Geomagnetic polarity measurements from Pleistocene deposits in Southwest France and their chronological implications

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Measurements of palaeomagnetic inclination in sediments from the French Pays Basque, representing three of the major Pleistocene biostratigraphic subdivisions previously identified, confirm normal polarity in all cases. Taken together with the palaeobotanical, stratigraphic and geomorphological evidence they suggest that the Moulignan, Senixian and Ilbarritzian stages lie within the early part of the present Brunhes normal polarity epoch and probably correlate with some unknown part of the "Cromerian Complex". The Bidartian is thought to lie within a normal polarity event during the Matuyama epoch and to correlate with part of the Tiglian 'A' sub-stage of the Netherlands.

1. Introduction

Along the coastline of the French Pays Basque to the southwest of Biarritz, Eocene limestones and marls outcrop as dissected actively eroding sea-cliffs. Most of the valleys formerly incised into the bedrock have been partially infilled by Pleistocene deposits now exposed at or near the present shoreline. Many of the sections include strata which are organic and have yielded a rich fossil vascular flora including over 200 taxa (Oldfield and Huckerby, in press). In a 6 km stretch from the Villa Marbella to the Plage de Senix there are ten separate exposures (Fig. 1) ranging in age from Pre- or early-Tiglian to mid-Flandrian. Together with the Full-and Late-glacial and Flandrian deposits at Le Moura less than 3 km inland, they form, within a very small area, one of the most accessible and informative sources of Pleistocene biostratigraphic data in Western Europe.

Their pollen-content and stratigraphic relationships (Oldfield 1960a, b, 1961, 1962, 1964a, b, 1968), macrofossil flora (Oldfield and Vokes 1969; Huckerby, Marchant and Oldfield 1972; Huckerby and Oldfield 1976) and implications in terms of the morphological evolution of the area (Oldfield 1967, 1968, 1969) have been extensively documented. Figure 1 identifies the location of each site and summarises some of the salient morphological features of the region. Figure 2 outlines, in terms of the sequence of the biostratigraphic subdivisions established in Oldfield (1968) and subsequently extended and modified by Huckerby and Oldfield (1976), the timespan and range of fossil plant material studied at each site and the position of the samples on which palaeomagnetic inclination measurements have been made. The sites occur in three main types of stratigraphic and topographical context as follows:

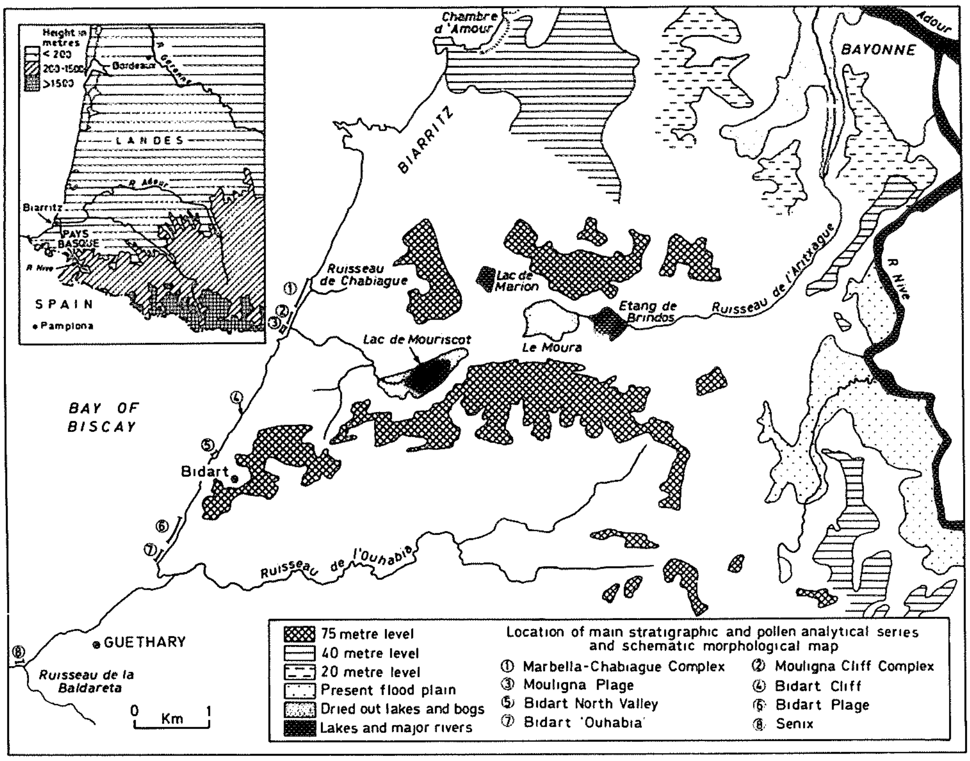


Fig. 1. Pleistocene sections in the French Pays Basque: location and geomorphological context.

Group 1

Near Bidart, two separate fossiliferous strata occur within a thick spread of torrent gravels which are truncated by a clearly marked and extensive 75–80 m marine platform. The earlier stratum (Bidart A) is a narrow buried soil profile the later, (Bidart B), a compact organic clay (Fig. 1, site 6). The infilled valley occupied by the gravels and the included finer deposits bears no relation to the present day drainage lines. Along with other similarly infilled valleys, all antecedent to the 75–80 in level, it reflects a period of incised east-west drainage and subsequent aggradation predating the initiation of the present day northward flowing R. Nive drainage. This later drainage pattern was superimposed on the 75–80 m level in response to tilting during the Pleistocene, associated with the uplift of the W. Pyrenées to the south and the further development of the Aquitaine sedimentary basin to the north.

Group 2

Lying within short, partially infilled though still topographically identifiable valleys cut both within the solid rock and the torrent gravels referred to above lie five major complexes: at Marbella-Chabiague (site 1), at Mouligna Cliff (site 2), at Bidart, both to north and south of the previously mentioned sections (sites 4, 5, and 7) and at Senix (site 8 in part), 1 km southwest of the centre of Guéthary. All these sites include polleniferous deposits which in each case are overlain unconformably

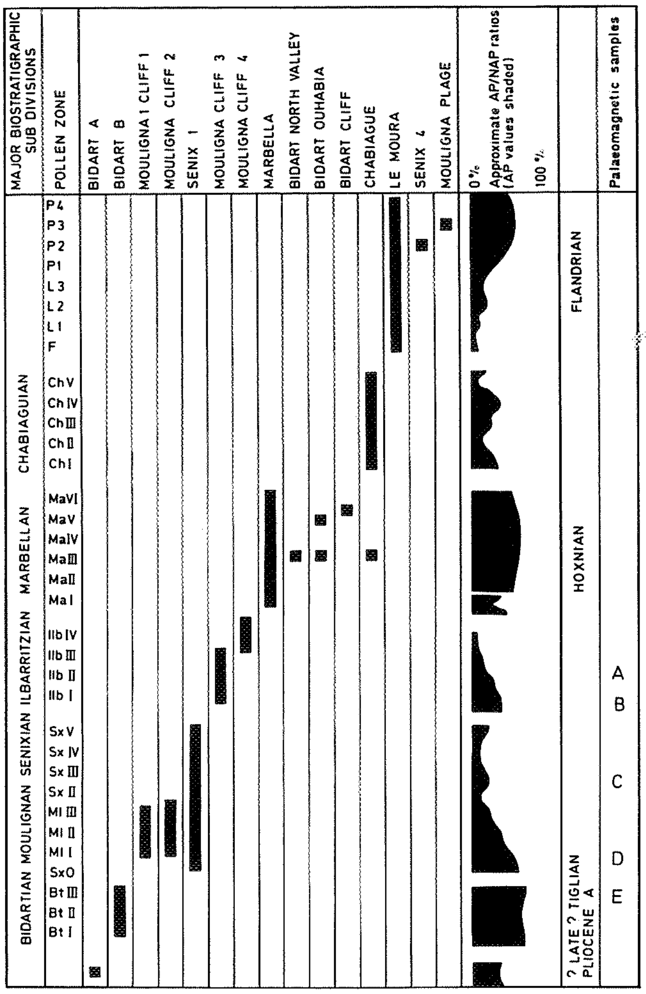


Fig. 2. The Pleistocene biostratigraphy of the sections studied. Each listed site is located on Figure 1. The biostratigraphic subdivisions identified and, their pollen-assemblage characteristics, summarised here in the tree pollen (AP/non-tree pollen (NAP) ratios are fully described in Oldfield (1968) and Huckerby and Oldfield (1976). Solid bars indicate the span of palaeobotanical evidence obtained at each site. Major W. European biostratigraphic subdivisions believed to correlate with the local stages are shown to the right of the AP/NAP curve. The lettered palaeomagnetic samples are from the following sites:
A – Mouligna Cliff (Ilbarritzian II = Ilbarritz upper)
B – Mouligna Cliff (Ilbarritzian I = Ilbarritz lower)
C – Senix (Senixian III = Senix upper-middle)
D – Mouligna Cliff (Moulignan I = Mouligna upper–lower)
E – Bidart Plage B (Bidartian III = Bidart upper)

by leached and partially cemented aeolian sands and loams. Likewise each of these suites of strata is dissected at some point by a more recently incised valley. All these successions are pre-Flandrian but postdate the initiation of the northward flowing Nive drainage system.

Group 3

Within the valleys incised into the strata referred to Group 2, both at Mouligna Plage (site 3) and at Senix (site 8 in part) lie estuarine and organic deposits exposed at or just above present day beach level. The aeolian sands and loams referred to in the previous paragraph do not overlie these sediments, though recent unleached and unconsolidated dune sand overlies them at Mouligna.

It is clear from their stratigraphical and topographical relationships that the three types of sites referred to above date from separate phases in the physiographic evolution of the area, and that they may be placed chronologically in the order in

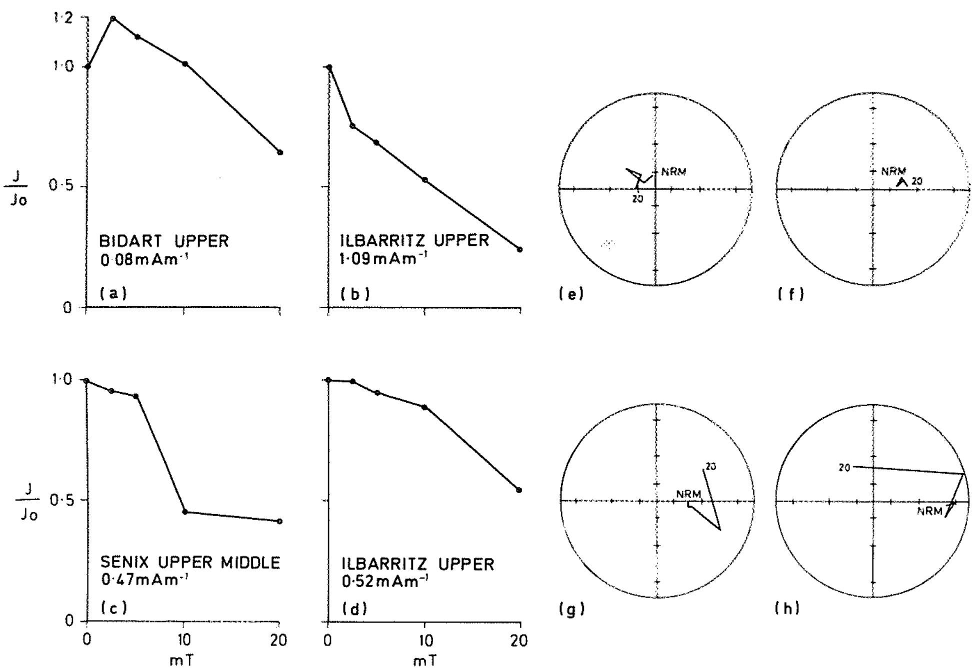


Fig. 3. Partial alternating-field demagnetization of samples from Bidart, Senix and Ilbarritz. In (a)–(d) normalized remanent intensity is plotted against peak alternating field. Diagrams (e) to (h) are stereographic plots of angular changes during demagnetization of these samples (e-Bidart; f-Ilbarritz; g-Senix; h-Ilbarritz).

which they have been described. The third group are mid-Flandrian in age (Oldfield 1960a, 1968) and will not be considered further in the present account.

As Figure 2 shows, the sites in Groups 1 and 2 span all or part of at least three Interglacial stages. The latest of these, the Marbellan, has been correlated on floristic and palaeoecological grounds with the Holsteinian (Hoxnian, Gortian) Interglacial elsewhere in W. Europe. The age of this and subsequent episodes is therefore well within the present Brunhes normal polarity epoch. The successions predating the Marbellan have proved much more difficult to correlate with Quaternary sequences elsewhere. The earliest material from the fossil soil profile at Bidart 'A' (Oldfield 1968; Huckerby and Oldfield 1976) has been dated, on floristic grounds, to an unknown stage close to the Plio-Pleistocene boundary. The site has not yielded material suitable for palaeomagnetic measurement. Lying chronologically between this earliest material and the Marbellan Interglacial sediments at the type site, are several undated complexes which can be placed in order on morphological stratigraphic and floristic grounds and which fall into both of the first two groups of sites identified above. Short monoliths c5cm × 5cm in cross-section and from 20 cm to 50 cm long were collected from limnic sediments at Bidart Plage B (Fig. 1, site 6),

Table 1. Results of minimum criteria tests on samples from all monoliths.

	Criteria			
	1	2	3	4
Bidart (upper)	P	P	P	P
Senix (upper-middle)	P	P	P	P
Ilbarritz (lower)	P	P	P	P
Ilbarritz (upper)	F	F	P	P
Mouligna (lower)	F	F	F	P
Mouligna (upper)	F	F	P	F

Criteria from Von Montfrans (1971).
Pass (P), Fail (F).

Mouligna Cliff (site 2) and Senix (site 8). They spanned episodes in each of the main biostratigraphic subdivisions Bidartian, Moulignan–Senixian and Ilbarritzian.

2. Palaeomagnetic polarity results

2a Geomagnetic polarity time scale

The geomagnetic field has reversed its polarity many times through the Earth's history. During the Plio-Pleistocene only a limited number of polarity changes occurred. These polarity changes have been found to be synchronous worldwide and a polarity time scale, of periods of normal and reverse polarity, has been constructed. It is based on K-Ar age determinations of basalts carrying a palaeomagnetic record of geomagnetic polarities. (Cox, Doell and Dalyrmple 1963; McDougal 1978). Sediments may be dated by matching their palaeomagnetic records to the geomagnetic polarity time scale (Opdyke 1972; Zagwijn *et al.* 1971). Not all sediments carry a true palaeomagnetic record of the geomagnetic field and laboratory and statistical studies can help in assessing the usefulness of the palaeomagnetic data as a dating tool.

2b Analyses

Paired subsamples of dimension 20 mm × 20 mm × 17 mm were taken in plastic boxes from six monoliths. The way up and inclination of the monoliths were noted. Their natural remanence and magnetic stability were investigated using a fluxgate magnetometer (Molyneux 1971) and an alternating field demagnetizer (Collinson 1975).

Table 2. Summary of NRM results for samples passing minimum criteria tests.

		Ī	α95	N	J_{min}	J_{max}
Bidart (upper)	NRM	41°	15°	22	0·06	0·13
Senix (upper-middle)	NRM	66°	21°	21	0·2	0·8
Ilbarritz (lower)	NRM	49°	9°	12	0·3	1·2
Ilbarritz (lower)	5mT	51°	10°	12	0·2	1·1
Ilbarritz (lower)	10mT	57°	12°	12	0·2	0·6

The remanent intensity was rather low, ranging from 0·06 to 1·2 mAm $^{-1}$. The coercivity of NRM was also low. Median destructive fields varied from 10 to 30 mT. The decrease of remanent intensity and change of direction with partial alternating field demagnetization up to 20 mT is shown in Figure 3.

2c Minimum criteria tests

All palaeomagnetic directions measured were of normal polarity, but because of the low intensity and stability of the remanence not all the results can be accepted as reliable indicators of geomagnetic polarity. The criteria of Van Montfrans (1971) were used to help assess the usefulness of the palaeomagnetic analyses.

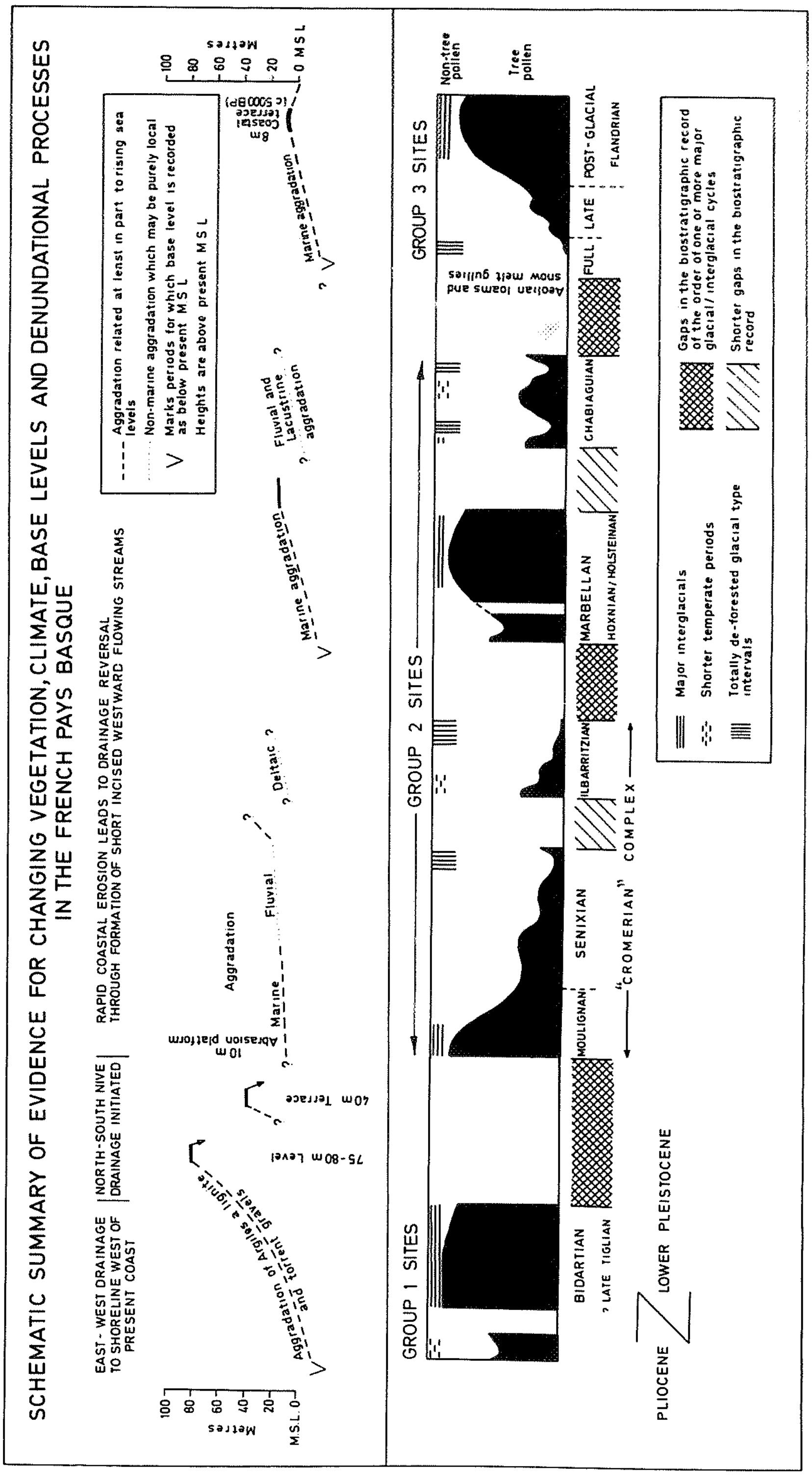
After examining Pleistocene sediments from 45 pits or exposures and 13 boreholes, Van Montfrans developed six criteria for accepting his measurements. Four of his criteria are applicable to the present study.

1. Paired specimens must have directions of magnetization lying within 40° of each other after partial demagnetization.
2. The remanence must change through less than 60° during partial demagnetization.
3. The remanence intensity, after partial demagnetization at 20 mT must be at least 25% of the NRM intensity.
4. The remanence inclination after partial demagnetization must be within 40° of the local geocentric axial dipole field inclination.

Table 1 shows that three out of the six monoliths satisfy all four criteria.

Further specimens from the three monoliths which passed these minimum criteria were analysed. Their NRM results are summarized in Table II. The mean inclination Ī and the distribution of directions, summarized by Fischer's α95, again

Fig. 4. Schematic summary of evidence for changing vegetation, climate, base levels and denudational processes in the French Pays Basque. The biostratigraphic, lithostratigraphic, morphological and radiometric evidence used to compile the diagram is set out fully in the papers listed in the second paragraph of the text. The suggested pre-Hoxnian correlations are based both on the previously published palaeobotanical and geomorphological evidence and on the geomagnetic polarity data presented in this paper.


SCHEMATIC SUMMARY OF EVIDENCE FOR CHANGING VEGETATION, CLIMATE, BASE LEVELS AND DENUNDATIONAL PROCESSES
IN THE FRENCH PAYS BASQUE
EAST - WEST DRAINAGE TO SHORELINE WEST OF PRESENT COAST
NORTH-SOUTH NIVE DRAINAGE INITIATED
RAPID COASTAL EROSION LEADS TO DRAINAGE REVERSAL THROUGH FORMATION OF SHORT INCISED WESTWARD FLOWING STREAMS
Metres
100
80
60
40
20
M.S.L. 0
Aggradation of Argiles à lignite and torrent gravels
75-80m Level
40m Terrace
10 m Abrasion platform
Marine
Aggradation
Fluvial
Deltaic ?
Marine aggradation
Fluvial and Lacustrine aggradation
Marine aggradation
8m Coastal terrace (c 5000 BP)
0 M S L
Aggradation related at least in part to rising sea levels
Non-marine aggradation which may be purely local
Marks periods for which base level is recorded as below present M S L
Heights are above present M S L
GROUP 1 SITES
GROUP 2 SITES
GROUP 3 SITES
Non-tree pollen
Tree pollen
Aeolian loams and snow melt gullies
BIDARTIAN
? LATE TIGLIAN
MOULIGNAN
SENIXIAN
ILBARRITZIAN
MARBELLAN
HOXNIAN / HOLSTEINIAN
CHABIAGUIAN
FULL
LATE
POST-GLACIAL
FLANDRIAN
"CROMERIAN" COMPLEX
PLIOCENE
LOWER PLEISTOCENE
Major interglacials
Shorter temperate periods
Totally de-forested glacial type intervals
Gaps in the biostratigraphic record of the order of one or more major glacial / interglacial cycles
Shorter gaps in the biostratigraphic record

consistently indicate normal polarity of remanence. The pilot specimen from Ilbarritz lower was near the limit of criterion 3, so all the additional specimens were subjected to partial alternating field demagnetization at peak fields of 5 and 10 mT. The gradual increase in inclination and slow change in $\alpha95$, (Table 2) despite the low remanence intensities, again suggests that the remanence has been sufficiently stable to retain a primary geomagnetic signature.

All the specimens analysed had normal palaeomagnetic directions and at Bidart, Senix and Ilbarritz (lower) these can be interpreted as being due to a geomagnetic field of normal polarity at the time of deposition of the sediments.

3. Chronological implications

3a The Bidartian

The normal polarity of the measured Bidartian samples places part at least of the Interglacial of that name within either the Brunhes epoch or one of several normal polarity events in the Matuyama. Close stratigraphic association with the Plio-Pleistocene fossil soil Bidart A, together with the abundance of *Fagus* pollen in two of the three biostratigraphic zones previously defined, prompted an initial correlation with the Tiglian 'A' sub-stage in the Netherlands (Oldfield 1968). Zagwijn (1975) relates part of this substage to the earliest normal polarity event recorded in the Matuyama at c.2.15 M.Y. This period of measured normal polarity in the Netherlands sequence corresponds with the mid- to late part of the Interglacial as do the palaeobotanical data from Bidart. For the present, in view of the compatibility of the stratigraphic, palaeobotanical and geomagnetic polarity evidence, the original correlation between the Bidartian and Tiglian 'A' may be retained.

3b The Moulignan, Senixian and Ibarritzian

Stratigraphic and palaeobotanical evidence alone failed to correlate these stages with any sequence established elsewhere except in so far as the inferred early Tiglian age for the Bidartian, and the Holsteinian age for the Marbellan provided outer limits to the range of possibilities.

Failure to obtain fully satisfactory polarity measurements from Moulignan sediments precludes confidence direct geomagnetic dating of the Interglacial stage represented. However, at Senix, the Interstadial and cold phase sequences of the Senixian succeed the Moulignan without any stratigraphic break. Both the Senixian and the succeeding Ilbarritzian stages show normal polarity and it is difficult to place these below the Brunhes/Matuyama boundary. Not only do they represent multiple and complex cold phase/Interstadial sequences but they are much more closely related to the deposits of the succeeding Marbellan (Holsteinian) stage in terms of their stratigraphic context and their position in the morphological evolution of the area (Fig. 4) than to the Bidartian strata. These factors reduce the likelihood of a correlation with either of the preceding normal polarity events within the post-Tiglian period of the Matuyama. A tentative correlation with some part of the "Cromerian" complex (*sensu* Zagwijn 1975), subsequent to substage Cromerian II, is proposed.

3c Conclusions

Even the addition of consistent geomagnetic polarity measurements to the range of stratigraphic, geomorphological and palaeobotanical studies completed on the Pleistocene deposits of the coastal French Pays Basque leaves the correlation and chronology of the stages between the earliest Plio-Pleistocene deposits and the Marbellan (Holsteinian) successions in some doubt. The normal polarity records are not inconsistent with previous inferences and the various lines of evidence when taken together, suggest a provisional correlation of the Bidartian with the Tiglian A substage in the Netherlands, and the Moulignan, Senixian and Ilbarritzian stages with some part of the "Cromerian" Complex as defined by Zagwijn (1975). The apparent absence of terrestrial Pleistocene deposits with reversed polarity is interesting in the light of similar findings from East Anglia (cf. Thompson 1977). Figure 4 summarises the stratigraphic, morphological and palaeoecological evidence from all the sites and tentatively relates the stages identified locally with those established in N.W. Europe.

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