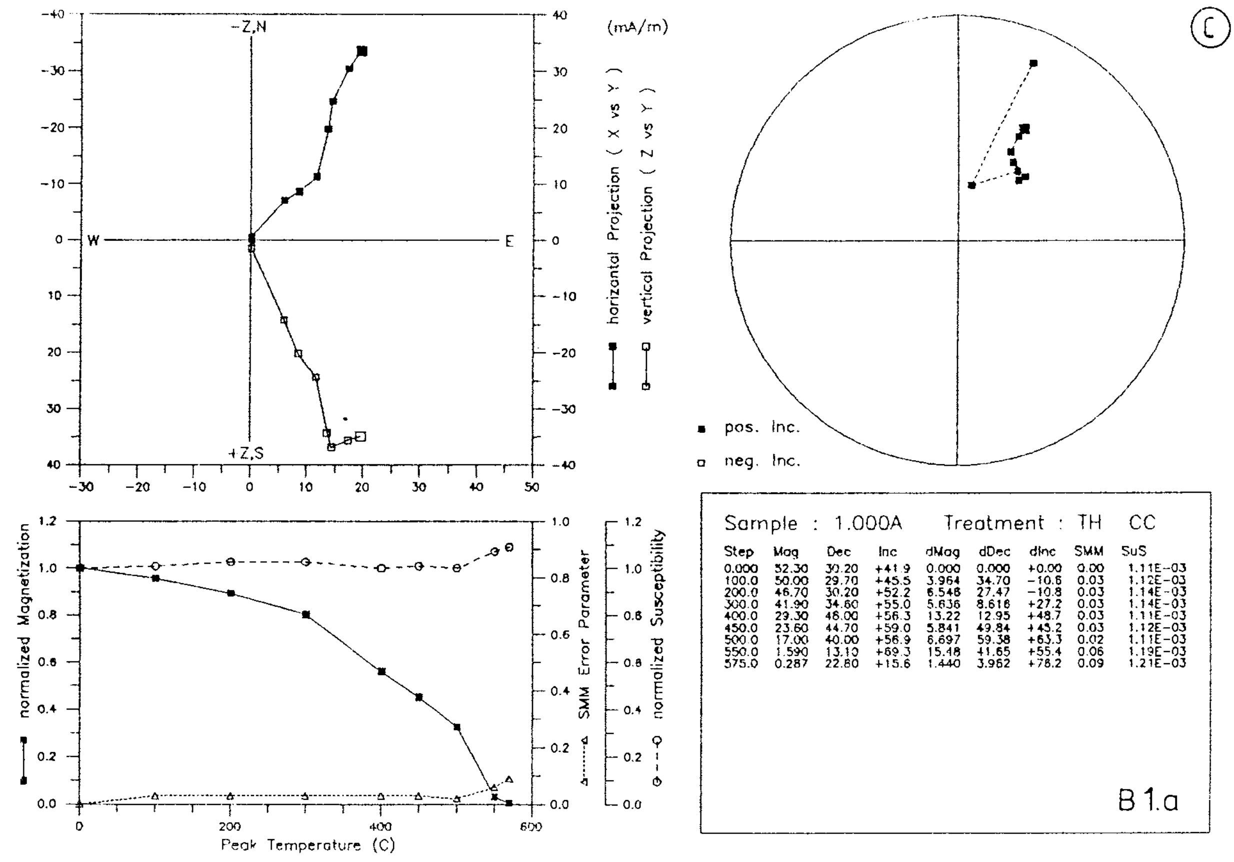
Fig. 2a. Zijderveld diagram and AC-demagnetization behaviour for a lapilli tuff sample. Overlapping coercitive spectra causing large circle distribution.



Sample : 11.000A Treatment : TH BC

Step	Mag	Dec	Inc	dMag	dDec	dInc	SMM	SuS
0.000	73.20	68.00	+39.9	0.000	0.000	+0.00	0.02	7.66E-04
100.0	74.10	63.20	+44.7	7.720	118.2	-42.0	0.04	7.23E-04
200.0	78.80	58.20	+41.3	8.147	203.9	+0.79	0.02	7.98E-04
300.0	81.10	55.70	+37.2	8.729	210.3	+28.2	0.01	6.83E-04
400.0	80.90	53.30	+34.0	5.301	186.3	+45.7	0.02	5.65E-04
450.0	79.60	52.00	+33.3	2.224	123.0	+43.6	0.02	5.41E-04
500.0	76.80	52.30	+32.0	3.332	38.32	+64.3	0.01	5.07E-04
550.0	72.60	51.10	+29.1	5.809	90.17	+68.1	0.01	5.06E-04
575.0	68.00	50.20	+28.8	4.714	64.74	+32.7	0.01	5.15E-04
600.0	50.60	52.70	+22.4	18.73	41.17	+46.0	0.01	5.43E-04
625.0	10.50	36.50	+13.3	40.73	57.10	+24.4	0.02	6.35E-04
650.0	0.365	35.40	+52.1	10.21	36.52	+12.0	0.02	6.82E-04

Fig. 2b. Zijderveld diagram and thermal demagnetization behaviour demonstrating a two component magnetization in lapilli tuffs.



Sample : 1.000A Treatment : TH CC

Step	Mag	Dec	Inc	dMag	dDec	dInc	SMM	SuS
0.000	52.30	30.20	+41.9	0.000	0.000	+0.00	0.00	1.11E-03
100.0	50.00	29.70	+45.5	3.964	34.70	-10.6	0.03	1.12E-03
200.0	46.70	30.20	+52.2	6.548	27.47	-10.8	0.03	1.14E-03
300.0	41.90	34.60	+55.0	5.636	8.618	+27.2	0.03	1.14E-03
400.0	29.30	46.00	+56.3	13.22	12.95	+48.7	0.03	1.11E-03
450.0	23.60	44.70	+59.0	5.841	49.84	+45.2	0.03	1.12E-03
500.0	17.00	40.00	+56.9	6.697	59.38	+63.3	0.02	1.11E-03
550.0	1.590	13.10	+69.3	15.48	41.65	+55.4	0.06	1.19E-03
575.0	0.287	22.80	+15.6	1.440	3.962	+78.2	0.09	1.21E-03

Fig. 2c. Characteristic Zijderveld diagram and thermal demagnetization behaviour for a basalt sample demonstrating magnetite with two components of magnetization.

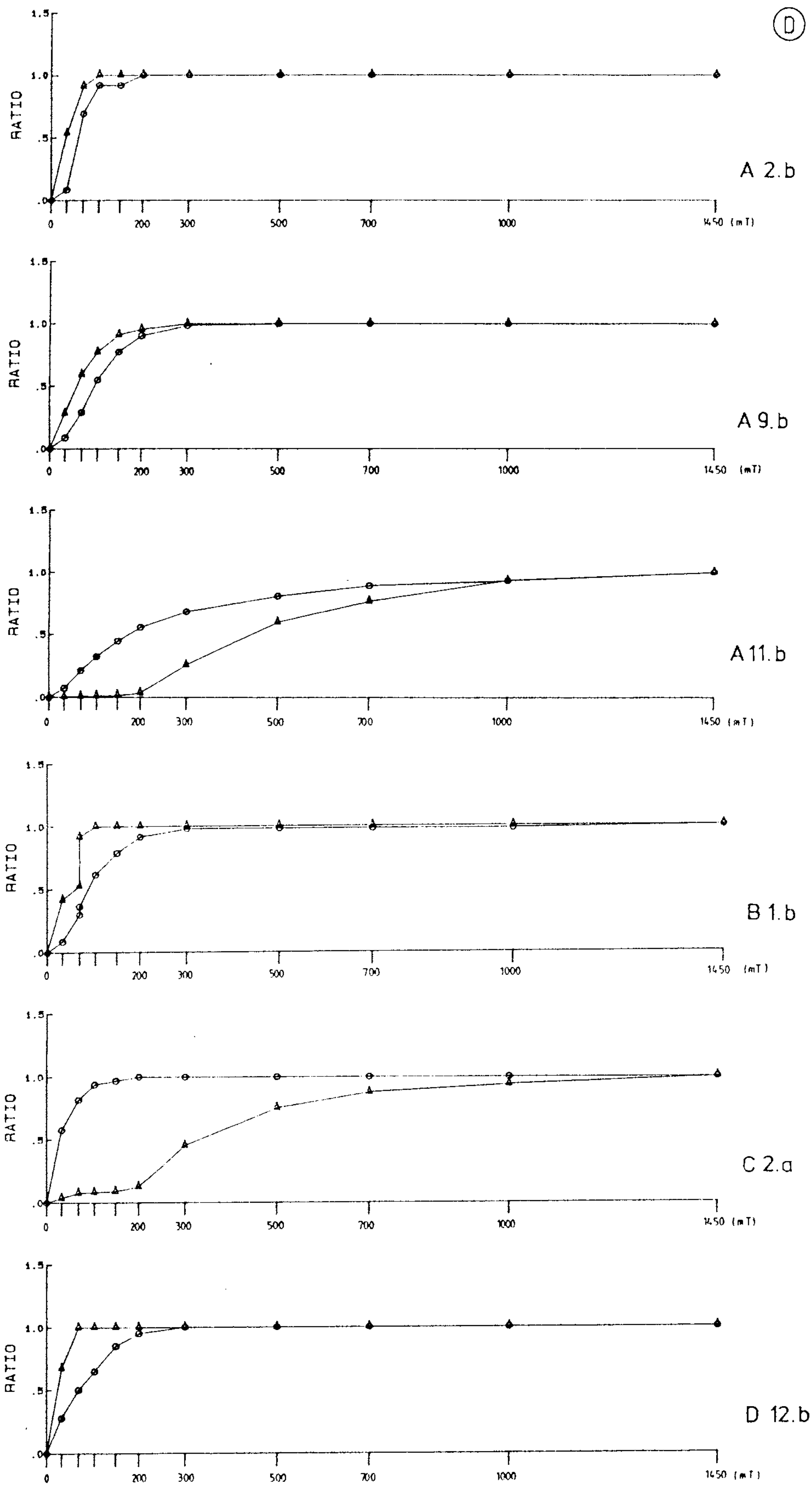


Fig. 2d. IRM-aquisition; A2.b demonstrates the magnetite behaviour in basalts; A9.b and A11.b titanohematite behaviour in lapilli tuffs. All curves show the influence of goethite. B1.b and D12.b demonstrating magnetite in basalts, C2.a titanohematite in tuffs. All curves are influenced by goethite.

cent of its NRM at temperatures between 300 °C and 550 °C (Fig. 2c). In general, susceptibility stayed relatively stable up to 400 °C and increased slightly at higher temperatures. The direction of remanence changed between 200 and 300 °C and remained stable above these temperatures, enabling the isolation of a well defined component of magnetization in the majority of samples. Isothermal remanent magnetization curves (Fig. 2d) showed titanomagnetite being the main carrier mineral of the characteristic remanent magnetization (ChRM) with some influence of goethite. Sample C2.a clearly shows the behaviour of titanohematite similar to the ones discussed above. Samples from ochre coloured pyroclastic breccias behaved similar to the basaltic samples during thermal demagnetization. The single sample from ochre coloured ash tuffs showed no stable remanent magnetization. After heating the sample to 100 °C more than 90 per cent of the NRM were already destroyed.

The pilot samples were analyzed in order to identify the optimum demagnetization range within which the characteristic magnetization was defineable. Three successive thermal steps of 300 °C, 450 °C and 500 °C were chosen for all remaining (basaltic and tuffitic) samples.

The bulk demagnetization improved the between-site grouping in the localities A, B and D. Individual site directions in locality C — mainly samples from green coloured lapilli tuffs — varied randomly. Almost all of these samples lost more than 90 per cent of their initial magnetization after heating them to 300 °C. Therefore they were rejected for fur-

Table 1: Paleomagnetic results from the Paleozoic of Graz, Austria.

Site	Locality	Rock type	Demag (TH)	Dec	Inc	VGP Lat (N)	VGP Long (E)
A4	A	green tuff	500	69.6	33.0	26.9	107.5
A5	A	basalt	500	51.3	55.9	51.1	102.2
A6	A	basalt	500	51.5	59.2	52.7	97.2
A7	A	basalt	500	63.1	44.1	36.6	105.6
A9	A	ochre breccia	300	45.9	57.8	55.8	103.1
A10	A	basalt	500	62.3	32.6	31.6	113.4
A11*	A	violet tuff	575	50.2	28.8	37.8	125.6
A15	A	basalt	500	58.4	60.1	48.6	91.8
B1	B	basalt	500	40.0	56.9	59.2	109.1
B2	B	basalt	500	72.8	44.1	30.0	98.7
B3	B	basalt	500	7.8	50.1	72.6	172.4
B4	B	basalt	450	65.8	44.7	35.1	103.1
B5	B	basalt	500	43.2	73.3	62.1	64.1
B6	B	basalt	500	75.6	63.8	39.9	77.8
B9	B	green tuff	300	35.8	71.3	66.4	70.6
B10	B	basalt	450	55.5	68.2	54.5	77.6
B11	B	basalt	500	8.8	76.3	72.6	28.3
B13	B	basalt	500	43.0	79.8	59.2	42.3
C1*	C	violet tuff	500	243.5	-7.7	-20.6	-57.1
C2*	C	violet tuff	625	255.3	-3.8	-11.3	-65.0
C3*	C	violet tuff	500	187.6	-43.5	-67.3	-2.7
D2	D	basalt	500	23.0	35.6	56.7	153.2
D4	D	basalt	500	19.1	75.1	71.7	44.9
D5	D	basalt	500	11.8	62.5	81.1	123.1
D6	D	basalt	450	359.3	60.7	84.5	-159.5
D7	D	basalt	500	45.6	54.3	54.0	108.6
D9	D	green tuff	500	34.5	65.5	66.8	91.4
D11	D	basalt	500	69.9	55.9	38.6	90.5
D12	D	green tuff	450	67.0	65.8	46.4	78.3
D13	D	basalt	500	36.7	59.3	62.8	106.9
D14	D	basalt	500	70.6	76.1	49.3	55.2
D15	D	basalt	500	66.6	56.9	41.4	91.3

Demag = demagnetization method, TH = thermal demagnetization (demagnetization temperature used to obtain characteristic direction is given in degrees centigrade); Dec = declination; Inc = inclination (samples not used for the calculation of an overall mean direction).

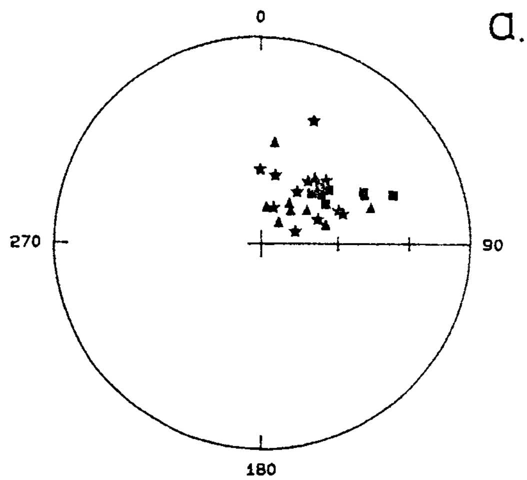


Fig. 3a. Stereographic plot of the ChRM directions.

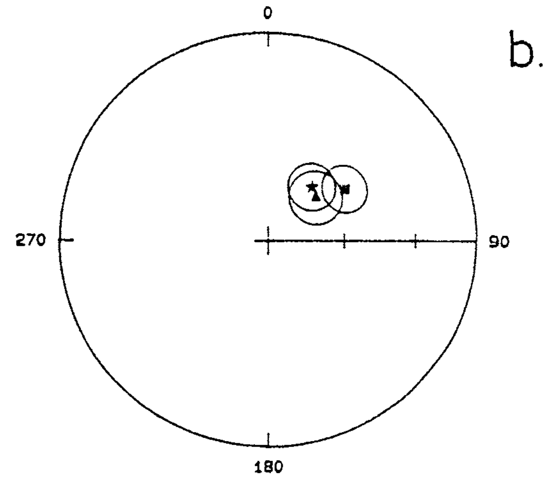


Fig. 3b. Stereographic plot of the site mean directions of the ChRM.

Table 2: Locality and overall mean directions.

Locality	Dec	Inc	α_{95}	κ
A	56.5	53.3	9.0	45.5
B	48.3	64.9	10.4	22.5
D	39.4	62.8	9.2	25.6
Mean	47.6	61.4	5.5	25.6

Dec = declination, Inc = Inclination, α_{95} = radius of 95% confidence circle, κ = precision factor.

ther analysis and were discarded. Site directions from violet coloured lapilli tuffs also showed no grouping and were excluded from the calculation of an overall mean direction.

28 samples showed a stable ChRM and were therefore considered for further analysis (Tab. 1). The majority of samples displayed declinations pointing NE with relatively steep positive inclinations, well away from the Earth's present magnetic field direction (Fig. 3a, b). The individual locality group characteristics were (Tab. 2):

(1) The locality mean directions of 7 of the basaltic and tuffitic reliable samples from locality A showed a clear grouping with an overall mean direction, giving unit weight to each sample, of Dec. = 56.5°, Inc. = 53.5° (κ = 45.5; α_{95} = 9.0°).

(2) Ten sample directions from locality B were similar and had an overall mean direction of Dec. = 48.3°, Inc. = 64.9° (κ= 22.5°; α_{95} = 10.4°).

(3) Eleven samples from locality D were similar to each other. The mean direction of these eleven samples is Dec. = 39.4°, Inc.= 62.8° (κ = 25.6°; α_{95} = 9.2°).

The three locality means cannot be considered statistically different at an 95% confidence level. Therefore an overall mean direction was calculated. The mean over 28 similar sample directions is Dec. = 47.6°, Inc.= 61.4° (κ = 25.6°; α_{95} = 5.5°), with a corresponding paleomagnetic pole at 57.6° N and 88.5° E (α_{95} = 9.2°).

In order to check the possible influence of the anisotropy of the magnetic susceptibility (AMS) all samples from all localities were measured on a kappa-bridge KLY-2. The observed degree of anisotropy was in all samples less than 3 % and therefore considered to be insignificant. In all three axis of the anisotropy ellipsoid no trend like girdles, was observed (Fig. 4). The mean direction, significant for the area of investigation, is considered to be uninfluenced by AMS-effects.

Microscopy of ferromagnetic minerals

The Paleozoic rocks in the study area have been submitted to metamorphosis during the Alpine orogeny as mentioned above. The influence of Alpine metamorphosis has been studied by Neubauer (1989). It is shown that the volcanic structure of the lavas, dikes and pyroclastics in the area of Haritzgraben is perfectly preserved. The existing alterations of minerals are dominantly a result of diagenesis and hydrothermal processes. Carbonatization, chloritization, sericitization of the matrix, transformation into phyllosilicates and in some areas partial carbonatization of bright phenocrysts are reported.

In our study we investigated the structure of the magnetic minerals by means of a scanning electron microscope. The grain sizes of magnetic minerals vary from submicroscopic to 100 µm in most of the samples. There are two generations of titanomagnetites present in the basalts. Isolated idiomorphic grains of primary titanomagnetites still show exsolution la-

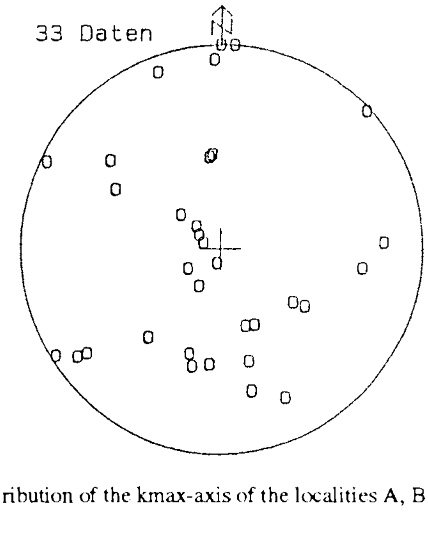


Fig. 4. Distribution of the kmax-axis of the localities A, B and D.

Fig. 5a. All three pictures demonstrates primary magnetite with crack fillings of secondary Fe-Ti-oxides.

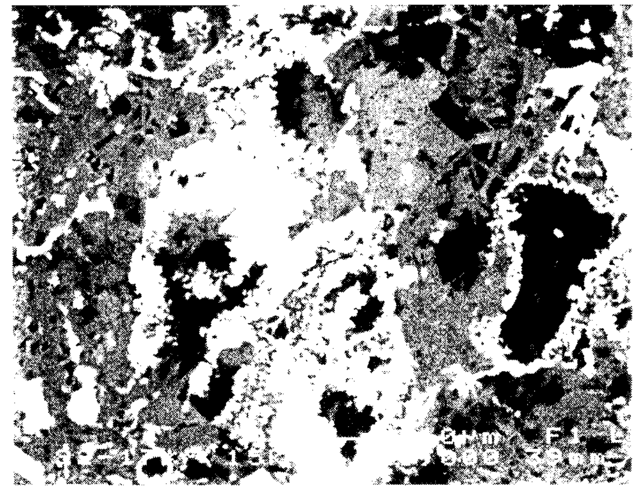


Fig. 5b. Titanohematite with skeletal structures; sometimes exsolution lamellae can be seen.

mellae, but in general they are strongly altered and transformed into secondary Fe-Ti oxides. Fig. 5a shows a xenomorphic shaped primary titanomagnetite. The mineral is replaced alongs its edges and cracks by a secondary Fe-Ti oxide. The grain on the right side of the micrograph is completely replaced by a secondary Fe-Ti oxide.

Fig. 5b shows skeletal titanohematite in a sample taken from violet coloured lapilli tuffs. The skeletal structure and the absence of any exsolution lamellae are probably a result of rapid cooling of these tuffs at their generation. There is only titanohematite present.

With these results from the microscopic study we concluded that the titanohematites in the violet coloured tuffs have not been affected by Alpine metamorphosis whereas primary titanomagnetites in the basalts, green coloured lapilli tuffs and ochre coloured pyroclastic breccias have been strongly altered by Alpine metamorphosis and have been transformed into secondary Fe-Ti oxides. Therefore the ChRM of these rocks is considered to be secondary.

Interpretation and conclusions

As mentioned above the target area represents a Silurian/ Lower Devonian basal unit of the uppermost nappe (Rannach Nappe) of the Graz Paleozoic (GP). The Silurian is dominated by alkaline mafic lavas and pyroclastics as seen in Eggenfeld and Haritzgraben. This volcanism continued through the whole Silurian due to a rift development (Schönlaub 1993). The volcanic island became covered by carbonate sediments during the Devonian, controlled by the Silurian volcanism (Ebner 1994). Block rotation occurred during the Lower Devonian due to extensional tectonics. This block rotation is documented by an angular unconformity between the "Crinoidenschichten-formation" (Pragian) and the "Dolomitsandstein-formation" (Zlichovian). These block rotations are not seen in the paleomagnetic record. As far as the metamorphism is concerned one can point out the survival of the original fabric of the lavas, dikes and pyroclastics. The alterations, seen under the microscope, are obviously due to diagenetic and hydrothermal processes. The formation of phyllosilicates, carbonatization and sericization of the matrix as well as chloritization are clear indications. The rockmagnetic investigations and the microscope analysis of the ferromagnetic minerals support this interpretation since the influence of secondary hematite can be seen.

Keeping all these facts in mind it is quite clear that the observed magnetization directions are not of primary origin. The secondary minerals carrying the ChRM, were formed during hydrothermal processes in the uppermost Miocene to Pliocene according to extensional tectonics in the East Styrian basin. This also applies to the titanomagnetite in the basalts as for the titanohematite in the tuffs. Using the paleoinclinations for dating the magnetization of the investigated area, a perfect fit can be seen with the Pliocene volcanites of the Styrian basin (Mauritsch 1972; Fritz 1992). There is absolutely no coincidence with Paleozoic and Cretaceous magnetization directions of the GP discussed by Fluegel et al. 1980, Agnoli et al. 1989. Geomagnetic investigations of the area (Bierbaumer & Burgschwaiger 1993) and a convincing modelling of the magnetic anomalies established a continuing volcanic horizon underneath the Eggenberg, prooving the island model postulated by geologists. This Silurian island was cut during the tectonic development. The present stage is the result of a dextral movement along the Rannach fault. This very young development, prooved by the homogeneous Pliocene magnetization direction, showing a clockwise rotation of about 48°, is most probably due to the tectonic development in the Styrian basin. The results demonstrate the high mobility of this area during the Pliocene.

Acknowledgements: We would like to thank Dr J. Obenholzner for his kindness to carry out the microscopic study as well as R. Gurtner for technical assistance. Further we will like to thank the two anonymous reviewers for their fruitful comments which improved the manuscript.

References

Agnoli F., Reisinger J. & Mauritsch H.J., 1989: Paläomagnetische Ergebnisse aus zwei ostalpinen Gosau-Vorkommen (Oberkreide) *N. Jb. Geol. Paläont. Mh.*, 5, 265-281.

Bierbaumer M. & Burgschwaiger E., 1993: Paläomagnetische und geomagnetische Bearbeitung des Diabasvorkommens Haritzgraben. *Unpubl. MsC Thesis, Montanuniversität Leoben*, 1-153.

Ebner F., 1976: Das Silur/Devon-Vorkommen von Eggenfeld - ein Beitrag zur Biostratigraphie des Grazer Palaeozoikums. *Mitt. Geol. Palaeont. Technik Bergbau Landesmus. Joanneum*, 37, 275-305.

Ebner F., 1994: Silurian/Devonian boundary section of Eggenfeld/Paleozoic of Graz., *IUGS Subcomm., Silurian Stratigraphy, Field Meeting, Bibl. Geol. B.-A.*, 30, 77-82.

Fisher R., 1953: Dispersion on a sphere. *Proc. Roy. Soc., A*, 217, 295-305.

Fluegel H.W., Mauritsch H.J., Heinz H. & Frank W., 1980: Palaeomagnetische und radiometrische Daten aus dem Grazer Palaeozoikum. *Mitt. Österr. Geol. Gesell.*, 71/72, 201-211.

Fritz I., 1992: Geomagnetische Untersuchungen an Vulkaniten aus dem Bereich Altenmarkt bei Riegersburch (Oststeirisches Neogenbecken). *Mitt. Naturwiss. Ver. Steiermark*, Band 122, 29-37.

Fritz H. & Neubauer F., 1988: Geodynamic aspects of the Silurian/Early Devonian sedimentation of the Paleozoic of Graz. *Schweiz. Mineral. Petrogr. Mitt.*, 68, 3, 359-367.

Marton E., Mauritsch H.J. & Pahr A., 1987: Paläomagnetische Untersuchungen in der Rechnitzer Fenstergruppe. *Mitt. Österr. Geol. Gesell.*, 80, 185-205.

Mauritsch H., 1972: Paläomagnetische Messungen an West- und Oststeirischen Vulkaniten. *Arch. f. Lagerstättenforsch.*, 13, 35-57.

Mauritsch H., Marton E. & Pahr A., 1991: Paleomagnetic investigations in highly metamorphosed rocks: Eastern Alps (Austria/Hungary). *Geophys. Transactions*, 36, 1-2, 49-65.

Neubauer F., 1989: Lithostratigraphie und Strukturen an der Basis der Rannachdecke im zentralen Grazer Palaeozoikum (Ostalpen). *Jb. Geol. B.-A.*, 132, 459-474.

Schönlaub H.P., 1993: Stratigraphy, Biogeography and Climativ Relationships of the Alpine Palaeozoic. In: Raumer J.F. & Neubauer F. (Eds.): *Pre-Mesozoic Geology in the Alps. Springer*, Wien, 65-91.