J Geophys (1988) 62:102–108

Journal of Geophysics

Paleomagnetism of Jurassic sediments from the western border of the Rheingraben, Alsace (France)*

M. Kądziałko-Hofmokl[1], **J. Kruczyk**[1], **and M. Westphal**[2]

[1] Institute of Geophysics, Polish Academy of Sciences, P.O. Box 155, 00-973 Warsaw, Poland

[2] Laboratoire de Paléomagnétisme, Institut de Physique du Globe, F-67000 Strasbourg, France

Abstract. Upper Bajocian oolithic limestones and Pliensbachian marls and marly ovoids from 9 sites distributed over 4 exposures at the western border of the Rheingraben (mean coordinates 47.8° N, 7.5° E) were sampled by 92 samples. The carriers of the natural remanent magnetization in the limestones are goethite and magnetite, and in the marls and ovoids the carrier is magnetite. After tectonic correction, the characteristic component of NRM isolated in the cleaning processes was mostly of normal polarity. The mean direction is $D=30.1°$, $I=53.2°$ ($N=7$, $k=92$, $\alpha_{95}=6.3°$) and the pole position is 63.1° N, 120.1° E. It is close to the Jurassic reference data for the stable European plate.

Key words: Paleomagnetism – Jurassic – Bajocian – France – Sediments

Introduction

Paleomagnetic data for the European Jurassic are scarce. This is mostly due to the fact that during the Jurassic mainly sediments poor in magnetic minerals, and therefore difficult for measurements, were formed. Nevertheless, in recent years several reliable publications appeared, concerning the stable European plate and mobile Europe. The data for stable Europe come from southern Germany (Heller, 1977, 1978), England (Hijab and Tarling, 1982), French-Swiss Jura (Johnson et al., 1984), Russian Platform (Khramov ed., 1984), Balkan in Bulgaria (Kruczyk et al., 1986) and Poland (Kądziałko-Hofmokl and Kruczyk, 1987). The available data helped Westphal et al. (1986) to calculate the reference pole positions. The rocks from mobile Europe were studied by: Mauritsch and Frisch (1978) – Austrian Alps; Soffel (1981) – Italy; Marton et al. (1980) and Marton and Marton (1981) – Hungary; Lowrie and Channel (1983) – Italy; Steiner et al. (1985) – Iberia; Kruzczyk et al. (1985) – Tatra Mountains in Poland. All those papers speak about possible rotations of investigated regions relative to stable Europe and, together with paleomagnetic data obtained for the stable plate, help us to understand the Mesozoic history of Eurasia.

* This research was supported by the Geodynamics of Poland Project – grant MR.I. 16.3.1.

Offprint requests to: M. Westphal

The purpose of the present note is to contribute to the paleomagnetic research by adding new data obtained from the region close to one of the most important geotectonic structures in Europe – the Rheingraben.

Geology and sampling

The sampling area lies in Alsace at the western border of the Rheingraben (Fig. 1). This region formed a post-Variscan peneplain that was covered by the sea during the Lower and Middle Jurassic, as was the rest of western Europe. The sediments studied were deposited during this transgression in the warm and shallow water. The regression began at the end of the Bajocian and this area rested above sea level during the Upper Jurassic and Cretaceous. Deformations due to Alpine orogenesis resulted in creation of synclines and anticlines of the basement, oriented WSW-ENE. This surface, which appeared to be horizontal, was later fossilized by Tertiary sediments. The formation of the Rheingraben began in the mid-Eocene. The uplift of border massifs, Vosges and Black Forsest, took place mainly in the Oligocene. The Pliocene and Quaternary movements induced an erosional activity that brought these massifs to their present altitude. Some normal faulting in the horst and graben occurred due to graben tectonics, but there is no sign of relative rotations (von Eller, 1976).

The sampled sediments comprised the Pliensbachian and Upper Bajocian deposits. The Pliensbachian rocks consisted of horizontally deposited grey marls, forming one lithostratigraphical unit, and grey-yellowish ovoidal marly nodules (called ovoids) from Schaeffer quarry (Sf in Fig. 1), site 8 and 9, respectively. The ovoids appear as a horizontal bed in the marls; they are the size and shape of a double fist with a horizontal long axis.

The Upper Bajocian white-yellowish oolitic limestones belong to the so-called Great Oolite facies, characteristic of this period for eastern France. They were sampled in three quarries: Bouxwiller (Bo in Fig. 1) – site 7, one stratigraphic level dipping 12° to the SSE direction; Imbsheim (Im in Fig. 1) – sites 1 and 2, situated 2 km distant from Bo on the opposite site of the Bastberg syncline. At site 1, samples were taken from three layers situated one under the other. Site 2 lies 50 m from and 2 m below site 1, and samples collected here represent one layer. The Im sites are inclined 15° to the WWS. The third quarry sampled was Scharrachberg (Sb in Fig. 1) – sites 3, 4, 5 and 6, situated about 20 km south of the former ones. Sites 3, 4, and

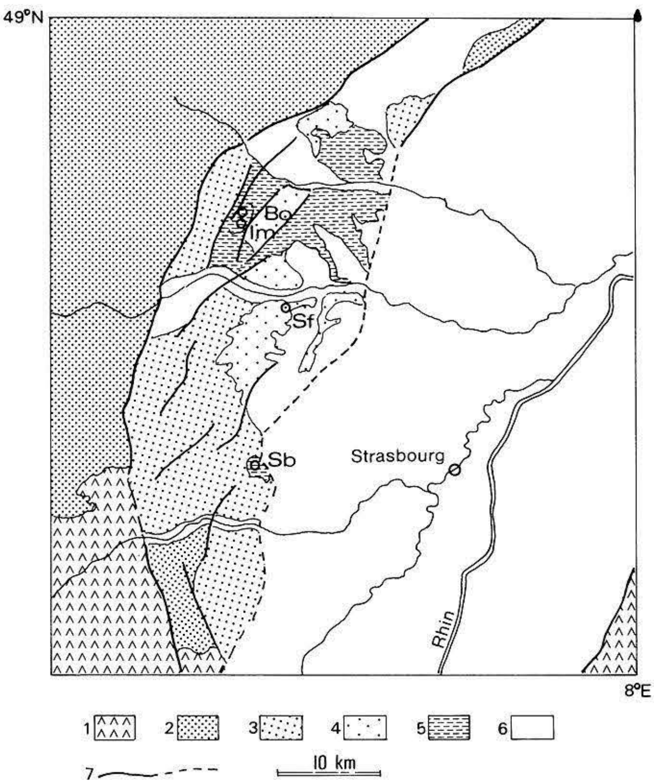

Fig. 1. Sampling area showing location of sites. *1*, Pre-Triassic basement; *2*, Buntsandstein; *3*, Keuper and Muschelkalk; *4*, Lias; *5*, Middle Jurassic; *6*, Post-Jurrassic cover; *7*, Main faults (hidden); *Bo*, Bouxwiller; *Im*, Imbsheim; *Sb*, Scharrachberg; *Sf*, Schaeffer quarry

5 lie on the north wall; sites 3 and 4 represent the same horizontal level and site 5 is situated higher. Site 6 lies on the south wall of the quarry and it represents one level whose relation to the other sites is unknown. The rocks here are inclined by 25° to EEN.

In each quarry, 15–25 oriented cores were drilled. At Sf, apart from the marl cores, seven separately oriented ovoids were also collected.

Laboratory methods and data analysis

Identification of magnetic minerals

Microscopic analysis of polished sections was applied to the oolitic limestones by means of a Min-4 ore microscope (resolution power 500). Limestones were also subjected to measurements of low-field magnetic susceptibility K before heating and after consecutive heating steps. The instrument used was a KLY-2 susceptibility bridge (noise level 4×10^{-8} SI). The K vs temperature T plots indicate mineralogical changes induced in specimens by heating in air. The continuous thermal demagnetization in field-free space of the isothermal remanence I_{rs} acquired in 1.8 T served as the main method of identification of magnetic minerals in all rock types studies. The I_{rs} vs T curves recorded during the first heating of a specimen to 600° C give the blocking temperatures T_b of magnetic minerals in rock in its natural state. The curves recorded during the second heating show the influence of the thermal treatment on the rock, resulting in changes in I_{rs} and the T_b spectrum (Kądziałko-Hofmokl and Kruczyk, 1976). Supplementary evidence was obtained from thermal and alternating-field (af) demagnetization curves of the intensity I_n of natural remanent magnetization NRM. They give spectra of T_b and coercivity characteristics of the minerals – carriers of NRM.

NRM studies

NRMs were measured in Strasbourg with a Digico spinner magnetometer (noise level 3×10^{-5} Am^{-1}) and in Warsaw with a Jelinek's IR-4 spinner magnetometer (noise level 5×10^{-6} Am^{-1}). Thermal demagnetization experiments were performed by heating the specimens step-wise to progressively higher temperatures in a nonmagnetic furnace installed in three pairs of Helmholtz coils (Strasbourg) or in a five-fold permalloy screen (Warsaw). During af treatment, specimens were subjected to progressively higher field intensities in three orthogonal directions at the same peak intensities (Strasbourg) or in apparatus provided with a two-axis tumbler (Warsaw), in a field-free space in both laboratories.

Analysis of the experimental results for each specimen was performed using orthogonal and stereographic projections of the vector end points remaining after each demagnetizing step and, for limestones, by the least-squares method of Kirshvink (1980).

Rock-magnetic and paleomagnetic results

Upper Bajocian oolitic limestones

Microscopic analysis applied to samples from Bo, Im and Sb quarries revealed only the presence of iron hydroxides – goethite and, in some cases, small amounts of lepidocrosite. In Bo and Sb, goethite resides in the cores of oolites either forming aggregates of small (1–10 μ) xenomorphic grains or occurring as one xenomorphic grain of several hundred microns with inclusions of other rock-forming minerals (goethite A). In the Im samples, apart from this form, goethite also appears as an irregular net of thin veins filling interstices between oolites – goethite B. Such a situation allows us to surmise that goethite A was formed earlier (deposited?) and goethite B later than oolites. Rarely appearing xenomorphic grains of lepidocrosite form intergrowths with goethite.

The magnetic low-field susceptibility before heating for most samples is positive and low – it does not exceed 1×10^{-5} SI. In some samples from site 6, negative K values of -2×10^{-6} SI were observed, indicating the presence of some diamagnetic minerals. The K vs T plots (Fig. 2) show a decrease of susceptibility in the temperature range 200°–300° C, due to dehydration of goethite. After heating to 300° C, K begins to rise and rises up to 10 times after the 400° heating step, indicating the appearance of new strongly magnetic minerals formed due to the heating. This result is consistent with the behaviour of magnetic susceptibility of goethite-containing marine limestones studied by Lowrie and Heller (1982).

The I_{rs} vs T curves typical of the limestones studied are shown in Fig. 3a and b. The low blocking temperatures (T_b about 80°–100° C) are characteristic of goethite. The highest blocking temperatures (500–550° C) indicate the presence of magnetite (see plot for site 3), sometimes in

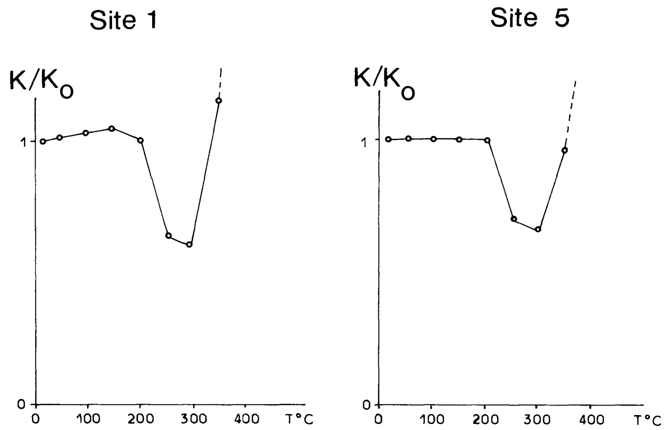

Fig. 2. Susceptibility as a function of temperature for two limestone samples

very small amounts. I_{rs} acquired by specimens after the first heating is several times greater than before the heat treatment. The second I_{rs} vs T curves show the presence of only one mineral with T_b characteristic of magnetite or maghemite.

The demagnetization curves of I_n are shown in Fig. 4a and b. A temperature of 50° C removes 20%–95% of NRM. This component is carried by low-T_b minerals (goethite) and its intensity depends on the low-T_b to high-T_b mineral ratio. The remaining component decreases during heating to 300°–400° C, and then its intensity begins to rise. The af treatment is not effective for specimens with geothite as the prevailing mineral, due to its high coercivity – site 5 in Fig. 4b. The I_n vs H plots for specimens also containing (apart from goethite) a considerable amount of high-T_b minerals indicate the existence of the two components of NRM with different coercivities – site 1 in Fig. 4b.

In view of the results presented, we argue that the NRM of the oolitic limestones is carried by goethite and magnetite. Magnetite is probably present in the form of very fine (superparamagnetic) grains and therefore invisible under the microscope Min-4. In Im, two forms of geothite are present.

The NRM intensities were found to be variable (see Table 1), but their response to demagnetization treatment was similar. Some of them could not be satisfactorily cleaned – the intensity of remanence quickly dropped below the noise level of the magnetometer.

Thirty-eight specimens from Im, 24 from Sb and 31 from Bo were demagnetized. The Bo results will not be discussed – the NRM intensities are very low and interpretation of demagnetization results is often impossible (see Table 1). Figure 5a and b presents the orthogonal and stereographic demagnetization plots characteristic of Im and Sb rocks. A temperature of 50° C removes the first, soft (against heating) component of NRM carried by goethite. Its direction is close to the present geomagnetic field direction ($D=358°$, $I=64°$), suggesting remagnetization of its carriers (goethite) in the present field. At higher temperatures, the orthogonal and stereographic plots become erratic due to the low intensity of the remaining component of NRM and it is often difficult to find linear parts of the cleaning diagrams going to the origin of the plot. After

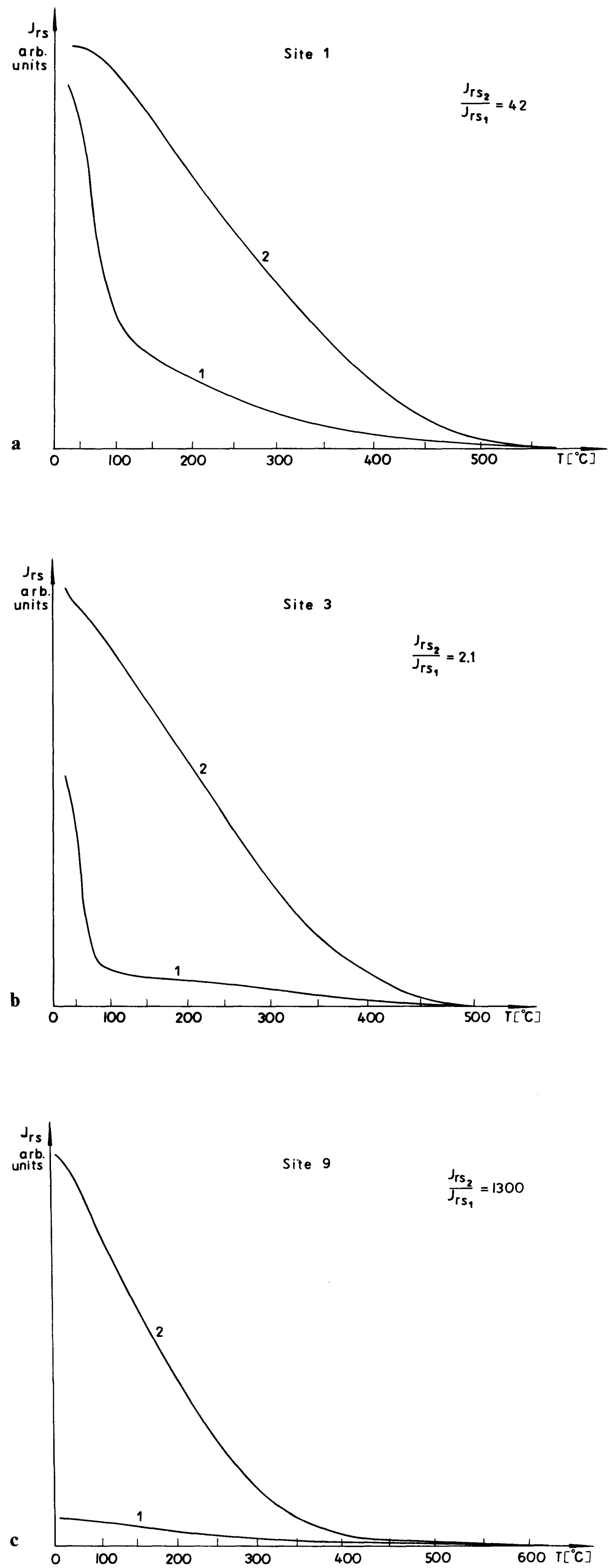

Fig. 3a–c. Thermomagnetic curves for **a**, **b** limestones and **c** ovoids. 1 – First heating curve; 2 – second heating curve

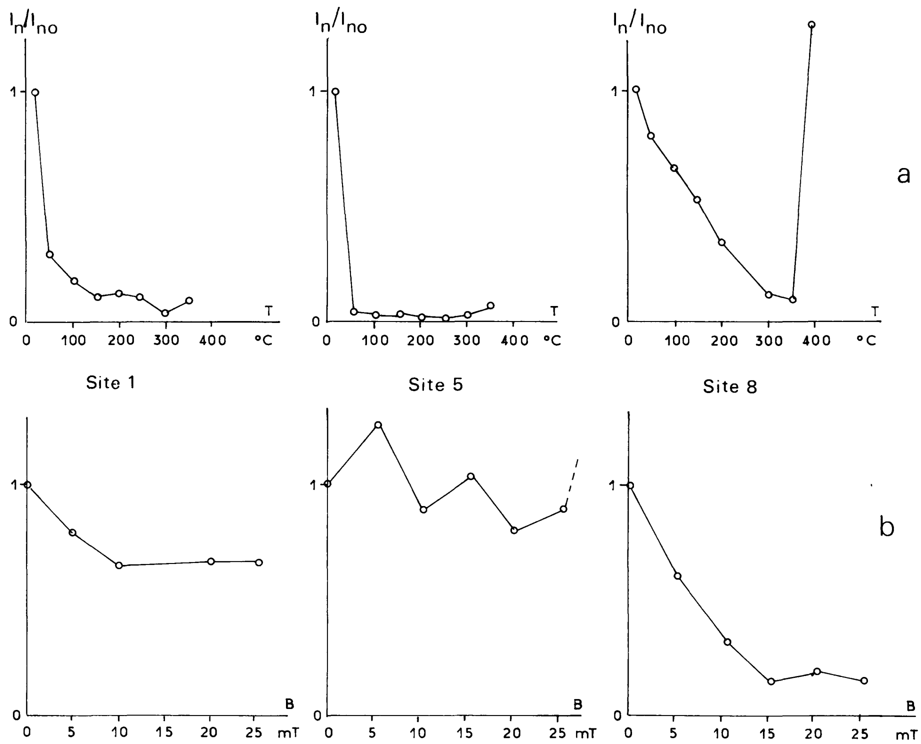

Fig. 4a and b. Decay of I_n **a** during thermal cleaning and **b** during af cleaning. Site 1 and 5 – limestones; site 8 – marls

Table 1. Site mean directions after bedding correction. n_1/n_2 – the number of sample directions used in the calculation to the number of samples demagnetized. D, I – declination, inclination. α_{95}, k – statistical parameters. NRM – intensity of the natural remanence. D, I and α_{95} in degrees

Exposure	Age	Site and polarity	n_1/n_2	D	I	α_{95}	k	NRM $\times 10^{-6}$ Am^{-1}
Imbsheim (Im)	U. Bajocian	1N	6/18	16.6	58.9	9.5	50	20–500
$\varphi = 48°47'$N		1R	6/10	212.9	−50.7	13.0	26	20–500
$\lambda = 7°28'$E		2N	10/12	18.3	41.1	10.0	23	20–500
Scharrachberg (Sb)	U. Bajocian	3N	8/9	34.6	50.4	14.0	18	100–650
$\varphi = 48°36'$N		4N	6/6	36.9	60.1	7.7	76	60–370
$\lambda = 7°30'$E		5N	4/4	35.7	55.8	7.0	155	150–600
		6N	7/7	38.2	52.7	4.5	169	50–170
		3R, 5R, 6R	5/7	223.1	−24.5	12.5	38	120–600
Bouxwiller (Bo)	U. Bajocian	7N	5/31	56.0	61.5	20.0	15	10
$\lambda = 48°49'$N								
$\lambda = 7°28'$E								
Schaeffer (Sf)	Pliensbachian	8N	13/20	329.0	57.3	6.7	39	200–550
$\varphi = 48°45'$N		9N	22/25	0.4	55.4	4.8	43	250–550
$\lambda = 7°35'$E								
Im + Sb								
Before bedding correction	U. Bajocian	1–6	7[a]/8	16.6	59.7	12.3	25	
After bedding correction				30.1	53.2	6.3	92	

[a] 3R, 5R, 6R excluded

heating to 350° C, the intensity of remanence increases following the mineralogical changes (see previous section).

In order to isolate the characteristic component of natural remanence CARM, the demagnetization results were analysed following the least-squares method. For the directions of CARM, we most often took either the Hoffman-Day directions or the directions of the longest lines fitted to the vectors subtracted in the temperature range preceding the rise in I_n. Usually these temperature ranges began higher than 50° C. In some cases the direction of the component subtracted between two consecutive heating steps, or the component remaining after heating to at least 50° C, was assumed to be the CARM direction. Figure 6a shows CARM directions isolated for Im and Sb after tectonic correction.

The CARM isolated in Im and Sb resides mostly in

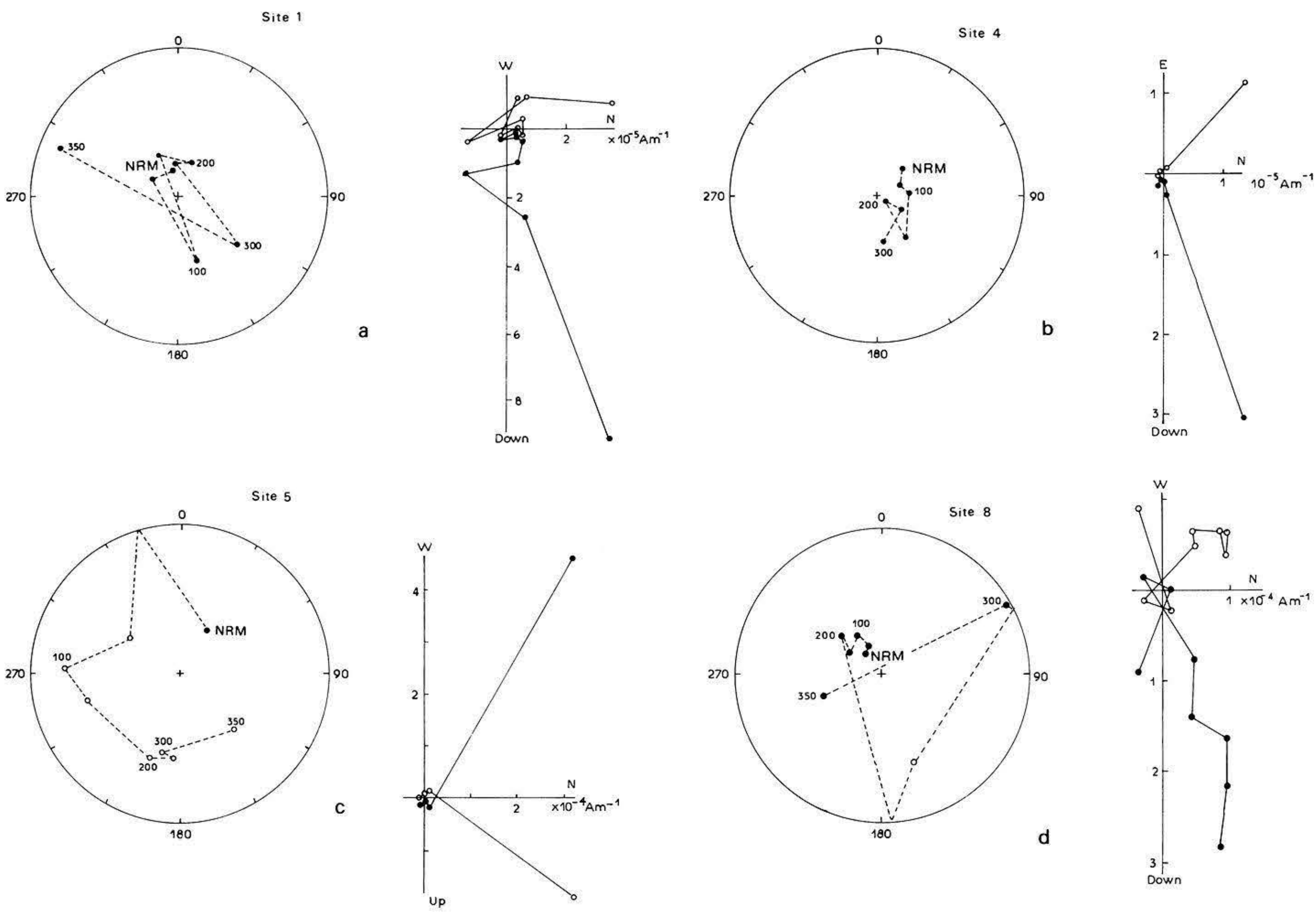

Fig. 5a–d. Orthogonal and stereographic demagnetization diagrams after bedding correction for **a**, **b** and **c** limestones and **d** marls. *Full circles* – horizontal plane. *Open circles* – vertical plane

magnetite. Only in some cases was CARM observed in the temperature range including room temperature (ex 20°–300° C), suggesting that this component is carried not only by magnetite but also by goethite not remagnetized in the present field. Most of the CARMs are of normal polarity. The sites means after tectonic corrections, together with the corresponding parameters of Fisherian statistics, are included in Table 1.

The group of CARMs of reversed direction is less numerous. In both quarries they appear only after removing the component of the present field direction, which shows that reversed CARMs are carried exclusively by magnetite.

The reversed CARMs were isolated in some specimens from sites 1, 3, 5 and 6. The demagnetization results also suggest the presence of a reversed component of NRM in site 4. It is probably of very low intensity and therefore masked by the component of normal polarity. There is no trace of a reversed component in site 2. Figure 5c shows the orthogonal and stereographic plots obtained for one site-5 specimen where two components, normal and reversed, were isolated. The normal one was identified as the line in the temperature range 20°–300° C, and the reversed one as the Hoffman-Day direction persisting from 100° C to the origin of the plot. The reversed directions are more scattered than the normal ones (see Fig. 6a). The reversed site mean directions for Im and Sb, together with corresponding Fisherian parameters, are included in Table 1.

The mean reversed direction obtained for Im (1R in Table 1) is exactly opposite to the normal mean directions for sites 1 and 2. The result obtained for Sb (3R, 5R, 6R in Table 1) differs considerably and is excluded from further calculations.

The difference in tectonic parameters of Im and Sb (3R, 5R and 6R excluded), however slight, allowed us to apply the fold test to all Upper Bajocian sites. The between-site means calculated before and after tectonic correction are shown at the bottom of Table 1. The parameters of Fisherian statistics show better grouping after correction, suggesting pre-tectonic origin of the isolated CARM.

Pliensbachian

Only one magnetic mineral appears in the Pliensbachian marls and ovoids – magnetite. The I_{rs} vs T curves shown in Fig. 3c reveal the blocking temperatures of about 570° C characteristic of this mineral. Heating in air to 600° C results in an enormous increase of I_{rs} that follows the appear-

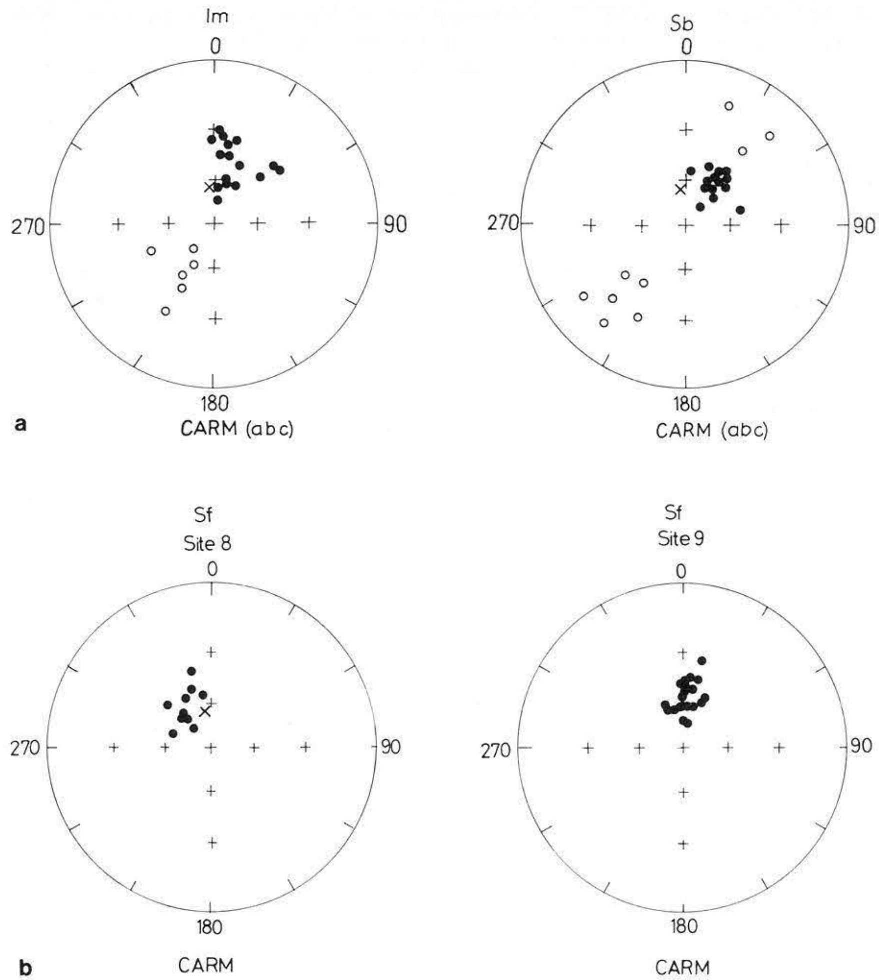

Fig. 6a and b. Directions of CARM after bedding correction for **a** limestones from Im and Sb and **b** marls and ovoids from Sf

Table 2. Paleomagnetic pole positions. N – number of data entered. Latitude, longitude and α_{95} in degrees

Sampling area	Age	N	Lat. N	Long. E	α_{95}	k	Polarity
Alsace (Im + Sb)	U. Baj.	7	63.1	120.1	6.3	92	M
S. Germany, Heller (1978)	U. J.	79	68.0	130.0	5.0		N
England, Hijab and Tarling (1982)	L.J.	185	76.9	134.7	2.5	19	N
Swiss – French Jura, Johnson et al. (1984)	U.J.	24	77.7	148.4	5.9	26	N
ibid.	U.Baj.	3	61.1	123.3	22.2	32	N
Poland (stable), Kądziałko-Hofmokl and Kruczyk (1987)	M.-U.J.	8	72.3	150.4	7.3	58	M
Bulgaria (stable), Kruczyk et al. (1986)	L.-M.J.	12	72.3	120.2	5.4	66	N
Stable Eurasia, Westphal et al. (1986)	M.-U.J.	4	70.0	128.0	7.0	187	

ance of a great amount of magnetite from nonmagnetic (clay?) minerals present in the rock. The results of demagnetization of I_n support this evidence. The NRM intensities of both rock types are of the same order (see Table 1). Twenty-five specimens of ovoids and 20 of marls were demagnetized, some thermally up to 400° C and some by af with a peak field of 30–40 mT. The I_n vs T curves show smooth decay to 350° C; and after heating to higher temperatures, I_n increases sharply due to newly formed magnetite (see site 8 in Fig. 4).

The directions of NRM, as orthogonal and stereographic plots in Fig. 5d show, already become scattered after heating to 200°–500° C. An intensity of 30–40 mT lowers measured remanences to the noise level of the magnetometer.

In order to isolate the characteristic remanence residing in marls and ovoids, we have adopted the criterion of minimum dispersion of directions of remanence remaining after different cleaning steps. The best grouping was obtained after 100°–250° C or, in the case of af cleaning, after 25–30 mT. The intensity of the component isolated ranged from 10% to 50% of I_n before cleaning. We assume it to be the CARM preserved in the marls and ovoids. In both cases, its direction is of normal polarity. Figure 6b presents the stereographic projections of the CARM directions for sites 8 and 9. The site mean directions, together with parameters of Fisherian statistics, are included in Table 1.

Discussion and conclusions

The magnetic carriers in the oolitic limestones were stated to be goethite and magnetite. We suppose that goethite A, which forms cores of oolites, is synsedimentary. Part of this mineral is remagnetized in the present field, but part of it (especially with higher T_b) could conserve the remanence acquired at the time of deposition (some Sb samples).

Magnetite, stated mainly as a result of the thermomagnetic method, is probably very fine grained. According to the discussion of mineralogy of marine limestones by Lowrie and Heller (1982), we assume that the magnetite observed here is depositional. In view of the above arguments, we argue that the isolated CARM carried by magnetite and, in some cases, by goethite is Upper Bajocian. This conclusion is supported by results of the fold test applied to site mean directions of Im and Sb. The between-site mean after bedding correction has much better Fisherian confidence parameters than before correction – see Table 1 – indicating that CARM is pre-tectonic. Hence, we argue that the results obtained – mean paleomagnetic field direction $D = 30.1°$, $I = 53.2°$ and paleopole position latitude = 63.1°, longitude = 120.1° – represent the Upper Bajocian geomagnetic field.

The appearance of normal and reversed directions suggests varying field polarity in the Upper Bajocian.

The NRM of the Pliensbachian deposits is carried by magnetite. The directions of isolated remanence components differ from the reference data, suggesting post-Jurrasic magnetization of marls and ovoids.

Acknowledgements. The authors wish to thank Dr. M. Jeleńska and Dr. J.B. Edel for assistance in the field work and helpful discussions.

References

von Eller, J.P.: Vosges-Alsace, collection guides géologiques régionaux. Masson 1976

Heller, F.: Paleomagnetism of Upper Jurassic limestones from southern Germany. J. Geophys. **42**, 475–488, 1977

Heller, F.: Rock magnetic studies of Upper Jurassic limestones from southern Germany. J. Geophys. **44**, 525–543, 1978

Hijab, B.R., Tarling, D.H.: Lower Jurassic paleomagnetic results from Yorkshire, England, and their implications. Earth Planet. Sci. Lett. **60** (1), 147–154, 1982

Johnson, R.J.E., Van der Voo, R., Lowrie, W.: Paleomagnetism and late diagnesis of Jurassic carbonates from the Jura Mountains, Switzerland and France. Geol. Soc. Am. Bull. **95**, 478–488, 1984

Kądziałko-Hofmokl, M., Kruczyk, J.: Complete and partial self-reversal of natural remanent magnetization in basaltic rocks from Lower Silesia. Pageoph. **114**, 207–213, 1976

Kądziałko-Hofmokl, M., Kruczyk, J.: Paleomagnetism of middle-late Jurassic from Poland and implications for the polarity of the geomagnetic field. Tectonophysics **139**, 53–66, 1987

Khramov, A.N. (ed): Materials of the World Data Center B. Paleomagnetic directions and pole positions. Summary catalogue 1. Moskva Nauka: 1984

Kirshvink, J.L.: The least-squares line and plane and the analysis of paleomagnetic data Geophys. J. R. Astron. Soc. **62**, 699–718, 1980

Kruczyk, J., Kądziałko-Hofmokl, M., Lefeld, J.: Results of paleomagnetic investigations and the tectonic position of Jurassic radiolarites and limestones of the Lower Sub-Tatric Nappe in the Tatra Mts. Publ. Inst. Geophys. Pol. Acad. Sci., **A-16**(1975) 177–130, 1985

Kruczyk, J., Kądziałko-Hofmokl, M., Nozharov, P., Petkov., N., Nachev, I.; Paleomagnetism of Jurassic rocks from the Balkan (Bulgaria) Bulg. Geophys. J. **12**, 4, 1986

Lowrie, W., Channel, J.E.T.: Magnetostatigraphy of the Jurassic-Cretaceous boundary in the Maiolica limestone (Umbria – Italy). Geology **12**, 44–47, 1983

Lowrie, W., Heller, F.: Magnetic properties of marine limestones. Rev. Geophys. Space Phys. **20** (2), 171–172, 192

Marton, E., Marton, P.: Mesozoic paleomagnetism of the Transdanubian Central Mountains and its tectonic implications. Tectonophysics **72**, 129–140, 1981

Marton, E., Marton, P., Heller, F.: Remanent magnetization of a Pliensbachian limestone sequence at Bakonycsernye (Hungary). Earth Planet. Sci. Lett. **48**, 218–226, 1980

Mauritsch, H.J., Frisch, W.: Palaeomagnetic data from the central part of the northern Calcareous Alps, Austria. J. Geophys. **44**, 623–637, 1978

Soffel, H.: Palaemognetism of a Jurassic ophiolite series in east Elba (Italy). J. Geophys. **49**, 1–10, 1981

Steiner M.B., Ogg, J.G., Melendez, G., Sequeiros, L.: Jurassic magnetostratigraphy, 2. Middle-Late Oxfordian of Abuilon, Iberian Cordillera, northern Spain. Earth Planet. Sci. Lett. **76**, 151–166, 1985/86

Westphal, M., Bazhenov, M.L., Lauer, J.P., Pechersky, D.M., Sibuet, J.C.: Paleomagnetic implications on the evolution of the Tethys Belt from the Atlantic Ocean to the Pamirs since the Triassic. Tectonophysics **123**, 37–82, 1986

Received December 11, 1986; revised version August 10, 1987 and October 9, 1987
Accepted October 12, 1987