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THE CRAG MOLLUSCA — A CONSPECTUS

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SUMMARY. Molluscan assemblages of the palynologically characterised Ludhamian, Thurnian, Antian, Baventian and Pastonian Stages of the East Anglian early Pleistocene (Icenian and Cromerian(Stages of Harmer) indicate a series of marine events which disagrees with Harmer's thesis. Progressive shallowing of the water is indicated, probably with temporary onsets of non-marine conditions in the colder periods (Thurnian, Baventian) and returns to marine conditions in the ensuing warm periods. Shallowing from about 40 m depth in Ludhamian times to about 8-15 m in Antian/early Baventian times is indicated by molluscan assemblages of Easton Bavents, Aldeby and Ludham. The late Baventian/Pastonian stratigraphy is not yet fully understood. The sequence is better established in the north of the region than in the area of Sizewell and Aldeburgh. *Macoma balthica* occurs in the north Norfolk early Baventian and Pastonian but not in deposits thought to be correlative in the Aldeburgh region. The Beestonian and Cromerian have not been fully studied.

Climatic fluctuation during the sequence has been demonstrated micropaleontologically but not by Mollusca. Boreal type mollusc assemblages with Lusitanic and Arctic admixture occur during temperate periods but no molluscs during cold periods (perhaps non-marine). The 'Dover Strait' probably did not exist at this time, so that re-establishment of populations after cold periods was by southward migration of boreal molluscs rather than migration of successively more thermophilous types from the south.

Introduction

The work of FUNNELL (1961; also FUNNELL & WEST 1962) and WEST (1961; also WEST & WILSON 1966, WEST 1968) has been concerned with Foraminifera, Pollen and Thermokarst phenomena. The new scheme of Stages in the Crag deposits which can be deduced is reviewed by WEST (1968). It has not been possible to fit these results with the stratigraphic scheme proposed by HARMER (1898, 1900, 1902, 1920). This may be because HARMER's method was not quantitative and he did not make any studies of the deposits at depth. Many layers, which HARMER correlated, have been found to belong to different Stages as one goes from one locality to another. Also HARMER did not know of the Ludhamian which is known only at depth. HARMER's great contribution in my opinion has been his monography of the Mollusca.

A new malacological investigation of the Norwich Crag Series and Cromer Forest Bed Series has begun, it has not extended to the Red Crag as yet. This paper discusses the principles on which the method is based then summarises the findings.

Methods

The counting proceedure for the Mollusca has already been published (NORTON, 1967). The method is paleoecological in outlook. It attempts to reconstruct environments on the evidence of the most frequent molluscs. Chronology is supplied by pollen-analytic studies. Some deposits of course cannot be dated in this way and studies of them are excluded from this paper. About one kilogramme of material is usually examined. From the enumerated death-assemblage an attempt is made to recognise species indicative of present-day

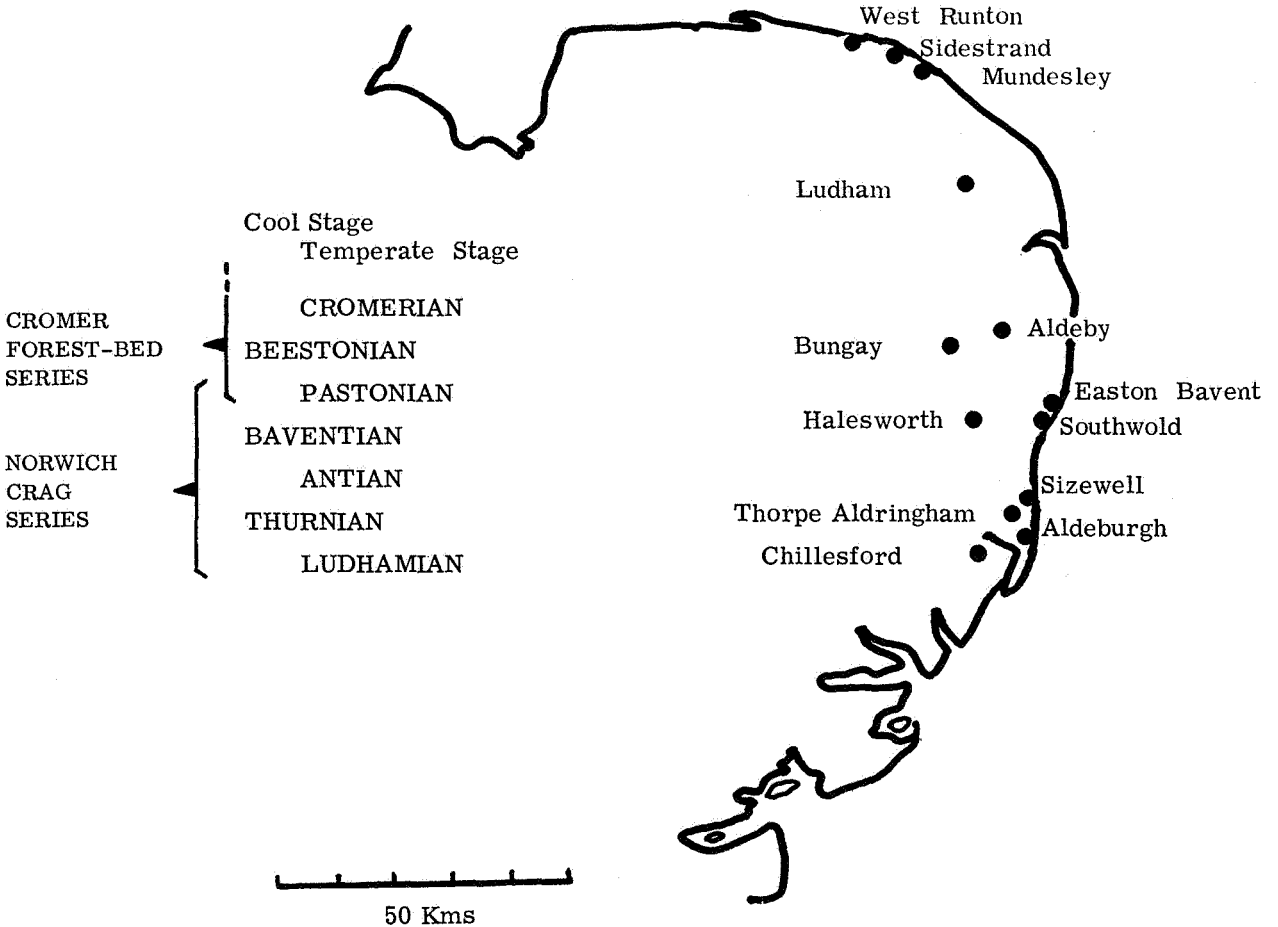

Figure 1. *Sketch-map of East Anglia with summary of Stage and Series names and localities mentioned in the text.*

ecotones (« Ecological Groups »). From the changing representation of these groups in the vertical sequence, attempts are made to reconstruct the changes in the life-environment and deposition-environment. Local sequences of Assemblage Zones are erected, each Zone having local, rather than general, significance. Eventually it may be possible, correlating laterally by pollen-analysis, to reconstruct the overall development of the marine environment.

Tentative picture of the sequence

I have made no new studies of the Coralline Crag or Red Crag. I have some understanding of the Norwich Crag Series. The relation between this and the Red Crag is not clear at present. Also the relation between the Norwich Crag Series and Cromer Forest Bed Series is not clear.

TABLE 1. *Ludhamian mollusc assemblages: Ludham*
Characterising species: mean frequencies %: depths O.D.

L.M.1 –163ft to –131ft		L.M.2 –131ft to –96ft		L.M.3 –96ft to –85½ft	
Rissoa curticostata	16	*Abra alba*	14	*Abra alba*	42
Anomia squamula	12	*Calyptraea chinensis*	13	*Calyptraea chinensis*	14
Calyptraea chinensis	8	*Caecum glabrum*	6	*Rissoa curticostata*	8
Abra alba	6	*Anomia squamula*	5	*Anomia squamula*	3
Hiatella arctica	5	*Rissoa curticostata*	5	*Mytilus edulis*	3
Cingula semicostata semicostata	4	*Turritella triplicata*	4	*Chrysallida spiralis*	3
		Mytilus edulis	3	*Cingula semicostata semicostata*	2
		Chrysallida spiralis	3	*Hydrobia ulvae*	1
		Hiatella arctica	2		

Ludhamian

This is the earliest Stage, named for Ludham. It is known only in the Ludham Borehole at present. The sediments are marine sands, 25 m thick at Ludham. They contain pollen indicating temperate conditions and a forest cover of mixed coniferous trees, including *Tsuga*. Within this I have recognised three molluscan Assemblage Zones.

The basal set of assemblages have a high frequency of individuals of species now extinct, often very small Rissoid gastropods. Muddy sublittoral ecotones have contributed the greatest proportion of individuals amongst the species which are still extant. The death assemblages are diverse and varied.

The middle set of assemblages are also varied with representatives of many ecotones, predominantly those associated with a muddy substratum. In this and the preceeding zone are many shells of species which were previously recorded only from the Coralline Crag and Red Crag. It is not clear what their significance is; whether they are reworked (most have not that appearance) or whether they indicate synchroneity, in part, of the Ludhamian Crag with the Red Crag.

I consider the two lower Ludhamian zones were deposited in water which was initially about 40 m deep and became steadily shallower. In the uppermost zone the assemblages are dominated by an apparently autochthonous *Abra alba* assemblage which, I consider, was deposited in a muddy bottomed sea about 15 m deep.

Thurnian

Marine or estuarine clays, 7 m thick at Ludham, with flora and Foraminifera indicating cool conditions with a subarctic park-landscape vegetation on the land surface. Molluscs are absent from this zone in the Ludham borehole, and at Southwold, where Thurnian pollen spectra also occur, there are no shells either.

Antian

Shelly marine sands, 3 m thick at Ludham, with mixed thermophilous forest vegetation including *Tsuga*. At Ludham, after the interval of non-deposition in the Thurnian, marine molluscs had begun to be deposited again in the top 1 m of Thurnian silts. They continue into the Antian. Here there is a *Spisula subtruncata — Lepton nitidum — Mytilus edulis — Hydrobia ulvae — Littorina littorea* assemblage, interpreted as having been deposited in 5-8 m of water. Sublittoral shells are much less frequent in the Antian death assemblages than in the Ludhamian.

Pollen correlations show that the Crag at Aldeby and Easton Bavents is also Antian. At Aldeby the shells are very much more worn than at Ludham, indicating more violent depositional conditions. Almost all the identifiable shells are of sublittoral species, predominantly those which would have lived in fine or muddy sand. The assemblages are much less diverse than those at Ludham; in life, they probably occurred at about 10-15 m, but the depth at which deposition occurred, in view of the possibility of extensive transport of the shells, is hard to assess.

The Antian/early Baventian Crag at Easton Bavents is divided into three subzones by Mollusca.

The deposits of the basal subzone contain shells, almost 70 % of which are too worn for complete identification. However, they do not seem to contradict the identifiable ones, of which the majority are intertidal shells, especially those of rocky open shores. Deposition does not seem to have been *in situ*. In the two subzones above, particularly the top one, the assemblages are dominated by sublittoral shells and show less wear. They are not so diverse as at Ludham or Aldeby and show a greater frequency of inhabitants of muddy sand. *Macoma calcarea* (the dominant form of the middle subzone) gives way to *Corbula*

TABLE 2. *Antian/Early Baventian mollusc assemblages*
Characterising species: frequencies as %

LUDHAM L.M.5 –67ft to –55ft O.D.		ALDEBY about +23ft to +25ft	
Spisula subtruncata	12	*Cyprina islandica*	6
Lepton nitidum	8	*Spisula elliptica*	5
Mytilus edulis	6	*Hiatella arctica*	5
Macoma obliqua	5	*Lepton nitidum*	4
Hydrobia ulvae	5	*Cochlodesma praetenue*	2
Littorina littorea	4	*Mysella bidentata*	1
Abra alba	3		
Cardium edule	3		
Clathrus clathratulus minutus	3		

TABLE 3. *Antian/Early Baventian mollusc assemblages — 2*

EASTON BAVENTS 'B'	Characterising species: frequencies as %		
	A	B	C
Littorina saxatilis	12	1	2
Littorina littorea	7	1	—
Cardium edule	7	1	—
Mytilus edulis	2	1	1
Corbula gibba	1	8	44
Macoma calcarea	—	11	—
Cyprina islandica	—	2	1

A: Subzone A, about +7 to +8ft O.D.
B: Subzone B, about 8 to 11ft O.D.
C: Subzone C, about 11 to 14ft O.D.

gibba in the top subzone. *C. gibba* is a more thermophilous from but the evidence of the pollen is that the climate was becoming colder at this time. The top subzone extends into the Baventian (cold) Stage.

As regards correlation between the Antian shelly sands at Ludham, Aldeby and Easton Bavents, there is nothing to be said. The three deposits are clearly of inner-sublittoral type but differ in the amount of violence the shells have suffered during the depositional processes.

Baventian

Marine, later perhaps estuarine, silty clays, 8 m thick at Ludham. On land the vegetation was an open-heath oceanic type, associated with cold climate. Mollusca are found in the early Baventian at Ludham, Easton Bavents (as already described) and Sizewell, where a thin band of clay with Baventian pollen occurs in the middle of 2 m of Crag. Mollusca occur in the late Baventian on the north coast of Norfolk.

TABLE 4. *Antian/Early Baventian mollusc assemblages — 3*
Characterising species: frequencies as %

LUDHAM L.M.6 –55ft to –40ft O.D.		SIZEWELL –24½ft to –19ft O.D.	
Calyptraea chinensis	10	*Abra alba*	43
Astarte montagui	4	*Corbula gibba*	4
Macoma calcerea	4	*Cardium edule*	3
Yoldia oblongoides		*Spisula subtruncata*	1
Nucella lapillus vulgaris	3	*Calyptraea chinensis*	1
Venus ovata	3		
Spisula subtruncata	3		
Anomia squamula	2		
Macoma praetenuis	2		

The Baventian Crag assemblages at Ludham contain large numbers of extinct *Yoldia* and *Macoma*, and fewer intertidal shells than the Antian Crag (this trend was noticed also between the subzones B and C at Easton Bavents). At Ludham, as at Easton Bavents, there are many badly worn shells, suggesting a rough depositional environment. This is also true of Sizewell. At Sizewell the Crag is characterised by an allochtonous *Abra alba* assemblage plus some shallow water shells, all very worn. The life-assemblage seems to have occurred in much finer material than the Sizewell deposits. It was apparently deposited sublittorally.

In north Norfolk Baventian pollen spectra are found inland in borings at Mundesley and in 'Weybourne Crag' at West Runton, Sheringham and Sidestrand. 'Weybourne Crag' at other sites contains pollen spectra later than Baventian, thus as a time-unit 'Weybourne Crag' must be abandoned. The Netherlands 'Weybournian' cannot be correlated with this facies, since this Dutch deposit has been shown not to exist — all the *Macoma balthica* recorded from it are *M. obliqua*, *M. calcarea* or *M. praetenuis* (SPAINK & NORTON, 1967).

Macoma balthica is first recorded in these late Baventian Crag deposits. It is unknown in the earlier Baventian/late Antian Crag further south.

Pastonian

Marine or estuarine silts with a temperate flora but no *Tsuga* (or only a few grains), found on the north Norfolk coast, where the Pastonian includes the freshwater peat known at some sites as the Lower Freshwater Bed of Reid's Cromer Forest Bed Series. (Neither Reid's sub-divisions of the Cromer Forest Bed Series, nor their sequence, can be maintained, and should be abandoned — WEST & WILSON 1966). The Pastonian Crag contains molluscan assemblages of "Weybourne Crag" type, of clearly littoral aspect, with *Macoma balthica* in profusion.

Pastonian pollen spectra have also been identified further south, at Ludham, Outney Common Bungay, Sizewell, Thorpe Aldringham, Aldeburgh and Chillesford. WEST (unpublished paper) considers the associated Crag outcrops (called by HARMER 'Norwich Crag') to be Pastonian. If this is so why is there no *Macoma balthica* in the shelly Crag at Thorpe Aldringham, Aldeburgh & Chillesford?

The following hypothesis is offered. To test it further work is needed on the morphology and tectonics of the Crag basin, using especially the samples from the U.E.A. Research Borings Programme (Fig. 2).

The north and south parts of the Crag Basin (Fig. 2) are separated by a chalk ridge running out towards Halesworth. The north basin subsided during Ludhamian times. Both parts, except for north Norfolk, subsided during Thurnian, Antian and Baventian times; the sea level was lowered glacio-eustatically in the Thurnian and Baventian. In late Baventian times a local marine transgression in north Norfolk allowed the incursion of the 'Weybournian' fauna (with *Macoma balthica*), forming deposits at Sidestrand and Mundesley The Pastonian was a time of regression on the north Norfolk coast, with deposition of thick estuarine silts. In these conditions the *Macoma balthica* stocks, with the rest of the 'Weybournian' fauna, became locally extinct. Later Pastonian, and younger, 'Weybournian' deposits on the north Norfolk coast are formed by reworking of the primary Baventian material. The Pastonian sea spread over the rest of the northern basin and the southern basin. Shelly Crag followed by silts was deposited in the south, silts alone in the northern basin. The shelly Crag lacks *Macoma balthica*, which had become locally extinct after its short northern incursion in the Baventian and did not recolonise. Finally during the deposition of the later part of the Cromer Forest Bed Series, eastward tilting of the whole basin became dominant, leaving the western part above sea level. (I thank Roger BECK for discussions in the formation of this hypothesis).

At Aldeburgh the Pastonian silts have *Mya truncata* and *Yoldia* sp *in situ*. Shelly brown sands 30 cm below contain a very varied assemblage characterised by *Spisula subtruncata*, *Mytilus edulis juveniles*, *Calyptraea*

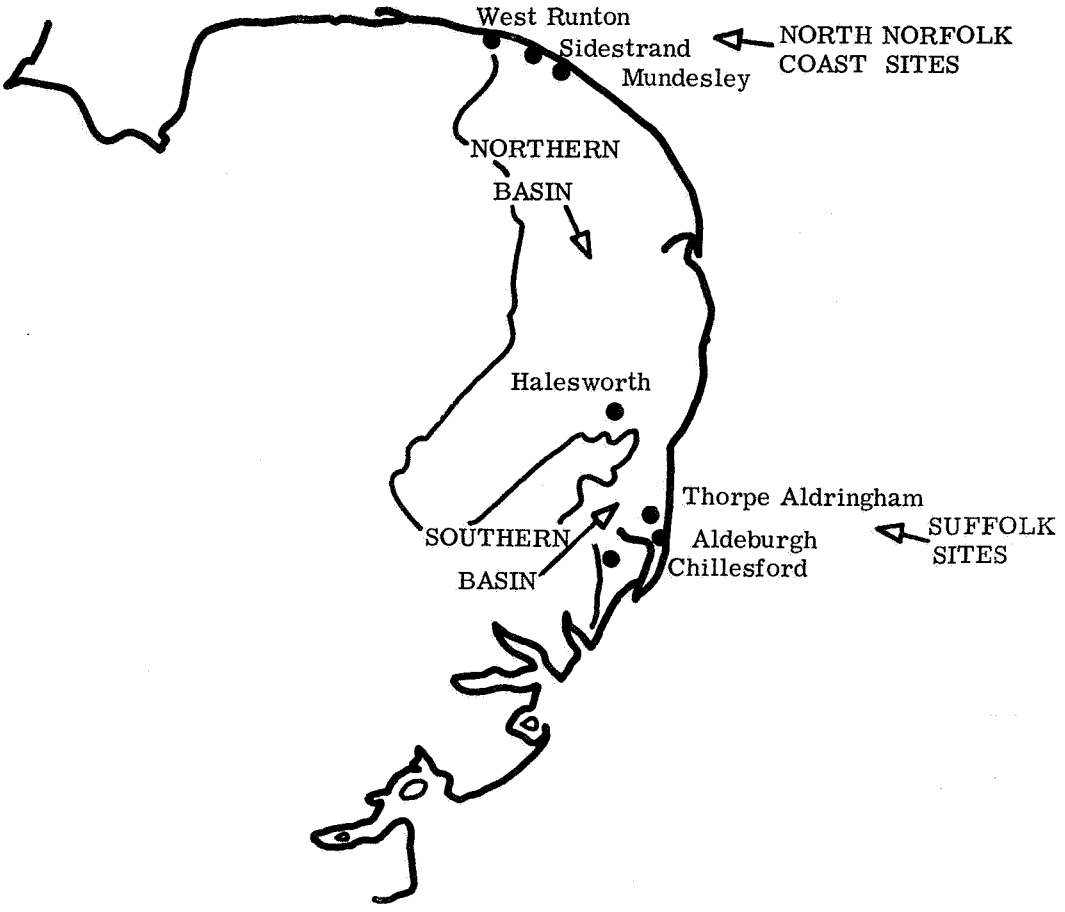

Figure 2. *Sketch-map of East Anglia showing the two main basins on the Crag base. The contour is at O.D.*

TABLE 5. *Pastonian mollusc assemblages*
Characterising species — frequencies as %

ALDEBURGH 30 cms below *Mya* bed. About 20ft O.D.		THORPE ALDRINGHAM 130 cms and 200 cms above Pastonian clay. About 25ft O.D.		
			130	200
Spisula subtruncata	30	*Hydrobia ulvae*	84	63
Mytilus edulis (juv)	17	*Cardium edule*	16	12
Calyptraea chinensis	9	*Littorina littorea*	3	6
Natica (juv)	6	*Corbula gibba*	1	3
Abra alba	6	*Abra alba*	1	2
Myacea (indet)	2			
Macoma obliqua	1			

chinensis, Abra alba, Natica sp and *Macoma obliqua*. This, and the overlying silts, appears to be a shallow sublittoral deposit.

At Chillesford the silts at the top of the section ("Chillesford Clay") have casts of *Mya* and other species *in situ*. The *Mya* bed is discontinuous. Below are sands ("Chillesford Sands", "*Scrobicularia* Crag") containing mostly worn shells with less than 10 % of indigenous ones. This appears to be an extensive reworking of Red Crag (with some native shells such as *Scrobicularia*); typical Red Crag occurs at the base of the Church pit section. The silts are Pastonian, but the sands could well be much older.

At Thorpe Aldringham (the "Aldringham Thorpe Pit") is a clay layer with Pastonian pollen. 130 cm and 200 cm above are shelly horizons. The lower has a *Hydrobiaulvae* — *Cardium edule* — Tellinidae — *Littorina littorea* — *Retusa* assemblage, impoverished and apparently of intertidal affinity. Above this is a *Cardium edule* — *Hydrobia ulvae* — *Littorina littorea* assemblage, also apparently intertidal.

Beestonian

Gravel deposits overlying the Pastonian on the north Norfolk coast, with ice-wedge casts and involutions and arctic freshwater plant beds. Shells occur in the gravel at West Runton. Almost all appear to be reworked. Many are freshwater; possibly these are the true Beestonian shells and the marine ones are derived from the Pastonian and Baventian. Reworking is known to have occurred in the formation of the Beestonian pollen spectra. True Beestonian pollen occurs in freshwater Beestonian deposits and Beestonian plus earlier pollen in marine Beestonian deposits.

Cromerian

Freshwater temperate muds and peats, upon which are estuarine and beach deposits of a marine transgression. I have not studied the molluscs of this Stage.

Lowestoftian

Deposits of cold conditions going up into Till of the Lowestoftian Glaciation.

Problems in the research

1. The use of molluscs for correlations. At present it is not possible to establish a chronology on the basis of Mollusca, as demonstrated by the previous section. This situation may improve when more studies of boreholes have been made, the U.E.A. borings being important here.

2. The Suffolk Pastonian problem. Is the hypothesis for the exclusion of *Macoma balthica* from the Suffolk Pastonian Crag, correct?

3. The use of Mollusca for the determination of climate. The sequence of assemblages gives an indication of steady overall shallowing of the basin as time went on. However, there is no clear picture of climatic changes as indicated by the pollen and Foraminifera. The Mollusca are mostly boreal species in the temperate Stages (with some Lusitanic and Arctic species). In cold periods the deposits generally lack mollusc assemblages. Reasons for this may be:

a) Molluscan communities have a broader climatic tolerance than vegetation or foraminiferal associations. The Boreal zoogeographic region has similar mollusc populations from Iceland to Dover, but vegetation varies from near-Tundra to broad leaved forest in this range.

b) The North Sea Basin was probably landlocked to the south at this time and formed an inlet of the North Atlantic like the Baltic Sea does now. The sole source of Mollusca would have been from the Boreal region between Scotland and Norway, enforcing a boreal mollusc population in temperate periods. In cold periods the reduction of sea level in the southern North Sea caused the onset of non-marine conditions there, times of silt and clay deposition, without marine Mollusca.

These hypotheses cannot be checked without investigation of sites in the 'main Atlant-

ic', since by using the 'internal' evidence provided by the North Sea early Pleistocene deposits we argue merely in a circle. For this reason new investigation on Tjörnes and other sites is beginning.

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