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CONTENTS

WORK ON THE CRAGS UP TO 1950

PART ONE. Coralline Crag, Lenham Beds, St. Erth Beds, Coprolite Bed.

Introduction.

The Crags of East Anglia have long been known to geologists on account of the easily collected, abundant shells and vertebrate remains. In earlier days the shells were crushed for use as chicken-grit, a practice which still continues on one farm, or were spread on fields as a lime dressing, Phosphatic pebbles were once extracted on a large scale from the base of the Crag for fertiliser, and the Crag itself has been used for road surfaces, as an absorbent to cover manure heaps and by the United States Air Force to cover ammunition dumps. The Coralline Crag, which sometimes forms a soft limestone, has been used for walling, and went into the making of Orford Castle and also several churches local to the outcrops.

The term “crag” was originally a local dialect word of unknown origin, applied to any loose, shelly sand in Suffolk. It is now used geologically to include all deposits of Upper Pliocene and Lower Pleistocene age in Britain, as well as beds in Iceland, Germany and elsewhere. However, it is still a very much used, convenient term for the East Anglian beds alone and it should be restricted to this use. The Red Crag itself is a formation of oxidised, iron-stained sands containing abundant molluscan fossils. The sands vary from yellow to red or brown in colour, and may be silty or contain clay seams, and are sometimes pebbly, especially near the base of the deposit. Over much of its outcrop it is false-beaded, sometimes on a grand scale, but in places the beds are horizontal and may be channelled. The shells are also varied, being either comminuted or finely preserved. The majority of fossils are molluscs, but brachiopods, echinoids, bryozoans, crustaceans, ostracods and foraminifers can also be found, and fish and mammal remains are not uncommon.

The main mass of shelly Red Crag outcrops over an area of some 250 square miles, from Walton-on-Naze in Essex north-eastwards to Chillesford and Wickham Market in Suffolk. It lies generally to the east of the A12 London to Lowestoft road, below the 100ft contour. Subsidiary outliers of supposed Red Crag age occur along the Gipping valley as far as Stowmarket, along the Stour valley to Sudbury and Clare, and at shallow depth near Braintree.

The fundamentals of crag stratigraphy were laid down by Lyell (1839), Charlesworth (1835, I836), Woodward (1836, in Whitaker, 1885) and others. By I890 the generally accepted subdivision of the crags was:-

Base Pleistocene	Arctic Freshwater Bed
Newer Pliocene cold temperate	Leda myalis Bed Forest Bed Series Weybourne Crag Chillesford Beds Norwich and Scrobicularia Crags Red Crag of Butley Red Crag of Walton
Older Pliocene warm temperate	Coralline Crag, St. Erth Beds, Lenham Beds, Boxstones.

Any crag bed lies either on an older crag deposit or on the London Clay. To the west, the crags lie on older Eocene deposits or the Chalk. Before 1948, all deposits below the Arctic Fresh-water Bed were referred to the Pliocene, on the grounds that they contained no beds of obvious glacial origin, but indicated a Pliocene cooling episode prior to the Pleistocene glaciation. The Plio-Pleistocene boundary is now placed at the base of the Red Crag, after the recommendation of the 18th International Geological Congress in 1948.

Although there was considerable controversy over some parts of the succession, several lines of evidence were used for formulating the stratigraphy.

(1) General appearance. Charlesworth (1835) noted that the crag could be divided into three well-defined beds - a lower one, white in colour, containing many "Corallines" (Bryozoa), which he termed the Coralline Crag a middle one, marked by its red colour and oblique bedding, which he termed the Red Crag; and a series of grey sands with clay beds and gravel horizons, showing rapid lateral changes of lithology, without oblique bedding, and which contain abundant mammal remains. This upper crag, which Charlesworth termed the Mammaliferous or Norwich Crag, occupied an area north of the Red Crag, from Aldeburgh to the north Norfolk coast.

(2) Superimposition. Many authors, e.g. Lyell (1839)? Prestwich (1849? I87I) and Whitaker (I885) describe the unconformable junction of the Coralline and Red Crags in the Aldeburgh - Gedgrave district and at Ramsholt and Tattingstone. At Sutton the Red Crag could be seen banked up against Coralline Crag cliffs, the Coralline Crag had been bored by Red Crag molluscs, and articulated mussel-shells littered the ancient cliff base. At Chillesford, the Chillesford Beds could be seen lying on Scrobicularia Crag, which, in turn, rested on Red Crag, but though the boundaries were considered conformable, their positioning was (and still is) a subject of controversy.

(3) Fauna. The change in fauna from bed to bed was important in establishing the stratigraphy. The decrease in the percentage of extinct forms from the Coralline ^rag, through the Red Crag to the Norwich Crag showed that the beds became increasingly younger throughout the sequence. A parallel increase in the percentage of northern and British extant forms, and decrease of southern forms showed that the climate changed from warm temperate in Coralline Crag time to cold temperate in Norwich Crag time. Figures quoted by various authors are summarised in Tables 1-3.

Thus the concept developed of successive crags overlapping each other as they are followed northwards. Comparisons were made, and similarities were found, with the present conditions around Britain and the Mediterranean allowing many authors to make interpretations as to the environment of deposition of the different crags.

Systematic and descriptive palaeontology also made great strides. Many authors cited long faunal lists of species found at various localities, e.g. Bell (I87I), Prestwich (I87I), though few quantitative studies were made. The molluscs were of special importance, attracting many of the earlier workers, who were interested primarily in collecting new specimens for their ‘cabinets'. Many cliff and pit sections were available at the time. But the methods used were inexact. Collectors rarely gave details of the position or even localities of their finds. Often a collector would empty his specimen boxes in a different locality from the one where he had originally collected, and later discovery of these rejected, shells by another collector gave rise to spurious distribution records. The scree at the base of the section was always searched, since rain washed out the shells, and these shells were mixed, with others actually found in the section face, so that the precise horizon from where the shells came was unknown.

However, the lists of molluscan species grew rapidly and culminated in the publication of S. V. Wood's monograph "The Crag Mollusca" (I848-I882) and F. W. Harmer's (I914-I925) later supplement. The last part of Harmer's supplement was published posthumously, having been completed by A. Bell who was over 90 years old at the time. Harmer's monograph did not cover the Lamellibranchia except the non-marine ones, but Bell completed the work on the Oysters (unpublished manuscripts in Ipswich Museum). The two monographs describe almost every species of mollusc which a collector is likely to find, but the descriptions of shells often lack the detail which is now considered necessary for accurate identification and there was a strong tendency to over-specification. The earlier work thus stands in marked contrast to that of recent works (e.g. Norton, 19645 Baldi, 1973) who have had to work with incomplete or juvenile shells.

The first scientific account of the Red Crag seems to have been by Dale (1704 in Reid, 1890), who mentions fossils found in the Red Crag at Harwich. Subsequent literature on the crag is voluminous. The older literature is effectively abstracted by Whitaker (1885) and Reid (1890) in memoirs for the Geological Survey of Great Britain. As well as discussing the faunas and interpretations foremost at the time, details are given of many sections now closed, and the memoirs form a useful guide to the local geology. Reid's memoir, in particular, marks the turning point between the controversial discussions of the earlier workers, and the more consistent views of Harmer, Boswell and others, Boswell (1927) 1928, 1929) was able to apply Harmer1s concepts to further memoirs of the Geological Survey.

Recently, however, the earlier work has been under close scrutiny and it can be seen that there are many gaps in the earlier workers1 knowledge of the crags. The Norwich Crag has now been re-appraised, but the Coralline Crag and the Red Crag have not.

The Coralline Crag

Charlesworth (1853) recognised the essential features of the Coralline Crag, describing it as loose, shelly sands with oblique debris. He also grasped the fact that, at some horizons, in situ bryozoan 'mats' existed and he considered that these 'mats' acted as sediment traps - an important aspect of the sedimentology which seems to have been forgotten by later workers. Charlesworth recognised the main mass of Coralline Crag outcropping in the Gedgrave - Aldeburgh district, together with the smaller outliers at Ramsholt and Sutton, which Lyell (1839) later fully described, and that at Tattingstone. Two further occurrences were recorded: by Whitaker (1885) at Waldringfield and by Wood and Harmer (1872) at Trimley in a ditch digging, but have not been found since, and may possibly have been Red Crag.

Charlesworth’s conclusions on the distinctions between the Coralline Crag were supported by Wood (1866) who compared-and contrasted the general characters of the two Crag faunas. Wood realised that the change in the faunas indicated deteriorating climatic conditions, and that the migrations, appearances and extinctions of species showed a significant time interval between the two deposits.

Prestwich (1871), in an important paper, divided the Coralline Crag into eight distinct zones:-

zone	thickness in feet	lithology	interpretation
h	6	sand and comminuted shells	further shallowing
g	30	entirely comminuted shells and Bryozoa, forming soft building stone; false bedding characteristic	tidal scour, currents reworking lower sediments, forming banks
f	5	sand with numerous entire small shells and seams of comminuted shells	shallowing sea, stronger currents with periods of quiet.
e	12	sands with numerous Bryozoa in life position, with small shells and Echini	greatest depth- between 500 and 1000ft

d	15	comminuted shells; large, double valves entire	deep, tranquil
c	10	marly beds; double valves in life position	
b	4	comminuted shells and Bryozoa with Cetacean remains	subsidence
a	1	phosphatic nodules and mammal remains	sea transgression with ice carried boulders

Prestwich considered these zones traceable - from pit to pit, with the upper ones overlapping the lower ones, eventually lying on the London Clay. He calculated the total thickness of Coralline Crag to be between 75 and 90 ft., but this was based on an addition of the maximum thickness of each unit in a composite section. At the end of the paper he gave a long faunal list which includes molluscs, bryozoans, corals and crustaceans, together with their depth ranges, geographical distributions, the localities at which they v/ere found, and their occurrences in Belgian and Italian deposits Jeffreys and Bell assisted in this compilation.

Wood and Harmer (1872) and Wood (1874) criticised this faunal list and identifications, maintaining the accuracy of their own. In particular, while Jeffreys grouped together similar forms and t treated them as varieties of species, Wood preferred to give each variety a specific name. Wood and Harmer also disagreed with Prestwich's divisions of the Coralline Crag and his interpretations. For example, they considered Prestwich's lower divisions (a-f) to be so variable, even in one horizon at the same locality, that the differences were merely facies variations. Instead, Wood and Harmer divided the Coralline Crag into:

3) a thin layer of abraded Bock Bed material

2) a hard Rock Bed of molluscs agglutinated by Polyzoa

1) marly sands rich in molluscs

all of which represented shallow, possibly intertidal shoals.

Another criticism was that there was no evidence for the enormous depths that Prestwich had proposed. Wood and Harmer estimated that c. 250ft was more accurate, a figure at which Godwen-Austen (1868) had previously arrived. Wood and Harmer also estimated the maximum thickness of the Coralline Crag to be nearer 60 ft than 75 ft or more.

A few years later, Kendall (1883) pointed out that all aragonite shells had been dissolved out of Wood and Harmer's top layer, and suggested that the Rock Bed below had been formed by carbonate re-precipitation. This observation has since remained unchallenged, though some authors still use the term Rock Bed in a Stratigraphic sense, and not as a diagenetic term. Kendall reasonably concluded that the consolidation of the Sock Bed must have occurred pre-Red Crag, as the Red Crag contains Rock Bed pebbles. Reid's memoir (1890) summarises all the older Coralline Crag literature, and Reid also gave details of most of the sections open at the time, faunal lists from several pits, as well as a general list of most vertebrate and invertebrate groups.

Reid was rather critical of previously used percentage methods for determining the character of the faunas. He noted that, using the same materials, Wood (1882) had listed 420 species of Coralline Crag Mollusca and Jeffreys (in Prestwich 1871) had listed 316 species (see tables 1-3). Reid concludes that such identifications were thus subjective - he calls them “personal equations” - rather than objective, and that it was dangerous to quote percentages for correlation. Godwen-Austen (1868) also criticised the percentage test as liable to fluctuation. Reid's comments are applicable to the Red and Norwich Crags as well, but seem to have been disregarded by many later workers, for it is only recently that different methods have been used.

The varied nature of the Coralline Crag, however, had been realised, ranging from rubbly limestones to pebbly or glauconitic calcareous sands, often false bedded and often with shell beds. The southern aspect of the fauna, with strong Mediterranean affinities, was characterised by such molluscs as Cardita corbis, C. senilis, Limopsis pygmacea and Ringicula buccinea, (all considered extinct by Jeffreys 1871), which are unknown at present as far north as Britain. Reid considered most of the molluscs to be characteristic of the lower Laminarian and upper Coralline zones and, together with the lack of intertidal or deep water species indicated a depth of 40-60 fathoms (following Wood and Harmer 1872). The environment was one of sand banks and shoals far from the shore in a warm, moderately shallow sea. The substrate was sufficiently consolidated for abundant, delicate Bryozoa to attach themselves and grow in the clear water. Many of the lighter forms of Bryozoa were rolled and abraded by strong currents sweeping across the sea floor, while the more massive, heavier forms were not.

Harmer’s later publications (1896, 1898) did not really change the overall picture outlined above. He gave the Coralline Crag the stage name Gedgravian, after the type locality at Gedgrave (zone of Mactra triangularis), and correlated it with the Casterlian (zone of Isocardia cor) of Belgium. In calculating the percentages of extinct, southern and northern species of molluscs, Harmer omitted Wood's rare or unique specimens, thus basing conclusions on common shells. He noted that most of the shells were either Italian Pliocene forms or extant Mediterranean forms (with one or two exceptions), and that northern forms were almost entirely absent. He concluded that, to account for this, there must have been an open connection between the southern part of the Worth Sea and the Atlantic to the south, and a closed for restricted connection to the north.

'Harmer reaffirmed his earlier views, by arguing strongly against Prestwich;-

(a) there was no stratigraphic or palaeontological evidence to show that Prestwich's divisions of the Coralline Crag at Sutton occurred anywhere else. For example, none of the zones were characterised by the disappearance or arrival of any species of mollusc or foraminiferid.

(b) there was no evidence of glacial conditions during the deposition of the basal bed, especially since the fauna indicated an absence of glacial conditions.

(c) there was no evidence of great depths of submergence, as the fauna was largely composed of the drifted remains of molluscs and bryozoans.

Locally, sorting by currents was important in giving alternations of bods containing a mass of small shells. Elsewhere, Bryozoa reefs wore developing in situ faunas with Mya, Panopaea and crustaceans in life positions. Baden-Powell (1960) suggested deposition in a water depth of between 60 and 160 ft.

(d) all the Coralline Crag was similar, except the Rock Bed, formed by cementation by carbonate originally dissolved from shells in overlying beds, and the basal transgressive detritus bed.

A further point of controversy arose over the introduction of the Boytonian stage by Bell (l91l). Bell described a section at Boyton where two and a half feet of Red Crag rested on one and a half feet of Coralline Crag. Bell stated that the Coralline Crag zone was rich in shells - some 200 species - which indicated a transitional stage between the Coralline and Red Crags. The zone was thought to contain typical Coralline Crag species together with typical Red Crag forms such as Nassa reticosa, Neptunea contraria, Cardium parkinsoni and Tellina praetenuis. Bell placed the Red Crag basement beds of Walton in this zone. Harmer originally argued against this, noting (as did Wood, 1879) that coprolite diggers at this locality brought out a mixture of Coralline and Red Crags, and it was impossible to say from which layer the shells had come. Harmer (1914-1925) eventually accepted this zone, but most later workers have disregarded it (Baden - Powell, 1960).

Since Harmer's monograph and Boswell's Geological Survey Memoirs (1927, 1928), which reaffirm Harmer's views, little work has been done on the Coralline Crag or its fauna. Carter (1951) discussed indigenous and derived foraminifera from one locality, at Sutton, and presents a method for the recognition of derived forms. However, he only discussed a few species and his work needs expanding to cover both a larger area and more species. Possibly his methods need revising. Lagaa-ij (1952) lists Coralline Crag Bryozoa in a detailed work on the Pliocene deposits of the Low Countries. This would form an excellent basis for a modern study of East Anglian Plio-Pleistecene Bryozoa. Baden-Powell (1960) presents a generalised survey of ideas, but adds no new knowledge.

To conclude, the Coralline Crag faunas are diverse, and have a Mediterranean aspect, indicating summer water temperatures of 20°C or more, and winter water temperatures of about 15°C. The significant numbers of planktonic foraminifers indicate open contact with the Atlantic, to the south, and the bryozoan, shelly sands are similar to those found at the present day in the western parts of the English Channel at depths of about 30m. It is apparent that although criticisms are now levelled at farmer, there has been very little new work on the Coralline Crag to update his views. Research on the Coralline Crag is thus a wide open field.

The Lenham Beds

Discovered in 1854 by Prof. T. R. Jones and W. Harris, the Lenham Beds are a series of decalcified, glauconitic sands and ironstones occupying solution hollows in the Chalk at about the 600ft. mark on the North Downs at Lenham. Wood (in Prestwich, 1858), rather cautiously, and Prestwich (1858) tentatively assigned a crag age to the deposits, comparing them to the Diestian of Northern France and Belgium. Reid (1890) described the original sections and several other nearby outcrops. Reid, and later Monkton (1902), concluded, with the help of a long comparative faunal list, that the Lenham beds were coeval with the Coralline Crag and Diestan deposits. Reid's list includes 67.species from Lenham.

Harmer (1898, 1906, 1902) concluded that the Lenham Beds, for which he erected the stage name 'Lenhamian’, are the same age as the "zone of Terebratula grandis" (Diestian), but that this zone was older than the Coralline Crag, with Miocene affinities. Harmer based his conclusions, with which Bell (1912) and Abbot (1916) agreed, on a detailed examination of the fauna and comparison with Miocene, Italian Pliocene and Coralline Crag shells. Newton (1916) gave complete descriptions of the Lenham Beds and similar beds at Netley Heath, listing 76 species of molluscs, with brachiopods, bryozoans, echinoderms annelids and fish.

Papers by Wooldridge (1926, 1927) are important in the determination of the Diestian shoreline. Woolridge gives full petrograpic descriptions and considers the Lenham Beds to represent sublittoral Pliocene deposits related to a marine plantation surface. Basal, littoral, transgressive shingle deposits occur at Headley •oath and also on the Chilterns around Berkhampstead and are considered the same age. A t a more recent date, Wooldridge (1960) considers the Lenham Beds, Netley Heath Beds and Walton Crag to be all the same age.

Chatwin (1927) discusses the fauna of the Netley Heath deposits, but concludes that they are of different age to the Lenham Beds.

Forms common at Lenham, such as Arca diluvii, Papillicardium papillosum and Ringiculella lenhamensis do not occur at Netley Heath where the fauna is dominated by Corbulomya complanta. Chatwin assigns a Waltonian age to the Netley Heath Beds, considering them younger than the Lenham Beds, a conclusion affirmed by Bull (1942), West (1972) and Mitchell et al (1973). A disturbed sandstone at Rothampstead also contains Red Crag fossils including Cardium parkinsoni, and is assigned to this age (Dines and Chatwin, 1930; Mitchell et al, 1973). More recently, the marine origin of the Lenham and Headley Heath beds has been questioned. Worssam (1963) and Smart et al (1966) suggest that the Lenham and Headley Heath Beds have been glacially transported to their present locations from Plio-Lower Pleistocene deposits in the southern bight of the North Sea. In arguing this hypothesis, Kellaway et al propose a Beestonian or late rage for the deposits. Letzer (1973), after detailed analysis of grain-size t distributions of sands from Headley Heath, suggests that the deposit is the result of aeolian sorting and sedimentation in a periglacial environment, the material being derived from Neogene deposits in the London Basin, to the north. In contrast to this, West (1969; 1972) accepts the idea of a marine origin for the beds, and John (see Shepard-Thorn, 1975) believes the Headley Heath deposits are the eroded remnants of a basically in situ Lower Pleistocene marine series.

The St. Erth Beds

Shelly clays at St. Erth, Cornwall, are described by Reid (l890), Wood (1885), Kendall and Bell (1886), who recorded 72 species of Molluscs, and others. While Wood and Kendall and Bell assign a Red Crag age to be correlated with the Coralline Crag. Harmer (1914-1925; agrees with Reid and adds that typical Red Crag shells and all northern species are absent.

In a recent comprehensive survey, Mitchell et al (1973) fully describe the sites and sections, the mineralogy and sedimentology, and the flora and fauna (molluscs, foraminifers and ostracods). The molluscs are preserved in a fragmentary state making identifications difficult and quantitiative studies possibly unreliable. Generally, however, a Bittium, Nucula, Myrtea, Venerupis assemblage is present, indicating accumulation beyond low-water mark in a depth of about 10m. No littoral species are present. The foraminifera show a close association with Pliocene deposits in western Prance, and belong to the same biozone characterised by forms of moderately warm, temperate seas, with no indication of climatic deterioration. Mitchell et al correlate the St. Erth Beds with the Coralline Crag.

The Lenham Beds and St. Erth Beds are briefly mentioned here partly because they are British Neogene deposits, and partly for the sake of completion. Furthermore, the occurrence of the Lenham Beds bears a direct relationship to the faunal, geographical and structural development of the North Sea basin prior to the formation of the Red Crag. A discussion of the St. Erth Beds fauna serves to illustrate that while foraminifera and pollen analysis tend to give a regional picture and are useful in correlation, the molluscs lead to an interpretation of more localised ecological conditions.

The Coprolite or Nodule Bed

At the base of the Red Crag a pebbly deposit containing large flints, phosphatic nodules, vertebrate remains and derived fossils occurs sporadically. This bed has been given a variety of names by different authors, and is frequently mentioned in the literature. It attracted the attention of geologists firstly because of the economic importance of phosphate and lime for agricultural use and, secondly, because of the unusual vertebrate remains and pebbles that the bed contained. In fact, the bed is little more than a basal conglomerate with a rather localised distribution. Because it was so extensively worked, much material was collected and described. The first mention seems to have been by Henslow (1844 in Reid, 1890), and it is apparent from the descriptions of Lankester (l868, 1870), Prestwich (l87l), Whittaker (1885), Reid (1890), Bell (1911, 1912, 1915, 1917, 1918) and others that several different sorts of derived material are present in the Red Crag basement bed;-

(1) Phosphatic nodules. Although called 'coprolites by Henslow, it was soon realised that very few of these nodules were in fact coprolites (Buckland, 1849 in Reid, I890; Lankester, 1868). Because the nodules, usually two or three centimetres in diameter, sometimes envelop Eocene fish and shark remains, it is thought that most of the nodules are derived from the underlying London Clay. Buckland (l849) suggested that the nodules were-formed bv the, putrefving matter from fish absorbed into, and consolidating surrounding clay sediment. Chemical analyses are given by Herapeth (1851 in Whitaker, 1895) and Voelcker (1860 in Reid,1890), and it seems that calcium phosphate usually forms between 50-60% of the nodule. The extraction of phosphate from the crags reached its heyday between the l850s and l880s, a record 12,000 tons being extracted in 1854. It is perhaps not surprising that so much was made of this deposit!

(2) Shells, sharks teeth and other vertebrate remains (e.g. Hyracothcrium, Coryphodon) also derived from the London Clay. (3) Shells and bone derived from the Coralline Crag.

(4) Pebbles of Coralline Crag, London Clay, flint and a variety of other lithologies. Bell (1915) and Bull (1942) considered ice rafting as a possible explanation for the larger pebbles, especially flints.

(5) Bone, shark and fish teeth, and mammals of Red Crag age. Indigenous Red Crag bone is less mineralised than other derived bone, being brown in colour and sometimes rather friable. Derived bone is usually lark in colour, or black and is glossy in appearance.

(6) Boxstones - sandstone pebbles of possibly Miocene age; called 'boxes 11 or "boxstones" by the coprolite workers because, on being broken open, some contain the hollow moulds of shells. Lists of species found in the boxstones are given by Reid (1890), Lankester (l870) and many others. Bell (1917) listed 115 species, the list being partly based on museum and several private collections. The estimates of the jacentage of boxstones that contain any fauna has varied considerably, from about 5% (Lankester, 1870) or 10% (Boswell, 1927) to 75% (Bell, 1912) though in my experience only about one boxstone in one hundred yields fossils. The pebbles vary in size, but are commonly 10-15 cm in diameter, well-rounded and subspherical. Boswell (1915a, 1928) discusses their petrography, which is very similar to that of the Coralline and Red Crags. The origin of the boxstones is still open to question. Wood (l859) had realised that they represent strata long since destroyed, and Bell (1918) suggested that the original beds, of which the boxstones are the only surviving trace, were deposited locally. Some authors (e.g. Lankester, 1870; Monkton, 1902) assign a Lenhamian (=Diestian) age for the pebbles, while others (e.g. Harmer, I898; Bell, 1915; Boswell, 1928) give an older date. Petrographically the boxstones are very different from the Lenham beds, and it is considered unlikely that they are synchronus. In any event, they are older than the Coralline Crag, since boxstones are found in that crag.

The basal position of the Coprolite Bed strongly suggests a remainé deposit incorporated into the Red Crag marine transgression, with the inclusion of Miocene, Pliocene and other debris from the pre-Red Crag land surface. This littoral aspect was noted by Wood (l859) and Lankester (1868), and was attributed to cliff waste by Wood and Harmer (1872). Many of the pebbles are commonly covered with barnacles, some pebbles with barnacles on both sides, indicating overturning. Although a pebble bed is present at the base of the Coralline Crag, at is less well developed and does not contain such remains as <u>Cervus</u>, <u>Equus</u> and <u>Elephas</u>, which are found in the Red Crag. Similarly, where each pebble beds are developed in the Norwich Crag, a different suite of mammals is represented. Lankaster (1870) attributed this either to imperfect knowledge of the mammal faunas, or more likely, different ages for the various pebble beds - a conclusion borne out by later research.

Finally Moir (in Sell, 1912) and Slater (1911) record massive flaked flints, supposedly of human origin, found in the Red Crag basement bed. If these flints are fashioned by man, they provide evidence of man living and working upon a London Clay land surface either before or during Red Crag times. Moir (1924) later describes and figures rolled and abraded Harrisonian Eolithic flint implements, which he found at Bramford, Sutton, Ipswich and at a horizon within he crag itself, at Foxhall, where, Moir concluded, had been an actual occupation. It is rather difficult to reconcile this conclusion with the accepted view that the Red Crag is largely a sublittoral deposit.

R. G. DIXON.

Part Two, and the Bibliography (References) will appear in a future Bulletin. Tables I - III appear on pages 14 and 15 of this Bulletin.

This Bulletin is for 1980, and the next issue,

no. 23, will be for 198l.

	Coralline Crag	Red Crag	Norwich Crag
Total living species	264	216	130
Northern seas	14	23	39
Southern seas	65	32	11
Mediterranean	200	167	67
Britain	185	157	87
West Europe	171	156	73
Scandinavia	135	135	86
Atlantic	99	84	38
Arctic	34	40	36
North America	--	17	14
Others	92	7	--
Extinct	16%	7.7%	6.5%
Total species	314	234	139

Table 1. Geographical distribution of living species of crag molluscs (after Prestwich 1871).

	Coralline Crag	Red Crag	Upper Red Crag	Fluviomarine Crag	Chillesford Series
Freshwater molluscs	--	5	9	22	19
Marine gastropods	193	178	108	64	46
Opisthobranchiata	14	5	3	4	3
Lamellibranchiata	169	135	74	71	73
Total species	376	323	194	161	141

Table 2. Frequencies of molluscan groups in the Crags (after A. and B. Bell 1871)

	Coralline Crag	Walton Crag	Newer Red Crag (not Scrobicularia Crag)	Fluvio-marine Crag	Chillesford Beds
Britain (not Mediterranean)	20	13	30	36	19
Britain and Mediterranean	154	61	78	38	44
Mediterranean (not Britain)	51	14	14	7	1
Neither Britain nor Mediterranean	24	10	22	12	9
Extinct	36.3%	33.7%	27.6 %	16.2%	16.1%
Total living species	249	98	144	93	73
Total species	391	148	199	111	87

Table 3. Geographical distribution of living species of Crag molluscs (after Wood 1872).

This Bulletin is for 1980, and the next issue, no. 23, is for 1981.

ANALYSIS OP PHOSPHATIC NODULES AND BONES PROM THE CRAGS TO DETERMINE PHOSPHATE CONTENT.

Background

The high phosphate content of certain nodules in the Suffolk crag deposits was discovered in the 1840s by the Rev. Professor J.S. Henslow. This was the start of the East Suffolk fertiliser industry. Fisons, Packards, and Colchesters dug on a commercial scale in the Newbourne, Foxhall, Waldringfield and Sutton areas, excavating from the Red Crag.

By the 1880s the local phosphate digging was coming to an end due to cheaper material being imported from abroad.

The phosphatic nodules themselves are often called coprolites (true" coprolites are fossil faeces) but it is not known whether they are or not. Fossil bones and teeth in the same deposits also contain similar concentrations of phosphate.

Figures available for phosphate composition are only generalised and there is no breakdown of these figures for specific geological sites; also must available figures are of specimens from Red Crag deposits only (Lower Pleistocene i.e. 1½-2 million years old). It was decided to try to analyse specimens from:-

a) Six specific Red Crag sites
b) One older Coralline Crag site
c) One younger Norwich Crag site.

Samples

a) Red Crag sites

1. Cliff Quay, Ipswich
2. Back Hamlet, Ipswich
3. Bucklesham
4. Waldringfield Heath
5. Battisford
6. Stutton - bone (probably whale).

b) Coralline Crag site

7. Sudbourne Park " - phosphatic nodules

c) Norwich Crag site

8. Easton Bavents - fish bones (probably skull or pectoral girdle).

There were two main problems connected with the phosphatic nodule analysis. Firstly, grinding them up finely enough to enable them to be dissolved. Secondly, actually getting the ground up material into solution.

A local commercial company was able to grind all the samples down to less than 0.5mm, and was able to suggest a method for getting these powders into solution plus a method of analysis.

The Colorimetric Phospho-vanado Molybdate method of Phosphate Analysis.

The colorimetric determination of phosphate by the yellow colour formed when a solution of orthophosphate is added to a reagent containing ammonium molybdate and ammonium vanadate in nitric acid. The colour is due to a complex in which the ratio of P_20_5:V_20_5:MoO_3 is approximately 1:1:22. The depth of the colour is measured differentially at 420 nm. There is a relative experimental error of ± 1% in this method.

Apparatus.

A spectrophotometer reading at 420 nm.

Reagents

(i) Ammonium Vanado-Molybdate Reagent

20 g powdered ammonium molybdate was dissolved in

approx. 500ml. of distilled water, with heating. When dissolved, 1g ammonium metavanadate was added and dissolved. The solution was cooled and 140 ml of concentrated nitric acid, in small portions, was added with swirling. The solution was cooled again and diluted to 1 litre with water and mixed thoroughly. It is was then stored in a dark Winchester flask.

(ii) Hydrochloric Acid
- concentrated

(iii) Nitric Acid
- concentrated

(iv) Phosphate Standard Solution
3.8346 g. potassium dihydrogen phosphate (previously dried at 105°C for 1 hour) dissolved and diluted is to 1 litre (i.e. 1 ml = 0.2 mg P_2O_5). A tenfold dilution is then made (i.e. 1 ml = 0.2 mg P_2O_5). Stored in dark Winchester flask.

(v) Potassium Dihydrogen Phosphate

(vi) Sodium Hydroxide
- N solution.

Procedure

The material having been ground to <0.5 mm before sampling, 5 g of the sample, weighed to the nearest mg, was added to 100 ml water in a 400 ml beaker and stirred thoroughly. The mixture was boiled. 10 ml of concentrated hydrochloric acid in a thin stream was added slowly to the boiling solution followed by 10 ml concentrated nitric acid. The mixture was boiled gently for 10 minutes then cooled and filtered, using a buckner funnel, into a 500 ml. volumetric flask. The residue was washed well with water. The filtrate was diluted to 500 ml. and mixed well. Further dilution of the solution was carried out until about 25 ml. of the final dilution contained between 5.0 and 6.2 mg. of P_2O_5.

Calibration of Instrument

Using a burette, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0 and 31.0 ml. of standard phosphate solution (0.2 mg P_2O_5/ml) was measured into a series of 100 ml. flasks, so that the flasks contained 5.0, 5.2, 5.4, 5.6, 5.8, 6.0 and 6.2 mg P_2O_5 respectively. 25 ml. of the composite reagent was added to each flask using an automatic pipette, and diluted to 100 ml. with water. The solutions were mixed well and allowed to stand for at least 15 minutes to allow the colour to develop fully. The spectrometer was set to read at 420 nm.

The apparent optical density of the 5.2, 5.4, 5.6, 5.8, 6.0, and 6.2 mg. standard solutions was determined using the 5.0 mg. solution as the reference standard. A calibration graph of optical density readings against known P_2O_5 content was plotted.

Analysis of Sample

25 ml. of the final dilution of a prepared test solution containing between 5.0 and 6.2 mg. P_2O_5 was transferred to a 100 ml. graduated flask, neutralised with approximately N sodium hydroxide solution, using phenolphthalein as indicator and then approximately N nitric acid added until the colour of the indicator was destroyed. The solution was cooled to 20 C and 25 ml. composite reagent added, using an automatic pipette, then made up to the mark, mixed well and allowed to stand for at least 15 minutes. At the same time, 25 ml. of the 0.2 mg/ml standard phosphate solution was transferred to a second 100 ml flask, 25 ml composite reagent added, the made up to the mark, mixed well and allowed to stand for at least 15 minutes.

The optical density of the test solution was determined using the 5.0 mg. solution as a reference standard, (where the optical density of the test solution was less than that of the 5.0 mg. solution, the optical density of the 5.0 mg solution was determined using the test solution as reference standard) .

Observations

(i) During dissolving process of samples - when the concentrated hydrochloric acid was added to the boiling solution, the whole solution frothed up the sides of the beaker leaving brown gritty deposits which had to be washed down again with water during the boiling process. On addition of nitric acid the frothing immediately ceased.

(ii) The resulting solution in samples 1, 2, 3, 4 and 5 were close to being colloidal and filtration was extremely difficult. There were no pulp pads available as suggested in the original method, so a Buchner funnel was used. The filter papers became completely clogged-up after only a few seconds and had to be changed frequently. This resulted in the residue not being washed as well as it should have been. The filtrate in samples 1, 2, 3, 4 and 5 appeared little different from the original solution i.e. yellow cloudy. Samples 6, 7 and 8 presented little difficulty being relatively clear and did not leave the fine reddish brown residue found in the other samples.

(iii) Although a calibration graph of a kind was obtained from the spectrometer, the instrument appeared to be faulty and results could not be repeated. A colorimeter which used distilled water as a comparison standard was used instead and produced a very good straight line graph of optical density against concentration.

Results

To obtain a depth of colouration in line with those of the standard solutions, several different dilutions of the first four samples were taken until a comparative reading could be found. The final dilution of the samples, those which covered the range for samples 1 to 7 inclusive, was as follows:-

25 ml sample diluted to 100 ml and mixed well

-further 25 ml sample taken and again diluted to 100 ml.

As 5 g was the original weight of the powdered phosphatic nodules before dissolving (assuming that all phosphate was dissolved) the final 500 ml. of the sample should have contained 5 g.

Calculation as follows:-

500 ml. of original dilution contained 5 g. sample,
∴ 25 ml. of original dilution contained 5/500 x 25 g sample.
This was made up to 100 ml,
∴ 100 ml. of 1st dilution contained 5/500 x 25 g sample,
∴ 25 ml. of 1st dilution contains 5/500 x 25 x 25/100 g sample.
This was made up to 100 ml,
∴ 100 ml. of 2nd dilution contained 5/500 x 25 x 25/100 g sample,
∴ 25 ml of second dilution contains 5/500 x 25 x 25/100 x 25/100 g sample.
(aliquot taken for actual test)
= ¼ x ¼ x ¼ = $^{1}/_{64}$ g sample = 0.015625 g sample.
∴ 0.015625 g. of the original sample was contained in each 25 ml aliquot taken for testing.

The original graph produced from the 5.0 mg. to 6.2 mg standard phosphate solutions was found to be too high for the results obtained. Rather than change an easy standard dilution of the samples a new set of standards were taken from 3.6 mg. to 5.0 mg. This was done by taking 18 ml, 15 ml, 20 ml, 21 ml, 22 ml, 23 ml, 24 ml and 25 ml. from a burette into 8 separate 100 ml. graduated flasks and made up as before. Again a good straight line graph was obtained.

Direct comparison with test samples was now possible

TEST RESULTS

SAMPLE	OPTICAL DENSITY (x10)	mg P_2O_5 in ALIQUOT	CALCULATION (P_2O_5 in 0.015625g sample)	% P_2O_5
1	1.75	3.70	0.0037	23.7
2	1.80	3.80	0.0038	24.3
3	1.85	3.90	0.0039	24.9
4	1.70	3.60	0.0036	23.1
5	1.73	3.66	0.00366	23.4
6	2.30	4.80	0.0048	30.7
7	1.95	4.10	0.0041	26.2
8	2.25	4.70	0.0047	30.1

CONCLUSION

Figures available from records dated back to last century - general comparison;-

Chemical substance analysed		% by weight
Moisture and a little organic matter		3 – 6
Phosphates	phosphate of lime (maj.)	44 – 61
	phosphate of magnesia	
	phosphate of iron	
Carbonate of lime, magnesia, fluorides, etc		20 – 25
Insoluble siliceous matter		10 – 30

It is extremely difficult to compare the above figures with present findings on P_2O_5 content. Also the analytical methods used may be somewhat different. Phosphate figures probably contain calcium percentage as well from calcium phosphate.

Results obtained 25/6/ 1976.

Strata	Location	% P_2O_5 by weight
Red Crag	1. Cliff Quay, Ipswich	23.7
	2. Back Hamlet, Ipswich	24.3
	3. Bucklesham	24.9
	4. Waldringfield Heath	23.1
	5. Battisford	23.4
	6. Stutton (bone	30.7
Coralline Crag	7. Sudbourne Park	26.2
Norwich Crag	8. Easton Bavents (bone)	30.1

The higher phosphate content of the last three samples may be due to the ease with which they were filtered. The constant changing of filter papers in the other samples must have caused some losses. There does not appear to be any significant difference between phosphate content of the nodules and the bones.

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