Aspects of the structure and composition of baleen, and some effects of exposure to petroleum hydrocarbons

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The structure and composition of baleen from seven species of whales was studied using tensiometry, X-ray diffraction, and elemental analysis. Baleen was found to be composed principally of amorphous and α-keratin. Hydroxyapatite (bone mineral, $Ca_{10}(PO_4)_6OH_2$) was present in all species. Certain elements, notably manganese, copper, boron, iron, and calcium were more highly concentrated in the fibers than in the matrix of the plate. The breaking strength of baleen plates from fin (*Balaenoptera physalus*), sei (*B. borealis*), and grey (*Eschrichtius robustus*) whales was comparable to that of buffalo horn, in the range of $2-9 \times 10^6\ N \cdot m^{-2}$. The stiffness of baleen was somewhat less than that of other keratinized tissues. Treatment with 10% (v/v) trichloroacetic acid for 8 days removed most of the calcium salts, denatured α-keratin, and made fin whale plates stronger and stiffer. Exposure to gasoline for 1.5 h or 14 days, crude oil for 8 days, or tar for 21 days resulted in loss of trace elements from baleen, and inconsistent changes in keratin organization. After tar exposure, fin whale baleen plates were stiffer and stronger. We presume that at sea, baleen would be relatively resistant to damage by spilled oil.

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La structure et la composition des baleines de fanons a été étudiée, chez sept espèces de baleines, par tensiométrie, diffraction de rayons X et par simple analyse. La kératine-α et la kératine amorphe sont les deux principaux éléments qui entrent dans la composition des baleines. L'hydroxyapatite (substance ménérale osseuse, $Ca_{10}(PO_4)_6OH_2$) se retrouve chez toutes les espèces. Certains éléments, en particulier le manganèse, le cuivre, le bore, le fer et le calcium, sont plus concentrés dans les fibres que dans la matrice de la plaque. La force de rupture des plaques chez le rorqual commun *Balaenoptera physalus*, le rorqual du Nord *B. borealis*, et la baleine grise *Eschrichtius robustus*, se compare à celle des cornes du bison et va de 2 à $9 \times 10^6\ N \cdot m^{-2}$. La rigidité des baleines est un peu inférieure à celle des autres tissus kératinisés. Un traitement d'une durée de 8 jours à l'acide trichloroacétique 10% (v/v) a dissous presque tous les sels de calcium, dénaturé la kératine-α et rendu les plaques du rorqual commun plus fortes et plus rigides. L'exposition des plaques à de l'essence pour 1,5 h ou 14 jours, à du pètrole brut pour 8 jours, ou à du goudron pour 21 jours entraîne la disparition des éléments présents à l'état de traces et produit des changements imprévisibles dans l'organisation de la kératine. Après exposition au goudron, les baleines des fanons du rorqual commun deviennent plus rigides et plus fortes. Il est permis de croire qu'en met les fanons seraient relativement résistants à un épandage de pétrole.

[Traduit par le journal]

Introduction

Baleen whales feed by straining water through a series of plates that form a comb on each side of their upper jaws. The plates consist of numerous round tubules cemented together and sandwiched between sheets of tough keratin. The matrix and covering wear away along the inner ege of the plate to expose hairlike tubules which form the filter (Pautard 1965).

There is some concern that mysticetes feeding in an oil spill would foul their baleen plates and fibers, and be unable to feed (Geraci and St. Aubin 1980). Heavier fractions adhering to the fibers may obstruct waterflow, while other components destructive to tissue may cause loss of integrity, breakage, or aberrant wear. We focussed on the latter effect using tensiometry, X-ray diffraction, and elemental analysis to examine the structure and composition of baleen from seven species representing the three major groups of mysticetes. The effects of oil were determined in isolated plates soaked in petroleum for periods greatly exceeding expected exposure at sea.

Materials and methods

Baleen samples were obtained from two minke whales (*Balaenoptera acutorostrata*), one right whale (*Eubalaena glacialis*), and one humpback whale (*Megaptera novaeangliae*) which were stranded along the New England and Nova Scotia coasts, and from two grey whales (*Eschrichtius robustus*), stranded along the California coast. Plates were also collected from two fin whales (*Balaenoptera physalus*) and two sei whales (*B. borealis*) taken by the Icelandic whale fishery. Baleen from four bowhead whales (*Balaena mysticetus*), taken by Alaskan Inuit, was stored at room temperature for up to 4 years; all other samples were frozen at −20°C to −5°C for 1–4 years. In the laboratory, the plates were removed at the gum line and placed into saline ($30\ g \cdot L^{-1}$) baths for 24–96 h to reverse any dehydration which might have occurred during storage.

Structural tests of baleen plates from fin, sei, and grey whales were performed using the method described by the American Society for Testing of Materials (ASTM) (Anonymous 1973) and an Instron tensiometer (Instron Corporation, Canton, MA) equipped with chart recorder. Samples from each plate were cut to specifications for either type IV or V so that the tubules within the keratinized matrix were

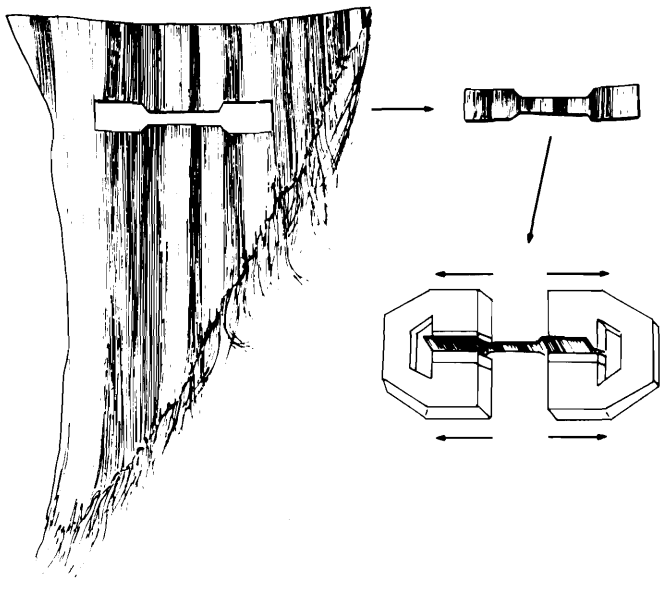

FIG. 1. Samples of baleen for tensiometry were cut to specifications established by the American Society for Testing and Materials (Anonymous 1973).

perpendicular to the long axis of the test piece (Fig. 1). Each piece was rehydrated in saline then mounted in the jaws of the tensiometer such that the force applied to each end tended to part the matrix without breaking the tubules.

We measured the strength of each sample according to Young's modulus, taken as the ratio of stress to strain. Stress was determined for minimum cross-sectional area, measured using calipers, and maximum load as follows:

$$\text{Stress } (\sigma)\ (\text{N}\cdot\text{m}^{-2}) = \frac{\text{maximum load (kg)}}{\text{minimum area (m}^2\text{)}} \cdot 9.8\ \text{m}\cdot\text{s}^{-2}$$

Strain was defined as the change in length of the sample prior to breaking in relation to its original length, as follows:

$$\text{Strain } (\epsilon) = \frac{\text{change in length}}{\text{original length}} = \frac{\Delta L\ (\text{mm})}{L\ (\text{mm})}$$

For X-ray diffraction analysis, two samples were usually cut from the medial and two from the lateral borders of the baleen plate. They were taken at the gum line and at a point 3/4 of the way down the length of the plate. Exposed fibers were also cut from this level. From fin whales, samples from the small medial plates and from below the gum line were also analyzed. Pieces of baleen 1 × 1 mm, individual fibers, or 1-mm tufts of fibers were mounted on plasticene and exposed to copper Kα X-rays for 8–12 h using a two-circle diffractometer. A Stoe X-ray camera (Stoe and Cie GMBH, Republic of Germany) recorded the diffraction pattern and measurements of the arcs were made from the developed negative. The *d*-spacing was calculated using the Bragg equation, as follows:

$$d = \frac{n\lambda}{2 \sin \theta}$$

where n is the order (1), λ is the wavelength of the X rays (1.54 Å or 0.154 nm), and θ is the measured diffracted angle.

Most diffraction patterns were obtained from dry samples, since wet samples yielded the same results. X-ray negatives were analyzed qualitatively and given a numerical ranking for α-keratin, amorphous keratin, and calcium salt on the basis of strength and definition of the arcs and rings. Categories used were as follows: 0, absent; 1, weak and cloudy; 2, weak to medium; 3, medium; 4, medium to strong; 5, strong and distinct.

Small-angle X-ray diffraction patterns were obtained for selected samples. Copper K_α X-rays from a Hilger model GX6 rotating anode generator (Elliott Automation, Boreham Wood, England) were point-focussed in a camera employing a bent-crystal monochromator and a Frank's mirror, to resolve any collagen reflections.

TABLE 1. Characteristics of X-ray diffraction patterns of control and trichloroacetic acid treated baleen from three mysticete species. The strength and clarity of arcs and rings were ranked on a scale of 0–5 (see Materials and methods). Four to six samples were taken from each of one or two plates for each species

Species	Treatment	No. of samples	Relative strength of diffraction patterns ($\bar{x}$ ± SD) α-keratin	Amorphous keratin	Calcium salts
Fin	Control	12	3.0±0.8	2.7±1.4	1.7±1.0
	TCA[a]	6	0.3±0.5	2.8±0.4	0.5±1.2
Right	Control	6	2.5±1.0	2.7±0.5	1.0±0
	TCA	6	0	2.7±1.0	0
Grey	Control	12	4.2±0.9	3.2±0.7	1.0±0
	TCA	6	0	2.7±0.8	0
Minke	Control	5	2.4±0.8	2.0±0.9	0.8±0.4
Humpback	Control	5	3.0±1.1	3.2±1.6	1.2±0.4
Sei	Control	6	2.8±0.4	3.0±0	3.0±1.3
Bowhead	Control	4	1.8±0.5	3.2±0.5	2.8±0.5

[a]Soaked for 8 days in 10% (v/v) trichloroacetic acid.

Baleen samples for elemental analysis were taken from the same locations as those for X-ray diffraction. They were finely ground, oven-dried, and divided into two portions. One 1.25-g sample was charred at 225–275°C and then ashed at 450°C for at least 2 h. The ash was dissolved in 2.5 mL of 2 *N* HCl, added to 10.0 mL of distilled H_2O, and filtered. The filtrate was analyzed for Mn, Cu, Zn, and Fe using a Varian atomic absorption spectrophotometer model 175 (Varian Techtron Ltd., Melbourne, Australia) with an acetylene flame. The filtrate was also analyzed colorimetrically for B using an Autotechnicon multichannel autoanalyzer (Technicon Instruments Corp., Tarrytown, NY). A separate 0.25-g oven-dried sample of ground baleen was boiled in 5 mL of concentrated H_2SO_4 for 1 h. A small aliquot of 30% H_2O_2 was added to the cooled solution before reheating it for 5 min; this was repeated until the solution was clear, after which it was heated and digested for 20 min and brought to 250 mL volume with distilled H_2O. This solution was analyzed for Na, K, and Mg by atomic absorption spectrophotometry using an acetylene flame, for Ca with a nitrous oxide flame, and for P and N colorimetrically as previously described. We established the precision and reproducability of elemental analyses by grinding an entire fin whale plate and analyzing 31 aliquots intermittently throughout the study.

Lipid concentration was determined gravimetrically in three to six samples of baleen fibers from each of 15 fin and 8 sei whales. Samples weighing 0.5–1.0 g were oven-dried for 16 h at 40°C, weighed to the nearest 0.1 mg, soaked for 1–2 h in chloroform, and reweighed after oven-drying as before.

Plates from selected species were soaked in lead-free gasoline for either 1.5 h or 14 days, west Texas crude oil for 8 h, or roofing tar for 21 days. We also immersed some plates in decalcifying solution (10% (v/v) trichloroacetic acid) for 8 days to determine the role of calcium as a structural component. After treatment, plates were wiped dry and processed for tensiometry, X-ray diffraction, or elemental analysis. Plates soaked in tar had to be cleaned using small amounts of gasoline, which we found to have no effect on most of the parameters examined.

Results and discussion

The principal components of baleen, as shown by wide-angle X-ray diffraction patterns, are keratin and calcium salts

TABLE 2. Composition of baleen plates from seven species of whales

Element	Fin[a]	Minke[b]	Sei[c]	Humpback[d]	Right[a]	Bowhead[e]	Grey[a]
Nitrogen (%)	7.5(7.5–7.5)	12.5, 12.5	13.4(12.5–14.0)	13.1(13–13.5)	11.4(11–11.5)	14.2(14–14.5)	10.8(10–12)
Phosphorus (%)	0.34(0.27–0.40)	0.21, 0.19	0.87(0.63–1.2)	0.17(0.16–0.19)	0.16(0.11–0.19)	0.10(0.09–0.12)	0.09(0.08–0.11)
Potassium (%)	<0.01(0–0.02)	0.06, 0.05	0.03(0.01–0.05)	0.07(0.03–0.09)	0.06(0.05–0.09)	0.03(0.02–0.04)	0.04(0.02–0.06)
Calcium (%)	0.4(0.30–0.64)	0.19, 0.25	1.79(1.34–2.38)	0.24(0.15–0.51)	0.18(0.14–0.20)	0.19(0.16–0.23)	0.14(0.12–0.16)
Magnesium (%)	0.06(0.04–0.08)	0.09, 0.09	0.05(0.04–0.06)	0.04(0.02–0.06)	0.05(0.03–0.07)	0.03(0.02–0.05)	0.08(0.05–0.10)
Sodium (%)	—	0.34, 0.30	0.41(0.27–0.57)	0.44(0.32–0.57)	—	0.30(0.23–0.43)	—
Manganese (ppm)	0.2(0–1)	0, 0	0.8(0–1)	0.8(0–1)	0.8(0–1)	0	1.5(1–2)
Copper (ppm)	18(17–21)	5, 6	21(13–27)	11(8–13)	10(8–14)	8(6–10)	6(4–10)
Zinc (ppm)	406(334–455)	299, 257	374(334–405)	367(323–406)	352(311–379)	216(175–248)	252(226–284)
Boron (ppm)	5(3–7)	4, 5	9(6–14)	16(7–22)	4(2–4)	6(4–7)	4(2–5)
Iron (ppm)	12(7–23)	26, 41	3(1–5)	28(19–43)	16(12–19)	20(12–38)	37(7–59)

[a]Four samples from one plate; mean (range).
[b]One sample from one plate from each of two whales.
[c]Four samples from one plate from one whale, one sample from one plate from a second whale; mean (range).
[d]Four samples from two plates from one whale, one sample from one plate from a second whale; mean (range).
[e]One sample from one plate from each of four whales; mean (range).

TABLE 3. Composition of baleen fibers from five species of whales

Element	Fin[a]	Sei[a]	Humpback[b]	Grey[a]	Right[a]
Nitrogen (%)	10.0	12.5	8.5, 7.3	11.0	6.55
Phosphorous (%)	0.8	2.25	0.14, 0.12	0.12	0.09
Potassium (%)	0	0.04	0.06, 0.07	0.03	0.02
Calcium (%)	1.37	4.6	0.44, 0.45	0.22	0.27
Magnesium (%)	0.07	0.20	0.12, 0.10	0.14	0.07
Sodium (%)	—	0.49	0.39, 0.41	—	—
Manganese (ppm)	10	6	11, 11	26	3
Copper (ppm)	34	33	17, 15	16	60
Zinc (ppm)	544	586	278, 235	268	195
Boron (ppm)	10	27	16, 21	9	4
Iron (ppm)	300	238	422, 419	543	111

[a]Fibers from one plate.
[b]Fibers from two plates.

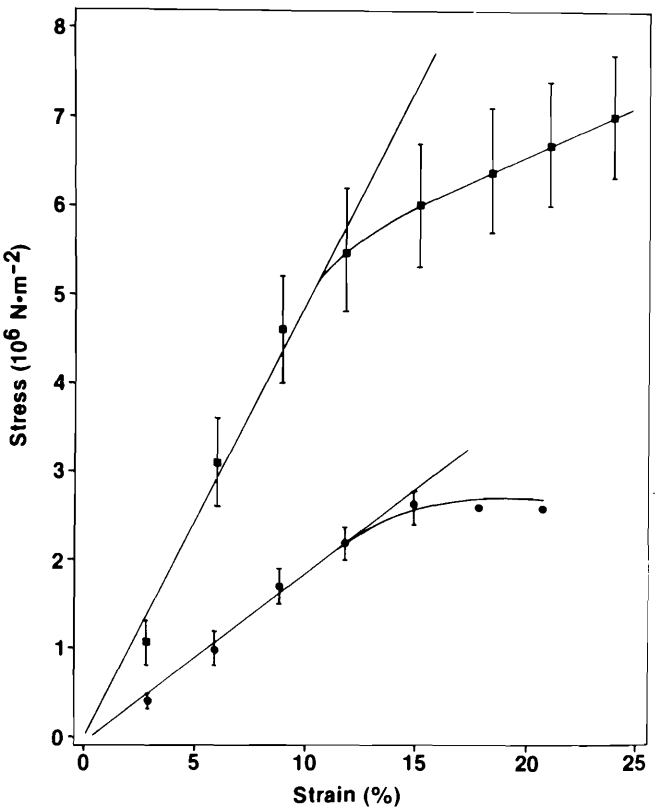

FIG. 2. Effect of trichloroacetic acid treatment on the tensiometric properties of fin whale baleen. Regression line was determined for the linear portion of each curve. Data were derived from six pieces cut from each of one treated (■) and one control (●) plate. Standard deviation bars shown only for those points with $n = 6$.

(Table 1). The absence of collagen distinguishes baleen from other calcified tissues, and represents one of the few examples of calcium salt depositions on a keratin matrix. Keratin was organized into an α-helix, which produced sharp meridional arcs at 0.515 nm and diffuse equatorial arcs at 0.98 nm (Fraser *et al.* 1972), and was also present in an amorphous form characterized by broad halos with maxima at about 0.45 and 0.95 nm. The small angle patterns showed the 9th and 17th orders of the large keratin spacing, as strong reflections at 2.5 and 6.6 nm, and confirmed the absence of collagen. X-ray diffraction patterns from the smaller medial plates of the fin whale were comparable to those for the larger primary plates.

Calcium salts, principally hydroxyapatite ($Ca_{10}(PO_4)_6OH_2$, bone mineral), were noted in all species (Table 1). In contrast to Pautard's (1963, 1965) reports, our X-ray diffraction patterns for bowhead baleen showed clear evidence of hydroxyapatite. Continuous sharp reflections at 0.225, 0.276, and 0.341 nm indicated a random array of small (2×10^{-7} to 10^{-5} m) crystals. The X-ray diffraction patterns for grey, humpback, minke, and right whale baleens commonly showed cloudy regions characteristic of very small crystallites ($<10^{-7}$ m). One grey whale sample gave a strong X-ray reflection corresponding to a 0.3-m spacing. This anomalous arc may indicate the presence of calcium oxalate or whewellite ($CaC_2O_4 \cdot H_2O$).

Hydroxyapatite in the embedded portion of the fin whale baleen plate was found only in a band at a depth of 36 mm from the gum line, and was absent in the other areas examined (16, 56, and 66 mm from the gum line). Presuming that calcium salts influence the stiffness of the plates, we feel that this band might promote hingelike bending in the region of the gum line, a characteristic of right whales (Lydekker 1922) which has not been described for rorquals such as the fin whale.

Analysis of the elemental composition of baleen plates and fibers confirmed some of the features noted in X-ray diffraction patterns (Tables 2 and 3). The nitrogen concentration was 7.5–14%, indicating that protein in the form of keratin comprises 47–87% of the dry weight. Calcium was present in the baleen of all species. Concentrations were highest

TABLE 4. Tensile properties of baleen from three species of whales. One plate from a fin whale was immersed in 10% trichloroacetic acid for 7 days prior to testing

Species	No. pieces tested[a]	Young's modulus (10^7 N·m^{-2}) $\bar{x}$ ± SD	Young's modulus (10^7 N·m^{-2}) Range	Breaking strength (10^6 N·m^{-2}) $\bar{x}$ ± SD	Breaking strength (10^6 N·m^{-2}) Range
Grey A	4	1.2±0.7	0.6–2.0	2.3±0.7	1.6–3.1
Grey B	4	1.3±0.6	0.9–2.2	1.9±0.5	1.2–2.3
Sei	10	11.0±5.4	7.8–25.7	8.9±2.6	4.4–13.3
Fin A	10	6.9±2.9	3.7–14.3	7.1±1.2	5.2–9.2
Fin B	7[b]	2.1±0.1	1.9–2.2	2.6±0.2	2.2–2.8
Fin B (TCA treated)	7[b]	4.9±0.7	4.0–5.9	7.7±1.1	6.3–9.5

[a]Cut from one plate for each whale, according to dimensions for ASTM type V.
[b]Tested using dimensions for ASTM type IV.

TABLE 5. Effect of petroleum exposure on keratin component of baleen, analyzed by X-ray diffraction on six samples for each treatment. The strength and clarity of arcs and rings were ranked on a scale of 0–5 (see Materials and methods)

Species	Treatment	Component: α-keratin	Component: Amorphous keratin
Right	Control	2.5±1.0	2.7±0.5
	Tar	4.2±0.4**	2.8±0.4
Grey	Control	4.3±1.0	3.3±1.0
	Gasoline	2.2±1.0**	2.5±0.5
	Crude oil	2.2±0.8**	2.3±0.5
	Tar	2.2±1.0**	1.7±1.0*

*$p < 0.5$, compared with controls using t-test.
**$p < 0.01$, compared with controls using t-test.

(1.34–2.38%) in sei whale baleen and lowest (0.14–0.19%) in grey and right whale samples. This was consistent with the relative strength of the calcium arcs observed using X-ray diffraction, though in bowhead samples concentration of calcium was low despite clear X-ray patterns for hydroxyapatite. Certain elements, notably calcium, manganese, copper, boron, and iron, were more highly concentrated in the isolated fibers (Table 3) than in the body of the plate, which is composed of fibers and matrix within a cornified cortex.

The strength at the breaking point of fin, sei, and grey whale baleen (Table 4) was comparable to that of air-dried buffalo horn, which breaks at 6.3×10^7 N·m^{-2} when stressed perpendicular to its long axis (Yamada 1970). When we tested the strength of baleen along its longitudinal axis, the results were too variable to permit any kind of comparison. Wide variation in strength was also noted for adjacent samples cut across each plate, but with no trend suggesting that plates weaken as they become thinner towards the tip. One possible source of this variation was the numerous irregular ridges in the cortex of the plate, which possibly correspond to growth cycles (Ruud 1940).

The average stiffness of baleen ranged from approximately 1.2×10^7 N·m^{-2} for grey whales to 11.0×10^7 N·m^{-2} for a sei whale; that of the fin whale was intermediate (Table 4). It would have been interesting to compare these values with those from right whale baleen, which is known for its flexibility. Unfortunately, right whale plates were too small to be tested with our apparatus. As some basis of comparison, the grey, fin, and sei whale plates tested were not as stiff as hair (2×10^9 N·m^{-2}), human thumbnail (1.7×10^8 N·m^{-2}), or cartilagenous tissues (Yamada 1970).

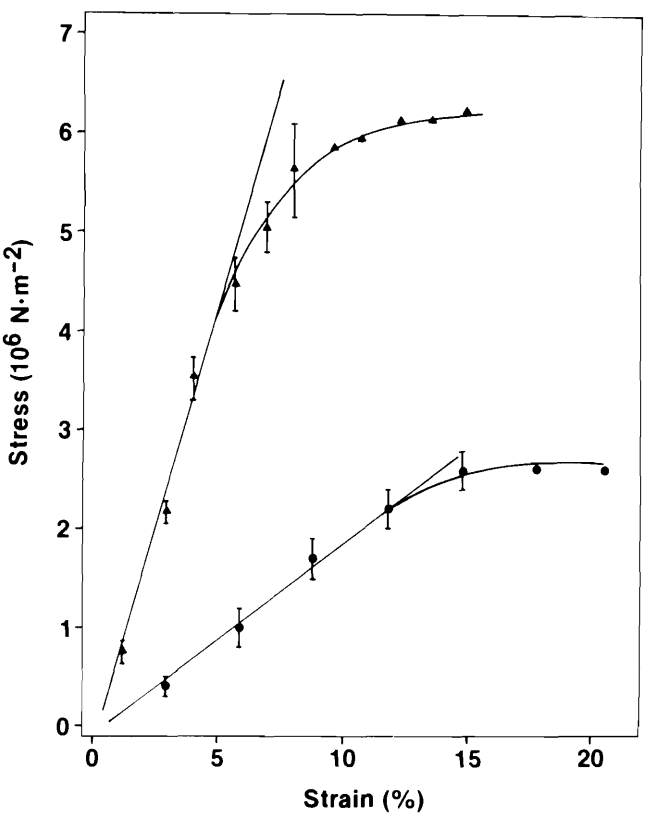

FIG. 3. Effect of tar exposure on the tensiometric properties of fin whale baleen. Regression line was determined for the linear portion of each curve. Data were derived from six pieces cut from each of one treated (▲) and one control (●) plate. Standard deviation bars shown only for those points with $n = 6$.

Treatment for 8 days in trichloroacetic acid (TCA) altered the structural properties and molecular organization of the baleen plates. X-ray diffraction arcs for calcium salts became very faint or absent in most treated samples (Table 1). Yet elemental analysis, performed only on treated fin whale plates, showed no change in calcium concentration; perhaps the technique was not sufficiently sensitive.

The loss of X-ray diffraction arcs for α-keratin (Table 1) indicated denaturation of protein by the direct action of TCA, or as a consequence of removal of calcium, which possibly

TABLE 6. Tensile properties of fin whale baleen, treated with crude oil, lead-free gasoline, or decalcifying solution. Tests were carried out on pieces cut to the dimensions for ASTM type IV (Anonymous 1973)

Treatment	n	Young's modulus (10^7 N·m^{-2}), $\bar{x}$ ± SD	Percent increase in length at point of yield, $\bar{x}$ ± SD	Stress at point of yield (10^6 N·m^{-2}), $\bar{x}$ ± SD	Breaking strength (10^6 N·m^{-2}), $\bar{x}$ ± SD
Control	7	2.1±0.1	10.6±1.6	2.0±0.2	2.56±0.18
Crude oil	6	2.0±0.1	9.8±1.8	1.7±0.2	2.55±0.32
Gasoline	6	1.8±0.1	9.4±2.4	1.7±0.3	2.62±0.17
Tar	6	8.8±1.4*	5.0±0.7*	4.3±0.4*	5.59±0.65*

*$p < 0.001$, compared with controls using t-test.

TABLE 7. Effects of petroleum exposure on the concentration of Mn, Cu, B, Fe, and Ca in fin and grey whale baleen fibers. One sample was analyzed for each treatment

Treatment	Elemental content: Manganese (ppm)	Copper (ppm)	Boron (ppm)	Iron (ppm)	Calcium (%)
Fin whale					
Control	10	34	10	300	1.37
Gasoline[a]	2	19	3	29	1.37
Gasoline[b]	6	19	5	18	1.02
Crude oil	3	15	4	128	1.11
Tar	6	14	7	86	0.14
Grey whale					
Control	26	16	9	543	0.22
Gasoline	2	9	3	95	0.15
Crude oil	4	7	4	295	0.11
Tar	3	7	4	22	0.12

[a]Exposure for 90 min.
[b]Exposure for 14 days.

plays a role in stabilizing the α-helix. These changes made fin whale plates significantly stronger and stiffer (Table 4, Fig. 2). The treated pieces could be stretched to 130–154% of their original length prior to breaking; control samples broke when stretched to 115–121%. Young's modulus was increased by a factor of 2.5, and there was a threefold increase in force required to break the test pieces (Table 4). Stress (relative increase in length) at the point of yield was not affected. The association between calcium and flexibility underscores our premise that its focal distribution within the portion of the plate embedded in the gum would facilitate bending at that level.

Gasoline, crude oil, and tar inconsistently affected X-ray diffraction patterns, elemental composition, and tensile properties of baleen. In grey whale samples, α-keratin arcs were less prominent following all treatments, and amorphous keratin was less distinct in plates exposed to tar (Table 5). By contrast, tar improved the resolution of α-keratin arcs in diffraction patterns of right whale baleen (Table 5). In the fin whale, there were no changes in the X-ray diffraction patterns following any petroleum treatment. Tar did, however, stiffen the plates of fin whales (Table 6, Fig. 3). Concentration of certain trace elements decreased in fin and grey whale baleen fibers (Table 7) but not the plates; there was no such change in the right whale samples. These observations reflect the difference in properties of baleen among whale species, rather than elucidate a single consistent effect of petroleum exposure.

In fact, the only consistent change was an apparent increase in nitrogen levels in both matrix and fibers, following all treatment (Table 8). Since the solution contained no detectable nitrogen, we interpret the increase to be a relative change caused by an absolute decrease in the dry weight of the sample. Lipids, which comprise up to 10% of the weight of baleen fibers (Table 9), were likely removed by the solvent action of the long-term immersion in petroleum, thus providing the mechanism for the change in dry weight. We did not determine the lipid content of treated fibers.

It is unlikely that whales at sea would be exposed to petroleum as intensively as was required to change the structure and composition of baleen plates in this study. The lighter solvent fractions can disappear within 24 h of a spill (Jordan and Payne 1980). Though the heavier fractions are more persistent, we have observed that sea water can rinse oil from fouled plates (Geraci and St. Aubin 1982) to the extent that we have yet

TABLE 8. Effects of petroleum exposure on the concentration of nitrogen in baleen from three species. One plate was analyzed for each treatment

Treatment	Nitrogen concentration (% dry weight): Fin Plate[a]	Fin Fibers[b]	Grey Plate[a]	Grey Fibers[b]	Right Plate[a]	Right Fibers[b]
Control	7.5(7.5–7.5)	10.0	10.7(10–12)	11.0	11.4(11–11.5)	6.6
Gasoline (90 min)	11.9(11.5–12)	12.5	11.9(11.5–12)	13.5	11.6(11–12)	11.0
Gasoline (14 days)	13.4(13–13.5)	13.5	—	—	—	—
Crude oil (8 h)	13.5(13–14)	13.0	13.6(13–14.5)	13.5	13.6(13.5–14)	7.8
Tar (21 days)	13.1(13–13.5)	12.0	13.0(12–13.5)	13.5	13.1(12.5–13.5)	12.0

[a]Mean (range) for four subsamples of one plate.
[b]$n = 1$.

TABLE 9. Lipid concentration in baleen fibers from fin and sei whales. Chloroform extractions were performed on three to six samples from each whale

Species	n	Lipid concentration (% dry weight) $\bar{x} \pm$ SD	Range
Fin whale	15	4.1±2.6	0.3–8.1
Sei whale	8	3.7±3.1	0.5–9.6

to detect the presence of petroleum residues on the baleen of 23 commercially harvested fin and sei whales. Our studies dampen the fear that exposure to spilled oil would lead to deterioration of baleen plates.

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