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Revision of the age of magnetization of the Montmartin red beds, Normandy, France

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Summary. A new roadcut has enabled us to sample the south-dipping limb of the Montmartin syncline for a palaeomagnetic reevaluation of an earlier result published by Jones, Van der Voo & Bonhommet. In combination with the results previously published in 1979 for the north-dipping beds of the syncline, a conclusively negative fold test is obtained. The resulting magnetization (declination/inclination = $206°/-3°$, $\alpha_{95} = 12°$, palaeopole at 38°S, 325°E) is interpreted to be of Late Carboniferous age, not Late Devonian as thought earlier. Simultaneously, we have re-evaluated the age of the rocks, previously thought to be Late Devonian on the basis of Acritarchs, Chitinozoans and spores. It has not been possible to reconfirm these fossils, not even in the same samples as studied originally; in contrast, the regional presence of Early Palaeozoic fossils suggests to us an age similar to that of other red beds in the Armorican Massif, which have been dated as Early Ordovician. The geodynamic implications of our finding that the Montmartin rocks are completely remagnetized, however, are of no great consequence for the geodynamics of the Hercynian belt. Pre-folding magnetization obtained from Silurian and Devonian rocks in Spain and Germany argue for the same conclusion as reached erroneously in our earlier study, namely that the Armorican Massif and adjacent parts of Hercynian Europe were adjointed to North America,

Great Britain, the Baltic Shield and the Russian Platform since at least Late Devonian time. If a Medio-European ocean existed during the Palaeozoic, it was virtually closed before the mid-Devonian and of insignificant width during Culm deposition in Early Carboniferous time.

Introduction

The Palaeozoic evolution and plate movements of the continental elements that assembled into Pangaea by Late Palaeozoic time are largely documented on the basis of palaeomagnetic data. These data are few and far between, however, so that each and every one of them assumes a relatively large importance, particularly for the Silurian and Devonian. For the Armorican Massif only one Devonian palaeopole was available, obtained from red beds thought to be Old Red Sandstone equivalents. This result from the Hyenville Formation in the Montmartin syncline (Jones, Van der Voo & Bonhommet 1979) has been pivotal in the discussions about the relative Late Palaeozoic positions of the North European foreland and the Hercynian massifs in Spain, France and Germany (Jones *et al.* 1979; Lefort & Van der Voo 1981; Van der Voo & Scotese 1981; Van der Voo 1982, 1983), whereas Eocambrian and Cambrian palaeomagnetic results from the Armorican Massif (Hagstrum *et al.* 1980; Duff 1980; Perigo *et al.* 1983) indicate that at that time the Armorican Massif and Gondwana were adjacent and drifting together with respect to the pole. Between Cambrian and Late Devonian times, an independent plate called 'Armorica' (comprising most of Hercynian Europe) has been invoked (Van der Voo 1982) which travelled away from Gondwana and towards the North European and North American equatorial continents. In this model, therefore, a Medio-European ocean is thought to have been in existence only before Late Devonian times, whereas a middle Palaeozoic ocean between Armorica and Gondwana did not close until the Carboniferous, thus causing the Hercynian orogency. Very recent additions to the data base have (1) confirmed the Late Devonian palaeogeography for Armorica (Bachtadse, Heller & Kröner 1983; Perroud & Bonhommet 1984) and (2) constrained the time of movement of Armorica to the interval between the Late Ordovician and the Late Devonian (Perroud, Van der Voo & Bonhommet 1984; Van der Voo, Johnson & Perroud 1984).

The similarity between the palaeopole obtained for the Montmartin red beds and the poles from Spain (Perroud & Bonhommet 1984) and Germany (Bachtadse *et al.* 1983) eliminated the urgency to re-examine the magnetization of the Montmartin rocks. Nevertheless, the construction of a new roadcut that exposed south-dipping beds for palaeomagnetic sampling, and a gradual realization that the red beds may be older than Old Red Sandstone equivalent, prompted us to undertake this study. As will be illustrated below, the red beds appear to be remagnetized after the (Carboniferous) folding, and this publication is intended to correct the tentative interpretation of our earlier study (Jones *et al.* 1979).

Discussion of the age of the red beds of the Hyenville Formation in the Montmartin syncline

The age of these red beds in Normandy, as well as those of other red formations in the northern Armorican Massif (Plourivo, Erquy-Cap Fréhel, and Jersey red beds), has always been controversial. Attributed first to the Cambrian (Bigot 1928), then to the Carboniferous (Pruvost & Waterlot 1936), the Hyenville Formation appeared to be definitively dated when Doubinger & Poncet (1964) published their discovery of a microplancton assemblage with Acritarchs, Chitinozoans and spores. The Late Devonian age assigned to the Hyenville Formation (Doubinger, Drot & Poncet 1966), however, posed new problems because elsewhere in the Armorican Massif the Devonian is comprised of limestones and shales. The presence of the transgressive Hyenville Formation, overlying the Late Precambrian Brioverian series, implied Bretonic orogenic phases of a much earlier age than the Tournaisian-aged phases recognized further south in the synclinoria of Laval and Ménez-Bélair (Pelhate 1971; Lejal-Nicol *et al.* 1982; Paris *et al.* 1982). It also puzzled palaeogeographers who until then had not considered the Old Red Sandstone facies to extend further south than Great Britain and the Ardennes.

The palaeontological data, moreover, seemed anomalous: the oxidizing environment of red beds is very unfavourable for the preservation of the organic material of Chitinozoans, whereas one of the cited discoveries, *Cyathochitina*, is normally not found in beds younger

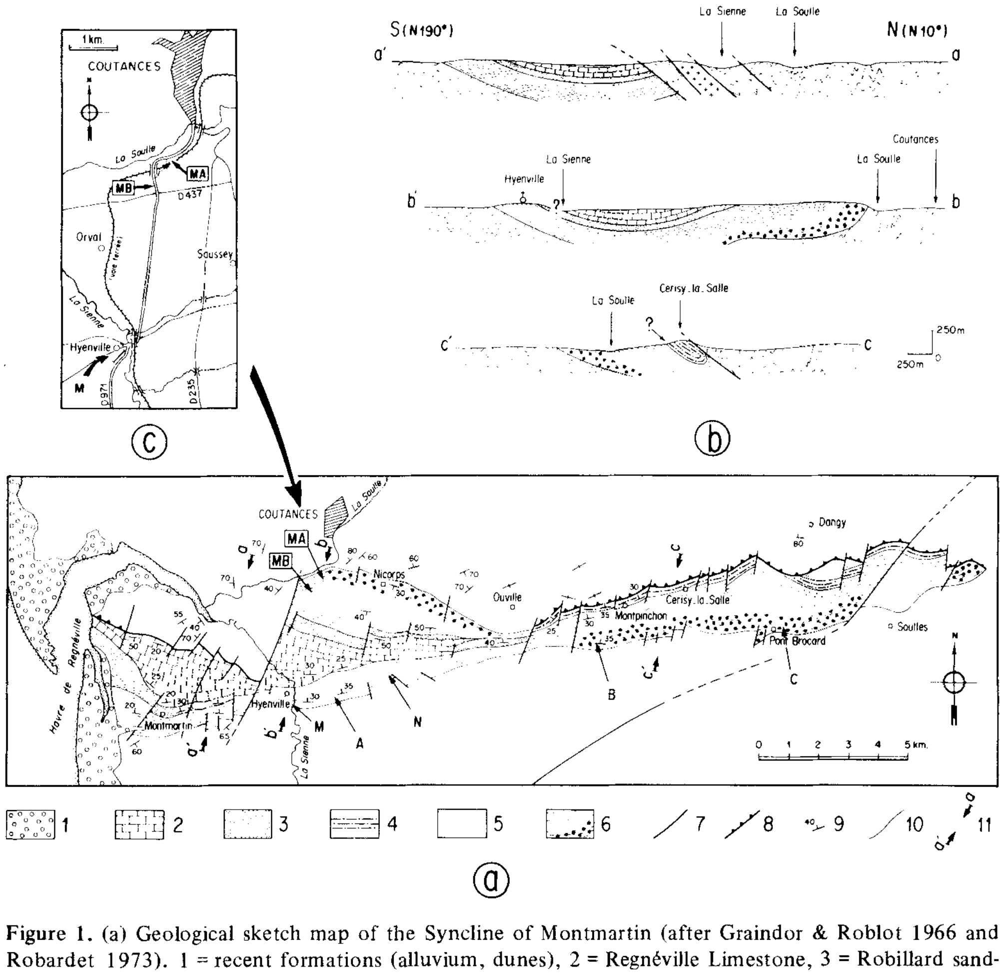

Figure 1. (a) Geological sketch map of the Syncline of Montmartin (after Graindor & Roblot 1966 and Robardet 1973). 1 = recent formations (alluvium, dunes), 2 = Regnéville Limestone, 3 = Robillard sandstone, 4 = Grès de Cerisy-la-Salle (lower Caradocian), 5 = Brioverian (Precambrian), 6 = red beds and conglomerates of the Hyenville Formation ('Poudingue de Nicorps' and 'Poudingue de Pont-Brocard'), 7 = faults, 8 = thrusts, 9 = strike and dip of the strata. 10 = geological contacts, 11 = location of the cross-sections of (b). Note that the geographical extent of the Robillard sandstone and the Grès dé Cerisy-la-Salle remains poorly known. A, B, C, M and N are the palaeomagnetic sites of Jones *et al.* (1979), MA and MB are the sites of the study (see c). (b) Schematic geological cross-sections through the Montmartin Syncline (after Robardet 1973). Legend is the same as for (a). (c) Location of the new sites, MA and MB, of this study located in the south-dipping beds (north flank) of the syncline. Site M is from Jones *et al.* (1979) in north-dipping beds; see cross-section b–b' of (b).

than Silurian (Jenkins & Legault 1979, p. 255). A further complication is introduced by the presence of an Ordovician fauna in the 'Grès de Cerisy-la-Salle' of the same Montmartin syncline (Doubinger *et al.* 1966). Despite some structural complications in thrust slices (Graindor 1964; Robardet 1973), these sandstones of Cerisy-la-Salle (Fig. 1a) appear to be clearly younger than the 'Devonian' red beds, as also noted by Doubinger *et al.* (1966, p. 963). The problems with the age of the Hyenville red beds, already mentioned by Jones *et al.* (1979, p. 290), led certain workers to discard one or the other of the micropalaeontological data sets (Doré 1969; Chauris 1971).

All these inconsistencies prompted several micropalaeontologists to attempt to reconfirm, without success, the palaeoplancton mentioned (but not illustrated) by Doubinger & Poncet (1964). One of us (FP) has been unable to find in a dense and systematic sampling of 60 m of the Hyenville Formation (18 samples) any microfossils or even organic material. In one of the original samples analysed by Doubinger in 1964, placed obligingly at our disposal thanks to Dr J. Poncet, we have also not been able to find any trace of microfossils. The existence of the assemblage of Acritarchs, Chitinozoans and spores in the Hyenville Formation is therefore in serious doubt, where as the Late Ordovician fauna in the sandstones of Cerisy-la-Salle has been reconfirmed (lower Caradocian: F. Paris, unpublished data).

In conclusion, it appears to be preferred to consider the Hyenville Formation as undated at best, and in all likelihood to be older than Devonian. A correlation with the red beds of Plourivo, Erquy and Cap Fréhel, with a radiometric age of 472 ± 5 Ma for intercalated (trachy-) andesites (Auvray *et al.* 1980) suggests to us an Early Ordovician age (Tremadocian or lower Arenig).

Palaeomagnetic analysis and the age of magnetization in the Hyenville Formation

The behaviour of the Natural Remanent Magnetization (NRM) of 40 samples from the south-dipping beds (sites MA, MB of Fig. 1) has been analysed using thermal, chemical, and alternating field demagnetization methods. Similar procedures were followed as for the earlier study of the north-dipping beds (Jones *et al.* 1979), and we refer to that paper for

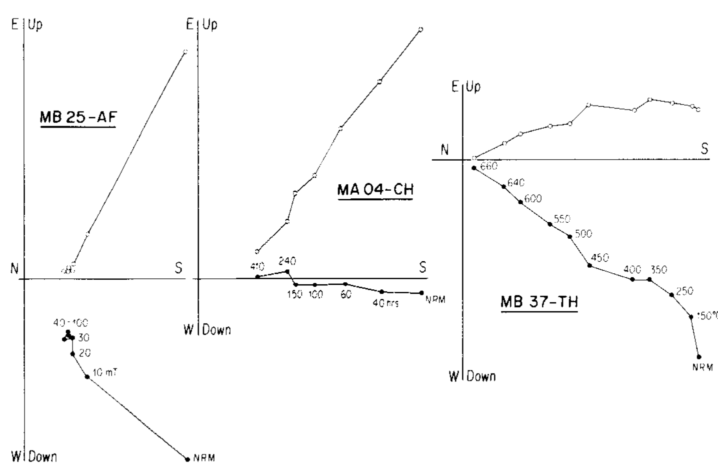

Figure 2. Demagnetization diagrams (Zijderveld 1967) showing the projections of the end-points of the magnetization vectors during progressive alternating field (AF), chemical (CH) and thermal (TH) demagnetization. Full (open) symbols represent projections on to the horizontal (vertical) plane. The results are not corrected for the tilt of the strata.

details. The measurements were made with the ScT cryogenic magnetometer of the University of Michigan.

Zijderveld (1967) diagrams of some 60 specimens were analysed for linear trajectories. Generally, the magnetization was univectorial (Fig. 2c), although in some specimens the linear decay of the magnetization vector was not completely towards the origin (Fig. 2a, b). The latter phenomenon suggests the presence of a second component, which could not be perfectly isolated in the treatment selected (e.g. alternating field up to 100 mT in Fig. 2(a), chemical leaching up to 410 hr in Fig. 2b). We recall that in the earlier study, similar univectorial behaviour was documented, although in that collection as well some linear trajectories bypassed the origin in the demagnetization diagrams.

In Fig. 3 the directions are shown as obtained from the analysis of the Zijderveld diagrams. As seen in Fig. 3(a), there is a good internal consistency between the components removed by thermal demagnetization (up to 670°C), the components removed by 150 hr of leaching and the end points of the AF demagnetizations (all these correspond to the characteristic

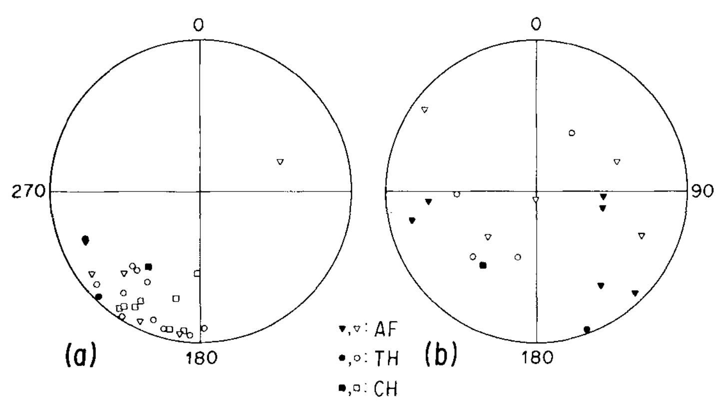

Figure 3. Magnetic components obtained from site MB. (a) Characteristic directions, (b) random directions (see text). Equal area (Schmidt) projection, without correction for the tilt of the strata. Close (open) symbols for projections on to the lower (upper) hemisphere.

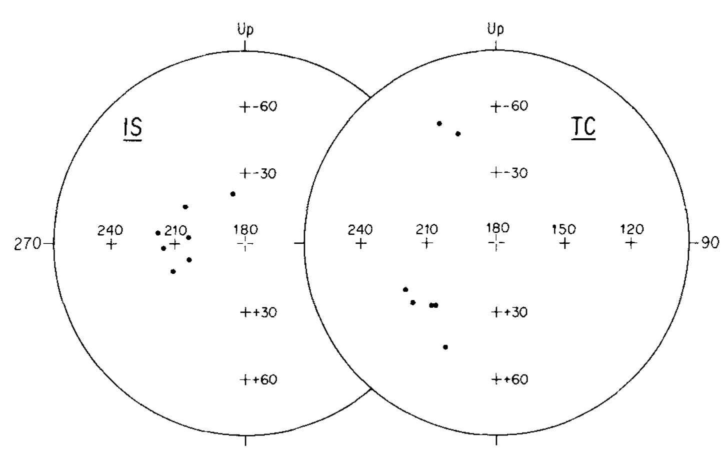

Figure 4. Mean directions for the seven sites of Jones *et al.* (1979) and this study, before and after correction for the tilt of the strata, in equal-area projection. A vertical projection plane has been used for clarity.

Table 1. Characteristic directions of the Montmartin red-beds.

Site	N	In-situ Decl./Incl.	Tilt-corrected Decl./Incl.	k	α_{95}	Reference
A	13	215/+02	219/+24	34	7	Jones et al. 1979
B	7	204/-02	209/+26	121	6	Jones et al. 1979
C	9	211/+12	209/+44	69	6	Jones et al. 1979
N	15	218/-04	221/+19	33	7	Jones et al. 1979
M	7	204/+07	209/+26	50	9	Jones et al. 1979
MA	23	185/-21	202/-47	13	9	This study
MB	23	206/-15	216/-50	18	7	This study
Mean Directions:						
In-situ	7	206/-03		27	12	
Tilt-corr.	7		213/+08	5	31	

N is the number of samples analysed, decl./incl. is declination and inclination in degrees, k and α_{95} are the statistical parameters associated with the mean; the ratio of the precision parameters (k_1/k_2) before and after correction for the tilt is 5.4 which is statistically significant at the 99 per cent confidence level (the critical ratio at 99 per cent confidence, for $N = 7$, is 4.16).

behaviour of haematite-pigment). On the other hand, other components (where present) are essentially random (Fig. 3b). This was generally also the case in the study of Jones *et al.* (1979) for the north-dipping beds. The directions of Fig. 3(a) and of Jones *et al.* are coherent and can therefore be called characteristic. It is thus justified to treat our two studies for a fold test (Table 1 and Fig. 4). This fold test is significant at the 99 per cent confidence level and clearly negative, indicating that the magnetization post-dates the folding.

The mean characteristic direction in *in situ* coordinates, moreover, gives a palaeopole at 38°S, 325°E, which is a typical Late Carboniferous pole for Europe. In the syncline of the Zone Bocaine, Cambro–Ordovician red beds gave a similar postfolding pole at 33°S, 332°E. The age of the folding is generally thought to be Late Carboniferous (Robardet 1973).

A great-circle remagnetization analysis (Halls 1976) was performed by Jones *et al.* (1979) on the other directions, but no convergence could be obtained. A re-analysis of these directions, combined with the results of Fig. 3(b), confirmed the lack of convergence indicating that these directions indeed must be considered random.

Discussion

The results of this study and its similarities with the post-folding results of Group B of Carteret (Perroud, Bonhommet & Robardet 1982a) and of Groups B, C, and D of the study by Jones *et al.* (1979) indicates that all these results must be considered as representative of

Table 2. Carboniferous palaeomagnetic data for the Armorican Massif.

Name of Formation	Decl./Incl.	k	α_{95}	Palaeopole	Reference
Remagnetised results					
Cambro-Ordovician red beds	207/+ 6	14	14	33 S, 325 E	Duff 1979 (pole B1)
Crozon dolerites	217/+29	21	10	23 S, 322 E	Perroud et al. 1983 (pole B)
Erquy-Cap Fréhel red beds	195/+ 2	11	12	39 S, 338 E	Jones et al. 1979 (pole C)
Plourivo red beds	213/+17	28	12	26 S, 321 E	Jones et al. 1979 (pole B)
Zone Bocaine	203/+ 8	22	13	33 S, 332 E	Jones et al. 1979 (pole D)
Carteret Group B	216/+28	32	14	18 S, 322 E	Perroud et al. 1982a
Rozel Group B	203/+ 0	145	7	37 S, 341 E	Perroud et al. 1982a
Laval syncline	220/- 6	15	12	33 S, 309 E	Edel & Coulon 1984 (pole A)
Thouars overprint	219/+20	15	18	23 S, 316 E	Perroud & Van der Voo 1985
Montmartin red beds	206/- 3	27	12	38 S, 325 E	This study
Unremagnetised results					
Flamanville granite	203/+14	-	15	30 S, 332 E	Van der Voo & Klootwijk 1972
Trégastel-Ploumanac'h granite	200/+ 9	121	7	34 S, 332 E	Duff 1979
North Brittany dykes	212/+10	40	-	30 S, 320 E	De Bouvier et al. 1979
Jersey dolerites, Grp. A	199/+16	71	9	31 S, 336 E	Duff 1980

the Late Carboniferous regardless of the rock age (Cambrian or Ordovician). Remagnetized results obtained by Duff (1979) and Perroud, Bonhommet & Van der Voo (1983) for other Early Palaeozoic rocks of the Armorican Massif and a Hercynian overprint in the Thouars Massif (Perroud & Van der Voo 1985) are generally similar. Unremagnetized results for Carboniferous rocks from the Armorican Massif support the Carboniferous age of these remagnetizations (Van der Voo & Klootwijk 1972; Duff 1979, 1980; De Bouvier, Bonhommet & Van der Voo 1979). These results are compiled in Table 2, and this list shows, as expected, a remarkable coherence in palaeopole locations.

The principal conclusion of this study is that there are no longer any Devonian palaeomagnetic data for the Armorican Massif. However, Devonian results from Spain and Germany (Bachtadse *et al.* 1983; Perroud & Bonhommet 1984) lead to the same conclusions that Jones *et al.* (1979) erroneously reached earlier. There are, therefore, no major changes in palaeogeographic models and geodynamic implications as a result of this study. It is important to note that the San Pedro Formation in Spain, the Franconian Forest and the Harz Mountain rocks in Germany have all yielded positive fold tests as well as mean directions with declinations which are significantly different from the expected Carboniferous directions. The palaeolatitudes (about 15°S) of these studies, however, indicate that the study areas were adjacent to the North European foreland; by geological implication, the Armorican Massif cannot have been separated from Great Britain by a wide north–south ocean.

In contrast, Late Devonian palaeolatitudes for Morocco (Hailwood 1974) and Beja, Portugal (Perroud *et al.* 1982b) indicate that a 2500 km wide north–south ocean separated most of Hercynian Europe from Gondwana and southernmost Portugal. This ocean closed in Early Carboniferous time and the subsequent collision caused the Hercynian orogency.

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