Title
High Levels of Cadmium in Atlantic Seabirds and Sea-Skaters

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100% because very limited sample sizes precluded determination of carbon dioxide, moisture, and ignition loss.

X-ray diffraction patterns of each sample revealed a poorly-crystalline apatite-like phase representing hydroxyapatite, $Ca_{10}(OH)_2(PO_4)_6$, a major component of calculus[11–13]. Considerable quartz was also present, together with some calcium silicate, $Ca_3Si_2O_7$, or calcium aluminium silicate, $CaAl_2Si_2O_8$. The similarity of the compositions indicates that the teeth were in contact for long periods with ground water from which silica precipitated within the relatively porous calculus structure.

Table 2 Major and minor elemental analysis of dental deposits

Element	% of oxides
SiO_2	40.02±10.78
Al_2O_3	6.17±2.02
CaO	26.01±8.88
K_2O	0.42±0.15
MgO	2.02±0.87
Na_2O	1.08±0.56
Fe_2O_3	3.96±1.20
TiO_2	0.77±0.21
P_2O_5	16.13±5.33

Values are means ± s.d. for six samples.

Brushite, $CaHPO_4.2H_2O$, and octacalcium phosphate, $Ca_4H(PO_4)_3.2H_2O$, which are two crystalline forms known to occur in some calculus samples[11–13], were not discernible. It was not clear whether magnesium whitlockite, $(Ca,Mg)_3(PO_4)_2$, another crystalline form found in some calculus, was present in any of the samples since certain major diffraction peaks for this substance fall in the same region as those characterising hydroxyapatite which was present. Insufficient sample sizes precluded fluoride analyses.

The presence of hydroxyapatite plus percentages of calcium and phosphorus similar to those reported for calculus[11–14] suggest, but do not confirm, that the accretions were originally laid down as dental calculus, not as lime or other simple calcium salts. Variations in the relative ratios of calcium, phosphorus, and magnesium indicate that some degradation has taken place on the calculus itself. This, together with the postmortem contamination, indicates that preservation of the material has been affected by environment, but not sufficiently to invalidate the basic conclusion.

The magnesium concentration in the samples was higher than that reported for modern calculus[11–14] but is compatible with the chewing of coca leaves since magnesium is a constituent of chlorophyll and a cofactor in some plant enzymes.

Since the lime was responsible for the deposits, the possibility that the people were chewing tobacco with lime cannot be ruled out altogether. Nevertheless, there is circumstantial evidence which argues in favour of coca use. In South America the historic distribution of chewing tobacco with lime was much more restricted than that of chewing coca with lime[3]. Furthermore, in the early historic period tobacco was used pre-eminently in ritualistic context whereas coca use was commonly secular and hedonic[3]. The huge calculus deposits imply habitual and, therefore, secular use. At Los Cerritos calculus deposits were more severe among males than females, suggesting that coca consumption by males was either more frequent or began at an earlier age.

Cultural evidence for the chewing of coca in coastal Ecuador appears as early as Valdivia times. Small ceramic lime pots have been found at Valdivian sites[15], including Real Alto. In addition, a figurine recovered from the Valdivia-type site clearly depicts a quid in the cheek of a woman[15]. Why, then, do the skeletons from Real Alto not show heavy deposits on the teeth? Presumably coca chewing expanded from a restricted, probably shamanistic, role in the Early Formative to a more popular, secular role in the Late Formative.

Since the climate of the Santa Elena Peninsula precludes the growing of coca, which thrives on the well-watered eastern slopes of the Andes, coca must have reached the coast by trade. Although there is evidence for trade routes as early as the Valdivia period[16,17] commerce had become much more extensive by late Chorrera times. Paulsen[18] presents evidence for the export of thorny oyster and conch shells from the Ecuadorian coast to the sierra beginning as early as 2800 BC. She concludes that the limited trade of the Early Formative had expanded to the Peruvian Andes by the first millennium BC. We propose that increased importation of coca to the south coast of Ecuador accompanied expanded exportation of mollusc shells to the sierra. In times of limited trade imported items would be at a premium and probably reserved for religious or curing purposes; expanded trade would make the exotic item, coca, available to a wider segment of the population for temporal use, in much the same manner as it is used by modern Andean peoples.

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High levels of cadmium in Atlantic seabirds and sea-skaters

THE possibility that cadmium may be an environmental pollutant has caused concern because it has toxic effects on many animal species including man, rat, rabbit, chicken, quail, and pigeon[1–4]. The occurrence of cadmium in wildlife is not unusual and samples of marine species taken from around the British coast contain low levels (less than 0.5 mg per kg in fish and less than 2 mg per kg in most shellfish); however, levels of up to 93 mg per kg were present in limpets, *Patella* sp., collected from areas of natural mineralisation or industrial sources of cadmium[5]. Seabirds generally contain higher residues than marine invertebrates. For example, Anderlini *et al.*[6] examined the amounts of nine metals in the livers of seven Antarctic and Pacific seabird species and noted that the maximum mean cadmium residue occurred in 10 ashy petrels *Oceanodroma homochroa* collected from their breeding grounds in California (mean residue was 53.2 ± 20.5 mg per kg). Parslow *et al.*[7] found up to 22.3 mg per kg dry wt cadmium in livers of eight puffins *Fratercula arctica* collected live from various British breeding colonies. It was suggested that pelagic birds might contain higher residues than coastal living species because a single fulmar *Fulmarus glacialis* examined by them contained 159 mg per kg cadmium. Anderlini *et al.* concluded that there was a correlation between increased concentration of cadmium in birds and exposure to industrial influences. Parslow *et al.* did not attempt to explain the residues they found in puffins, but Bourne[8] concluded that individual birds were becoming increasingly contaminated through feeding near areas of local pollution around the British coast. It is debatable whether cadmium should be regarded as a pollutant to seabirds. We report here the occurrence of cadmium residues in the tissues of apparently healthy, breeding seabirds which are considerably higher than any previously found. More important, we conclude that the cadmium has a natural rather than an industrial origin, since we have found high cadmium residues in a marine insect, *Halobates*, which is widely distributed in tropical regions far from sources of industrial cadmium. This insect is only one example of the sources from which birds obtain their cadmium residues.

Table 1 Cadmium residues in individual St Kildan seabirds

Species	Sex	Cadmium concentration (mg per kg dry wt) Liver	Kidney
Fulmar	1* ♂	9.1	46.7
Fulmarus glacialis	2* ♀	50.1	184
	3 ♂	7.7	32.8
	4 ♀	49.4	240
Manx shearwater	1} ♂	26.0	133
Puffinus puffinus	2} ♀	39.9	231
	3 ♂	14.6	67.0
	4 ♂	15.6	113
Puffin	1} ♂	18.9	109
Fratercula arctica	2} ♀	14.1	75.1
	3 ♂	29.4	125
Leach's petrel	1 ♂	57.0	68.5
Oceanodroma	2‖ ♀	21.5	128
leucorhoa	3 ♂	20.6	80.0
Storm petrel	1 ♂	9.2	30.2
Hydrobates	2 ♂	14.4	52.9
pelagicus	3 ♂	20.8	37.7
	4 ♀	26.5	36.7
Razorbill	1} ♂	2.4	14.6
Alca torda	2} ♀	1.8	16.0
	3 ♂	1.4	18.2

Birds were killed by exsanguination and their tissues immediately frozen using solid CO_2 and kept below -20 °C until analysed for heavy metals. Metal analyses were performed by atomic absorption spectroscopy after tissues had been digested with concentrated nitric acid. Parentheses show birds known to be paired.

*Birds known to have an egg. Fulmars 3 and 4 were prospecting birds not yet ready to breed. All other subjects were thought to be breeding but this could not be confirmed due to inaccessability of the nest site.

‖This bird had a shelled egg in the oviduct.

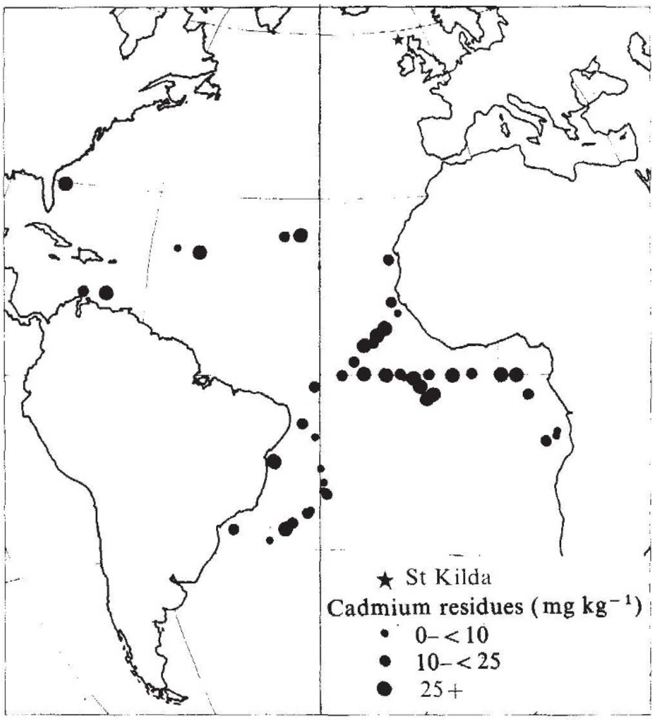
In June–July 1976 21 seabirds representing six species were collected, under licence, at a major breeding colony on St Kilda, a remote island group 80 km west of the Outer Hebrides, Scotland. All the animals were apparently healthy and unaffected by the metal levels they carried (Table 1). In all species, residues were higher in the kidney than in the liver, as in cadmium-contaminated humans[1]. Cadmium residues were considerably higher in the pelagic species (shearwaters, puffins, and petrels) than in the razorbill, which feeds in the region of the continental shelf throughout the year[9,10]. Since the pelagic species on St Kilda are unlikely to be exposed to industrial cadmium, it seemed possible that there might be important sources of cadmium in the open ocean.

Leatherland *et al.*[11] examined a range of plankton organisms and their predators, although very small samples were involved. They found appreciable levels of cadmium in some species, the maximum being 13 mg per kg dry wt in the decapods *Systellaspis debilis* (four examined) and *Ophophorus* sp. (two examined). Plankton samples are usually of a variably mixed species composition and it is not easy to isolate a single species from a wide range of localities to check for geographical variations in cadmium content.

Sea-skaters of the genus *Halobates* (Gerridae: Heteroptera) are pelagic marine insects. They live at the sea surface and feed on zooplankton trapped at the air–sea interface. Relatively high cadmium contents have been detected in *Halobates* from various parts of the Pacific Ocean, and these may reflect correspondingly high cadmium levels in the waters where the samples were collected[12]. It seems unlikely that the high cadmium levels detected in the sea-skaters resulted from atmospheric pollution, as no cadmium was detectable (< 5 mg per kg dry wt) in another gerrid, *Rheumatobates aestuarius*, collected from coastal mangrove lagoons in the Gulf of California, close to the area where *Halobates* was found at sea with very high cadmium levels (up to 200 mg per kg dry wt)[12]. Since these insects are widely distributed in the oceans and single-species samples can be obtained over a large area, their cadmium contents can indicate the distribution of this heavy metal in the surface layers of the ocean.

Samples of *Halobates micans* were obtained from tropical areas of the Atlantic Ocean. These were rinsed of all foreign matter with acidified distilled water, digested in concentrated nitric acid and then analysed for cadmium using atomic absorption spectrophotometry. The distributions of residues in the samples were not uniform (Fig. 1) but there was no pattern suggesting pollution. The mean concentration in 111 samples was 22.7 ± 3.1 mg per kg dry wt, ranging from 0 to 309 mg per kg (in a sample from the Gulf of Guinea). In many instances several samples were collected at one

Fig. 1 Cadmium content of *Halobates micans* collected from 47 sites along survey routes in the Atlantic; the species is confined to warmer waters. In cases when more than one sample was collected from the same site the highest value has been plotted. St Kilda was the collecting locality for the seabirds analysed for cadmium (Table 1). Sources of *Halobates* samples and acknowledgments are given by Cheng[12].



site and in Fig. 1 maximum values are depicted; the mean for these was 30.5 ± 6.7 mg per kg (n = 47).

The concentration of cadmium in the ocean varies little from the depths to within 0.5 km of the surface layer, but declines rapidly near the surface, conceivably as a result of incorporation into living organisms[13]. Some of the areas where the higher cadmium residues occur, for example, off the coast of West Africa, have little industrial activity, but have upwelling ocean currents of cold water which bring to the surface nutrients, and possibly cadmium too. Areas of ocean upwelling are known to be important wintering locations for pelagic seabirds, because they are rich feeding grounds, and it is likely that the birds accumulate at least some of their residues in these places. The Manx shearwater spends the contranuptial season off the coast of South America, while the storm petrel winters off South Africa and Leach's petrel very widely in the tropics; puffins ringed on the western coast of Britain have been recovered south of the Straits of Gibraltar but the precise wintering grounds remain to be defined[14]. We cite the *Halobates* data as an indication of the widespread occurrence of cadmium in tropical waters. It is doubtful whether many seabirds take large quantities of *Halobates* though the phoenix petrel *Pterodroma alba* and blue-grey noddy tern *Procelsterna cerulea* have been proved to eat them in the Pacific[15,16]. We might, therefore, expect these insects to be among the sources from which such birds as storm petrels could obtain cadmium.

We conclude that the high cadmium concentrations found in seabirds originate from natural sources, rather than from industrial activity, and that the birds, having evolved in an ecosystem containing cadmium, have developed, through natural selection, mechanisms which enable them to tolerate this metal. One such mechanism, now being investigated, involves production of a metal-binding protein which has been identified in the fulmar—it has many of the properties of metallothionein.

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Pectolytic anaerobic bacteria cause symptoms of cavity spot in carrots

Cavity spot, a disease which causes considerable damage to the mature storage roots of carrots in several countries including the United Kingdom and the United States[1], has been reported to be caused by calcium deficiency, either actual or induced by excessive potassium levels in the soil[2]. We have examined diseased carrots in East Scotland since 1966 and have been unable to confirm the relationship with calcium levels. Evidence reported here indicates that pectolytic bacteria of the anaerobic genus *Clostridium* are the cause.

In the light of observations that the incidence of cavity spot was greatest in wet seasons on poorly drained land, and that more roots had lesions in waterlogged than in freely drained pots, the effect of restricting aeration to roots was investigated. Carrots were grown in plastic pots containing UC sand–peat compost (a mixture of three parts peat to one part coarse sand, formulated at the University of California) and when the crown diameters were greater than 20 mm, the compost surface was sealed with paraffin wax (melting point 55 °C). Roots of similar size were also lifted from the field, washed carefully and transplanted to similar pots. The pots were placed in trays containing 25 mm of water and kept in a controlled environment cabinet at 20 °C with an 18-h daylength of 12,000 lx. Analyses of gas composition in the compost (gas chromatogram, Pye model 106, MS 5A column, length 152.4 mm, oven temperature 100 °C) indicated that anoxic conditions developed within 48 h. After 5 or 6 d the wax was removed and the pots were returned to the glasshouse bench. Characteristic lesions were observed 3 weeks later. The proportion of roots affected was greatly increased when soil from a field outbreak was added to the roots before sealing. For example, the percentage of roots with lesions in an experiment in which all pots were sealed and supplemented with field soil or autoclaved field soil, or not supplemented, were 72, 28, and 24% respectively ($P < 0.001$ on contingency analysis).

Because there was evidence of a heat-labile factor in field soil and because no fungi or bacteria which were pathogenic on re-inoculation had been isolated by conventional techniques, isolations and subsequent inoculations were carried out under hydrogen in McIntosh and Fildes anaerobic jars fitted with palladium catalysts. Using a reducing medium with a pectate layer[3], we isolated pectolytic bacteria at 25 °C from lesions formed on roots in sealed pots supplemented with field soil. Isolates were repeatedly sub-cultured from single colonies on streaked pectate plates and when grown in liquid basal medium anaerobically and inoculated to carrots, lesions identical to those caused by the soil supplement developed in sealed but not in open pots. The bacteria were recovered from these lesions by anaerobic culture.

Similar bacteria were obtained from several fields where cavity spot had occurred by inoculating carrot disks with about 1 g soil, and they were also recovered from some natural lesions incubated, like the disks, in anaerobic conditions. The colonies were cream coloured and the bacteria grew rapidly in anaerobic conditions at 25 °C producing a plaque in the pectate layer of up to 20 mm diameter in 2 d. Pectolysis on media and on carrot disks was still evident at 10 °C and no growth occurred on agar or on carrot disks in air. The bacteria were gram negative rods, 2.8–5.2 × 0.6–0.8 nm, which produced sub-terminal ovoid endospores, 1.4–2.4 × 0.8–1.0 nm. Gelatin was not liquified within 7 d at 25 °C. The organism was identified as a member of the genus *Clostriduim*[4], although results of further tests did not agree with those of any described species.

Cavity spot often occurs on poorly drained, compacted soils and it is most common after heavy rainfall in midsummer when the soil biomass and the high root population of carrots grown for canning may deplete oxygen more rapidly than it can be replaced by diffusion from the atmosphere. In these conditions it is suggested that the anaerobic bacteria described here may initiate cavity spot lesions. Pectolytic *Clostridium* spp. have been implicated in the rotting of potatoes in storage but they have not been associated previously with a field disease syndrome.

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