Tissue Structural Studies and Other Investigations on the Biology of Endangered Whales in the Beaufort Sea

Volume II

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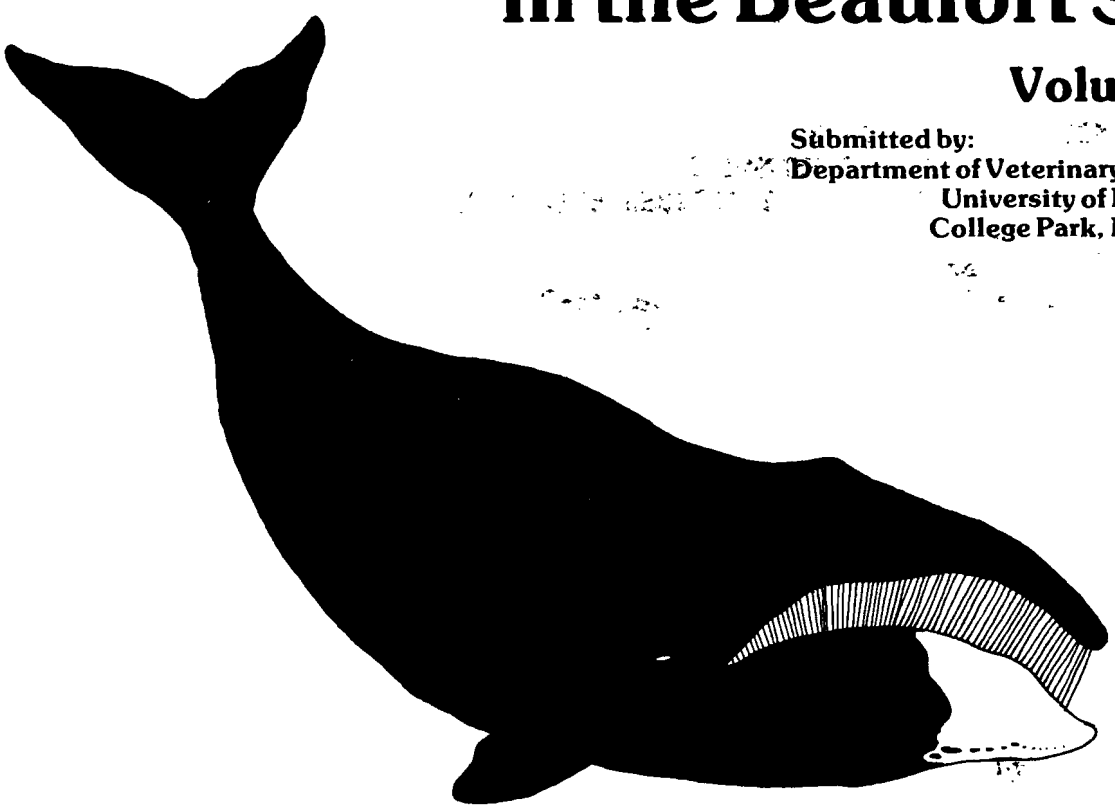
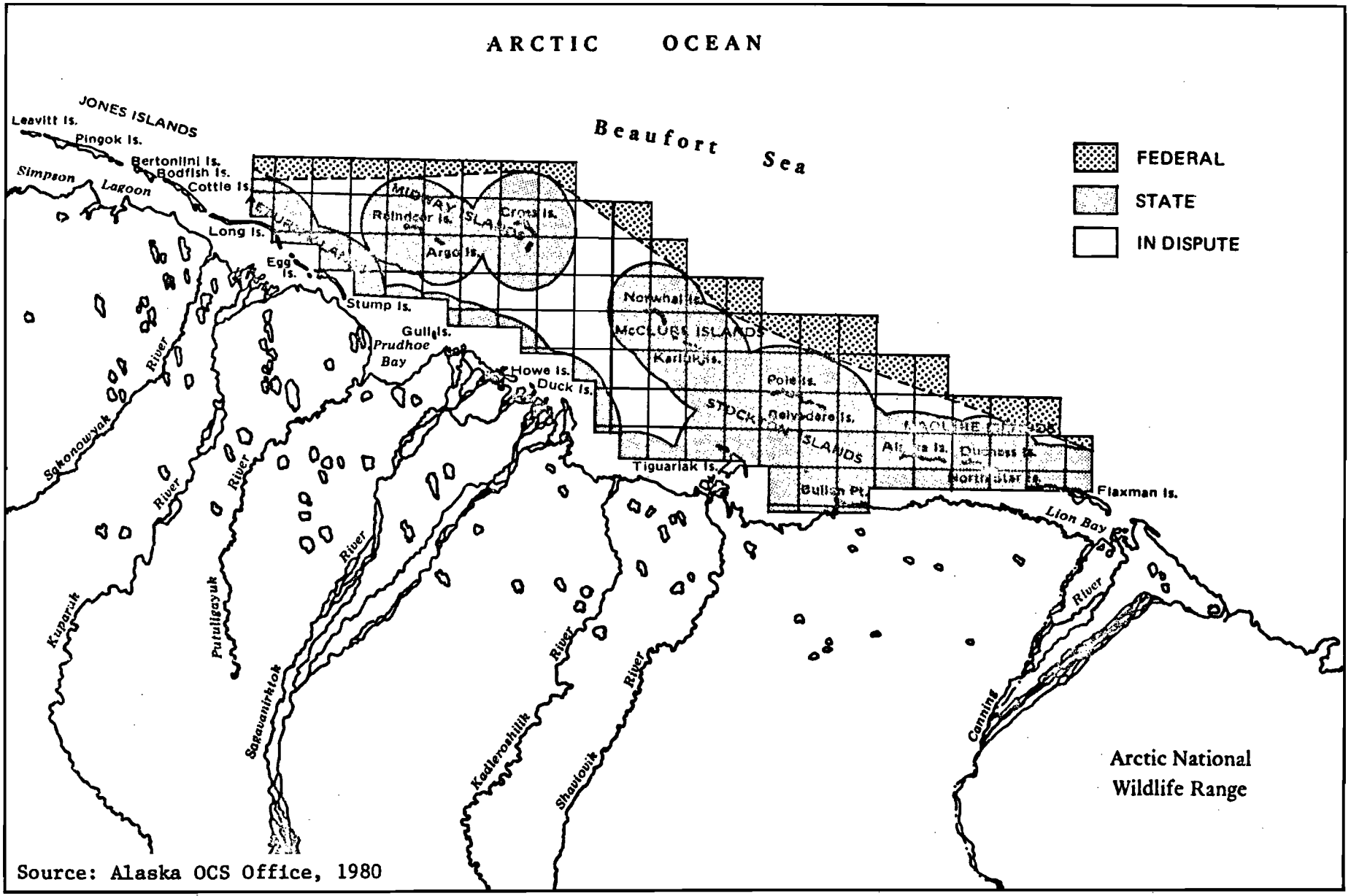


Final Report for the Period April 1, 1980 through June 30, 1981.

Prepared for:
U.S. Department of the Interior Bureau of Land Management Alaska OCS Office Anchorage, Alaska



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TISSUE STRUCTURAL STUDIES AND OTHER INVESTIGATIONS ON THE BIOLOGY OF ENDANGERED WHALES IN THE BEAUFORT SEA

Volume II

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STRUCTURAL STUDIES OF THE STOMACH AND SMALL INTESTINE OF THE BOWHEAD WHALE BALAENA MYSTICETUS

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INTRODUCTION

The literature which has accumulated on the alimentary system of cetaceans is spread over several centuries. It is sometimes contradictory, depending on the interpretation of a particular investigator, and, due to the large number of cetacean species and the variations inherent in each, has defied all but the roughest generalizations. Information on the digestive anatomy of the bowhead whale has been particularly scarce due largely to its limited availability for study.

Among the first to give a detailed account of cetacean gastrointestinal anatomy was Tyson (1680) with his dissections of the porpoise (Phocoena). He noted the compartmentalized arrangement of the stomach, a fact repeatedly confirmed for cetaceans, both odontocetes and mysticetes, by other investigators in the centuries which followed. However, opinions often varied on the number of chambers and their respective functions.

In 1874, Murie published a report on the caàing whale (Globiocephalus melas) in which he described four stomach compartments. Weber (1885) examined the stomach of the white-beaked dolphin (Lagenorynchus albirostris) and also counted four chambers in the stomach proper and an initial dilatation of the small intestine called the duodenal ampulla. In 1889 Turner presented information on the stomach of seven species of odontocetes. He found the number of chambers to vary with species but reported the absence of a forestomach (generally the first compartment in cetaceans) in two species of beaked whales studied.

A very thorough account of the cetacean stomach was presented in 1898 by Jungklaus. Included in his report are descriptions of four odontocetes and one mysticete, the blue whale (Balaenoptera musculus). Both adult and embryonic materials were examined. For the odontocetes he counted four to five stomach chambers depending on species. In the blue whale he described four chambers apart from the duodenal ampulla.

Berzin (1972), reporting on his examination of four sperm whales, found three compartments for the stomach itself and a duodenal ampulla initiating the small intestine. Writing on the smaller odontocetes, Harrison et al (1970 & 1977) gave an account of their gross, microscopic and ultramicroscopic findings for the digestive tract in Tursiops, Delphinus and Stenella. They reported four stomach compartments and a duodenal ampulla in these genera as did Smith (1972) in his gross and microscopic study of the gastrointestinal tract of the harbor porpoise (Phocoena phocoena). However, in their investigation of the La Plata dolphin (Pontoporia blainvillei) Yamasaki et al (1974 & 1975) noted the absence, as in beaked whales, of the first gastric chamber (forestomach).

In 1971 Hosokawa and Kamiya reported on one species of odontocete (sperm whale) and three species of mysticetes (sei, fin and blue whales). For the mysticetes they described four stomach compartments. However, their fourth chamber is the duodenal ampulla - a structure included with the small intestine in most studies. Therefore this is somewhat in disagreement with the interpretation of Jungklaus (1898).

Slijper (1962) described three chambers for the cetacean stomach (except for the beaked whales for which he reported the absence of the forestomach). He briefly considered the structure of the intestine and discussed function along the gastrointestinal tract, giving comparative information for other mammalian species.

In 1972 Green briefly described the gross anatomy of the digestive system for both odontocetes and mysticetes. He assigned three chambers to the stomach and mentioned that the duodenal ampulla is often mistaken for a stomach compartment, while in reality it serves as a beginning for the small intestine. Reporting on microscopic anatomy, Simpson and Gardner (1972) also spoke of three stomach chambers. Importantly, they noted the frequent occurrence of lymphoid elements along the gastrointestinal tract.

In 1979 Kenney and Everitt and Fetter and Everitt presented a preliminary description of various tissues collected from harvested bowhead whales.

Specimens from the alimentary tract were among the tissues examined both grossly and histologically. These authors noted that the bowhead stomach is compartmentalized and mentioned the abundance of lymphoid structures in the mucosa of the esophagus and gastrointestinal tract.

OBJECTIVES

1. Determine the gross, microscopic and ultramicroscopic structure of the stomach and proximal small intestine for Balaena mysticetus.
2. Compare these findings to the analogous structures in other cetaceans.
3. Compare these findings to the analogous structures in other selected mammals.
4. Interpret the function of the stomach and proximal small intestine for Balaena mysticetus as determined by the anatomic findings.

MATERIALS AND METHODS

Specimens used in this study represented bowhead whales harvested during the spring hunts of 1979 and 1980. Materials for gross examination were supplied by RU 180 and came from five whales (80B1, 80B2, 80B7, 80B8 & 80B9). Tissues for histologic analysis were examined in seven individuals. Five of these were collected by RU 180 in 1980 (80B1, 80B2, 80B7, 80B8 & 80B9). The other two came from whales harvested in the spring of 1979 (79B1 & 79B2). See the report of RU 180 for further details on the tissues collected. Collected samples were fixed in the field in 10% buffered formalin.

In the laboratory, small blocks of tissue were cut from the collected samples. After additional fixation in either 10% buffered neutral formalin or Bouin's solution, the tissues were dehydrated through a graded series of ethanol, cleared in xylene and embedded in paraffin. Sections were cut on a rotary microtome at approximately 6 μm, mounted on glass slides and exposed to a variety of stains. Structural stains included hematoxylin and eosin (H&E), Verhoeff-van Giesson, Masson's trichrome and thionine. For the histochemical demonstration of mucopolysaccharides, Alcian blue was counterstained with periodic acid-Schiff (AB/PAS). These sections were coverslipped with Permount, examined under a light microscope, analyzed and photographed.

Additional tissues supplied by RU 180 (esophagus, colon, anal canal, pancreas and liver) were also examined, analyzed and reported in this investigation. Ultrastructural studies were not possible due to the difficulties of achieving adequate tissue fixation under field conditions.

RESULTS

ESOPHAGUS - Gross observations

Grossly, the esophagus is a thick walled, muscular tube (Fig 14-1). The outside and inside diameters vary with the individual whale (Table 14-1). Depending on location along the length of the esophagus, glandular and/or nodular areas can be seen in the mucosa and submucosa (Fig 14-1) which on histologic section are found to represent either mucoserous glands or lymphoid nodules. The latter are more plentiful, and both communicate with the mucosal surface by way of crypts. Generally, neither glands nor nodules encircle the lumen completely (Fig 14-1). Areas of mucosal surface harboring tonsil-like lymphoid nodules beneath it are distinguished by pores representing the openings of the nodular crypts. Between these nodular regions the mucosa is smooth and unpitted (Fig 14-2).

ESOPHAGUS - Histologic observations

The esophagus is lined by a stratified squamous epithelium which receives deep invaginations (up to 80% of epithelial thickness) from the lamina propria beneath it (Fig 14-3). Three layers are discernible in the epithelial coat. The deepest is the basal cell layer, stratum basale, consisting of a single layer of cuboidal to columnar cells (Fig 14-3). This layer has a more basophilic appearance than the more superficial strata (due to crowding of the cells and smaller, denser nuclei). The middle layer, stratum spinosum, is thickest (Fig 14-3). Nuclei are larger than in the basal cells and, while still basophilic, are more lightly staining. The number of nuclei per unit area appears to decrease in the more superficial portions of this layer. The cells themselves flatten progressively as the esophageal lumen is approached (Fig 14-4). The outermost layer, stratum corneum, is rather shallow and distinguishable by a sudden eosinophilia. Additionally, the nuclei suddenly become smaller, denser and begin to flatten. And, in the most superficial portion of the layer, the nuclei may either be absent or exist only as faint remnants (Fig 14-4).

The lamina propria consists primarily of collagenous connective tissue (Figs 14-3 & 14-5). In some specimens mucoserous glands are recognized here both structurally and histochemically. The mucous portion consists of cells with a pale staining cytoplasm and a nucleus flattened against the base of the cell. In the serous glands the cytoplasm is acidophilic and contains a rounded, centrally placed nucleus (Figs 14-5, 14-6 & 14-7). Most serous cells are arranged as demilunes to the relatively more abundant mucous glands. With AB/PAS the cytoplasm of the mucous cells assumes a purple to pink coloration

(a positive reaction for mucus) (Fig 14-8). Lymphoid elements are common and take two forms. Diffuse lymphocytes are frequently scattered beneath the basal layer of the epidermis (Fig 14-9). Secondly, in some sections, lymphocytes may occur as dense accumulations or nodules (Figs 14-10, 14-11, 14-12 & 14-13). The esophageal epithelium may thin over these nodules (Fig 14-14). Crypts leading into the nodules are lined by a stratified layer of cells which is covered most superficially by an extremely squamous single cell layer.

The actual location along the esophagus from which samples were taken was known for two of the four bowheads examined (79B1 and 80B1). The 79B1 specimen was approximately 11 cm long and began just caudal to the oropharnyx. That of 80B1 began at about the level of the tracheal bifurcation and was approximately 30 cm in length. Mucoserous glands and lymphoid nodules are not found in every section examined. Glands of the mucoserous type are seen only in the cranial portion of the specimen from whale 79B1; that is, just caudal to the oropharynx. Lymphoid nodules are also present in this initial segment of esophagus from 79B1 and continue throughout it. In the specimen from whale 80B1 which began approximately at the tracheal bifurcation, there are no mucoserous glands. Sections for processing and examination were taken at the level of the tracheal bifurcation and at points 9 cm and 16 cm distal to the tracheal bifurcation). Lymphoid nodules were present in the initial portion and are well developed; in the 9 cm section they are less so; and in the 16 cm section there are none. However, diffuse lymphocyte populations are found beneath the epithelium caudal to this point. A possible interpretation is that 1) mucoserous glands occupy only that portion of the esophagus just caudal to the oropharynx and 2) lymphoid nodules are most plentiful cranially, but continue further caudally than the mucoserous glands.

In the two other whales examined, the section from 80B2 had well developed lymphoid nodules and some mucoserous glands (Fig 14-11) while the 79B2 specimen contained neither. Additional samples of known position will be necessary to more precisely define the distribution of these components along the esophageal wall.

Other elements identified in the lamina propria include plasma cells, occasional eosinophils and blood vascular components. Although a few bundles of smooth muscle can be seen oriented parallel to the long axis of the esophagus, the muscularis mucosae is not very well developed (at least at the level of the

tracheal bifurcation where it was primarily examined).

The muscularis externa tends to form three layers of skeletal muscle with inner longitudinal, middle circular and outer longitudinal layers. The submucosa contains considerable amounts of adipose tissue along with collagenous connective tissue.

STOMACH AND PROXIMAL SMALL INTESTINE - Gross observations

The stomach (Fig 14-15) is compartmentalized and consists of non-glandular and glandular portions. The nonglandular compartment corresponds to the forestomach and the glandular region is further divisible into three parts termed the fundic chamber, connecting channel and pyloric chamber. The pyloric sphincter marks the exit from the pyloric chamber and leads into a dilated sac (duodenal ampulla) which represents the initial part of the small intestine. Emerging from this dilatation is the duodenum proper which has a smaller, consistent diameter. The hepatopancreatic duct meets with and runs within the wall of the duodenum proper shortly after the termination of the duodenal ampulla. In whale 80B7 this duct empties into the lumen of the duodenum proper 33 cm distal to the duodenal ampulla.

In the fixed state the forestomach is a thick sac-like structure with considerable submucosal fat deposition. It is the largest of the stomach compartments and is lined by a creamy white mucosa similar to that found in the esophagus; however, there are no pores in the mucosa and there is a great deal of infolding of the lining in all directions (Fig 14-16).

The fundic chamber is a smaller, thinner walled compartment whose reddish mucosa is in sudden and marked contrast to the forestomach lining preceding it. Its lining is thrown into folds which are somewhat larger than those of the forestomach and tend to be directed longitudinally (Fig 14-17).

In one whale, 80B7, the connecting channel could be adequately examined. It begins as a small orifice (about 2.5 cm) in the midregion of the fundic chamber and continues as a tubular structure of small diameter (2.5-3 cm in the fixed state) in the fundic wall (Fig 14-18). Then, leaving the fundic chamber behind, it soon empties into the final, or pyloric, stomach chamber. The mucosa of the connecting channel is of the reddish glandular type. In 80B7 the connecting channel is 20 cm in length.

The pyloric chamber is also tubular but has a larger diameter (6.4 cm in

80B2) than the connecting channel. It is rather thin walled and, like the two chambers preceding it, has a reddish mucosal lining distinguished by longitudinal folds (Fig 14-19). The sphincter at the exit of this chamber appears as a 3 cm slit in the fixed state in 80B2.

The duodenal ampulla is a dilated sac similar in size to the fundic chamber of the stomach. The mucosal lining is dark and characterized by numerous longitudinal folds (Fig 14-20).

There is no sphincter separating the ampulla from the duodenum proper. Well developed transverse folds characterized the bile stained mucosa in this portion of the intestine. The hepatopancreatic duct was partially intact in specimen 80B7. It enters the duodenal wall shortly after the termination of the ampulla, finally emptying into the duodenal lumen some 33 cm distally (Fig 14-21).

FORESTOMACH - Histologic observations

Like the esophagus the forestomach is lined by stratified squamous epithelium and projects deeply into the lamina propria below it (Fig 14-22). The cellular arrangement agrees with the esophagus in that 3 layers are discernible. The basal cell layer is still more basophilic due to cell crowding and nuclear densities. The middle cell layer still comprises the bulk of the epithelial lining with its cells flattening as the forestomach lumen is approached. The superficial layer takes on the same eosinophilia with the nuclei suddenly becoming denser and flattened. However, a relatively greater portion of the overall epithelial thickness (about 1/4 of the total depth) is devoted to the superficial layer. The outer half of this layer is for the most part devoid of nuclei (Fig 14-23).

The lamina propria consists primarily of collagenous connective tissue and contains no lymphatic nodules or glandular elements in the sections examined. However, diffuse lymphocytes are numerous, congregating especially in that portion on the lamina propria closest to the epithelial base. Plasma cells are seen, as are occasional eosinophils. Vascular elements are also present.

The muscularis mucosae consists of a scattered array of smooth muscle bundles of varying diameters, appearing in cross section as well as in longitudinal and oblique sections. In the most superficial portions of the muscularis mucosae, the bundles are surrounded by considerable collagenous connective tissue. However, deep to this, adipose tissue predominantly surrounds the bundles. Below the muscularis mucosae, the submucosa consists primarily of

adipose tissue.

JUNCTION OF FORESTOMACH AND FUNDIC CHAMBER - Histologic observations

The stratified squamous epithelium of the forestomach yields abruptly to a glandular mucosa in the fundic chamber (Fig 14-24). The lining of the forestomach in this junctional region is structurally similar to that previously described for the forestomach in general. The most superficial stratum of the epithelium retains an eosinophilia with its nuclei becoming suddenly dense with a tendency to flatten. In one specimen (80B1) this superficial layer contains numerous basophilic granules which accumulate horizontally in the flattened cells of this region and become more plentiful as the junction of the forestomach and fundic chamber is approached (Figs 14-25 & 14-26). These granules, except for a very few in the junctional area, are not seen in 80B8.

In the fundic chamber the mucosal surface extends into a multitude of gastric pits (foveolae) (Fig 14-27). However, postmortem autolysis has caused considerable erosion of this area resulting in an absence of the cells lining the surface and preventing definite measurement of the depth of the pits. Lining the pits is a single layer of columnar cells (Fig 14-28). Structurally, these cells are typically mucous with a pale cytoplasm and somewhat flattened nucleus abutted against the base of the cell. With the AB/PAS technique, the cytoplasm assumes a magenta and very granular appearance (Fig 14-29). The gastric pits lead into the glands themselves. The depth of the glandular portion is approximately four times that of the pits (Fig 14-27). The cells embodied by the glands are also morphologically of the mucous type (Fig. 14-30). With AB/PAS, cytoplasm coloration for most of the glandular cells is pink except in its most superficial portion (neck) where blue tends to predominate (Fig 14-29). In one specimen (80B8) a transition is seen in the glandular area where the cells of the glands begin to repopulate with nonmucous cell types as the junctional area is left behind. The result is that the mucous cells comprise a more narrow zone in whale 80B8 (approximately 2.1 mm wide). They are quickly replaced by rather large eosinophilic cells and somewhat smaller basophilic ones which are negative histochemically with AB/PAS and which are structurally typical of parietal and chief cells, respectively.

The lamina propria consists of collagenous connective tissue whose vascularity appears to exceed that of the foregoing nonglandular region. Both diffuse and nodular lymphoid elements can be identified. While lymphocytes are

somewhat scattered beneath the forestomach epithelium, nodular as well as diffuse accumulations are seen in the fundic chamber, taking their positions among the glands themselves. Plasma cells are extremely plentiful in the lamina propria between the glands (Figs 14-31 & 14-32). Eosinophils are occasionally seen.

The muscularis mucosae consists of a notable scattered array of smooth muscle bundles running in every direction but occurring primarily in cross section (and therefore representing a circular band in relation to the long axis of the stomach). In the upper portions, the bundles are dispersed in a field of collagenous connective tissue which is, however, rapidly replaced by adipose cells as the submucosa is approached (Fig 14-33).

FUNDIC CHAMBER - Histologic observations

The mucosa of the fundic chamber is entirely glandular (Fig 14-34). Gastric pits, lined by columnar mucous cells, precede entrance into the glands (Figs 14-35 & 14-36). Structurally the cells lining the pits are mucous with pale staining cytoplasm and nuclei positioned toward the bases of the cells (Figs 14-34 & 14-37). These cells stain positive with AB/PAS (Figs 14-38 & 14-39). In most sections the pits are each seen leading into one gland. However, in some preparations two glands could be seen to communicate with a single pit (Fig 14-37). And, since examination is only in two dimensions, it is possible that a gastric pit could lead into more than two glands. The glands are simple branched tubular structures (Fig 14-40) which are straight for most of their length but coiled distally. The glandular region is approximately 1.5 mm deep (about 5 times the depth of the associated gastric pits). In the proximal portion of the gland (neck region) the cells structurally (H&E) and histochemically (AB/PAS) appear to be primarily mucous (Figs 14-37 & 14-38). However, two color reactions for mucus (positive AB/PAS) are apparent. At the mouth of the gland a dark blue cytoplasm predominates while slightly deeper in the gland the reaction becomes pink rather abruptly (Fig 14-39). A few parietal cells can be identified in the neck region with their acidophilic cytoplasm. Parietal and chief cells comprise the remainder, and bulk, of the gland (Fig 14-41). The parietal cell has a diameter of about 15 μm. It is positioned away from the lumen of the gland and has an acidophilic cytoplasm with a round, basophilic nucleus centered within it. With a diameter of approximately 10 μm, the chief cells are noticeably smaller than the parietal cells. This cell is situated next to the lumen of the gland, has a basophilic cytoplasm and a round, more

darkly basophilic nucleus positioned toward the basal lamina side of the cell. It appears subjectively that the chief cells become relatively more numerous than the parietal cells in the deeper portions of the glands.

The lamina propria consists of collagenous connective tissue containing a well developed vascularity. Lymphocytes are common, distributed both diffusely and in small aggregations in the lamina propria between and beneath the glands. Plasma cells are frequent and occasional eosinophils are seen; however, plasma cells do not appear to be so abundant here as in the cardiac region of the chamber. The muscularis mucosae consists of scattered bundles of smooth muscle.

CONNECTING CHANNEL, PYLORIC CHAMBER and DUODENAL AMPULLA

No tissues were available for histologic study.

SMALL INTESTINE - Histologic observations

The section examined was taken approximately 10 cm from the junction of the small intestine with the colon. Considerable erosion has occurred over most of the lumenal surface of this specimen. However, in one area, villi can be distinguished (Figs 14-42 & 14-43). Comprising the epithelium of the villi are numerous absorptive and goblet cells. The absorptive cell is columnar with an acidophilic cytoplasm. The round to oval basophilic nucleus tends to be positioned toward the base of the cell (Figs 14-44 & 14-45). Microvilli, with a depth of approximately 1-2 μm, extend from the surface of absorptive cells to form a well defined striated border. The goblet cells found between the absorptive cells are also elongated but, because they are filled with a secretory product, are expanded laterally and crowd the absorptive cells on either side. The nucleus is compressed at the base of the cell (Figs 14-41, 14-44 & 14-45). The bases of the villi lead into the intestinal glands (crypts of Lieberkühn). Mucous cells, swelled considerably with their secretory product, predominate in the glands (Figs 14-43 & 14-46). With AB/PAS the cytoplasm of the goblet cells in the villi stains dark purple while in the mucous cells of the glands below, the color ranges from purple to pink (positive reactions for mucus).

The lamina propria is composed of collagenous connective tissue. Lymphocytes are very common, occurring both diffusely and as nodules. Where found, the nodules extend through the depth of the glands and somewhat beneath them (Fig 14-42), as does the collagenous connective tissue. Plasma cells are

occasionally seen but are not so common here as in the stomach. Eosinophils, on the other hand, are relatively more numerous than in the stomach.

Although a few smooth muscle bundles are visible, a well defined muscularis mucosae band is not formed. Instead, the lamina propria itself is transformed into a submucosa which, rather than consisting largely of adipose cells as in the stomach, is composed of more loosely arranged collagenous connective tissue. The lamina propria/submucosa layer is very thin (about 2 mm).

SMALL INTESTINE AND COLON JUNCTION - Gross observations

The junction of the small intestine and colon was examined grossly in one whale (80B7). The rather small diameter (about 5 cm) of the small intestine contrasts sharply with the sudden dilation of the colon (about 22 cm) (Figs 1-36 & 14-47). There is no evidence of a cecum. The mucosal lining of the small intestine is lightly colored and is thrown into several longitudinal folds. However, at one point (about 15 cm preceding the colon dilation) there are several transverse folds situated between the longitudinal folds on either side. Pores can be seen in the lining of the small intestine and nodular accumulations are visible beneath the epithelial lining in cross section. The mucosal surface of the colon is darker and the pores are more obvious. Well developed transverse folds are interposed upon lesser longitudinal folds.

COLON - Histologic observations

For this report the term colon is synonymous with the large intestine. No attempt is made to distinguish the regions of the colon or rectum. The mucosal lining of the colon is characterized by long, straight, tubular glands which are dominated by columnar mucous cells (Figs 14-48 & 14-49). Structurally these cells have a globular appearance with the nucleus pushed to the basal side (Fig 14-50). Histochemically they stain positive (magenta, blue and pink) with AB/PAS. Unlike the glands in the gastric area, these glands do not coil at the base. In the sections examined, the glands average about 1.5 mm in depth.

The lamina propria between the glands contains extremely high numbers of lymphocytes and plasma cells. Lymph nodules are very prominent in this region, extending beneath the glands and pushing up between them (Fig 14-51). Two lymphocytic densities are apparent in these nodules. In the main body of the nodule a circular portion is created in cross section in which the lymphocytes are not as dense as in a second region which sits cap-like on the

nodule toward the intestinal lumen. Near the junction of the colon with the anal canal a mucous gland can be identified in the lamina propria (Fig 14-52). A few nerve bundles are present.

Very slight bundles of smooth muscle represent the muscularis mucosae in this region.

Although somewhat more loosely arranged the submucosa consists of collagenous connective tissue similar to the lamina propria. Vascular and nerve elements are seen, including Meissner's plexus. No adipose tissue is recognized.

Only a portion of the muscularis externa is present for examination. This portion consists of smooth muscle.

COLON AND ANAL CANAL JUNCTION - Gross observations

This area was examined in 80B9. The mucosal surface of the colon has a light brownish, glandular appearance, broken by rather subtle, but numerous pores. The lining abruptly changes to a white, nonglandular type upon reaching the anal canal. The anal mucosa is very obviously characterized by numerous pits (shown in histologic section to lead, as they do in the colon, into lymph nodules).

ANAL CANAL - Histologic observations

The anal mucosa is lined by stratified squamous epithelium which receives rather deep invaginations from the lamina propria below it (Fig 14-53). An acidophilic layer is seen with H&E in the most superficial portion of this lining. The nuclei in this band also change, becoming smaller and denser than those of the deeper epithelial cells. No true cornification of the lining can be demonstrated since nuclei are present all the way to the mucosal surface.

The lamina propria consists of collagenous connective tissue in which lymphoid elements are very abundant, both in nodular and diffuse forms (Figs 14-54 & 14-55). Lymphocytes tend to be most densely arranged around the perimeter of the nodules and in that portion oriented toward the anal lumen. In one section (80B1) a mucous gland can be identified (positive with AB/PAS), closely guarded on either side by dense lymphocytic accumulations. There appear to be no serous cells associated with it. A few nerve bundles can be identified.

The muscularis mucosae is formed by much larger bundles of smooth muscle than those seen in the sections of colon examined. In contrast to the predominance of collagenous connective tissue between those bundles in the colon,

adipose cells are very abundant here.

In the submucosa there is considerable vascularity. Collagenous connective tissue and adipose tissue are both common. For one specimen in particular (80B1) both arteries and veins are rather large. The veins in this section are additionally distinguished by extremely dense accumulations of eosinophils in the connective tissue around them (Figs 14-56, 14-57, 14-58 & 14-59). Although eosinophils are generally plentiful throughout the submucosa, their numbers around these veins are much greater, extending right up to the endothelial lining.

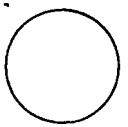
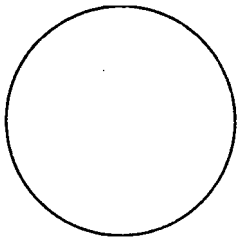
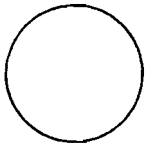
In one whale (80B9) three areas of surface erosion could be seen grossly in the initial portion of the anal canal. Two of these measured approximately 1 cm in diameter; the third was smaller with a diameter of about 2 mm. One of the large erosions was removed as a block of tissue and serially sectioned.

Epithelium in the eroded area is entirely missing (Fig 14-60). The area is heavily infiltrated with cellular elements beginning at the eroded surface and extending into the submucosa. The approximate depth of this reactive core is 6.3 mm. By far the bulk of the cells are lymphocytes (Figs 14-61 & 14-62). However, progressing deeper into the reactive cellular mass, increasing numbers of plasma cells and eosinophils can be found (Fig 14-63). Capillaries are plentiful in the mass. Areas of fibrotic invasion are evident as extensions of the surrounding lamina propria and submucosa (Fig 14-64). With these components, the lesion is defined as a chronic ulcer.

PANCREAS - Histologic observations

As in other mammals the basic unit of the bowhead pancreas is a secretory acinus, composed of a single layer of cuboidal cells (Figs 14-65 & 14-66). The round, basophilic nucleus tends to be displaced toward the basal side of the cell. With H&E pink staining granules can be identified in the apex of the cell next to the acinar lumen. These granules also give a pink reaction with the AB/PAS technique. Centroacinar cells are seen in association with many of the acini, contributing to an intercalated duct which drains the acinus into the intralobular ducts that are also recognized in the sections examined (Figs 14-66 & 14-67). Collagenous connective tissue septae divide the substance of the pancreas into lobules. Found within these septae are interlobular ducts with their cuboidal to columnar lining as well as vascular elements and nerve

TABLE 14-1 ESOPHAGEAL COMPARISONS (cm) FOR BOWHEAD WHALES 79B1, 80B1 & 80B2

Whale	Outside Esophageal Dimensions	Circumference	Inside Esophageal Diameter*	Relative Proportions of Inside Diameters
79B1	6 X 7	9.5	3	
80B1	6.5 X 10	19	6	
80B2	4.5 X 7	11	3.5	

*Calculated from formula $C = 2\pi r$ where C = circumference, $\pi = 3.14$ and r = radius

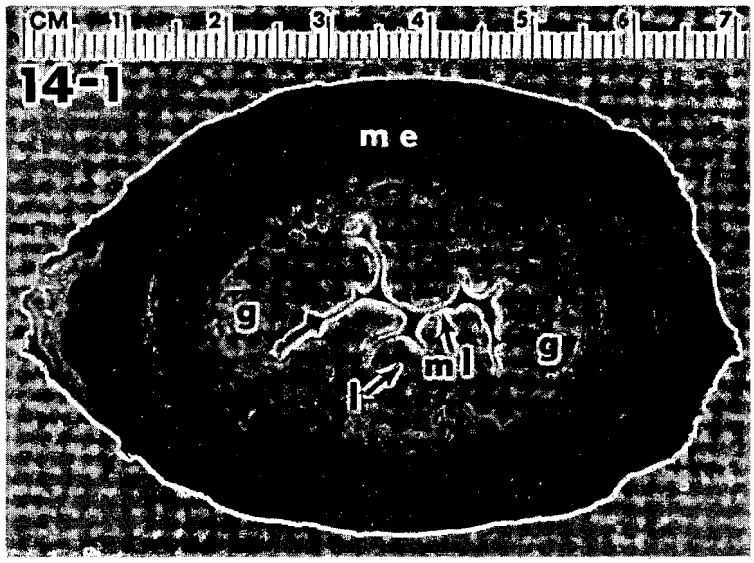


Figure 14-1 Cross section of esophagus from 80B2. Note white mucosal lining (ml), areas of lymphoid nodules (l), mucoserous glands (g) and thick muscularis externa (me).

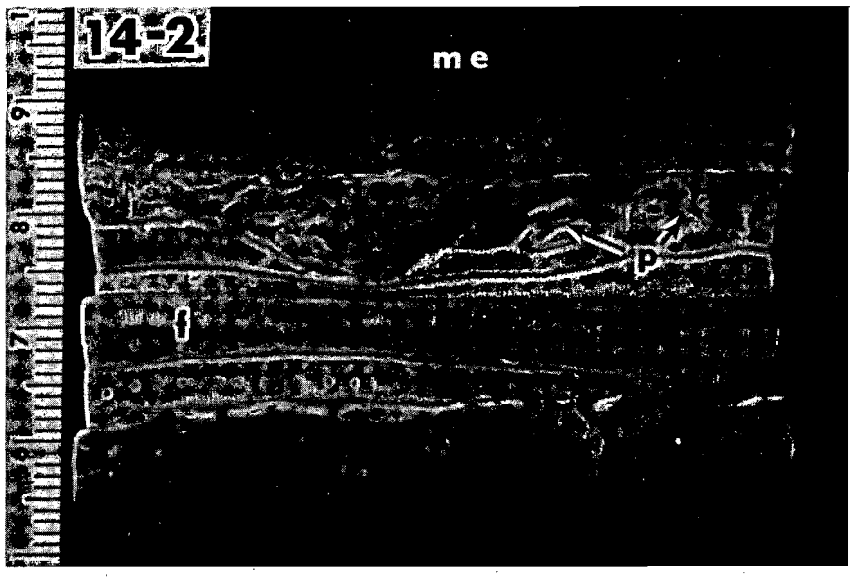


Figure 14-2 Longitudinal section of esophagus from 80B2. Note pores (p) on mucosal surface leading to lymphoid nodules. Also note absence of pores on some areas of the surface. Longitudinal folds (f) and thick muscularis externa (me) are indicated. Scale is in centimeters.

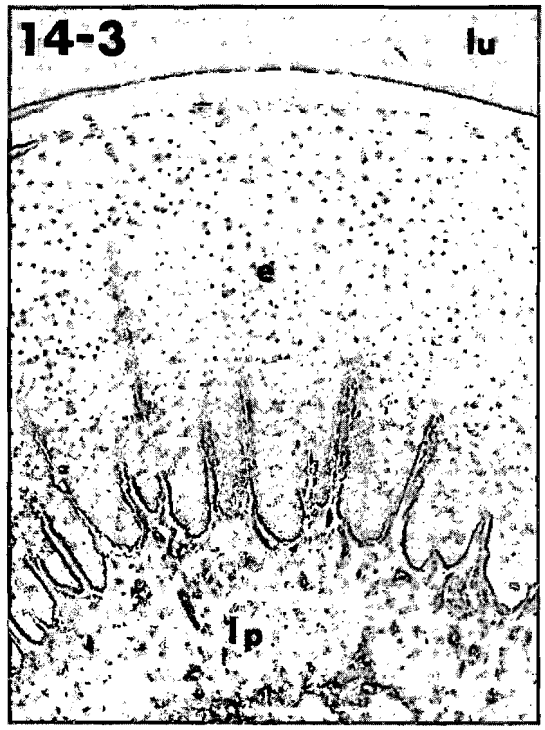


Figure 14-3 Cross section of a longitudinal fold of esophageal mucosa from 79B2. Esophageal lumen (lu), epithelial lining (e) and lamina propria (lp) are seen. H&E. 6.3X. *

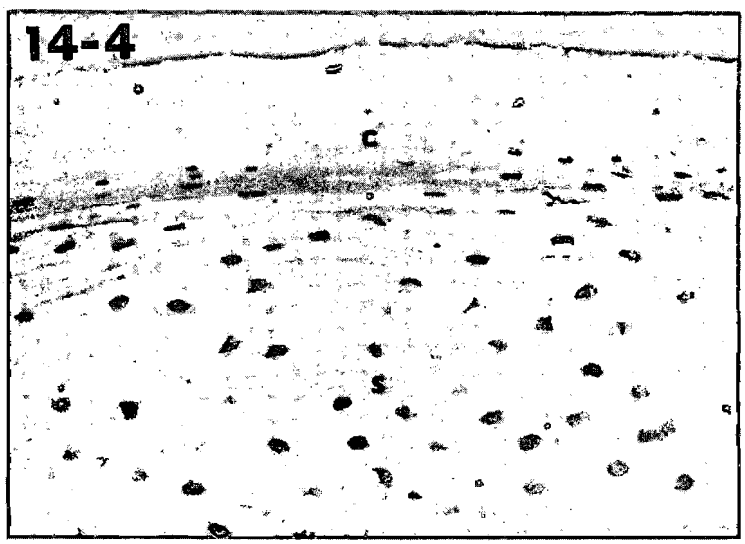


Figure 14-4 Higher magnification of esophageal lining shown in Fig 14-3. Note flattening of cells in the stratum spinosum (s) and the stratum corneum (c) where the nuclei become condensed and flattened or exist only as remnants. H&E. 25X.

*Magnifications given in the figures of RU 1480 are those of microscope objective.

Figure 14-5 Note crypt (c) leading from esophageal lumen into glandular area (g) in 79B1. H&E. 2.5X.

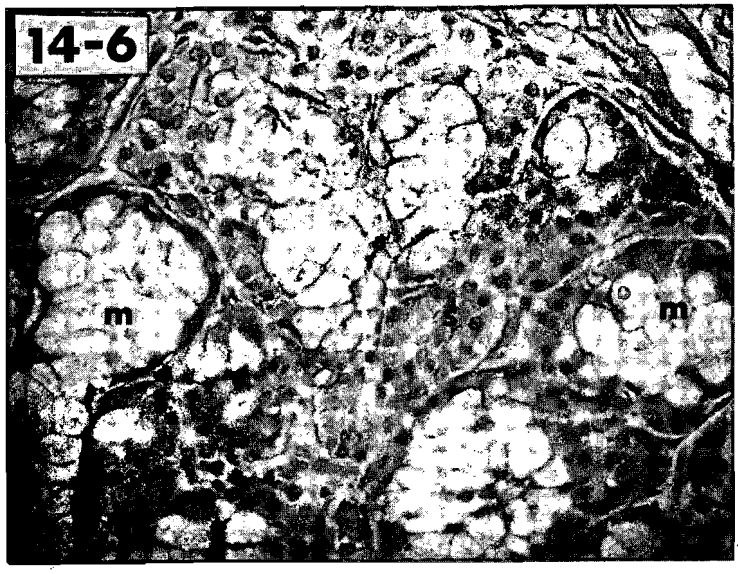


Figure 14-6 A higher magnification of glandular area shown in Fig 14-5 demonstrates both mucous (m) and serous (s) elements. H&E. 25X.

Figure 14-7 Mucoserous glands (g) found in area of esophagus just caudal to oropharynx in 79B1. Note associated duct (d) whose lumen contains mucoserous product. H&E. 6.3X.

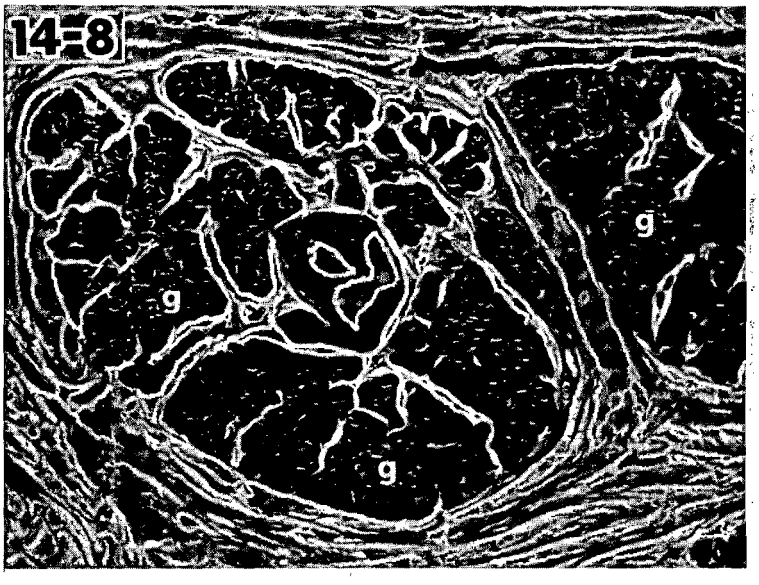


Figure 14-8 Positive reaction for mucus in glandular area (g) of esophagus caudal to oropharynx in 79B1. AB/PAS. 2.5X.

Figure 14-9 Diffuse arrangement of lymphocytes (l) beneath esophageal epithelium (e) in 80B1. H&E. 6.3X.

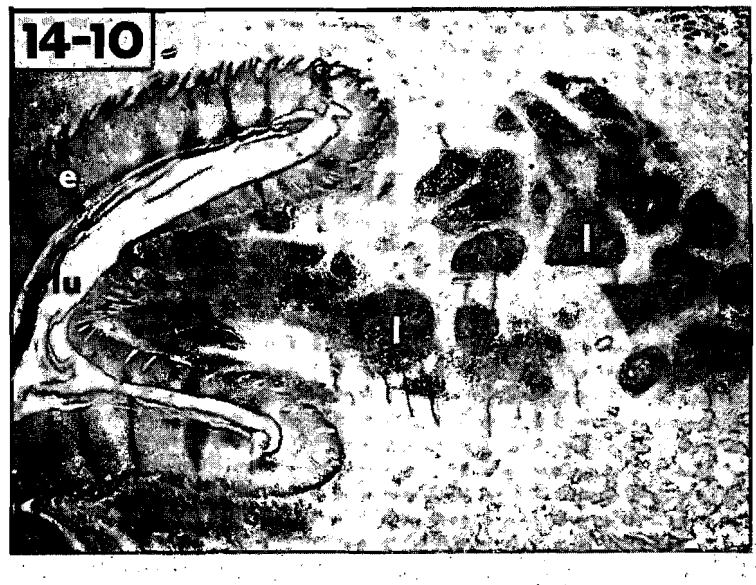


Figure 14-10 Nodular accumulation of lymphocytes (l) beneath esophageal epithelium (e) in 80B1. Esophageal lumen designated (lu). H&E. 1X.

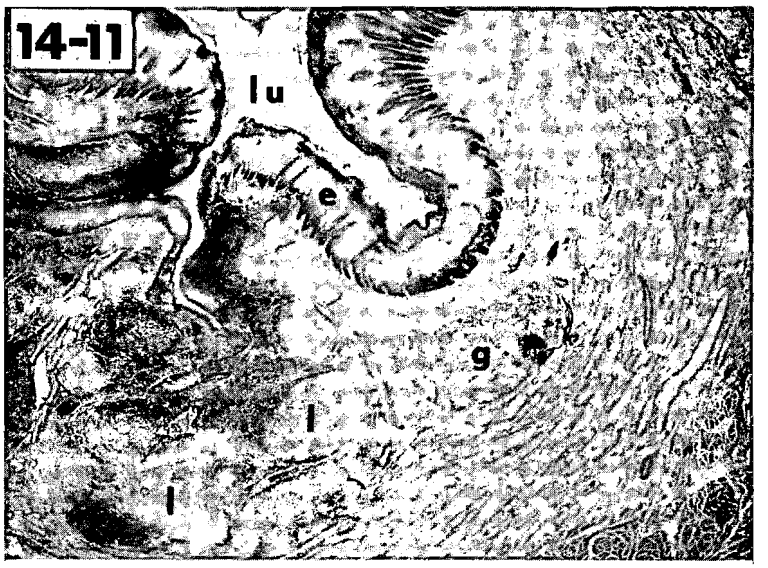


Figure 14-11 Lymphoid nodules (l) and mucoserous gland (g) seen beneath esophageal epithelium (e) in 80B2. Lumen indicated (lu). H&E. 1X.

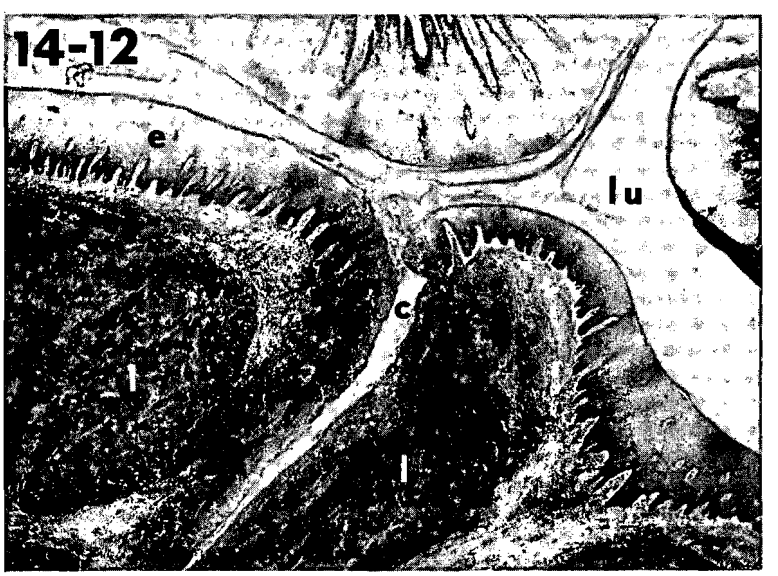


Figure 14-12 Lymphoid nodules (l) beneath esophageal epithelium (e) in 80B1. Note crypt (c) leading from lumen (lu) into nodule. H&E. 2.5X.

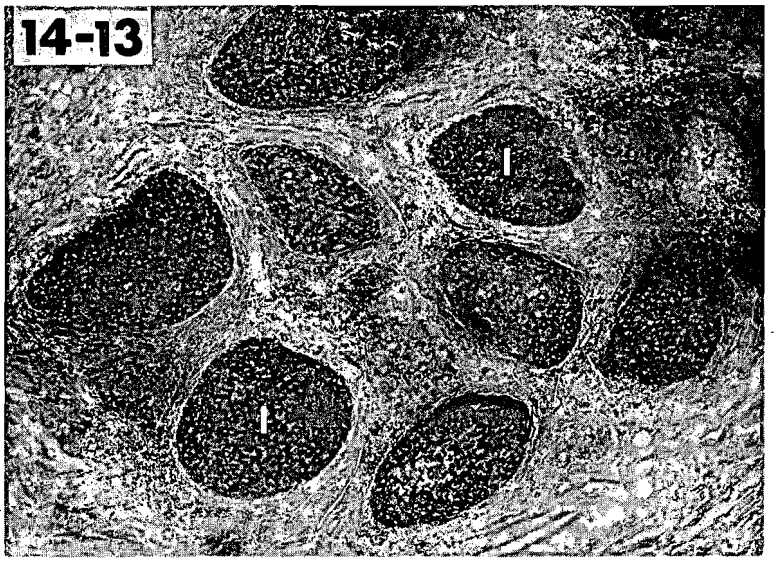


Figure 14-13 Lymphoid nodules (l) beneath esophageal epithelium in 80B1. H&E. 2.5X.

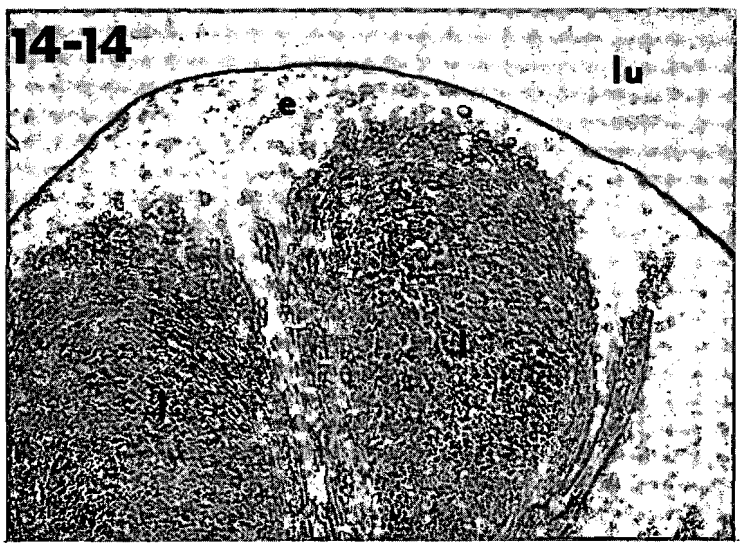
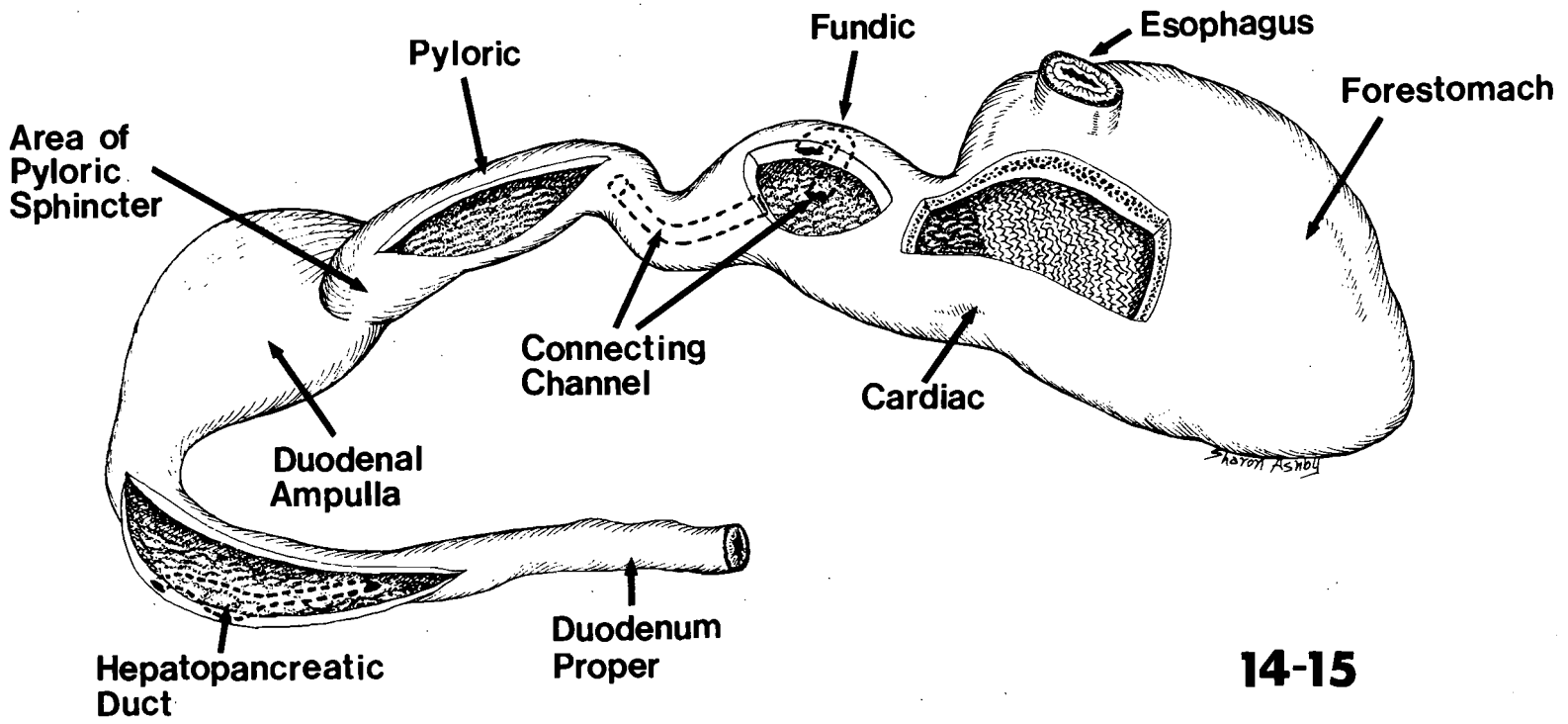


Figure 14-14 Lymphoid nodules (l) with thinning of overlying esophageal epithelium (e) in 79B1. Esophageal lumen indicated (lu). H&E. 6.3X.

Figure 14-15 Illustration of the bowhead stomach and proximal small intestine. The forestomach, the first chamber, is nonglandular. Like the esophagus, lined by a stratified squamous epithelium. The second compartment, the fundic chamber, is entirely glandular. Histologically, a cardiac region consisting of mucous glands can be demonstrated in the initial part of this chamber. The remainder of the lining houses the primary glands of enzymatic digestion (composed of parietal and chief cells). Leading from the fundic chamber is a tubular structure of small diameter known as the connecting channel. This channel leads into a tubular structure of larger diameter which is the fourth stomach division, the pyloric chamber. The pyloric sphincter serves as the entrance into the duodenal ampulla, an initial dilatation of the small intestine. This leads into the duodenum proper with a much narrower and consistent diameter. The hepatopancreatic duct enters the wall of the duodenum shortly after the termination of the ampulla. It runs in the wall for some distance before finally entering the lumen of the duodenum.


Pyloric
Fundic
Esophagus
Forestomach
Area of Pyloric Sphincter
Connecting Channel
Cardiac
Duodenal Ampulla
Duodenum Proper
Hepatopancreatic Duct

14-15

Figure 14-16 Mucosal lining and wall of forestomach in 80B7. Part of the wall has been cut away to expose the creamy white lining distinguished by numerous ridges (arrows). A tongue depressor has been used to prop the forestomach open. Considerable fat deposition (f) can be seen in submucosa of forestomach wall. A portion of fundic chamber (fd) is seen in upper right of photo.

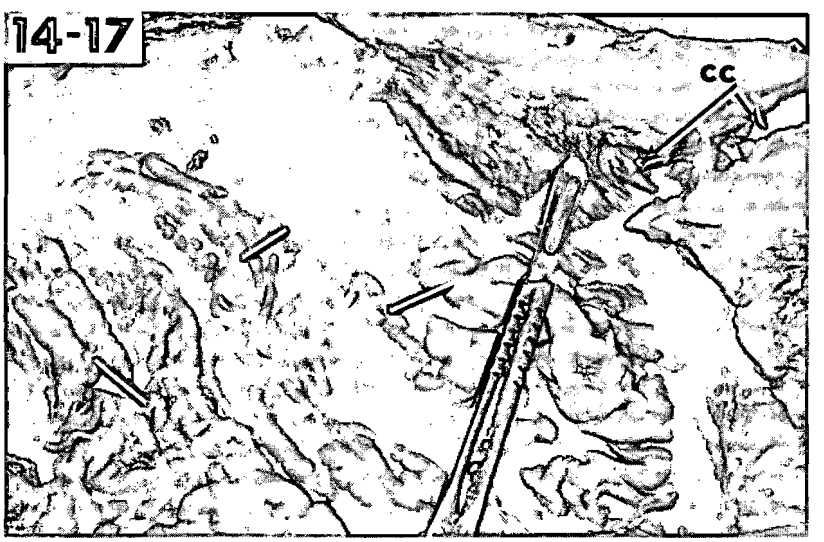


Figure 14-17 Extensive folds (arrowheads) characterize the mucosal lining of the fundic chamber in 80B7. In the wall of this compartment, the connecting channel can be seen on its way to the pyloric chamber. The channel has been opened longitudinally in this photo to expose the lumen (cc).

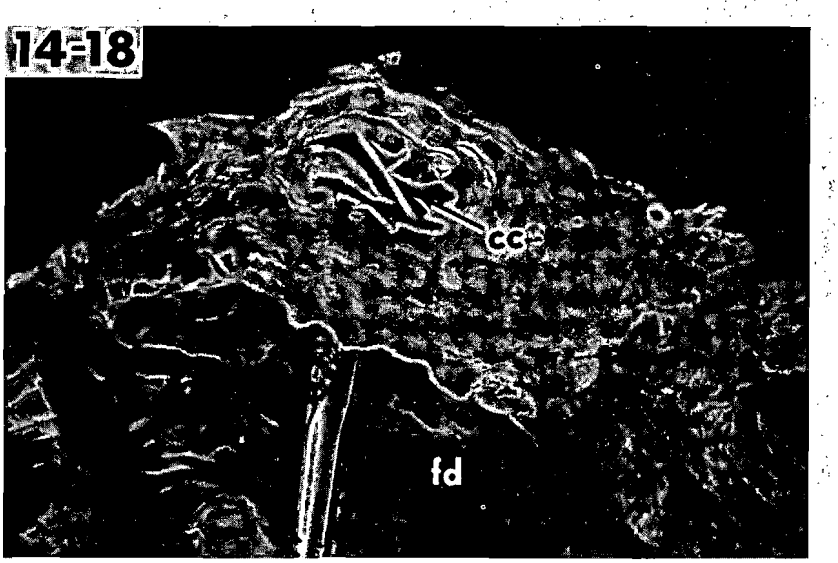


Figure 14-18 Connecting channel (cc) is seen in cross section as it runs in the wall of the fundic chamber in 80B7. A wooden applicator stick has been used to prop open the lumen of the channel. Note mucosal lining of fundic chamber (fd).

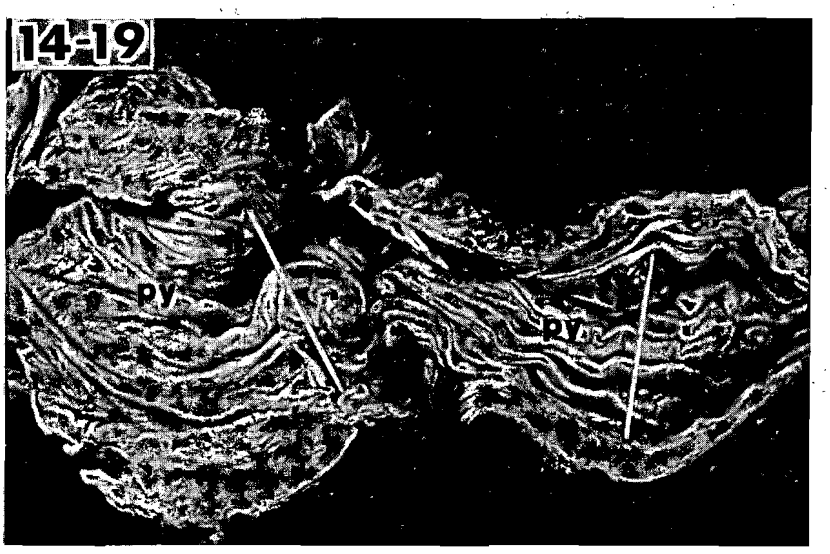


Figure 14-19 Exposed lumen of the pyloric chamber (py) distinguished by longitudinal folds of mucosal lining in 80B7. Note tubular nature of this chamber. Wooden applicator sticks have been used to expose mucosa. Direction of ingesta flow is to the right.

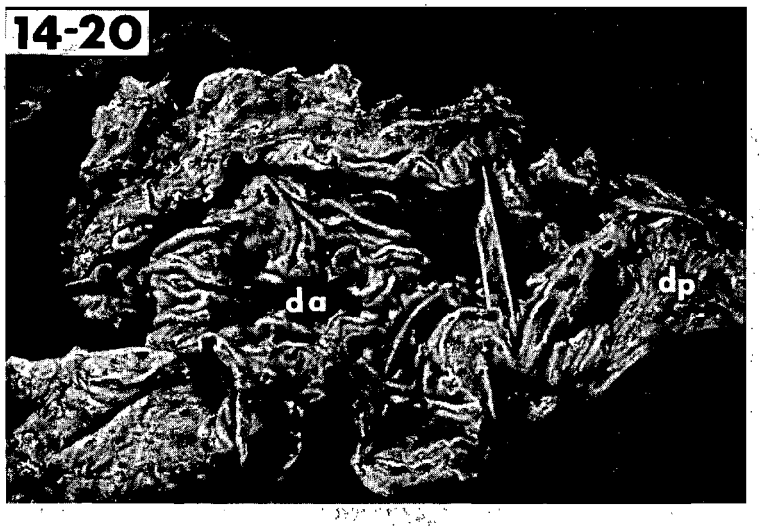


Figure 14-20 Mucosal surface of duodenal ampulla (da) illustrating extensive folding, primarily in a longitudinal direction in 80B7. A tongue depressor assists in exposing the lumen. The duodenum proper (dp) begins at the right of the photo.

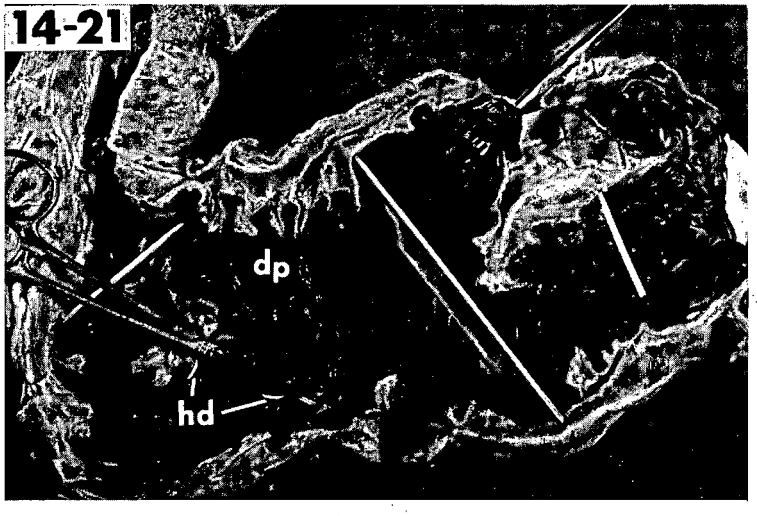
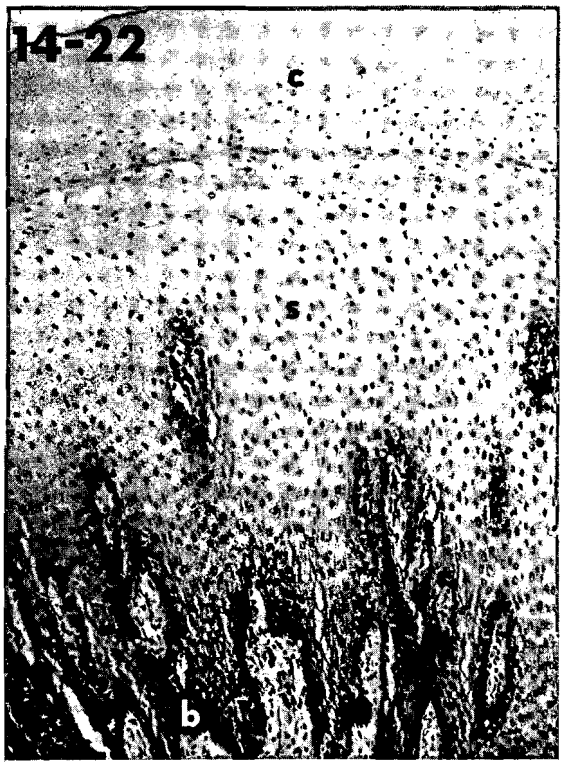


Figure 14-21 Mucosal surface of duodenum proper (dp) in 80B7 shortly after its beginning at the duodenal ampulla. Note the predominantly transverse folding of the lining. The mucosa in this region is heavily stained with bile, giving it the extremely dark appearance in this photo. The hepatopancreatic duct (hd), running in the wall of the duodenum, has been opened to allow placement of the hemostat in its lumen. The tips of the hemostat emerge through the orifice which represents the junction of the hepatopancreatic duct and intestinal lumen.



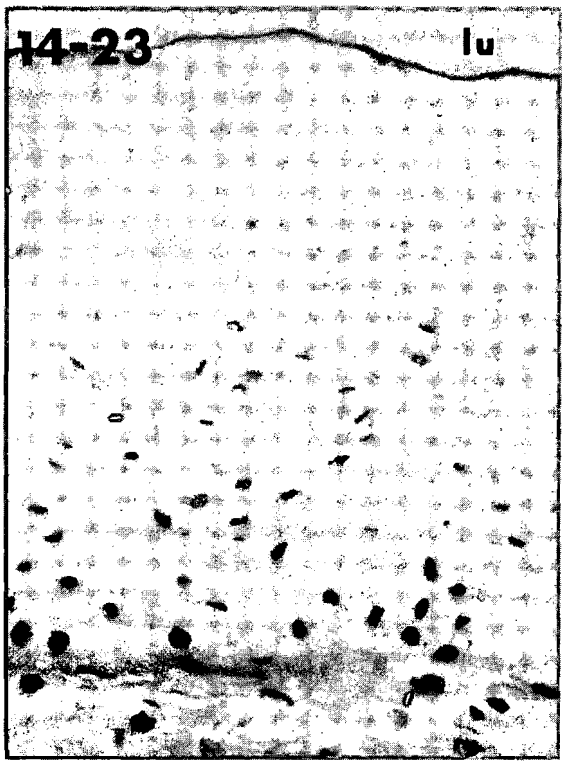


Figure 14-22 Stratified squamous epithelium lining forestomach mucosa in 80B8. Note three regions: 1) stratum basale (b) composed of deeply basophilic, cuboidal cells, 2) stratum spinosum (s) of more lightly staining cells and 3) stratum corneum (c) with pyknotic nuclei. H&E. 10X.

Figure 14-23 Superficial layer of esophageal epithelium marked "c" in Fig 14-22. Note pyknotic nuclei in deeper portion and absence of nuclei in surface portion. Lumen indicated (lu). H&E. 40X.

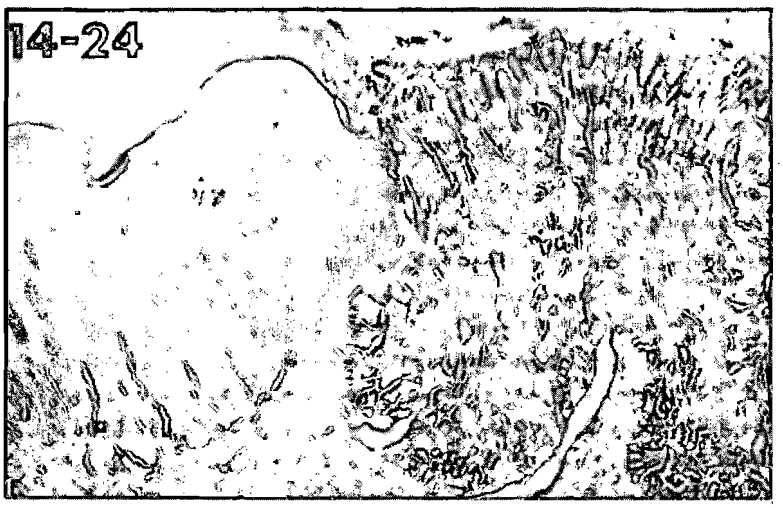


Figure 14-24 Note abrupt junction of stratified squamous lining of forestomach (fr) with glandular lining of fundic chamber (fd) in 80B1. H&E. 2.5X.

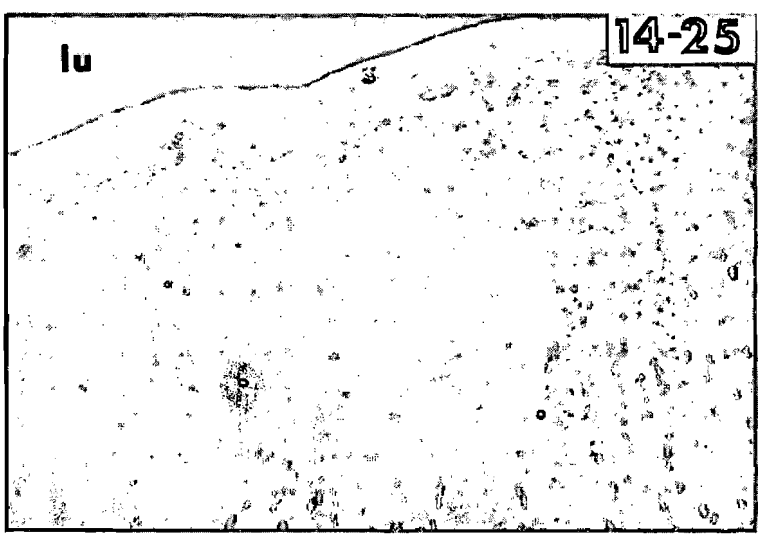


Figure 14-25 Higher magnification of forestomach epithelium shown in Fig 14-24. Note different staining quality of superficial layer (s) next to lumen (lu). H&E. 6.3X.

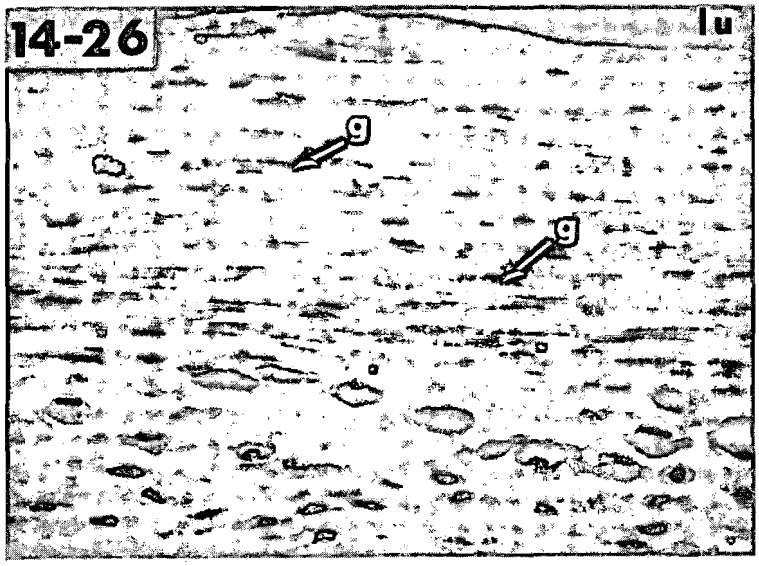


Figure 14-26 Higher magnification of superficial layer labeled "s" in Fig 14-25. Note keratohyalin granules (g) arranged horizontally within cells. Lumen indicated (lu). H&E. 40X.

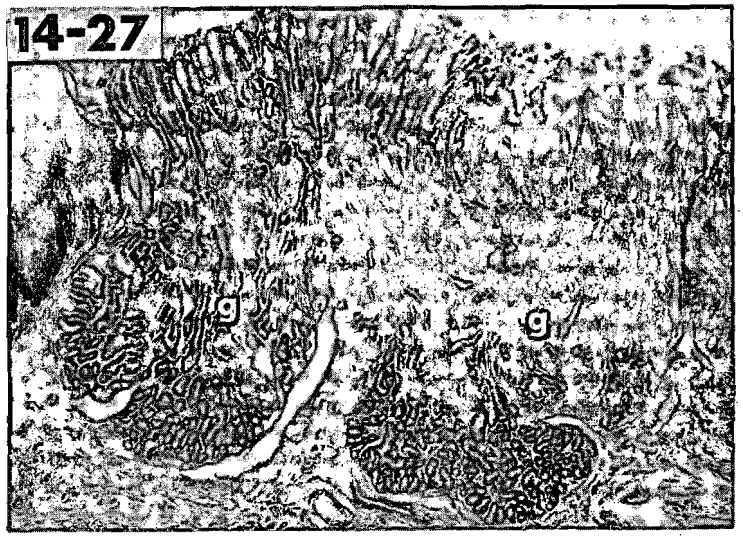


Figure 14-27 Overview of glandular area (g) in fundic chamber of 80B1. H&E. 2.5X.

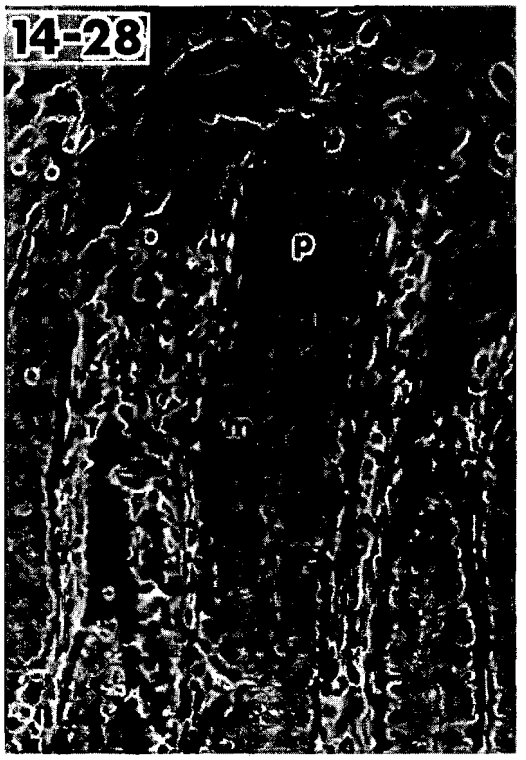


Figure 14-28 Note typical mucous cells (m) lining the gastric pit (p), each with a pale staining cytoplasm and nucleus flattened against the basal side of the cell in 80B1. H&E. 25X.

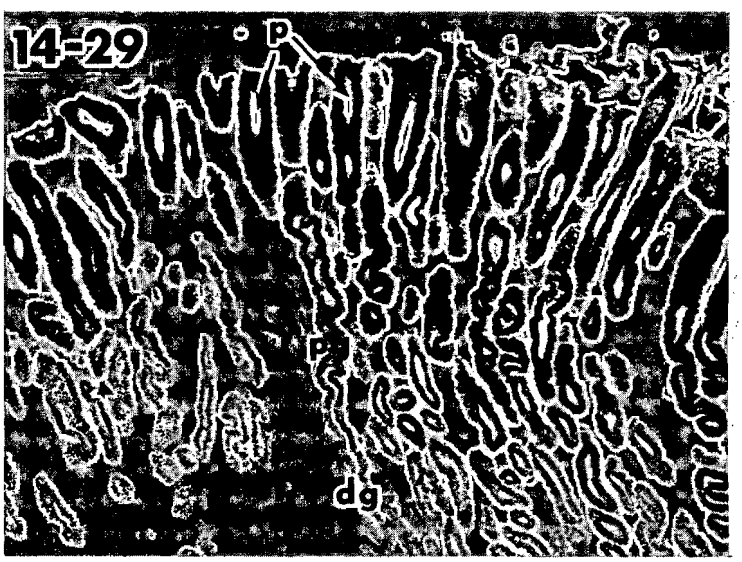


Figure 14-29 Histochemical stain of fundic chamber near junction with forestomach in 80B1. Cells lining gastric pits (p) stain magenta; proximal glandular area (pg) below is light blue; distal glandular (dg) area is pink. All reactions are positive for mucopolysaccharides. AB/PAS. 6.3X.

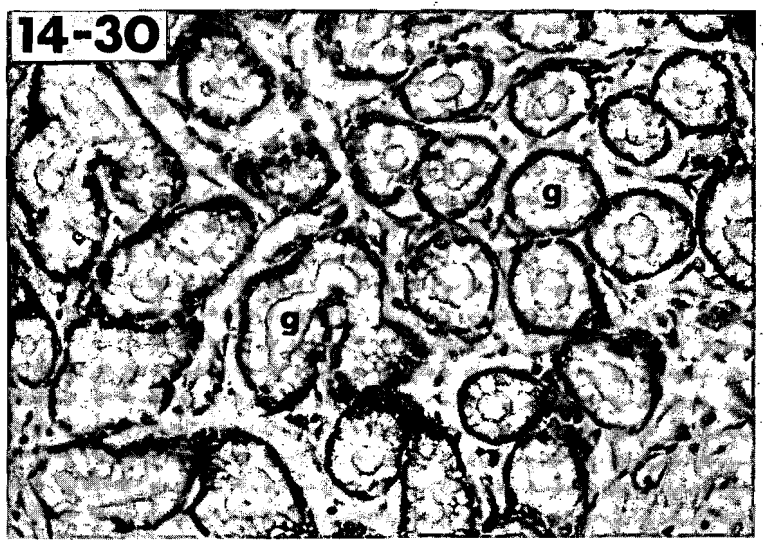


Figure 14-30 Basal portion of mucous glands (g) in fundic chamber near junction with forestomach in B081. H&E. 10X.

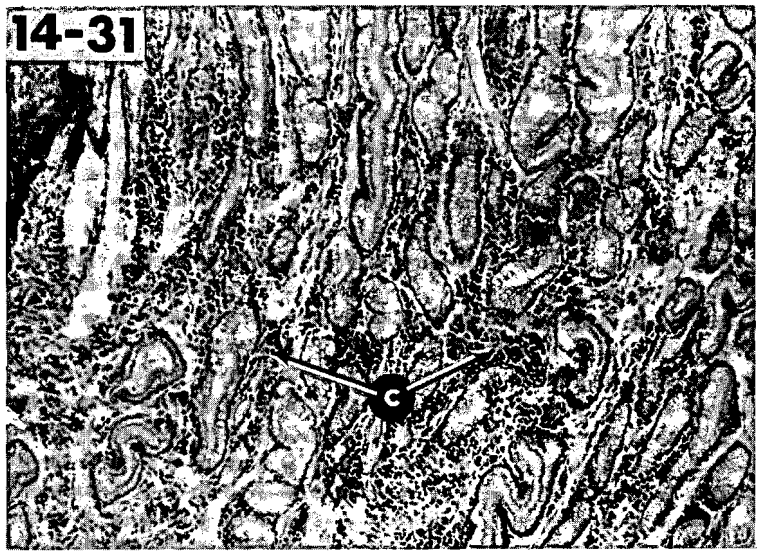


Figure 14-31 Mucous glands in the initial portion of fundic chamber of 80B1. Note numerous cellular accumulations (c), primarily plasma cells, between glands. H&E. 10X.

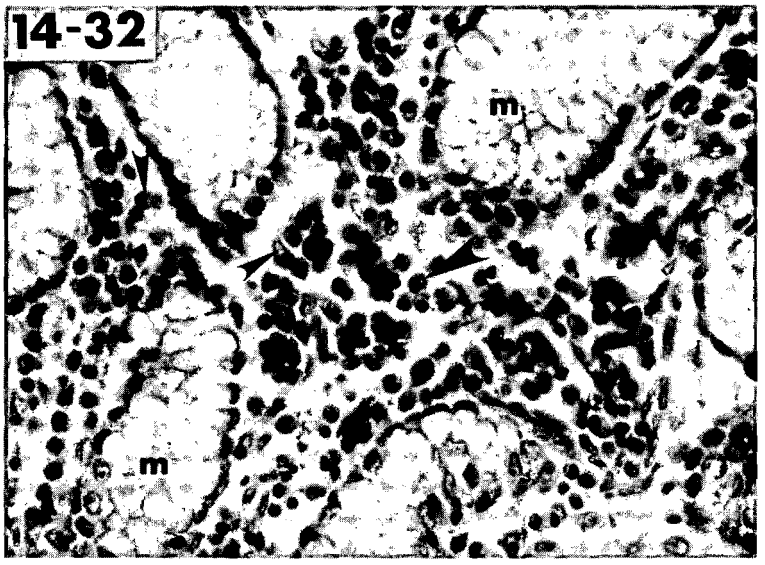


Figure 14-32 Higher magnification of cellular elements (primarily plasma cells [arrowheads]) between mucous glands (m) shown in Fig 14-31. H&E. 40X.

Figure 14-33 Lamina propria (lp) and smooth muscle bundles of muscularis mucosae (arrowheads) beneath initial glandular region in fundic chamber in 80B1. Note adipose tissue (a) surrounding muscle. H&E. 2.5X.

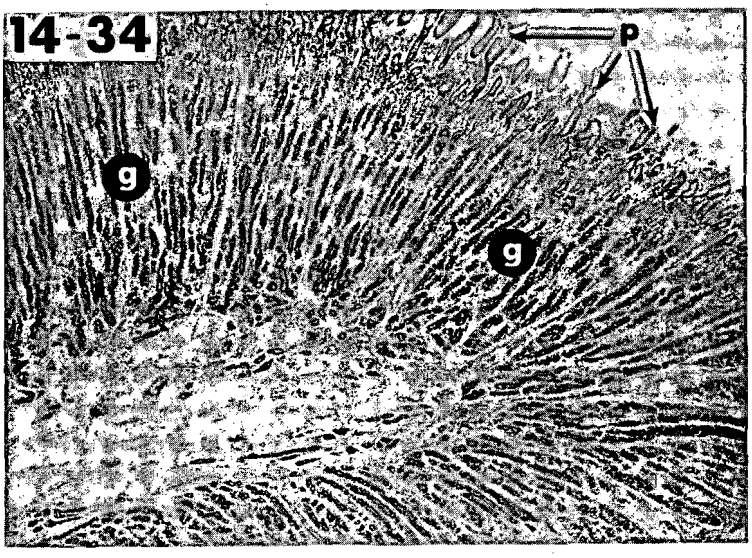


Figure 14-34 Overview of mucosa of fundic chamber 79B2. Note gastric pits (p) and straight tubular glands (g) which are coiled distally. H&E. 2.5X.

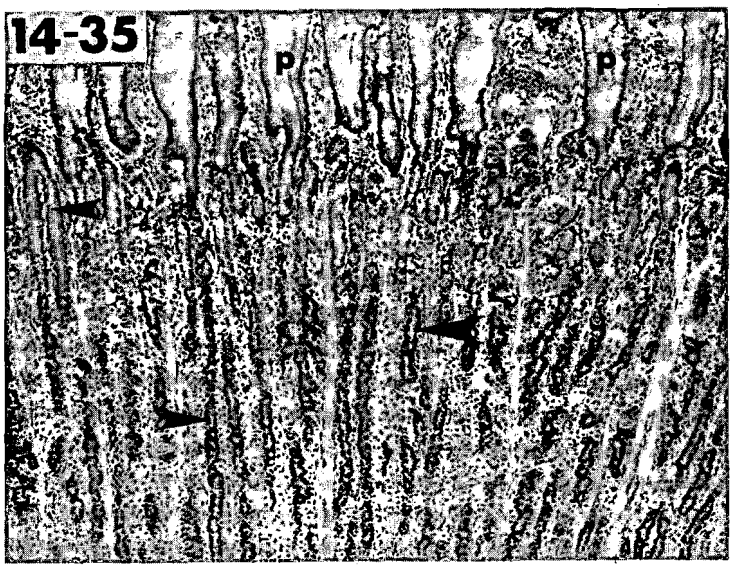


Figure 14-35 Higher magnification of Fig 14-34 showing gastric pits (p) and glands (arrowheads). H&E. 6.3X.

Figure 14-36 Higher magnification of Fig 14-34 showing distal gastric glands (arrowheads) with coiling at base. H&E. 6.3X.

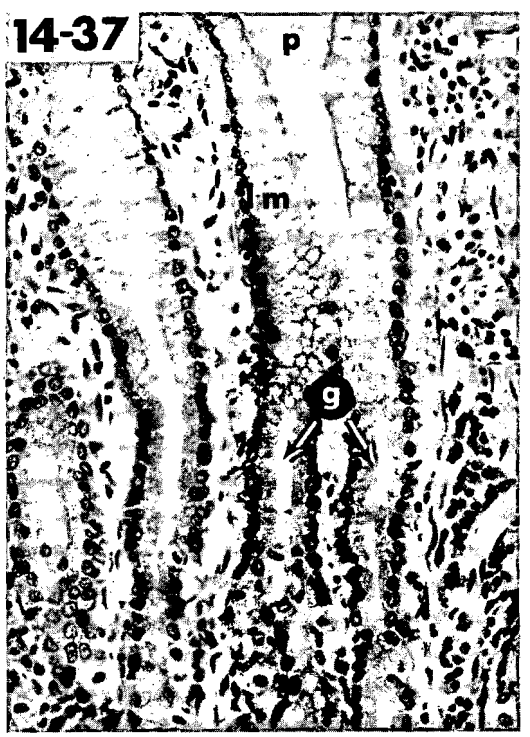


Figure 14-37 High magnification of gastric pits (p) showing typical mucous cells (m) comprising their lining. Note that the pit on the right leads into two gastric glands (g). H&E. 25X.

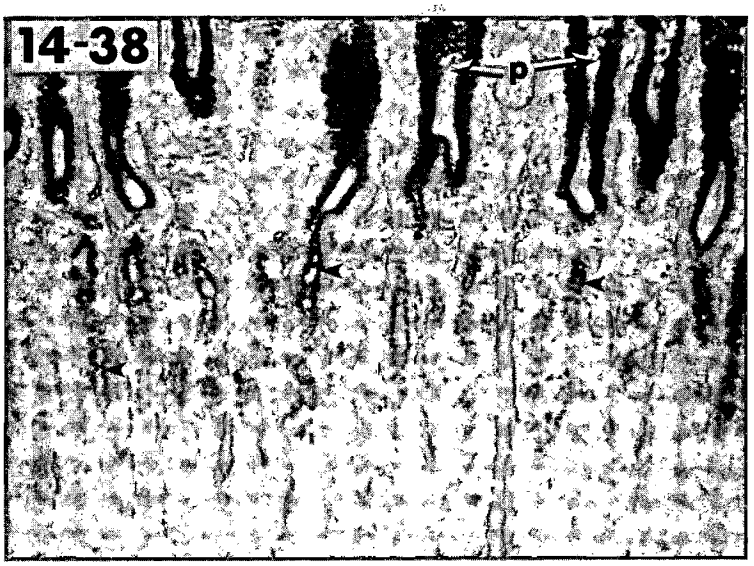


Figure 14-38 Histochemical stain of mucosal lining of fundic chamber in 79B2 showing dark staining cells lining gastric pits (p) and lighter staining area in the necks of the glands (arrowheads). AB/PAS. 10X.

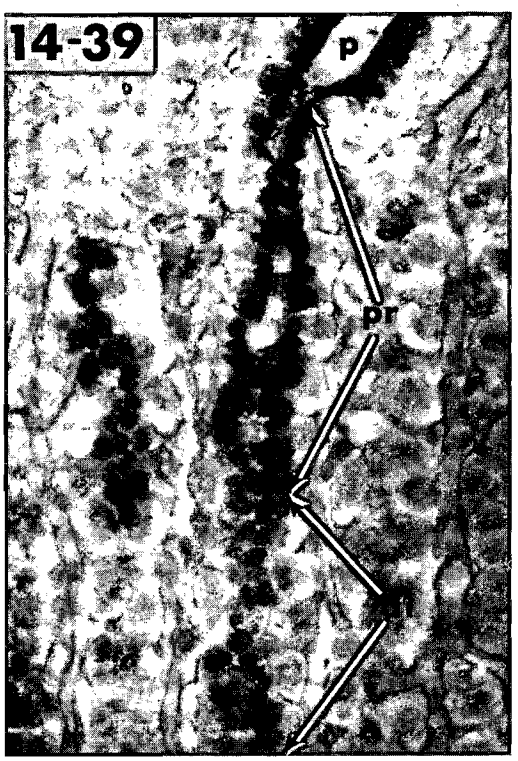


Figure 14-39 Higher magnification of histochemical stain shown in Fig 14-38 showing base of gastric pit (p) and neck area of gland (pr & di). Note darker staining quality in proximal portion (pr) of neck and lighter staining distally (di). AB/PAS. 40X.

Figure 14-40 Branching of gastric glands (g) in fundic chamber of 80B2. H&E. 25X.

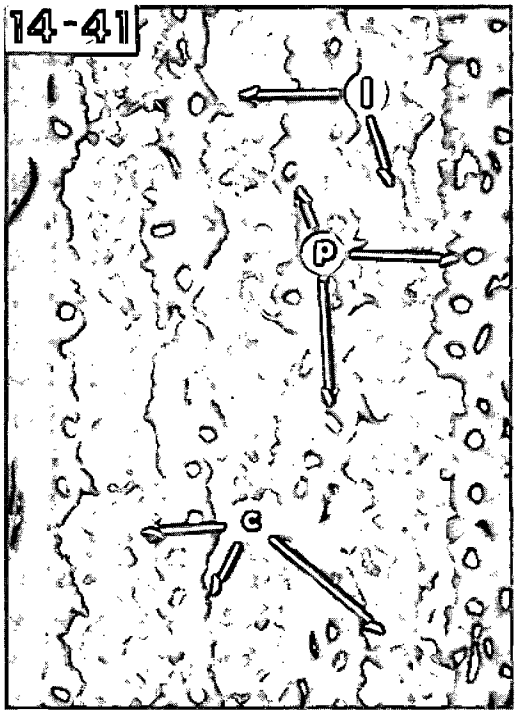


Figure 14-41 Three gastric glands form fundic chamber of 79B2. Note parietal cells (p) and chief cells (c). Two glandular lumens are indicated (l). H&E. 40X.

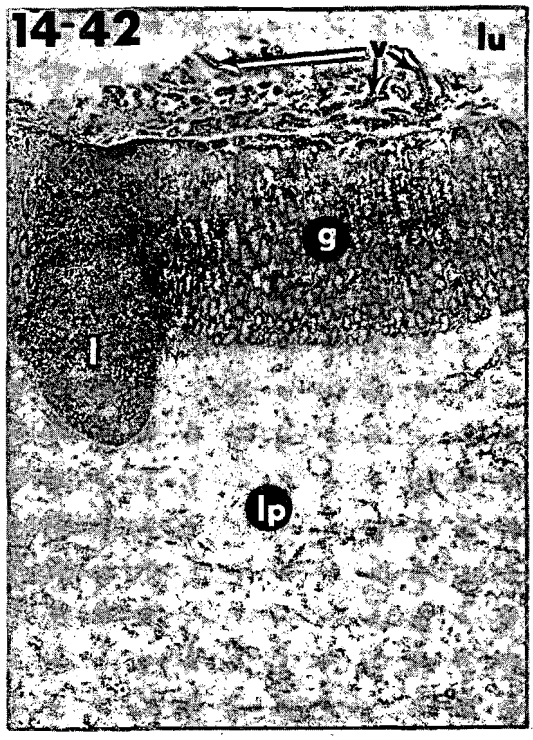


Figure 14-42 Mucosa of small intestine about 10 cm proximal to junction with colon in 80B7. Note remnants of villi (v), intestinal gland (g), lymphoid nodule (l), and lamina propria (lp). Lumen is indicated (lu). H&E. 2.5X.

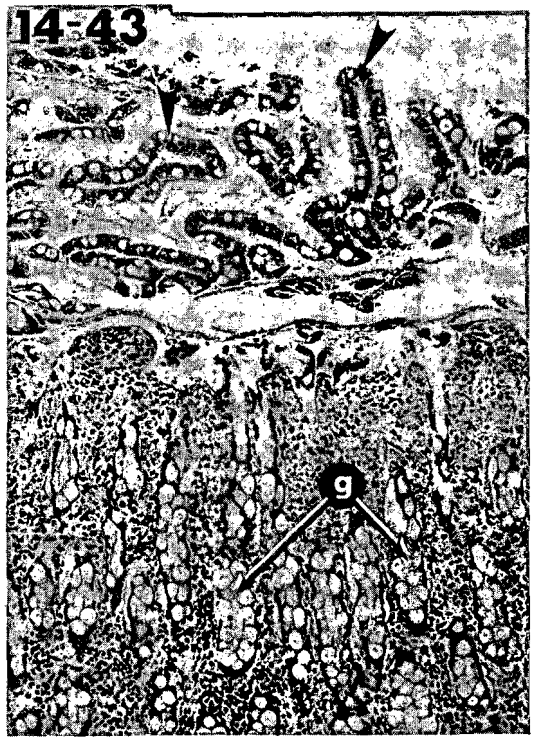
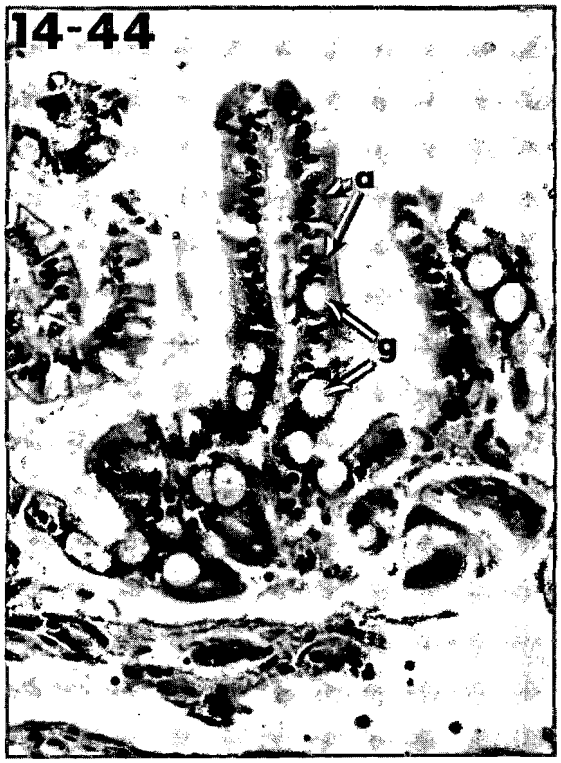


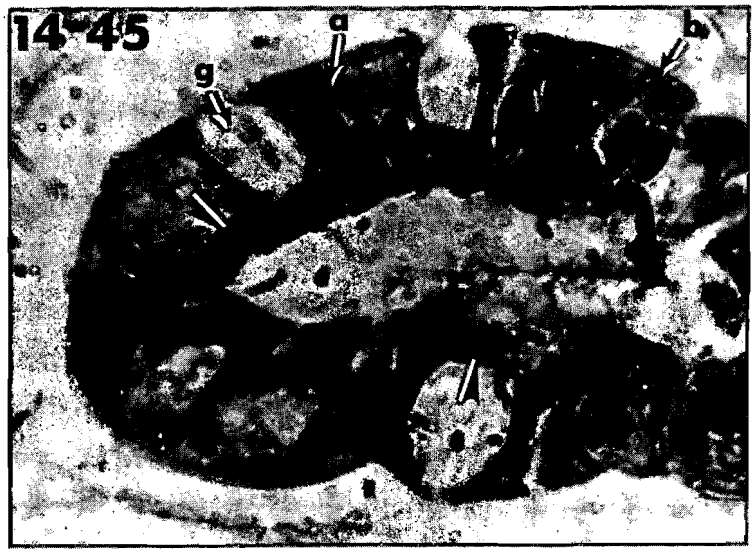
Figure 14-43 Higher magnification of small intestine lining seen in Fig 14-42. Note villi (arrowheads) and intestinal glands (g). H&E. 10X.

Figure 14-44 Higher magnification of small intestine lining seen in Fig 14-43. Note villi with goblet cells (g) and absorptive cells (a). H&E. 25X.

Figure 14-45 Higher magnification of villus of small intestine shown in Fig 14-43. Note goblet cells (g), absorptive cells (a) and striated border (b). In the goblet cells, the nucleus is pushed to the basal side of the cell (arrowheads). H&E. 100X.

Figure 14-46 Distal glandular area (g) in mucosa of small intestine in 80B7. Note predominance of goblet cells, swelled with their secretory product. Lamina propria is indicated (lp). H&E. 25X.


14-44
a
g


14-45
a
b
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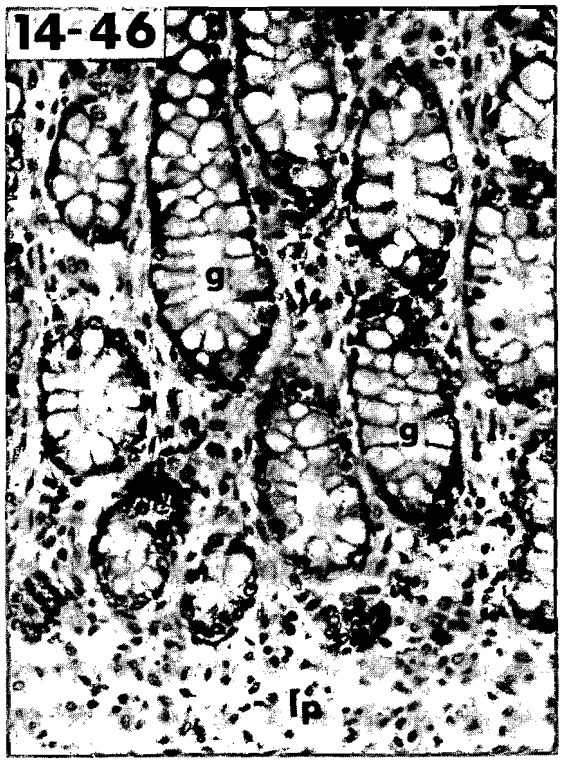
14-46
g
g
p

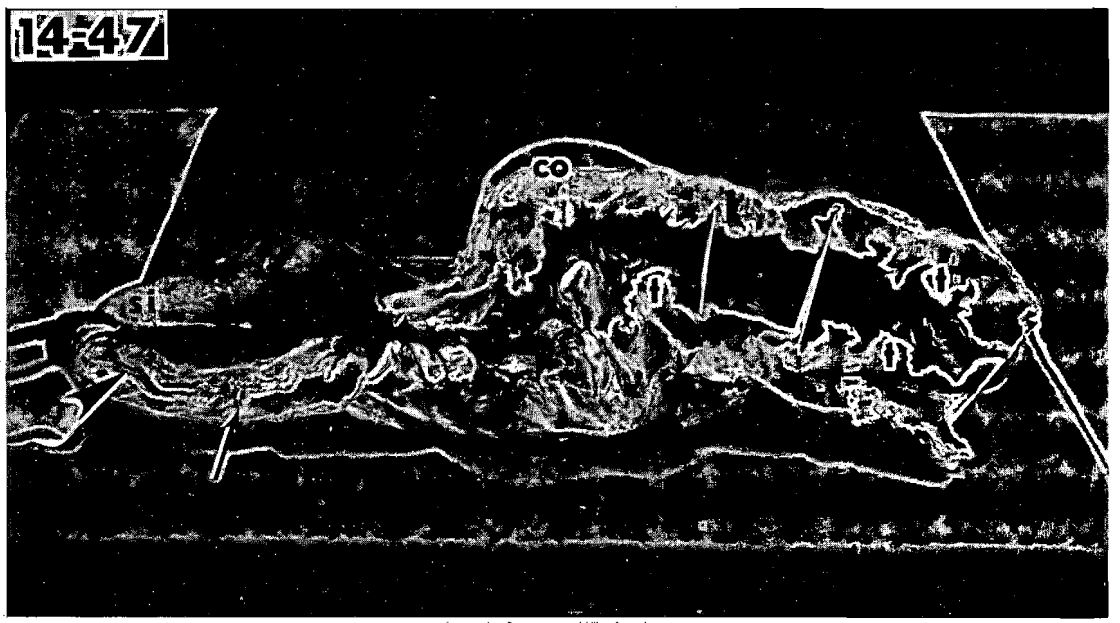

Figure 14-47 Junction of small intestine (si) with colon (co) marked by a sudden dilation at the middle of the specimen and continuing to the right. To the left, the small intestine makes a sharp "U" bend. Only the lumen portion is continuous with the colon. Note the narrow lumen (arrowhead) and area of transverse folds (arrow) of the small intestine. The mucosal surface of the colon is characterized by longitudinal folds which are interrupted by even more pronounced transverse folds (t). The lumen of the colon is propped open with tongue depressors. No cecum was found.

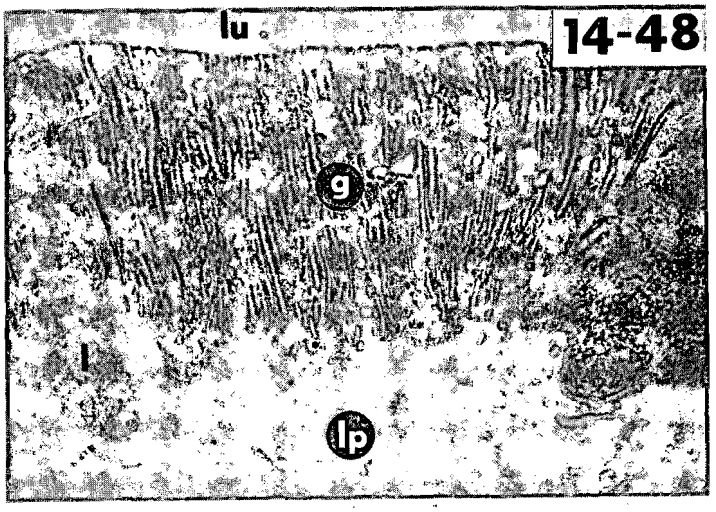

Figure 14-48 Mucosal lining of colon in 80B1. Note glandular (g) area and lamina propria (lp). Lumen (lu) is indicated. Lymphoid nodule (l) is seen to the left. H&E. 2.5X.

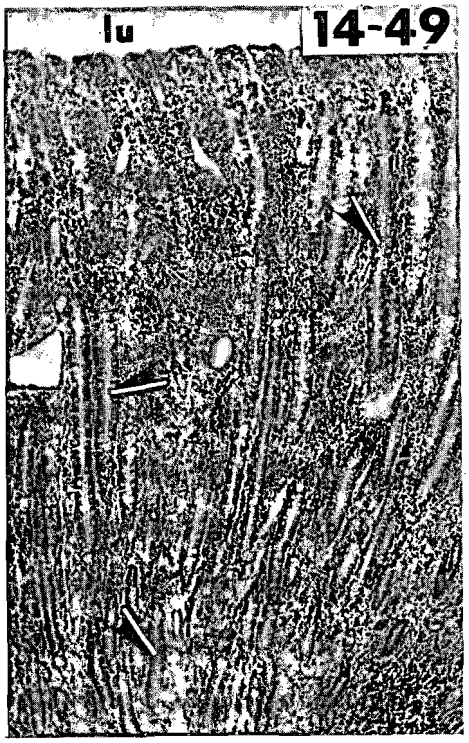

Figure 14-49 Mucosal lining of colon in 80B9. Note glands (arrowheads) and abundance of cells (mainly lymphocytes) between glands. Lumen is indicated (lu). H&E. 6.3X.

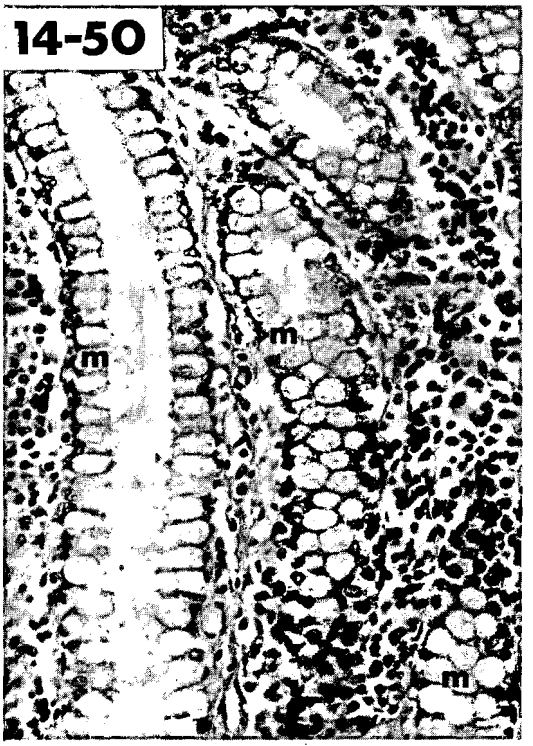

Figure 14-50 Glands in mucosa of colon in 80B9. Note predominance of mucous cells (m). H&E. 25X.

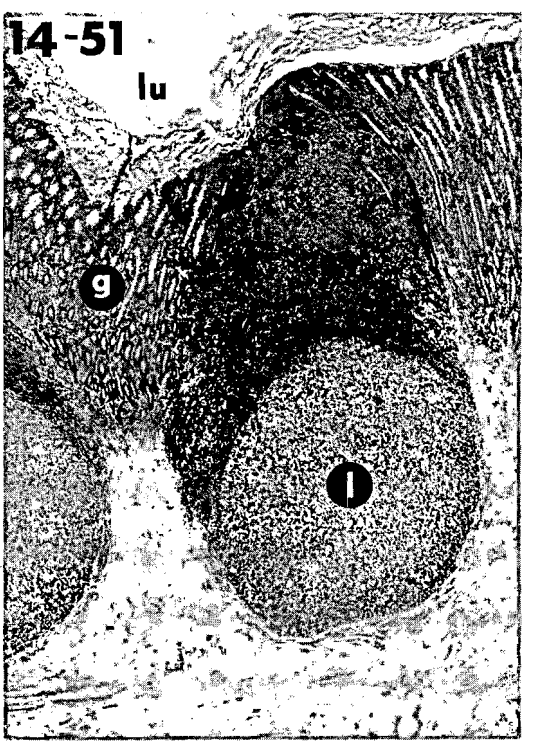

Figure 14-51 Mucosal lining of colon in 80B1. Note glands (g) and lymphatic nodules (l). Lumen is indicated (lu). H&E. 2.5X.

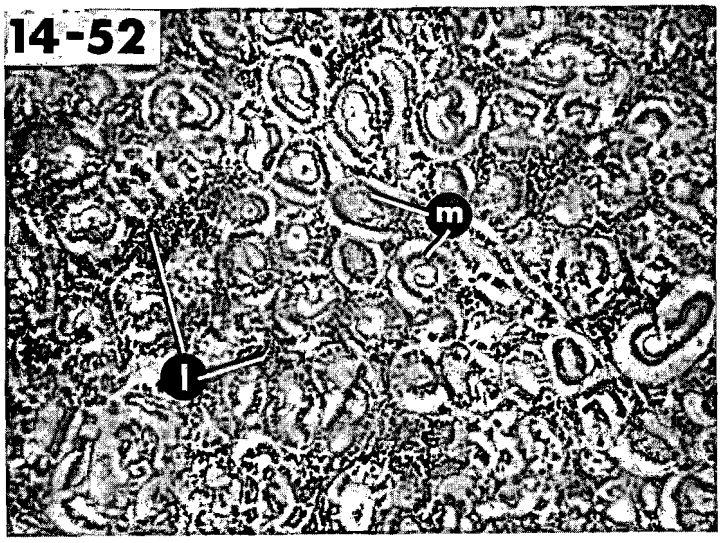

Figure 14-52 Mucous gland in mucosa of colon near junction with anal canal in 80B9. This was found beneath the intestinal glands lining the mucosa. Note mucous cells (m) comprising the gland and the abundance of lymphocytes (l) between tubules. H&E. 10X.

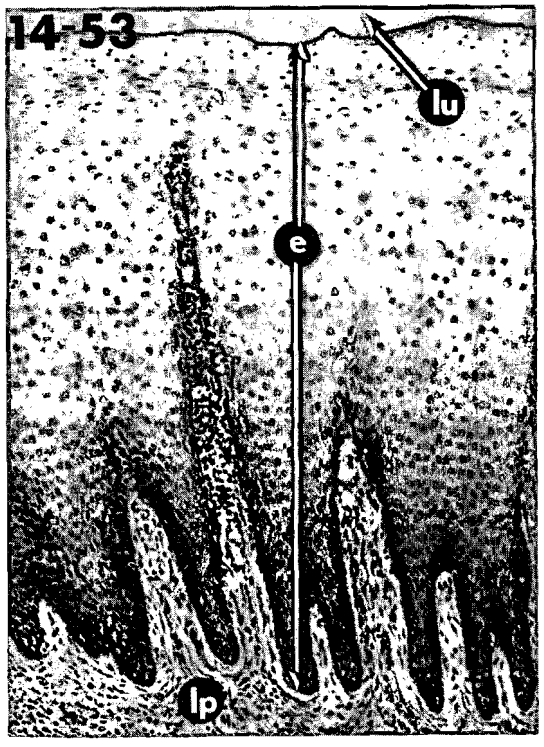

Figure 14-53 Epithelial lining (e) of anal mucosa in 80B1. Note deep invaginations of lamina propria (lp) and presence of nuclei even to the most superficial portion of epithelium. Lumen is indicated (lu). H&E. 10X.

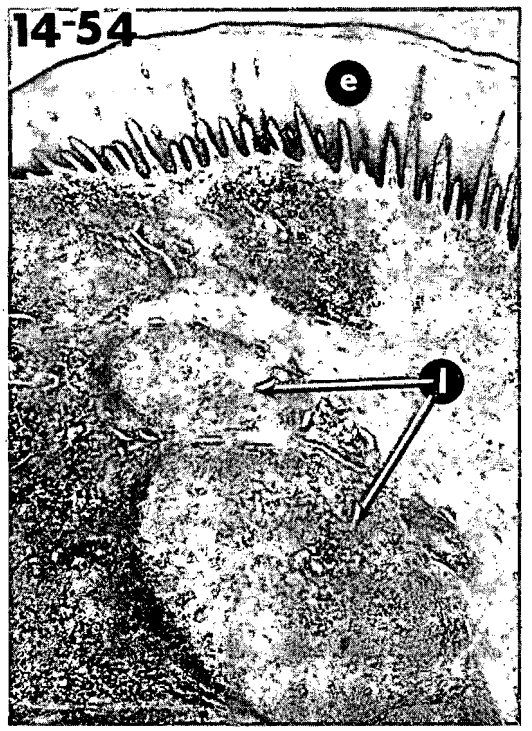

Figure 14-54 Anal mucosa from 80B1 with stratified squamous epithelium (e) and closely associated lymphoid nodules (l) beneath it. H&E. 2.5X.

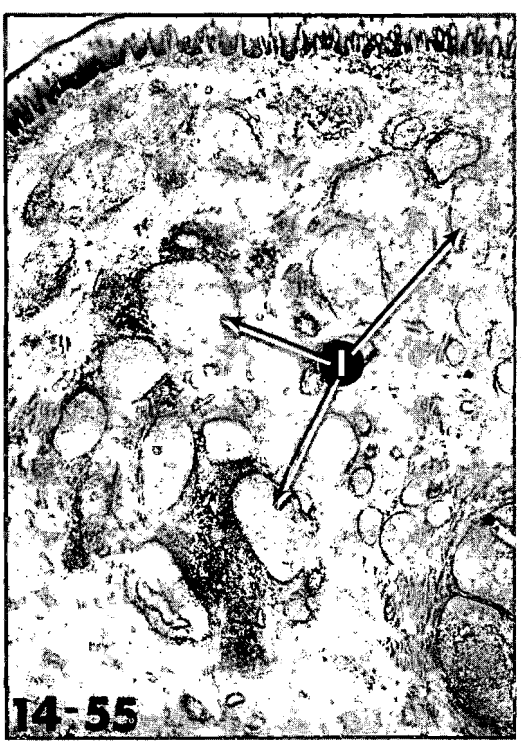

Figure 14-55 Mucosa and submucosa of anal canal in 80B1 showing stratified squamous lining and numerous lymph nodules (l) beneath it. H&E. 1X.

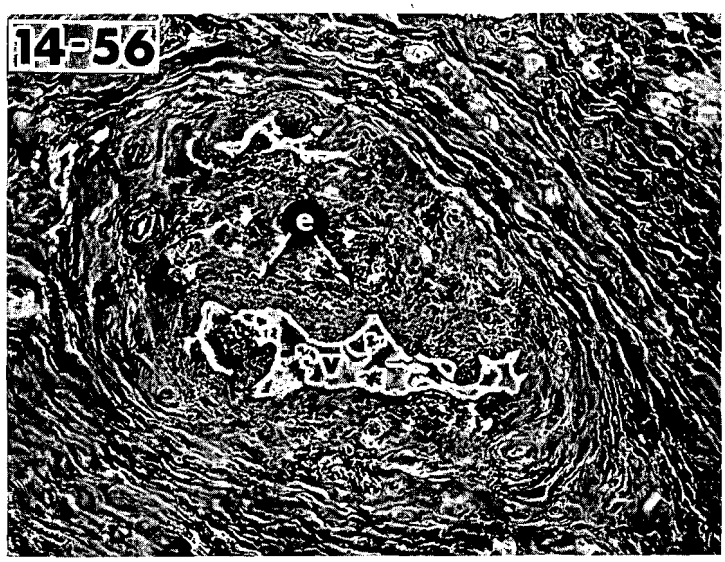

Figure 14-56 Cross section of vein (v) in submucosa of anal canal surrounded by numerous eosinophils (e) in 80B1. H&E. 6.3X.

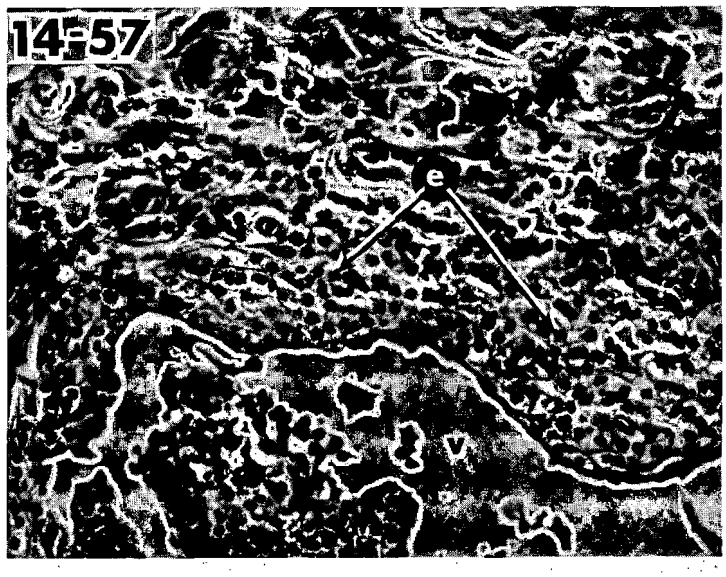

Figure 14-57 Higher magnification of vein cross section in Fig 14-53. Note eosinophils (e). Lumen of vein indicated (v). H&E. 10X.

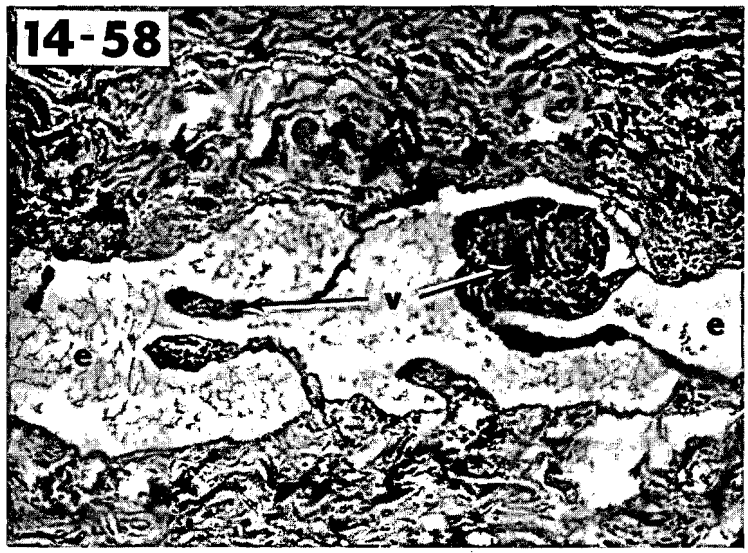

Figure 14-58 Vein in longitudinal section showing valves (v) which have been infiltrated with eosinophils in 80B1. Lumen of vein is indicated (e). H&E. 10X.

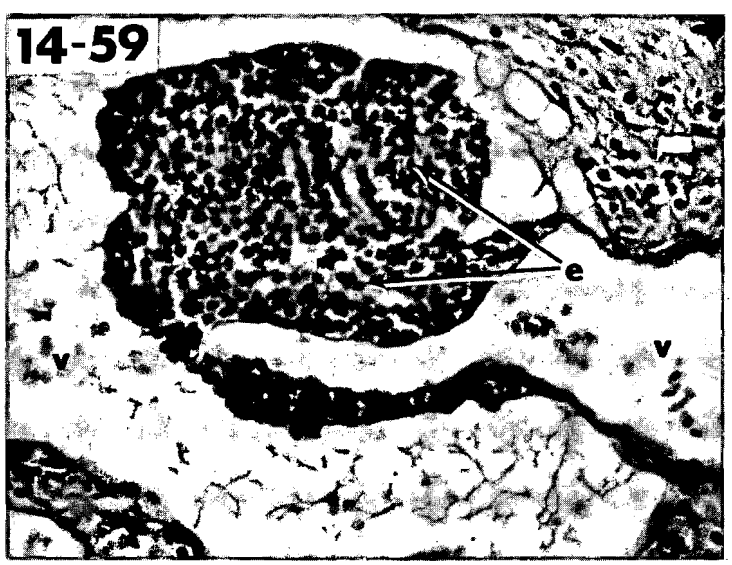

Figure 14-59 Higher magnification of valve of vein infiltrated with eosinophils (e) in Fig 14-58. Lumen of vein indicated (v). H&E. 25X.

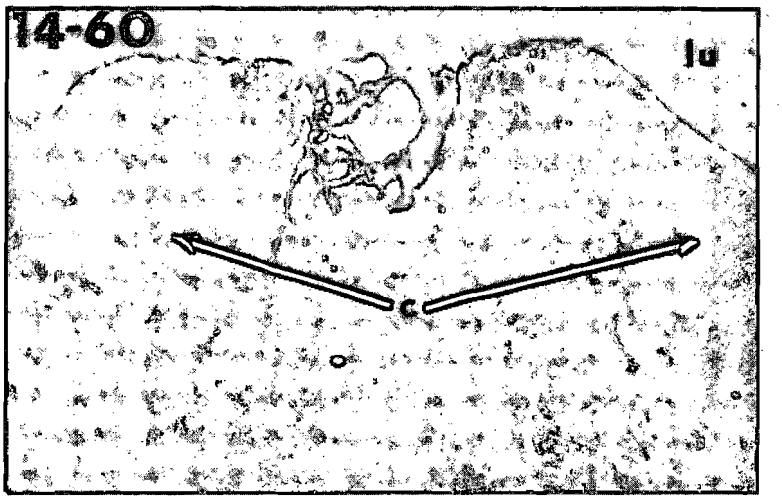

Figure 14-60 Overview of anal ulcer in 80B1 showing area of cellular infiltration (c). Note absence of epithelium over reactive area. Lumen of anal canal indicated (lu). H&E. 1X.

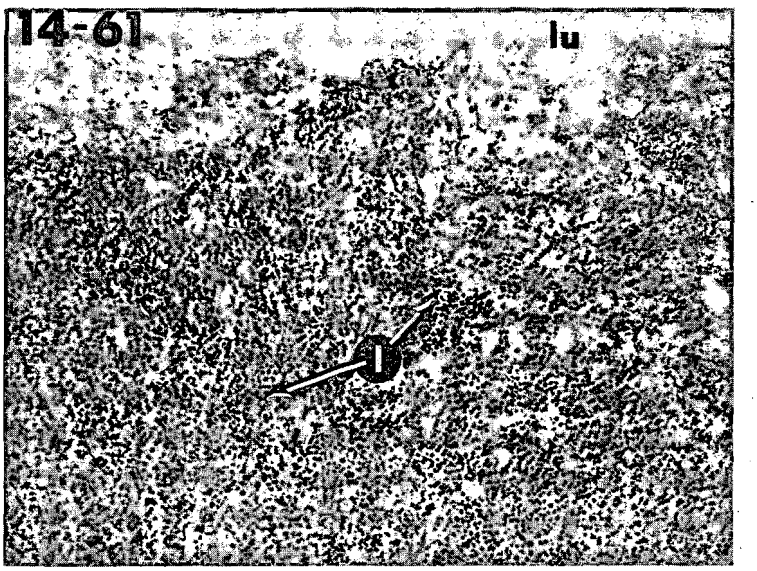

Figure 14-61 Superficial portion of ulcer illustrated in Fig 14-60. Note cellular accumulations (l) - mostly lymphocytes. Lumen indicated (lu). H&E. 10X.

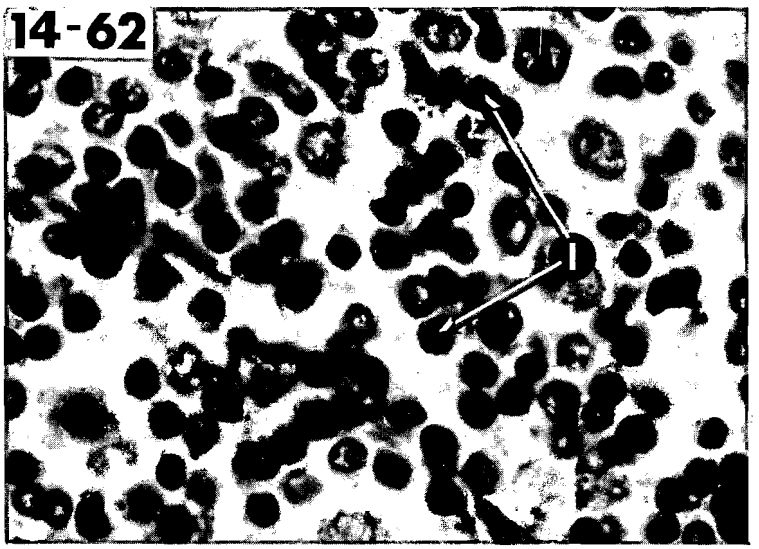

Figure 14-62 Higher magnification of lymphocytes (l) in ulcerated area of 80B9. H&E. 100X.

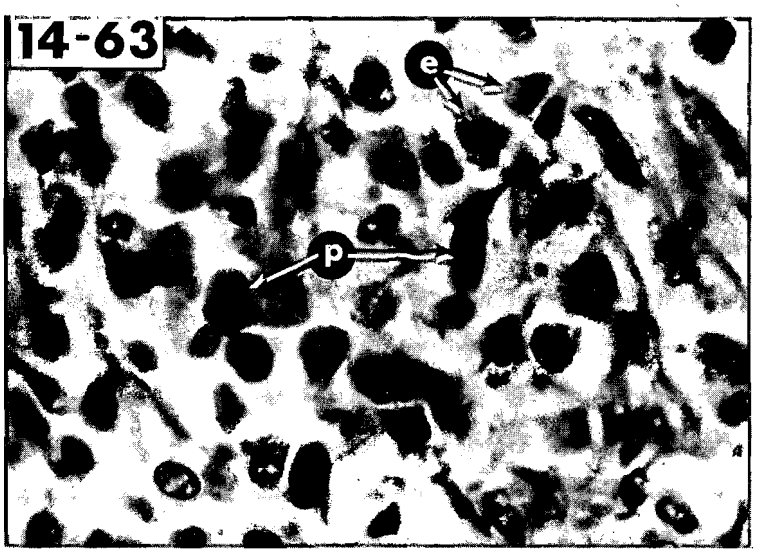

Figure 14-63 Plasma cells (p) and eosinophils (e) in deeper portion of ulcer of 80B9. H&E. 100X.

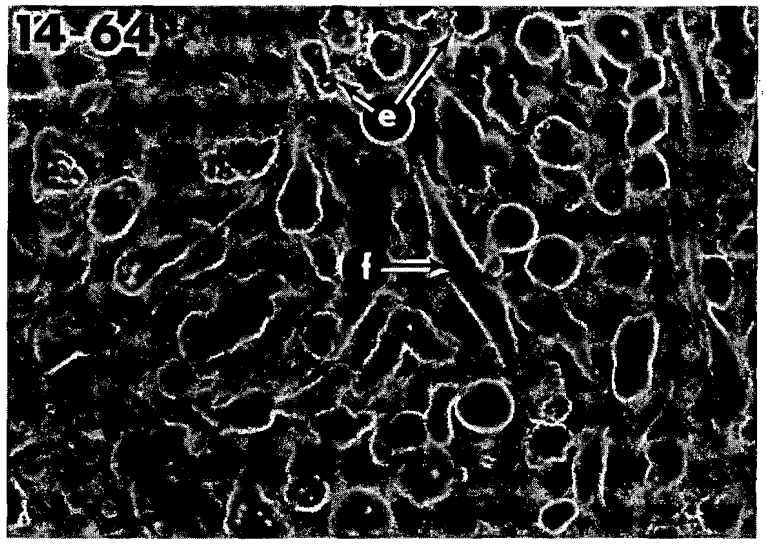

Figure 14-64 Fibrotic elements (f) and eosinophils (e) invading ulcerated area of 80B9. H&E. 100X.

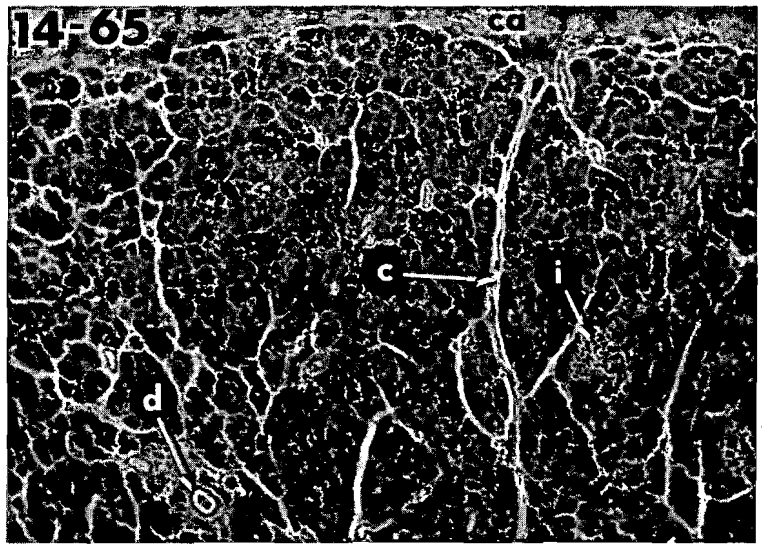

Figure 14-65 Overview of pancreas in 80B2. Note lobules separated by connective tissue septae (c), intralobular duct (d) and islets of Langerhans (i). Capsule indicated (ca). H&E. 6.3X.

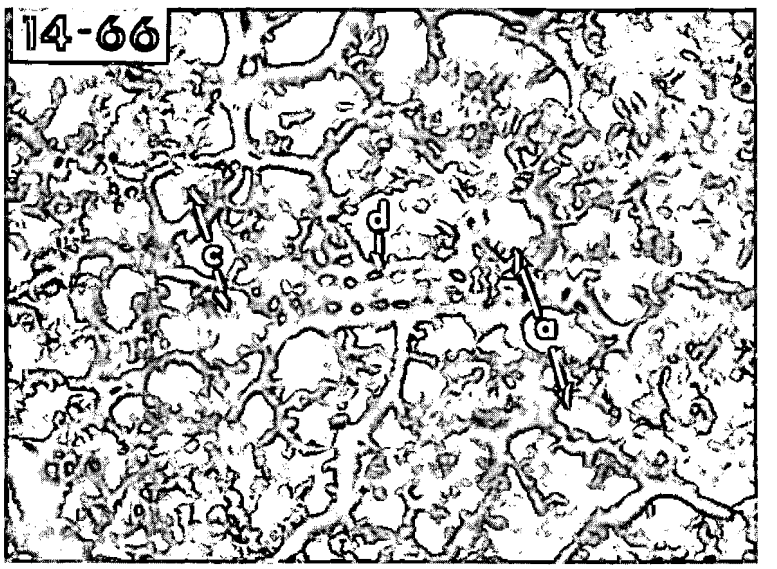

Figure 14-66 Pancreatic acini (a) lined by cuboidal cells in 80B8. Note intralobular duct (d) and centroacinar cells (c). H&E. 25X.

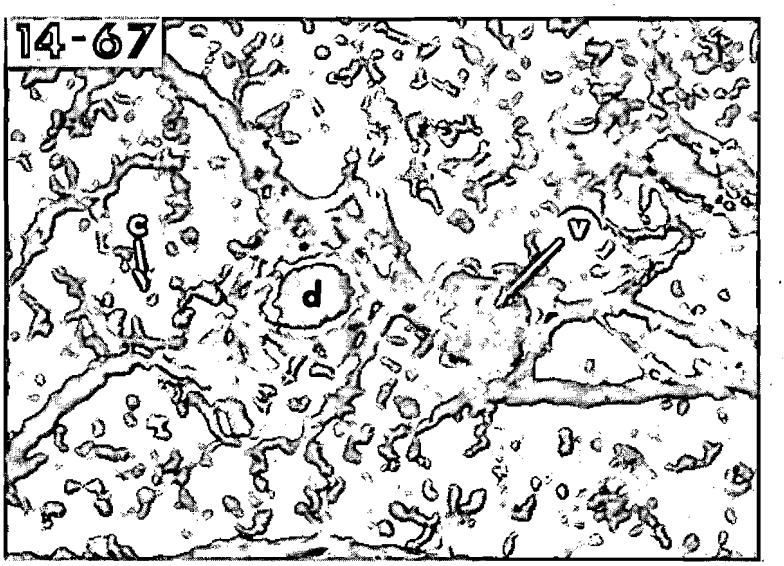

Figure 14-67 Note centroacinar cells (c), intralobular duct (d) and vascular elements (v) in pancreatic lobule of 80B2. H&E. 25X.

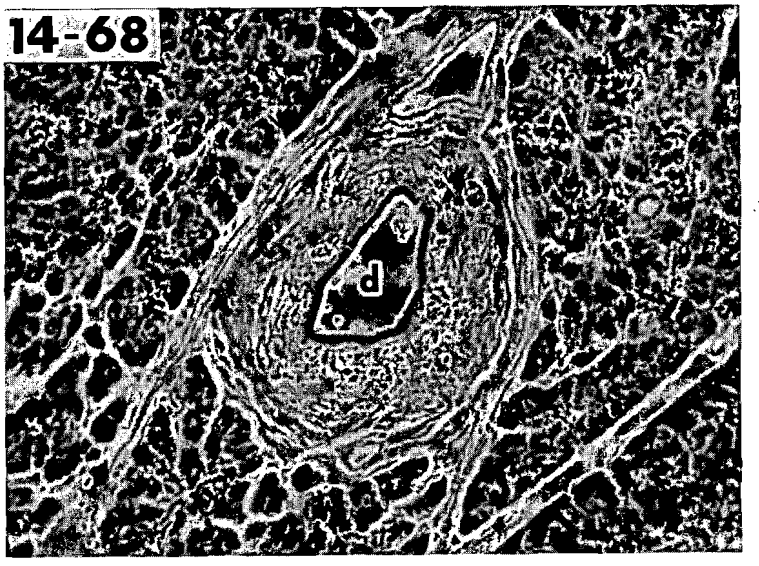

Figure 14-68 Note interlobular duct (d) in pancreas of 80B1. H&E. 10X.

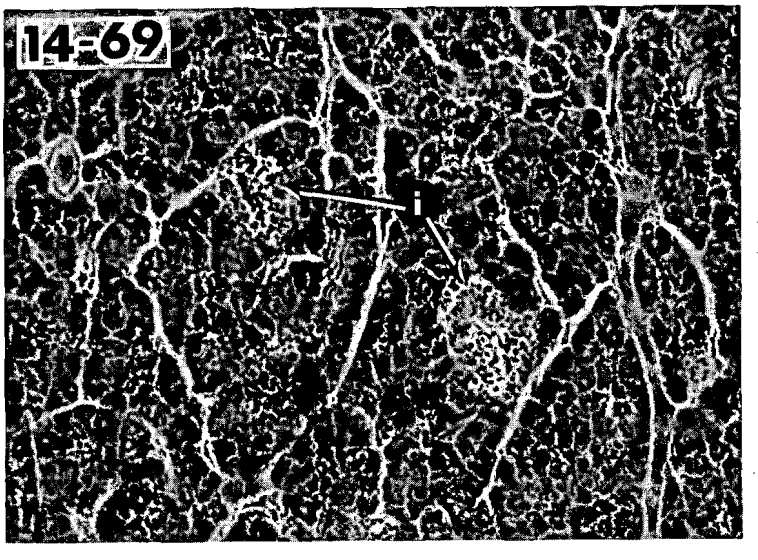

Figure 14-69 Note islets of Langerhans (i) in 80B2. H&E. 10X.

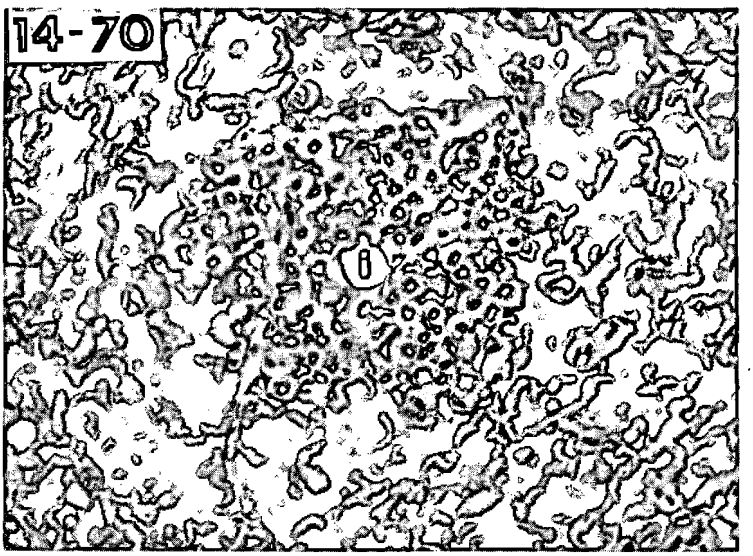

Figure 14-70 Higher magnification of islet of Langerhans (i) from 80B2. H&E. 25X.

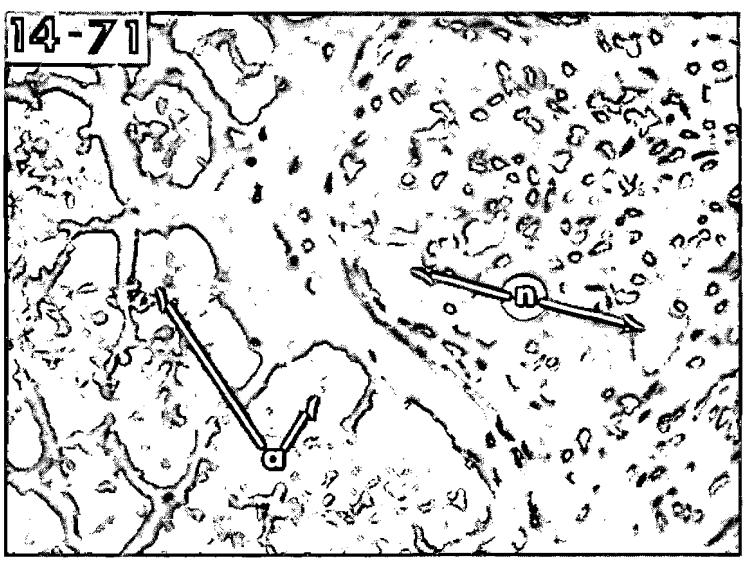

Figure 14-71 Neuron cell bodies (n) in a ganglion within the pancreas in 80B8. Note surrounding acini (a). H&E. 25X.

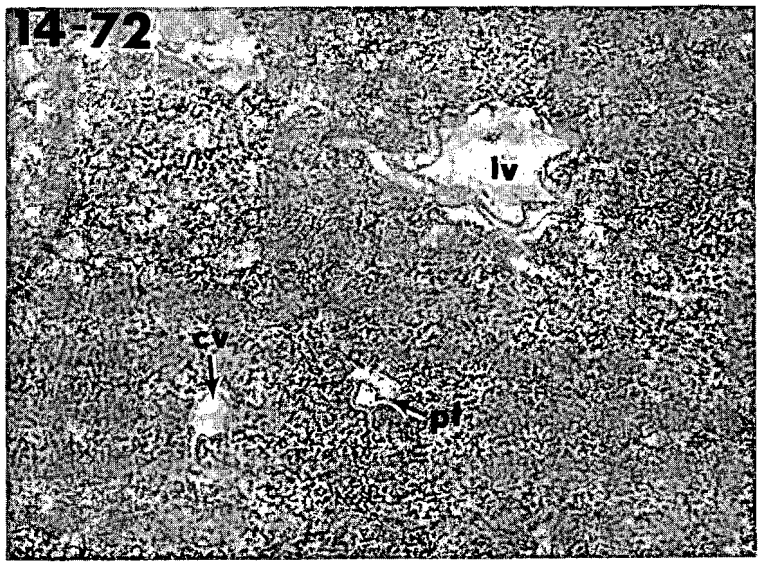

Figure 14-72 Overview of liver in 80B1. Note central veins (cv), portal triad (pt) and interlobular vein (iv). H&E. 2.5X.

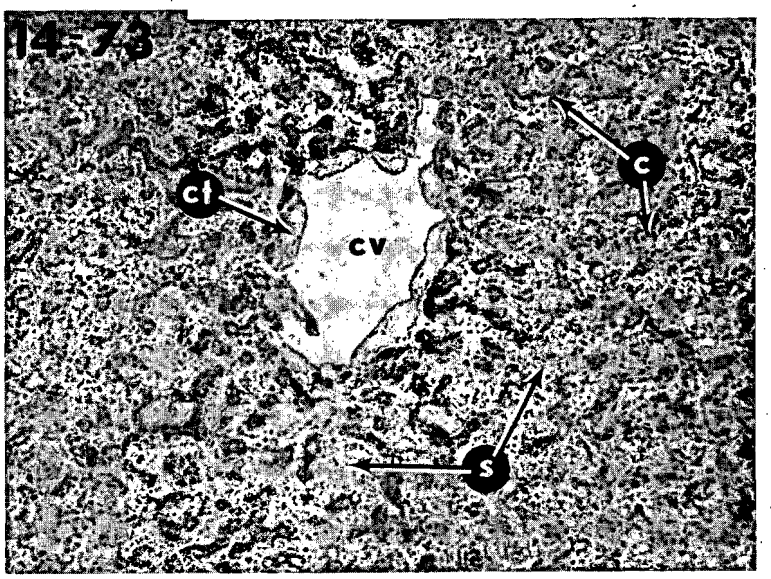

Figure 14-73 Central vein (cv) in 80B1 liver. Note connective tissue (ct) lining vein. Hepatic plates (c) and sinusoids (s) are indicated. H&E. 10X.

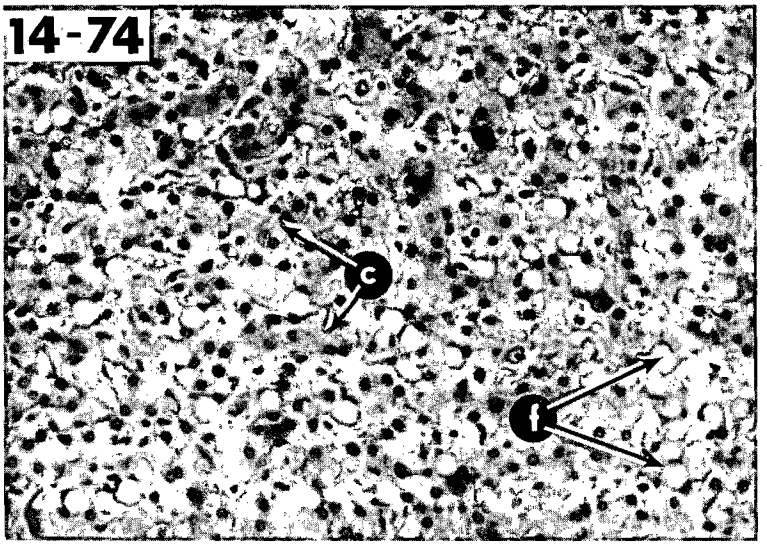

Figure 14-74 Plates of hepatic cells (c) with evenly distributed fat-like cells (f) in 80B1. H&E. 25X.

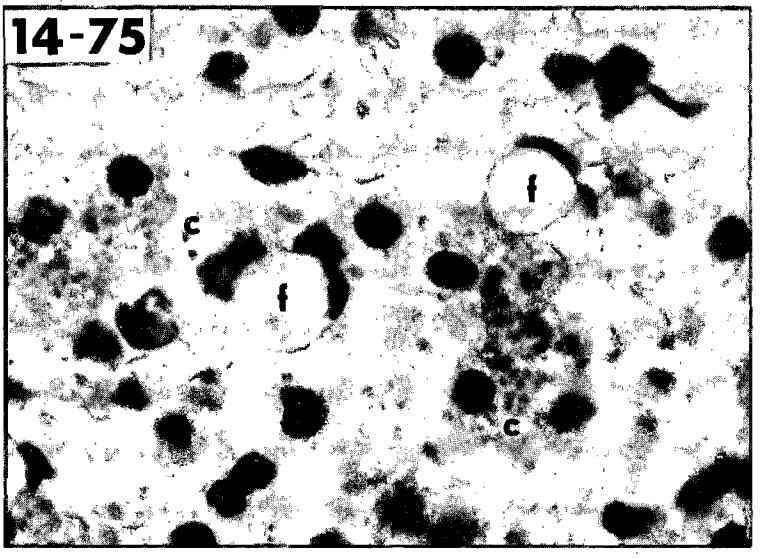

Figure 14-75 Higher magnification of Fig 14-74 with hepatic plates (c) and fat-like cells (f). H&E. 100X.

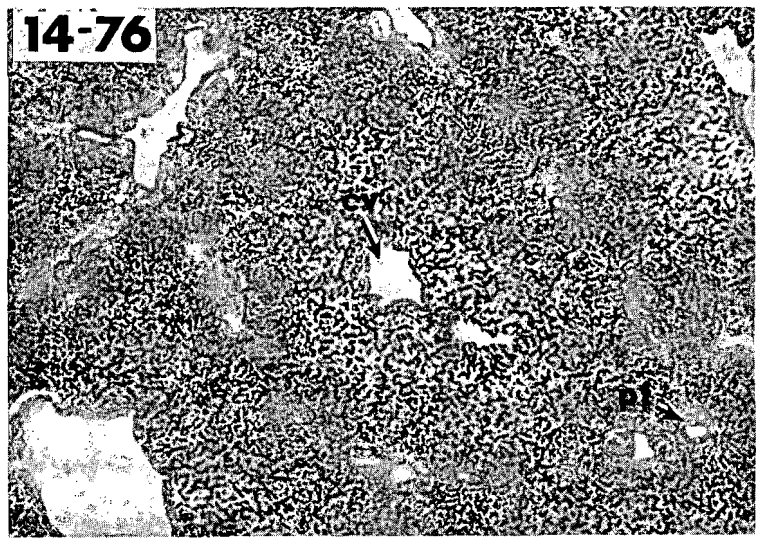

Figure 14-76 Histochemical stain of liver 80B8 showing hepatic lobules with central vein (cv) and portal triads (pt). AB/PAS. 2.5X.

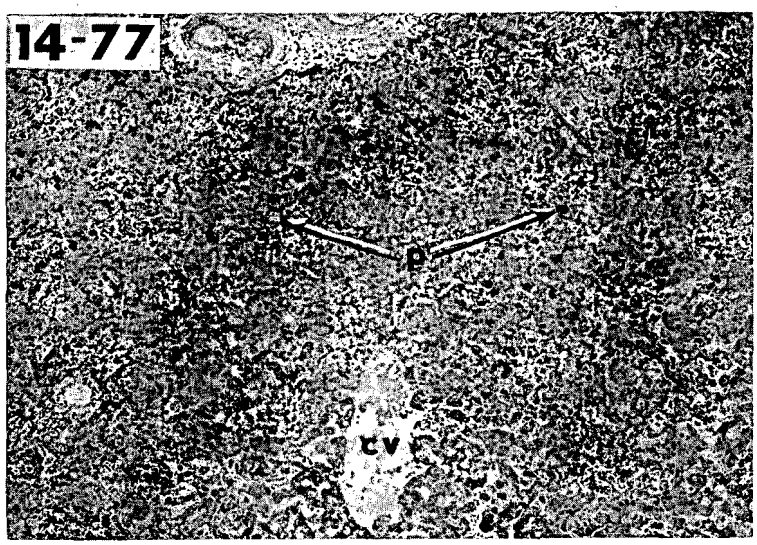

Figure 14-77 Liver parenchyma in 80B8 showing extensive collections of dark pigment (p). Central vein indicated (cv). H&E. 6.3X.

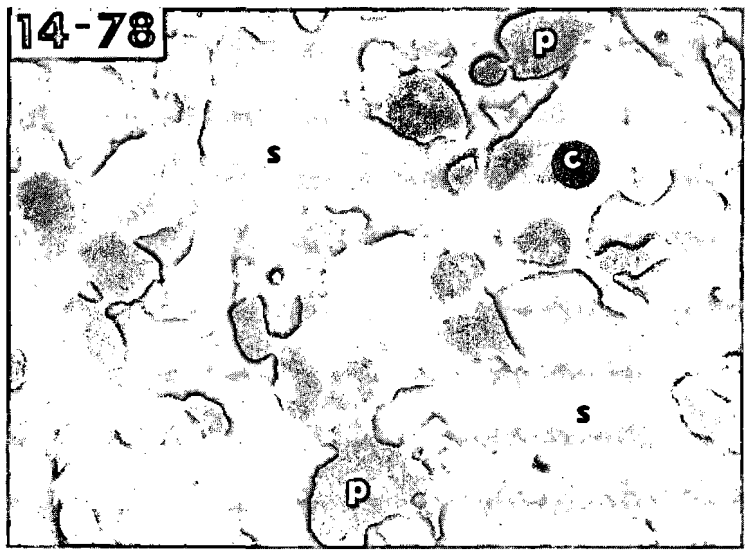

Figure 14-78 Higher magnification of hepatic plates (c) and sinusoids (s) in 80B8. Note dark pigment (p) in sinusoids. H&E. 100X.

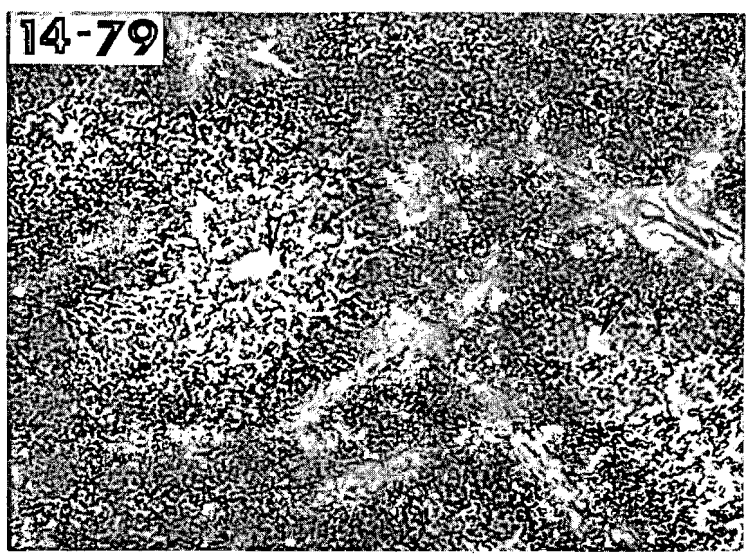

Figure 14-79 Note dilation of sinusoids toward central veins (arrowheads) in 80B8. AB/PAS. 2.5X.

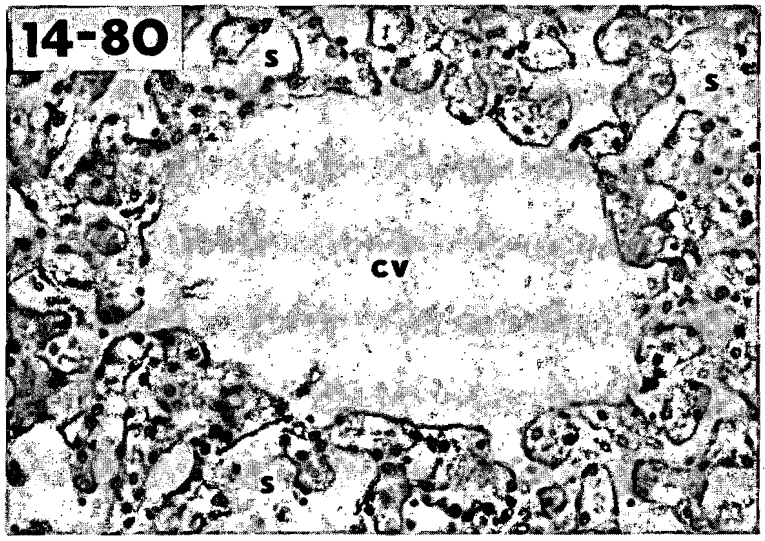

Figure 14-80 Higher magnification of sinusoidal dilation (s) near central vein (cv) in 80B8. H&E. 25X.

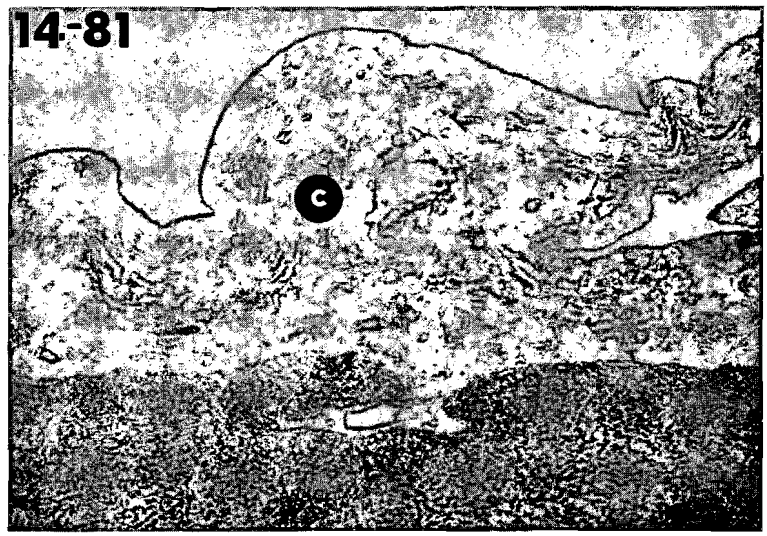

Figure 14-81 Note thick capsule (c) of liver of 80B1. H&E. 2.5X.

bundles (Fig 14-68). Groups of more lightly staining cells corresponding to the islets of Langerhans are seen within the bodies of the lobules (Figs 14-69 & 14-70). No differentiation of cell types within the islets could be made with the H&E stain. In one specimen (80B8) a ganglionic mass was seen within the substance of the pancreas (Fig 14-71). Structurally, this mass corresponds to a peripheral parasympathetic ganglion and is, if it agrees with other mammals, the recipient of preganglionic fibers conducted to it by way of the vagus nerve trunk.

LIVER - Histologic observations

Hepatic tissues from two individual bowheads (80B1 and 80B8) were examined. Structural differences were marked enough that the two will be described separately.

In 80B1 the classic liver lobule can be identified with portal triads stationed peripherally around a central vein, and communicating with it via a radiating array of sinusoids (Fig 14-72). Identifiable within the portal triads are arteries, veins and bile ducts. The bile ducts themselves tend to be rather small and at times difficult to distinguish. Lining the central vein is a rather thick complement of collagenous connective tissue (Fig 14-73). The hepatic plates creating the sinusoids generally appear to be two layers thick. Within the cytoplasm of the plate cells, small, golden brown granules are seen throughout with H&E. Another cell type scattered evenly within the liver parenchyma and generally situated along the edges of the plates can be seen. It has a "signet ring" appearance with a round, clear, nonstaining cytoplasm and basophilic nucleus flattened to one side of the cell (Figs 14-74 & 14-75). Within the sinusoidal spaces red blood cells are abundant and occasional accumulations of brownish pigment are seen. These pigment collections often appear to be contained within the cytoplasm of cells.

The basic liver lobule arrangement for whale 80B8 is the same as described for 80B1 (Fig 14-76). However, the globular cells with the flattened nucleus, so abundant in 80B1, cannot be identified in 80B8. The golden brown granules are present in the plate cells of this specimen as in 80B1. Remarkable in this whale, however, are extremely abundant accumulations of a very dark brown pigment (on H&E) in the sinusoids and apparently contained within the cytoplasm of individual cells (Figs 14-77 & 14-78). While these aggregations are seen also in 80B1, they are much more abundant in 80B8. In both whales, but especially in

80B8, there is a tendency for the sinusoids to be dilated increasingly as they approach the central vein (Figs 14-79 & 14-80). Venous tracts larger than the central vein are also present in the parenchyma and correspond to the sublobular and hepatic veins described for other mammals. These are lined by considerable collagenous connective tissue. A rather thick vascular capsule surrounds the liver and consists of collagenous connective tissue (Fig 14-81).

DISCUSSION

The basic structural organization of the esophagus is in general agreement with that of the domestic mammals and man in that it consists of a thick walled muscular tube lined by stratified squamous epithelium. In the most superficial portion (stratum corneum) of the epithelial lining a tendency for keratinization (cornification) was shown by a change in staining quality (increased eosinophilia with H&E) and by nuclear degeneration (pyknosis and nuclear remnants). Harrison et al (1970) and Yamasaki et al (1974), however, found no evidence of keratinization in the wall of the dolphin species which they examined. Keratinization of the lining is seen among the domestic mammals in the ruminants (especially) and horse. Pigs have a slight tendency for cornification. In carnivores (dog, cat) the esophagus is usually not keratinized according to Stinson and Calhoun (1976). However Evans and Christensen (1979) state that cornification does occur in the esophagus of the dog. Although a few keratohyalin granules can be demonstrated in man, keratinization does not occur (Bloom and Fawcett 1975). It is felt by some authors that an increase of coarse food intake (e.g. plant matter) enhances the need for a protective layer along the esophageal mucosa which is met by the keratinization process. If the roughness of the ingesta influences this process it could be speculated that the exoskeletons of the euphausiids, copepods and other components of the zooplankton (Lowry et al 1978) swallowed by the bowhead might sufficiently abrade the esophageal lining to at least initiate the keratinization observed.

Examination of the tissues available in this study suggest that mucoserous glands may be found predominantly in the cranial portion of the esophagus just caudal to the oropharynx where they occupy both the lamina propria and submucosa. This is a situation similar to that found in the submucosa of the esophagus at the pharyngoesophageal junction in the horse, cat and ruminant (Stinson and Calhoun 1976). In the dog, pig and ox these glands are of the mixed type (both mucous and serous) as found for the bowhead. However, in the dog and pig the distribution of these glands is more extensive. In the pig these glands are present in

the cranial half of the esophagus and in the dog they are found along the entire length of the esophagus. In man two types of esophageal glands are recognized based on structure: 1) esophageal cardiac glands (so named because of their structural resemblance to the cardiac glands of the stomach) found in the lamina propria just caudal to the oropharynx and just before entry into the stomach, and 2) esophageal glands proper located along the length of the esophagus in the submucosa. Both types are said to be entirely mucous (Bloom and Fawcett 1975; Weiss and Greep 1977). Dolphins are said not to have submucosal glands in the esophagus (Harrison et al 1970; Simpson and Gardner 1972; Yamasaki et al 1974). However, mucoserous glands have been observed by us in the submucosa of cranial esophagus of Tursiops in slides prepared by the Armed Forces Institute of Pathology. In these slides as well as in some sections of the bowhead esophagus these glands emptied into ducts which eventually met crypts sent down by the esophageal epithelium.

Lymphocytic elements were quite well developed both in nodular and diffuse forms in some of the sections examined. Those sections known to come from the cranial esophagus were especially endowed with lymphocytes. In portions of the mucosal lining of the esophagus, pores were grossly observed leading into these lymphoid nodules (and less frequently into mucoserous glands). Histologically, invaginations of the esophageal epithelium were sometimes seen forming crypts which led into an aggregation of lymphoid nodules (follicle). Such an arrangement prompts an analogy with the structure of tonsils as described in the oropharynx of dolphins and other mammals. Stinson and Calhoun (1976) mention occasional lymph nodules in the lamina propria of the domestic mammals.

The muscularis mucosae was very weakly developed in the bowhead esophagus. In the La Plata dolphin (Pontoporia blainvillei) Yamasaki et al (1974) stated that the muscularis mucosae was not conspicuous while Harrison et al (1970) described it as thick in the dolphin genera they studied (Tursiops, Stenella, Delphinus). In the domestic mammals, it exists as a longitudinal band of smooth muscle fibers, although it is absent from the cranial esophagus in the dog and pig (Stinson and Calhoun 1976; Evans and Christensen 1979). In man the muscularis mucosae replaces the elastic layer of the pharynx at the cricoid cartilage and extends the length of the esophagus (Bloom and Fawcett 1975; Weiss and Greep 1977).

All portions of the muscularis externa examined for the bowhead consisted of skeletal (striated) muscle. There was a tendency for three layers to

form, an inner longitudinal, middle circular and outer longitudinal. Since no tissues with certainty represented the caudal esophagus it is as yet not possible to make a final statement regarding muscle type at this level. However, in those tissue sections known to come from the cranial esophagus, skeletal muscle was found exclusively. In dolphins two layers are generally recognized -- an inner circular and outer longitudinal. In the La Plata dolphin Yamasaki et al (1974) found skeletal muscle in the first half of the esophagus, a mixture of skeletal and smooth in the middle and exclusively smooth in the lower esophagus. Harrison et al (1970) reported that in Tursiops, Stenella and Delphinus, skeletal muscle was found until near the end of the esophagus where smooth muscle replaced it. In the dog Evans and Christensen (1979) report two oblique external muscle layers which are striated throughout their length. Ruminants are also said to have a striated muscularis externa. In the horse, the cranial 2/3 is striated and the caudal 1/3 is smooth. In the pig, striated muscle becomes mixed with smooth muscle near mid-esophagus and is entirely replaced by smooth muscle caudally. The cranial 4/5 is said to be striated in the cat (Stinson and Calhoun 1976). In man, the arrangement is similar to the pig (Bloom and Fawcett 1975). Therefore, the character of the muscularis externa in the bowhead appears most similar to that of the dog and ruminant. However, further study will be necessary to confirm or refute this.

The stomach of the bowhead was multi-chambered. Although there is some variation among species, this generality applies to other cetaceans as well (Simpson and Gardner 1972). As noted in the introduction, over the years there has been some disagreement among investigators regarding the number of stomach chambers. Although there may be many reasons for the differences in opinion, two predominate. One involves recognition of the connecting channel as a stomach chamber. Reluctance to accord compartment status to this structure naturally alters the chamber count. Secondly, there has been some confusion regarding the duodenal ampulla -- some investigators designate this the final stomach compartment, while others claim it to be the start of the small intestine. We chose to acknowledge the connecting channel as a chamber in its own right and view the duodenal ampulla as the beginning of the intestine, an approach which appears to be the most common. This gives four chambers for the bowhead stomach, one nonglandular and three glandular. The fact of multi-compartmentalization itself invites an initial comparison with ruminants -- a mammal group well known for its many chambered stomach. However, in reality, the comparison is a

superficial one. In the ruminant the chambers are also four in number, but the first three (rumen, reticulum, omasum) are nonglandular and the last (abomasum) is glandular. In the bowhead, on the other hand, only the first chamber (forestomach) is nonglandular while the last three (fundic chamber, connecting channel, pyloric chamber) are glandular. Thus in the ruminant, the bulk of the compartmentalization occurs in the nonglandular portion of the stomach and for the bowhead (and other cetaceans) the divisions involve primarily the glandular region. The forestomach is the largest of the stomach chambers in the bowhead and forms a potentially expandable sac-like structure. Noting its nonglandular nature, Jungklaus (1898) described the forestomach as an "esophageal bulb" -- an evolutionary extension of the esophagus. It is found in most cetaceans; however, its absence has been noted in the family Ziphidae (beaked whales) (Turner 1889; Slijper 1962) as well as in the La Plata dolphin (Yamasaki et al 1974).

It is generally believed that this chamber serves as a temporary storage compartment for ingesta (which in cetaceans is swallowed whole without prior mastication). It is also said to initiate the digestive process with the mechanical kneading action made possible by its heavily muscled walls. However, the degree of digestion taking place here has remained something of a mystery. In dolphins which we have dissected the forestomach often contained fish and squid in various stages of breakdown. Yet in the following (fundic) chamber, the ingesta was already reduced to a gruel. Indeed, the orifice leading from the forestomach to the fundic chamber is often too small to accomodate passage of any but the most dissolved ingesta. This has been noted by others and there has been consequent speculation on the possibility of chemical digestion occurring to some extent in the first chamber (Tyson 1680; Turner 1889). Digestive glands have not been reported in the forestomach of any cetacean. Nor were they found in this chamber in the bowhead in the present study. Ridgway, working with Tursiops (Smith 1972), has measured the pH of forestomach contents and found them to be acidic (pH range 2.7-4.5). This suggests the possibility of the long suspected reflux of gastric juices from the fundic chamber into the forestomach making possible a low pH in a compartment which has no inherent way to produce such an acidity. And, using an endoscope, Ridgway has witnessed this reflux from the second chamber into the first (Ridgway 1972). Anatomical similarities between the bowhead and cetaceans in general suggest that these functional findings in Tursiops might be tentatively applied to the bowhead.

The outermost layer (nearest the lumen) of the epithelium lining the

bowhead forestomach was relatively thicker than in the esophagus. The character of the nuclei in the forestomach (pyknotic in the deeper portion and absent in the outer) gives the layer some claim to designation as a stratum corneum. More extensive development of keratin is a logical finding in this region for two reasons. First, the forestomach remains in contact with the ingesta in its roughest form for a longer period of time. This would ostensibly enhance keratin production. Secondly, the possible reflux of acidic gastric juices into this chamber may necessitate additional protection of the lining if auto-digestion is to be avoided. It is generally claimed that the forestomach lining is keratinized in the dolphin as well (Harrison et al 1970; Simpson and Gardner 1972; Smith 1972). Green (1972), however, stated that the lining was not keratinized.

In the domestic mammals other than the ruminants, the stomach is single chambered. However, nonglandular and glandular divisions can be found within it in some animals. In the horse for example, approximately the initial half of the stomach is nonglandular, ending at the glandular junction along a line known as the margo plicatus (Getty 1975; Stinson and Calhoun 1976). To a lesser extent, a nonglandular region extends from the esophagus into the initial portion of the stomach chamber of the pig. For the dog and cat no such non-glandular region exists (Stinson and Calhoun 1976; Evans and Christensen 1979), nor does it in man (Weiss and Greep 1977; Bloom and Fawcett 1979; Ham and Cormack 1979).

The fundic, or second, chamber in the bowhead stomach was shown histologically to contain the glands of digestion. However, in the initial portion of this chamber, the glands were not digestive in nature but rather were comprised entirely of mucous cells. This region corresponds then, by structural definition, to the cardiac region described in other mammals. However, in their study of Tursiops, Stenella and Delphinus, Harrison et al (1970) made no mention of a cardiac region. Similarly, we were not able to find such glands in our examination of Tursiops. Nor did Smith (1972) describe such a region for Phocoena. On the other hand, Yamasaki et al (1974) did find typical cardiac glands in the initial portion of the main stomach in Pontoporia. In 1971 Hosokawa and Kamiya examined the stomachs of the fin, sei, blue and sperm whales. Of these, they reported cardiac glands only for the blue whale. As far as we have been able to determine, their study is the only previous report of a cardiac region in a mysticete.

The cardiac region of the bowhead gave three positive histochemical

color reactions when exposed to AB/PAS. A blue reaction is generally said to be positive for an acid mucopolysaccharide while a pink one signifies a neutral mucopolysaccharide (Thompson and Hunt 1966; Sheehan and Hrapchak 1973). Thus the magenta coloration of the gastric pit cells indicates the presence of both acid and neutral mucopolysaccharides. In that portion of the neck of the gastric gland near the pit, the color reaction was blue, indicating production of an acid mucopolysaccharide. Just distal to this, the neck stained predominantly pink suggesting that neutral mucopolysaccharides were produced by these cells. The production of mucus in the neck of the gland identifies these cells as mucous neck cells. Hosokawa and Kamiya (1971) reported mucous neck cells in their study of the fin, sei, blue and sperm whales. They were also found by Simpson and Gardner in their investigations (1972). The possibility of mucous neck cells was reported by Yamasaki et al (1974) for Pontoporia, and Smith (1972) claimed to have found them in Phocoena. However, Harrison et al (1970) could find no such cells in the dolphins they examined. Both a cardiac region and mucous neck cells have been reported in the domestic mammals (Stinson and Calhoun 1976) and in man (Bloom and Fawcett 1975; Weiss and Greep 1977). Plasma cells were very abundant between the glands of the cardiac region. It has been established that these cells are the principal producers of humoral antibodies and originate from B lymphocytes (Bloom and Fawcett 1975; Ham and Cormack 1979). An initial impression from the tissues examined was that the numbers of plasma cells were particularly high in this region. Such an abundance might possibly be termed a plasmocytic inflammation if found in a similar location in the domestic mammals. However, until more tissues can be examined from the same region the significance of this observation in the bowhead cannot be determined.

Mucous reactions were also seen in the gastric pits and gland necks of the remainder of the fundic chamber. However, outside the cardiac region the makeup of the glands themselves was very much different. For most of the fundic chamber the glands were of the digestive type, comprised of parietal and chief cells. Parietal cells were occasionally seen in the necks of the glands among the mucous cells. In the main body of the gland, parietal cells seemed most numerous in the upper portions but were increasingly outnumbered by chief cells deeper in the gland. It is commonly noted that cetaceans have relatively higher numbers of parietal cells than land mammals. Chief cells still outnumber parietal cells 3:1 but by a lesser margin than in other mammals (Harrison et al 1970; Hosokawa and Kamiya 1971; Yamasaki et al 1974). In man, for example, the

chief cells outnumber the parietal cells 5-6:1 (Hosokawa and Kamiya 1971). Two suggestions have been made for this relatively greater abundance of parietal cells in cetaceans. One is that greater production of HCl (by the parietal cells) may be necessary to accomodate the metabolic rate of cetaceans which is generally recognized to be high. Secondly it has been suggested that each individual parietal cell may be less effective in its production of HCl so that greater total numbers are required to achieve the same result (Smith 1972). We have made no attempt as yet to derive a ratio for the bowhead.

The connecting channel was found to exist in the bowhead as a tubular structure of rather small diameter, forming a "U" shaped bend and joining the fundic and pyloric chambers. It has been recorded for the caàing whale (Murie 1874; Jungklaus 1898), the white beaked dolphin (Weber 1885; Turner 1889), Sowerby's whale (Turner 1889), the narwhal and beluga (Turner 1889; Jungklaus 1898), the bottlenosed dolphin and spotted dolphin (Harrison et al 1970), the harbor porpoise (Turner 1889; Jungklaus 1898; Smith 1972), the La Plata dolphin (Yamasaki et al 1974), the blue whale (Jungklaus 1898; Hosokawa and Kamiya 1971), and the sei and fin whales (Hosokawa and Kamiya 1971). Thus the connecting channel has been reported for both odontocetes and mysticetes. However, Hosokawa and Kamiya (1971) do not give it the status of a separate stomach chamber and note that proportionally it is best developed in the newborn. In the bowhead, although this channel is admittedly much smaller than other stomach compartments, it is grossly distinct from them with obvious importance for the flow of ingesta if the gruel is to reach the pyloric chamber. For this reason we have counted this channel as the third stomach compartment. The connecting channel was not examined histologically in our study. In other cetaceans its lining has been found to consist of mucous glands (Harrison et al 1970; Smith 1972; Simpson and Gardner 1972; Yamasaki et al 1974).

The pyloric chamber in the bowhead was also a tubular structure, but of considerably larger diameter than the connecting channel preceding it. This agrees with findings in other species of cetaceans (Green 1972). Although not examined histologically in our study, this chamber is said to house mucous type glands in other cetaceans (Harrison et al 1970; Simpson and Gardner 1972; Smith 1972; Yamasaki et al 1974). Microscopically, then, this chamber corresponds to the pyloric region of the abomasum in ruminants and the pyloric antrum of the stomach chamber in other mammals, including man (Stinson and Calhoun 1976; Bloom and Fawcett 1975).

A narrow sphincter terminated this chamber in our study and led into a dilated sac, the duodenal ampulla, which began the small intestine. This is in accord with the arrangement described for other cetacean species (Green 1972). As recently as 1971, however, Hosokawa and Kamiya treated the duodenal ampulla as the fourth chamber of the stomach in their examination of the fin, sei, blue and sperm whales. They used this approach in spite of recognizing a pyloric sphincter between the pyloric chamber and ampulla. Histologically these investigators found that the proximal half of the lining of the ampulla was structurally very similar to the pyloric chamber whereas the distal half was more closely related to the intestinal mucosa.

In the bowhead, the bile duct and pancreatic duct had already joined (hepatopancreatic duct) upon reaching the intestinal wall shortly after the termination of the ampulla. However, this duct continued to run in the intestinal wall for some distance before emptying into the intestinal lumen. This is similar to the situation reported for the La Plata dolphin by Yamasaki et al (1974). However, Green (1972), speaking of cetaceans in general, and Hosokawa and Kamiya (1971), describing the fin, sei and blue whales in particular, reported that the hepatopancreatic duct discharged directly into the duodenal ampulla. Murie (1874), writing on the caàing whale, described the duct's entrance into the ampulla just as it tapers into the duodenum proper. All investigators seem to agree that the bile and pancreatic products are carried via a single duct in cetaceans, at least from the time of reaching the intestine. In the domestic mammals, the bile and pancreatic ducts generally remain separate and join the intestinal lumen through separate orifices (Getty 1975; Evans and Christensen 1979). In man the bile duct and pancreatic duct may open into the intestinal lumen separately or through a single orifice (Gray 1970).

The small intestine of the bowhead was also examined grossly at its termination and junction with the colon, at which point the intestinal diameter abruptly enlarged. No cecum was found. The absence of a cecum is in disagreement with the observation of Slijper (1962) that mysticetes do have a cecum, although a very short one. However, he gives no information on the particular mysticete species on which his opinion is based. Omura et al (1969) report the absence of a cecum in the black right whale (Eubalaena). It is widely agreed that odontocetes lack a cecum (Murie 1874; Slijper 1962; Smith 1972; Yamasaki et al 1975; Harrison et al 1977) -- the single exception being the Gangetic dolphin, Platanista gangetica (Slijper 1962; Takahashi and Yamasaki 1972). The lack of a

cecum generally makes gross separation of the small and large intestines difficult in odontocetes, although Green (1972) notes that in the pigmy whale and beaked whales the large intestine is more prominent than in other odontocetes. In the bowhead, the absence of a cecum creates no difficulty in distinguishing the small and large intestines due to the dramatic change in diameter which occurs at their junction.

The absence of a cecum in the odontocetes (with one exception) and in the black right whale and bowhead (among the mysticetes) is in contrast to the domestic mammals in which such a structure is universally found (Stinson and Calhoun 1976). Andrew and Hickman (1974) note that there is no cecum in some mammals e.g., the insectivores.

Histologically, the small intestine was examined approximately 10 cm proximal to its junction with the colon. Typical villi comprised of absorptive cells (with microvilli) and goblet cells led into the crypts of Lieberkühn which were composed predominantly of mucous cells. These findings agree with those for other cetaceans. This arrangement was noted for Tursiops, Stenella and Delphinus by Harrison et al (1977). Additionally, these investigators reported the presence of enterochromaffin and Paneth cells in the crypts. Among the domestic mammals, Paneth cells have been reported for the horse and ruminants but are said to be lacking in the pig, dog and cat (Titkemeyer and Calhoun 1955). More sections need to be examined with the application of special stains before the occurrence of these additional cells types can be properly assessed for the bowhead. Simpson and Gardner (1972) noted an absence of villi from the proximal duodenum; however, villi began to appear farther down the tract and extended until the colon was reached. These authors maintain that Paneth cells are lacking in porpoises. Yamasaki et al (1975) could not find typical villi in the small intestine of Pontoporia but felt that inadequate fixation may have been responsible. Kleynenberg and Yablokov (1964) could not find typical villi in the beluga.

Lymphocytes were very common in the lamina propria of the sections of bowhead small intestine examined. They were arranged both diffusely just beneath and between the crypts of Lieberkühn and as nodules in the same area. The nodules began between the crypts and extended beneath them, approaching the submucosa. Simpson and Gardner (1972) described diffuse lymphocytes in the lamina propria of both the large and small intestines from the pylorus to the anus. They mentioned the presence of lymphoid nodules in the submucosa of a "short

segment of small intestine about 5 m distal to the pylorus" in the Atlantic bottlenosed porpoise. Yamasaki et al (1975) reported lymphoid nodules to be much more common in the lamina propria of the duodenum than in the pyloric stomach. They noted these nodules near the ileo-colic junction as well. The glands of Brunner found in the duodenal submucosa of the domestic mammals (Stinson and Calhoun 1976) are said to be absent in the cetaceans examined by Simpson and Gardner (1972). The initial portion of the small intestine was not examined histologically in the bowhead and no statement can yet be made concerning the occurrence of these glands in this species.

The villi and crypts of the mucosa found for the bowhead and reported in other cetaceans are very much in agreement with the structural organization in the domestic mammals (Stinson and Calhoun 1976) and man (Bloom and Fawcett 1975). However, our findings for the bowhead initially suggest that the length of the villus may not be proportionately as great as in other mammals. Our examination was in the terminal portion of the small intestine where villi are generally said to be longest in other species. In some cetaceans it has been determined that fewer villi are present than for mammals generally (Ridgway 1972).

In the domestic mammals, diffuse lymphocytes (in the lamina propria) and solitary lymphoid nodules (in the lamina propria and submucosa) are found throughout the length of the small intestine (Stinson and Calhoun 1976). The large aggregations of lymphoid nodules (Peyer's patches), reported to be most developed in the submucosa of the ileum of the domestic mammals and man, have yet to be confirmed for the bowhead.

The colon in the bowhead is grossly characterized by longitudinal folds which were interrupted by heavier circular ones. Many pores distinguished the surface of the mucosal lining. Long straight tubular glands composed of goblet cells comprised the mucosa. Plasma cells were very abundant in the lamina propria between the glands. Lymphocytes were commonly observed in diffuse and nodular forms. These findings are consistent with the account given for cetaceans (Simpson and Gardner 1972; Yamasaki et al 1975) and for the domestic mammals (Stinson and Calhoun 1976). However, we can find no report of the occurrence of a mucous gland deep to the surface intestinal glands as was found in one section of bowhead colon. Since only one such gland was found, its significance is difficult to speculate upon. However, since the gland was found near the colon's junction with the anal canal and since a similar gland was located beneath the epithelium of the anal canal, its occurrence in the colon may be

related to its proximity with the anal canal.

The glandular lining of the colon ended abruptly at the entrance to the anal canal which was lined by stratified squamous epithelium. Although no true keratinization was observed, the outermost stratum next to the lumen was characterized by increased eosinophilia and the presence of pyknotic nuclei. This nuclear change is similar to the early stages of the keratinization process, suggesting that this lining is capable of forming a stratum corneum should surface abrasion require it. Yamasaki et al (1975) noted that the stratified squamous lining of the anal canal in Pontoporia was nonkeratinized. In the domestic mammals and man a stratified squamous nonkeratinized epithelium is described for the anal canal (Stinson and Calhoun 1976; DiFiore 1974).

Lymphocytes were very common in the anal lamina propria in both diffuse and nodular forms. Several nodules frequently clustered together forming large lymphoid follicles extending into the submucosa. Grossly the anal mucosa was distinguished by numerous pores which communicated with these nodules by way of crypts -- the existence of which justifies a description of these follicles as tonsillar structures.

In 1966 Uys and Best reported well developed lymphoid tissue in the anal area of six male sperm whales (Physeter catodon). These lymphoid collections appeared as "lumps" externally visible around the anal opening. Crypts leading from these follicles to the squamous epithelial surface (although it is not clear whether the authors mean the external surface or anal canal lining) prompted use of the term "anal tonsil" by these investigators. The extent to which they considered these accumulations pathologic is not certain. Although over 2,000 carcasses were said to have been examined, these follicles were reported for only 6 individuals. Cowan and Brownell (1974) in their examination of gray whales (Eschrichtius robustus) found subepithelial lymphoid nodules in the wall of the anal canal just distal to the recto-anal junction. These nodules were aggregated into follicles which communicated by way of epithelial lined crypts with the surface of the anal canal. In describing this arrangement the authors used the term lymphoepithelial organ as well as "anal tonsil".

Although gut associated lymphoid tissue is common among the cetaceans (Simpson and Gardner 1972) the occurrence of tonsillar-like follicles in communication with the overlying epithelium is less frequently reported. Yamasaki et al (1975) were unable to find a lymphoepithelial organ in the anal wall of Pontoporia. However in an examination of the striped dolphin, Stenella

coeruleoalba, Yamasaki et al (1977) were able to locate well formed "anal tonsils" in the proximal three-fourths of the anal canal. Similarly they reported these lymphoid structures (although less well developed) in the proximal half of the anal canal of the Ganges dolphin, Platanista gangetica. In the Amazon river dolphin, Inia geoffrensis, they found diffuse lymphoid accumulations throughout the anal canal but no definite evidence of "anal tonsils". Among the domestic mammals, the occurrence of this tonsillar-like arrangement in the gut has been noted only for the dog and pig (Ortmann 1960). Cowan and Brownell (1974) note a morphologic resemblance of the "anal tonsil" in the gray whale to the avian bursa of Fabricius and even suggest that a functional correlation between the two might be considered. The bursa of Fabricius, a lymphoid aggregate occurring in the dorsal cloacal wall of chickens just distal to the junction of the intestine and cloaca (Hewitt 1952), is said to have the same significance in the activation of B lymphocytes as the thymus is known to have for T lymphocytes. Thus removal of the bursa in chickens causes a distinct suppression of the capacity for humoral immunity (Warner and Szenburg 1964). It should be noted, however, that the bursa of Fabricius is a structure of young chickens. At puberty the bursa begins to atrophy and by one year of age has virtually disappeared (Foust 1952). In contrast, the seven gray whales examined by Cowan and Brownell (1974) were adults. The bowheads investigated in our study were sexually immature. In their investigation of Platanista, Yamasaki et al (1977) were unable to find "anal tonsils" in one 76 cm specimen. However, this was a young animal and since "anal tonsils" were found in the adult specimens, the situation appears, as noted by these investigators, to be the reverse of that occurring in chickens. That is, it may be that in cetaceans the lymphoepithelial organ becomes better developed with maturity while in the chicken it begins involution at puberty. Because of this fundamental difference and the current lack of immunologic data to support a T cell maturation role, an analogy between the "anal tonsil" of whales and the avian bursa of Fabricius must remain tenuous.

In the wall of the anal canal of one bowhead, a mucous gland bordered on either side by lymphoid nodules was identified. An apparently similar arrangement exists in gray whales for whom Cowan and Brownell (1974) noted mucus secreting acini at the base of the "anal tonsil". Yamasaki et al (1977) described mucous glands in the same location in the Ganges river dolphin. Among the domestic mammals, the wall of the anal canal is described as nonglandular in

the horse and ruminants. However, for the dog, cat and pig modified sweat glands (anal glands) are reported in the submucosa. In the dog and cat a fatty secretion is produced; in the pig it is mucous. Additionally, glands of the anal sacs are described in dogs and cats, consisting of apocrine sweat glands in the dog and both apocrine and sebaceous glands in the cat. Finally, circumanal glands, comprised of modified sebaceous and sweat glands, are found in the mucosa of the anal canal of the dog near its junction with the skin (Stinson and Calhoun 1976). These circumanal glands, termed anal glands by Gray (1970), are also described in man (Bloom and Fawcett 1975). It would seem then that the mucous acini found in the wall of the anal canal in the bowhead and gray whale bear only a slight resemblance to the anal glands described for the domestic mammals and man.

Two very interesting instances of pathologic change involving the anal canal were noted in two of the bowheads examined. These lesions will be briefly mentioned here although no attempt will be made in this report to evaluate their pathologic significance. In one of the whales (80B9) three areas of erosion were noted on the surface of the anal canal near the junction of the canal with the large intestine. These were observed and measured by investigators at the harvest site (RU 180). Histologic processing of one of these lesions revealed a complete absence of surface epithelium. Cellular elements in the reactive area consisted mainly of lymphocytes although plasma cells, eosinophils and fibroblasts were very common, especially in the deeper portions. These characteristics classify this lesion as an ulcer. Ulcerated lesions were described in the anal canal of the gray whale by Cowan and Brownell (1974) in association with the anal tonsils. It appears from their brief description (their 1974 paper did not dwell on pathologic aspects) that the ulcers were located directly over the anal tonsils themselves. Two types of ulcers were recognized: 1) ulceration with inflammation and 2) ulceration with loss of regional structure. In the bowhead lesion, the abundance of lymphoid tissue allows at least the suggestion that ulceration may have centered over an area of lymphoid nodules in this case as well. Ulcerative lesions are reported to be common in the forestomach (which also has a stratified squamous lining) of both free-living and captive dolphins and are manifested by a variety of clinical signs (Sweeney 1978).

A second instance of pathologic change was observed around the veins in the submucosa of the anal canal in 80B1. It was characterized by an intense

infiltration of eosinophils around the veins. These cells crowded up to the endothelium of the vein and even invaded the substance of the valves. In the valves the result was an inflammatory thickening which in life undoubtedly compromised valve function. Eosinophils were very common in the stroma of the submucosa itself (although much less abundant than around the veins). Notably the eosinophils showed no tendency to collect in similar fashion around the arteries of the region. Although classically eosinophils are considered response cells to parasitic insult, the significance of this reaction will not be speculated on in this report.

The basic unit of the exocrine pancreas in the bowhead was the secretory acinus. Each acinus was comprised of pyramidal cells whose apical portion (next to the lumen) was filled with zymogenic granules. Centroacinar cells were frequently seen in the acinar lumen, beginning the intercalated duct which quickly gave rise to the intralobular ducts. Connective tissue septae divided the parenchyma of the pancreas into lobules and served as a conduit for the interlobular ducts, nerve trunks and vascular elements. The endocrine pancreas consisted of readily identifiable islets of Langerhans. Differentiation of the cell types within the islets was not possible with the stains used in this study. Hill (1926) found the islets of Langerhans to be plentiful in the porpoise but reported that the cell number for each islet seemed small. Simpson and Gardner (1972) noted that the islets were few in number in the cetaceans they examined. In the bowhead there was no impression of a number or size difference for the islets as compared to mammals generally. No evidence of a Pacinian corpuscle, frequently reported for the cat, was found in the bowhead. It appears from this initial investigation that pancreatic organization in the bowhead is in agreement with that described for the domestic mammals and man (Stinson and Calhoun 1976; Bloom and Fawcett 1975).

Histologically the liver of the bowhead is contained within a thick capsule of collagenous connective tissue. In accordance with the classic hepatic lobule concept of liver organization, the parenchyma could be visualized as a collection of lobules, each surrounded by connective tissue and composed of plates of cells separated by sinusoids which radiate toward, and empty into, a central vein. With H&E stain it appeared somewhat more difficult to distinguish this lobulation in the bowhead than in the domestic mammals. However by applying the AB/PAS stain this arrangement was more easily discerned because of the contrast created between the hepatic plate cells and the surrounding connective

tissue. Other models of liver organization such as the portal lobule and liver acinus concepts also have merit (Stinson and Calhoun 1976) and can probably also be applied to the bowhead. Positioned in the connective tissue around the periphery of the lobules (and thus between neighboring lobules) are the portal triads containing vascular elements and bile ducts. The lobules themselves consisted of hepatic plates spaced to create a series of sinusoids which united with a central vein. Dilation of the sinusoids was commonly seen as they approached the central vein. In contrast to the domestic mammals, considerable collagenous connective tissue lined the walls of the central veins. Even in the pig where hepatic lobules are well demarcated by the connective tissue surrounding them, the walls of the central veins do not show such a fibrous accumulation. In some sections of the bowhead liver the central veins could be seen to drain into larger veins (often called sublobular or interlobular veins in other mammals). The lining of these larger veins also contained considerable amounts of connective tissue.

In an examination of Caperea, Cave and Aumonier (1961) had difficulty in distinguishing the classic pattern of liver lobulation and were unable to consistently recognize definite central veins within the parenchyma. This same obscurity was noted by these investigators for the sperm whale (Physeter catodon) and the humpback whale (Megaptera novaeangliae) leading them to suggest that this was a general feature of the liver in cetaceans. For this reason they proposed an alternate theory of hepatic drainage which stated that enlarged sinusoids unite directly to form sublobular veins at the periphery of the lobule. These authors recognized, then, the same sinusoidal dilation in the livers of the three whale species examined as we found for the bowhead. However, rather than dilating toward a central vein as we have described in this report, these investigators believe that the sinusoids dilate in the vicinity of and empty directly into an interlobular vein. The same authors note that for the small odontocete, Lagenorhynchus cruciger, however, the hepatic arrangement is more in agreement with the general mammalian form.

The hepatic plates forming the walls of the sinusoids appeared to be two cell layers thick. The cytoplasm of the hepatocytes was remarkable in that it contained an abundance of a yellowish brown pigment. Although special analytic techniques have not yet been applied, this pigment has the appearance of hemosiderin. In 1980 Fouty and Gornall reported finding a strange form of hemochromatosis in the bowhead liver. Hemochromatosis is a rare condition seen

in man characterized by the deposition of large amounts of a pigment "indistinguishable from hemosiderin" in the cytoplasm of hepatic and pancreatic cells (Smith and Jones 1968). It is thought to be caused by a genetic defect in metabolism and is accompanied, among other things, by cirrhosis of the liver. However Fouty and Gornall found no evidence of liver scarring or other liver damage in their bowhead liver specimens. This agrees with the findings of our study. Although true hemochromatosis has not been reported for animals as it is seen in man, heavy hemosiderin deposition has been known to occur in horses affected with equine infectious anemia and in anemias associated with copper and cobalt deficiencies (delaying the formation of hemoglobin such that iron in the form of hemosiderin is phagocytized by various cells). A lesser degree of hemosiderin deposition is said to occur during any episode of hemolytic anemia because of the resulting release of hemoglobin. This process is termed hemosiderosis (Smith and Jones 1968). These comparisons make the occurrence of hemosiderin deposits all the more interesting since neither a hemolytic anemia nor inborn metabolic defect would be suspected for all of the several bowheads examined. Fouty and Gornall noted that the degree of pigment deposition increased in larger, older whales. The significance of hemosiderin accumulation in the hepatocytes of whales that otherwise appear to be normal remains to be learned. Hemosiderin deposits were not found in the pancreas of either of the two whales for whom heavy pigmentation was observed in the liver. It is interesting to note that of the two livers examined by us, one was from an Ingutuk (80B8) and the other was from a regular bowhead (80B1). Thus the results of this study suggest that this rather unusual form of pigment metabolism is found in both.

One other type of pigment was observed in the livers of both whales. However it was by far more common in the Ingutuk. It was a very dark pigment located in the sinusoids. In some instances it appeared to be contained within the cytoplasm of apparently phagocytic cells. However, when a distinct nucleus of such a cell could not be discerned it was impossible to judge whether the pigment was extracellular or intracellular. The pigment mass itself was not only much darker but generally considerably larger than the yellowish brown pigment of the hepatocytes. It had the appearance of melanin with H&E preparations. However, since the dark appearance of the pigment faded somewhat when other stains were applied, a change not usually seen with melanin, the specific identity of this pigment must await further testing.

Another interesting finding in the bowhead liver was an abundance of

globular cells distinguished by an expanded cytoplasm and nucleus flattened to one side. These were scattered randomly throughout the parenchyma and had the appearance of the fat storing cells described by Ito (1951 & 1968) in the liver of man. Although we have not yet applied special stains for content, the non-staining nature of the cytoplasm and its negative histochemical reaction for mucus at least does not refute the suggestion that these are in fact fat storing cells. These cells, also called lipocytes, have been studied in the rat liver and are positioned in the space of Disse between the hepatocytes and the endothelium of the sinusoid. In this way they aid in supporting the endothelial wall and may be classified as an interstitial cell of the liver parenchyma (Ham and Cormack 1979). They are now recognized as separate and distinct from the Kupffer cell. Notably, these cells, so abundant in the liver of the regular bowhead examined, could not be identified in the liver of the Ingutuk (possibly they were not seen due to a lack of cytoplasmic filling). The significance which these cells hold for the metabolism of the animal in which they are found is not yet clear. Should they be an index of food intake and storage it would be interesting to speculate on their active abundance in only one of two whales examined -- especially since both were harvested during the spring migration when stomachs are generally found to be empty and feeding has only begun (Lowry et al 1978). However, stomach fluid was noted and sampled by RU 180 for whale 80B1. Further observations will be necessary to aid in defining the nature and occurrence of these cells in the liver of the bowhead.

SUMMARY

The alimentary canal of the bowhead shares many similarities with that of other cetaceans (both mysticetes and odontocetes) in particular and other mammals in general. The esophagus is a thick walled tube of relatively narrow gauge and is lined by a stratified squamous mucosa with a tendency for keratinization. Both mucoserous glands and lymphoid nodules are frequent in its walls, especially at the cranial end. The stomach itself is comprised of four chambers, the first of which is the largest and is nonglandular. The lining of this first chamber, the forestomach, differs from that of the esophagus only by more extensive infolding, a greater tendency for keratin production and the apparent absence of both subepithelial glands and well-developed lymphoid collections.

The remaining three compartments of the stomach are glandular in appearance and consist of the fundic chamber, connecting channel and pyloric chamber. The entire lining of the fundic chamber is distinguished by a multitude

of gastric pits (foveolae) which are lined by columnar mucous cells and which lead into the glands themselves. In the initial portion of the fundic chamber these glands are mucous, thus forming a cardiac region. For the mysticetes a cardiac region has been previously reported only for the blue whale. The remaining glands of the fundic chamber contain the cells of chemical digestion, the parietal and chief cells. Mucous neck cells were also identified in the proximal portions of the glands.

The connecting channel is a narrow gauge tubular structure with a glandular appearing mucosa leading from the fundic chamber. After making a "U" shaped bend it empties into the final, or pyloric, chamber. The pyloric chamber, whose lining is also glandular in appearance is tubular but has a larger diameter than the connecting channel. It communicates with the small intestine though a narrow pyloric sphincter.

The small intestine begins as a dilated sac termed the duodenal ampulla. This sac tapers rather abruptly into the duodenum proper which has a more narrow but consistent diameter. Shortly after the beginning of the duodenum proper the intestinal wall receives the combined duct (hepatopancreatic duct) for the transport of bile and pancreatic products. This duct travels in the intestinal wall for a distance before discharging its contents into the intestinal lumen. The mucosa of the small intestine is lined by villi which lead into the crypts of Lieberkühn.

The small intestine ends abruptly where a sudden enlargement in intestinal diameter marks the start of the colon. No cecum is present. The colon mucosa is lined by straight tubular glands dominated by columnar mucous cells. Lymphocytic elements are common throughout the wall of the colon.

The mucosal lining changes abruptly to a stratified squamous epithelium upon junction of the large intestine with the anal canal. Numerous crypts lead into well developed subepithelial aggregations of lymphoid nodules in this region. One of three surface erosions in the anal canal was examined histologically and identified as an ulcer. An apparently pathologic accumulation of eosinophils was noted surrounding the veins in the submucosa of the anal canal. This cellular invasion appeared to affect valve structure within the veins.

The bowhead pancreas consists of both exocrine and endocrine fractions which are structurally very much in agreement with mammals generally. The liver, on the other hand, contained an abundant deposition of yellowish brown granules (possibly hemosiderin) in its hepatocytes. In other mammals the presence of

these granules would indicate a pathologic process. A melanin-like pigment was also observed in the hepatic sinusoids, especially in the Ingutuk. A cell type, apparently corresponding to the lipocyte, was seen randomly and abundantly scattered throughout the hepatic parenchyma in the regular bowhead. Although this cell could not be identified in the Ingutuk, a lack of cytoplasmic filling may have obscured its presence. The lobular arrangement for the bowhead liver is similar to other mammals, with sinusoids emptying into central veins which in turn discharge into larger, sublobular veins. Regions of sinusoidal dilation could be seen as has been reported for a few of the other great whales. In contrast to land mammals, the central and sublobular veins were lined by considerable collagenous connective tissue.

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REFERENCES

Andrew, W. and C. P. Hickman. 1974. Histology of the Vertebrates, a comparative text. C.V. Mosby Co., St. Louis.

Berzin, A. A. 1972. The Sperm Whale (Kashalot). Israel Program for Scientific Translations, Jerusalem. Translated from Russian.

Bloom, W. and D. W. Fawcett. 1975. A Textbook of Histology. pp. 639-742. W. B. Saunders Co., Philadelphia.

Cave, A. J. E. and F. J. Aumonier. 1961. The visceral histology of the primitive cetacean, Caperea, (Neobalaena). J. Roy. Micr. Soc. 80(1):25-333.

Cowan, D. F. and R. L. Brownell, Jr. 1974. Gut-associated lymphoepithelial organ ("anal tonsil") in the gray whale. In: Functional Anatomy of Marine Mammals, Vol. 2, R. J. Harrison (ed.) pp. 321-327. Academic Press, London.

Di Fiore, M. S. H. 1974. Atlas of Human Histology, 4th Ed. pp. 152-153. Lea & Febiger, Philadelphia.

Evans, H. E. and G. C. Christensen. 1979. Miller's Anatomy of the Dog, 2nd Ed., pp. 455-506. W. B. Saunders Co., Philadelphia.

Fetter, A. W. and J. I. Everitt. 1979. Tissues (structure/function) (RU 280a). In: Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of the Beaufort Sea Lease Area, J. Kelley and G. Laursen (eds.), pp. 331-358. Final Report to the Bureau of Land Management from the Naval Arctic Research Laboratory, Barrow, Alaska.

Foust, H.L. 1952. Anatomy. In: Diseases of Poultry, H. E. Biester and L. H. Schwarte (eds.), p. 13, Iowa State College Press, Ames, Iowa.

Fouty, R. A. and T. A. Gornall. 1980. Hemochromatosis in the bowhead whale (Balaena mysticetus). Paper presented to the International Association for Aquatic Animal Medicine, 11th Annual Conference and Workshop, Vancouver, Canada.

Getty, R. 1975. Sisson and Grossman's The Anatomy of the Domestic Animals, Vols. 1 & 2, 5th Ed. W. B. Saunders Co., Philadelphia.

Gray, H. 1970. Anatomy of the Human Body, 28th Ed., C. M. Goss (ed.), pp. 1206-1263. Lea & Febiger, Philadelphia.

Green, R. F. 1972. Observations on the anatomy of some cetaceans and pinnipeds. In: Mammals of the Sea, Biology and Medicine, S. H. Ridgway (ed.), pp. 264-265. Charles C. Thomas Co., Springfield, Illinois.

Ham, A. W. and D. H. Cormack. 1979. Histology, 8th Ed. J. B. Lippincott, Philadelphia.

Harrison, R. J., F. R. Johnson and B. A. Young. 1970. The oesophagus and stomach of dolphins (Tursiops, Delphinus, Stenella). J. Zool., Lond. 160: 377-390.

Harrison, R. J., F. R. Johnson and B. A. Young. 1977. The small intestine of dolphins (Tursiops, Delphinus, Stenella). In: Functional Anatomy of Marine Mammals, R. H. Harrison (ed.), Vol. 3, pp. 297-331. Academic Press, New York.

Hewitt, E. A. 1952. Digestion. In: Diseases of Poultry. H. E. Biester and L. H. Schwarte (eds.), pp. 32-33. Iowa State College Press, Ames, Iowa.

Hill, W. C. O. 1926. A comparative study of the pancreas. In: Proceedings of the General Meetings for Scientific Business of the Zoological Society of London, pp. 581-631.

Hosokawa, H. and T. Kamiya. 1971. Some observations on the cetacean stomachs with special considerations on the feeding habits of whales. Sci. Rep. Whales Res. Inst., Tokyo, 23:91-101.

Ito, T. 1951. Cytological studies on stellate cells of Kupffer and fat-storing cells in the capillary wall of the human liver. Acta Anat. Nippon 26:2.

Ito, T. and S. Shibasaki. 1968. Electron microscopic study on the hepatic sinusoidal wall and the fat-storing cells in the normal human liver. Arch. Histol. Jap. 29:137.

Jungklaus, F. 1898. Der Magen der Cetaceen. Jena Z. Naturw. 32:1-94.

Kenney, R. M. and J. I. Everitt. 1979. Tissues (structure/function) (RU 579b). In: Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of the Beaufort Sea Lease Area, J. Kelley and G. Laursen (eds.), pp. 227-263. Final Report to the Bureau of Land Management from the Naval Arctic Research Laboratory, Barrow, Alaska.

Kleynenberg, S. Y. and A. B. Yablokov. 1964. Beluga -- Results of Monographic Investigation of the Species. Moscow, Academy of Sciences of the U.S.S.R.

Lowry, L. F., K. J. Frost and J. J. Burns. 1978. Food of ringed seals and bowhead whales near Point Barrow, Alaska. Can. Field-Nat. 92(1):67-70.

Murie, J. 1874. On the organization of the caàing whale, Globiocephalus melas. Trans. Zool. Soc. Lond. 8:235-301.

Omura, H., S. Ohsumi, T. Nemoto, K. Nasu and T. Kasuya. 1969. Black right whales in the North Pacific. Sci. Repts. Whales Res. Inst. 21:1-78.

Ortmann, R. 1960. Über den lymphatischen Apparat der Analregion und die sogenannte "Analtonsille" bei Saugetieren. Eine vergleichend histologishe Studie. Z. Anat. Entwicklungs., 121:459-477.

Ridgway, S. H. 1972. Homeostasis in the aquatic environment. In: Mammals of the Sea, Biology and Medicine, S. H. Ridgway (ed.), pp. 590-747. Charles C. Thomas Co., Springfield, Illinois.

Sheehan, D. C. and B. B. Hrapchak. 1973. Theory and Practice of Histotechnology. pp. 86-101. C. V. Mosby Co., St. Louis.

Simpson, J. G. and M. B. Gardner. 1972. Comparative microscopic anatomy of selected marine mammals. In: Mammals of the Sea, Biology and Medicine, S. H. Ridgway (ed.), pp. 340-353. Charles C. Thomas Co., Springfield, Illinois.

Slijper, E. J. 1962. Whales. Hutchinson & Co., London.

Smith, G. J. D. 1972. The stomach of the harbor porpoise Phocoena phocoena (L.) Can. J. Zool. 50:1611-1616.

Smith, H. A. and T. C. Jones. 1968. Veterinary Pathology. pp. 72-75. Lea & Febiger, Philadelphia.

Stinson, A. W. and M. L. Calhoun. 1976. Digestive system. In: Textbook of Veterinary Histology, H. Dellman and E. Brown (eds.), pp. 207-264. Lea & Febiger, Philadelphia.

Sweeney, J. 1978. Noninfectious diseases. In: Zoo and Wild Animal Medicine, M.E. Fowler (ed.), pp. 599-600. W. B. Saunders Co., Philadelphia.

Takahashi, K. and F. Yamasaki. 1972. Digestive tract of Ganges dolphin, Platanista gangetica. II. Small and large intestines. Okajimas Fol. Anat. Jap. 48:427-452.

Thompson, S. W. and R. H. Hunt. 1966. Selected Histochemical and Histopathological Methods. pp. 462-467. Charles C. Thomas Co., Springfield, Illinois.

Titkemeyer, C. W. and M. W. Calhoun. 1955. A comparative study of the structure of the small intestine of domestic animals. Am. J. Vet. Res. 58:152.

Turner, W. 1889. Additional observations on the stomach in the ziphoid and delphinoid whales. J. Anat. Lond. 23:466-492.

Tyson, E. 1680. Phocoena, or the anatomy of a porpess dissected at Gresham College, with a preliminary discourse concerning anatomy and a natural history of animals, London, printed for Benjamin Toole. Reprinted in: Dublin's Philosophical Journal, 2:48-260, 192-207, 1826.

Uys, C. J. and P. B. Best. 1966. Pathology of lesions observed in whales flensed at Saldanha Bay, South Africa. J. Comp. Path. 76:407-412.

Warner, N. L. and A. Szenburg. 1964. Immunologic studies on hormonally bursectomized and surgically thymectomized chickens; dissociation of immunologic responsiveness. In: The Thymus in Immunobiology, R. A. Good and A. E. Gabrielsen (eds.), pp. 395-411. Harper & Row, New York.

Weber, M. 1885. Anatomisches uber Cetaceen. II. Über den Magen der Cetaceen. Gegenbaur Mikrosk. Jahrb. 13:637-663.

Weiss, L. and R. O. Greep. 1977. Histology, 4th Ed. McGraw-Hill, Inc., New York.

Yamasaki, F., K. Takahashi and T. Kamiya. 1974. Digestive tract of La Plata dolphin, Pontoporia blainvillei. I. Oesophagus and stomach. Okajimas Fol. Anat. Jap. 51:29-52.

Yamasaki, F., K. Takahashi and T. Kamiya. 1975. Digestive tract of La Plata dolphin, Pontoporia blainvillei. II. Small and large intestines. Okajimas Fol. Anat. Jap. 52:1-26.

Yamasaki, F., S. Komatsu and T. Kamiya. 1977. A comparative morphology of anal tonsils in Platanistidae. Sci. Rep. Whales Res. Inst., Tokyo, 29:95-100.

RESEARCH UNIT 1580

HEARING IN THE BOWHEAD WHALE, BALAENA MYSTICETUS, AS ESTIMATED BY COCHLEAR MORPHOLOGY

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INTRODUCTION

There is concern that activities associated with the development of oil and gas resources off the north slope of Alaska may have significant impacts on the marine environment and its inhabitants. Among the probable perturbations are expected increases in ambient noise at various frequencies. To assess the impact of such increases on bowhead whales, Balaena mysticetus, it is necessary to understand their auditory response capabilities, particularly within the frequency spectra likely to be generated.

To date, auditory response capabilities have generally been measured through direct interrogation of live individuals which are presented with a sound of known frequency and source level and their ability to hear that sound is determined from behavioral or electrophysiological responses (Francis 1975). Such techniques have been utilized in various pinnipeds and small odontocete cetaceans (see Norris and White 1978 for review). However, because of their large size and rarity in captivity (see Evans 1974), hearing abilities in mysticete cetaceans have not been tested. Instead, the few available estimates of mysticete hearing abilities have resulted from consideration of the comparative morphological characteristics of their auditory organs (eg. Fleischer 1976a).

We examined bowhead whale auditory morphology, focusing on the basilar membrane and support structures, as a basis for assessing the

species' auditory response capabilities. The observed structures were then compared to those of other cetacean species. Results support only guarded speculations about the bowhead whale's probable hearing abilities.

OBJECTIVES

The stated objective of this project was to estimate the auditory response capabilities of the bowhead whale by:

1) examining mass ratios of the ossicles and details of cochlear morphology (length and width of basilar membrane and fine structure of trabeculae of the spiral laminae) and making inferences about hearing ability within the theories of cochlear mechanics, and
2) comparing observed cochlear morphology of the bowhead whale, and resultant inferred hearing abilities, with that of other cetaceans.

METHODS

We obtained a total of 44 earbones of eleven cetacean species, six odontocetes and five mysticetes (Table 15-1).[1] There were no data available on sex, external dimensions or location of collection for any specimen. Specimens were either dry museum preparations or preserved in 10% formalin. Materials were examined to the extent that quality of their preservation and owners' guidelines for use permitted. Whenever material permitted, we weighed all or part of the ossicular chain (malleus, incus and stapes), counted the cochlea turns, determined basilar membrane dimensions and characterized the internal structure of spiral laminae. Unless otherwise noted, all measurements reported below were taken from bowhead specimen FED 4403 L (see Figs 15-1 through 15-3 for identities and names of parts as referred to in the text).

Ossicular mass ratios have been related to hearing capabilities in bottlenose dolphins, Tursiops truncatus (Fleischer 1978). We weighed

[1]Unfortunately, political and logistical difficulties at Alaskan collection sites prevented personnel of Research Unit 180 from procuring any Eskimo harvested bowhead whale ears for this study. The bowhead specimens we used were obtained through the Los Angeles County Museum. They were collected by Dr. Floyd Durham during his trips to the Arctic in the 1960's.

elements of the ossicular chain of 32 odontocetes and 8 bowheads on a Sartorious model 2003MPI torsion balance and calculated ossicular mass ratios by:

$$M/S : I/S : S/S \qquad \text{(following Awbrey et al 1979)}$$

and

$$\frac{M + I}{S} : S/S \qquad \text{(following Fleischer 1978)}$$

where symbols indicate weight of malleus (M), icus (I) and stapes (S) (see Fig 15-2).

To examine the morphology of the inner ear it was necessary to open the cochlea. Using a standard surface preparation technique (Hawkins and Johnson 1968) the basilar membrane and its support structures were exposed for removal or for examination in situ. This was accomplished for this study in one bowhead (FED 4403L) and one Dall porpoise, Phocoenoides dalli. Specimens previously prepared in this manner (Awbrey et al 1979) were also examined (Table 15-3). The membrane was stained with OsO_4. Autolysis rapidly destroys the Organ of Corti, so none were present.

The number of turns and general morphology of the cochlea were determined with the basilar membrane in situ. Next, the length and width of the basilar membrane of the bowhead specimen were measured by removing the membrane, mounting it on a microscope slide, photographing it, then measuring its image on photomicrographs. The odontocete specimens were measured by projecting the basilar membrane image onto a calibrated microscope screen.

Basilar membrane specimens from the above bowhead whale and from a Dall porpoise were decalcified in 5% TCA, imbedded in paraffin and serially cross sectioned at 5 μm thicknesses. These cross sections made possible further descriptions of the internal structure of the spiral laminae. The spiral laminae form the support structure for the basilar membrane. An increase in stiffness of the spiral laminae apically to basally (referred to hereafter as the stiffness gradient) is created by changes in the laminae's trabeculated internal construction. The basilar membrane width decreases apically to basally. These changes combine to form a similar stiffness gradient in the entire inner ear

structure. This gradient largely determines the inner ears' vibrational capabilities and thus the frequencies it can detect (Steele 1974).

Two other cochleas were treated in a different manner, one damaged specimen from a bowhead (FED 4383R) and one from a Dall porpoise. The ventral sides of these cochleas were removed using a bone saw. This exposed the tympanal aspects of the basal turns and permitted direct photographic examination and comparison of the basilar membranes *in situ*.

Heliocotrema area has been related to low frequency hearing capabilities (Dallos 1970). The area of the helicotrema was determined by direct examination *in situ* of an opened bowhead cochlea.

Selected segments of the spiral laminae from dried cochleas of a bowhead whale (FED 4403), a right whale, *Balaena glacialis* (USNM 269161), and a minke whale, *Balaenoptera acutorostrata* (USNM 314864), were removed, gold plated, mounted on stubs and examined and photographed under a Cambridge S4 scanning electron microscope (SEM). These photomicrographs permitted further examination of the trabeculae of the spiral laminae. Observations were then compared to those from similar photomicrographs taken by Fleischer (1976b) of the laminae of *Tursiops truncatus*.

RESULTS

Ossicular weights and ossicular mass ratios are presented in Table 15-2 for 29 individuals of 6 odontocete species and 9 bowhead whales. The results show that the mean of the ossicular mass ratios for the bowhead specimens is intermediate between those of delphinid and those of phocoenid species.

The numbers of turns in the cochlea and the dimensions of the basilar membranes of 29 individuals of 5 odontocete species and 1 bowhead whale are given in Table 15-3. The bowhead basilar membrane was 2.5 to 7.5μm thick. The membrane was not separated into tecta and pectinate segments so there was no apparent hinging pattern. The approximately round helicotrema was 0.43 mm in radius with an area of 0.57 mm^2. The limbus varied in thickness from approximately 100μm apically to 135μm near the basal end.

A series of photomicrographs illustrates the successive changes in the basilar membrane width along an apical-basal gradient of a bowhead whale cochlea (FED 4403L). Fig 15-4 shows the tympanal side of the basal turn. The extreme basal end of the cochlea is broken off. The smooth increase in the width of the basilar membrane is illustrated in Figs 15-5 through 15-7. For comparison, photos are presented of Dall porpoise cochleas (Fig 15-8, Figs 15-9 and 15-10) from approximately the same locations and perspectives. Special attention is directed towards the visible differences between the 2 species in basal coiling patterns and basilar membrane widths.

Figs 15-11 through 15-13 present a series of radial and basal cross sections of a bowhead primary spiral lamina. The overall thickness of the primary spiral lamina increases from 60 to 300μm between the apex and the basal end. On the axial side at the basal turn, the vestibular faceplate is 100μm thick, the tympanal faceplate is 80μm thick. Apically, where the basilar membrane is connected to the laminae, the two faceplates of the primary lamina are separated by 8μm; basally they are connected.

The structure of the laminae change along the length of their long axis, primarily by incorporating into their internal structure three size classes of lumen, created by progressively more complex interpartitioning. Apically there is a large lumen (25-60μm in diameter) which carries nerves to the Organ of Corti. At this location this lumen lies on the tympanal side of the lamina. By the middle segment of the cochlea, secondary lumen form in the internal partitions to the larger lumen. Finally, near the basal end, tertiary lumen form inside recesses in these partitions. The diameter of the bone making up this meshwork increases basally from 5 to 10μm. By this construction, internal cross-beaming with increased interstitial spaces, and thicker faceplates, the laminae become thicker and stiffer along this apical to basal gradient.

The cochlea of the Dall porpoise is also characterized by an increasing stiffness gradient, apically to basally (Figs 15-14 through 15-16). The porpoise's inner ear structures are stiffer than those in the bowhead whale, because of the relatively denser, more closely-knit meshwork and cross-bracing of the laminae and the relatively narrower basilar membrane.

TABLE 15-1. CETACEAN EARBONES EXAMINED. (SEE TEXT FOOTNOTE 1).

Specimen Number	Scientific Name	Common Name	Description of Materials	Preservation Dried	Preservation Formalin	Examination a	b	c	d	e	Lending Institution
Mysticeti											
Balaenidae											
LACM 54464	Balaena mysticetus	Bowhead whale	Entire tympano-periotic complex with ossicles	x		x	x				Los Angeles County Mus.
LACM 54471	"	"	Incus	x		x					"
FED 4405	"	"	Malleus	x		x					"
FED 4403	"	"	Periotic(L&R)		x		x	x	x	x	"
FED 4383	"	"	Periotic with ossicles		x	x		x			"
FED 4334	"	"	Incus	x		x					"
FED 4319	"	"	Malleus	x		x					"
FED 4391	"	"	Incus	x		x					"
USNM 269161	Balaena glacialis	Right whale	Tympano-periotic	x						x	Smithsonian
Balaenopteridae											
USNM 314864	Balaenoptera acutorostrata	Minke whale	"	x						x	"
FED	Balaenoptera odeni	Brydes whale	"	x			x				Los Angeles County Mus.
Eschrichtidae											
FED 4361	Eschrichtius robustus	Gray whale	"	x			x				"
Odontoceti											
Phocoenidae											
BKL 110 R	Phocoenoides dalli	Dall porpoise	Periotic with ossicles		x	x		x	x		Hubbs/Sea World Res. Inst.
BKL 074 R	"	"	"		x	x		x			"

TABLE 15-1. (CONTINUED)

Specimen Number	Scientific Name	Common Name	Description of Materials	Preservation Dried	Preservation Formalin	Examination a	b	c	d	e	Lending Institution
BKL 082 R	Phocoenoides dalli	Dall porpoise	Periotic with ossicles		x	x		x			Hubbs/Sea World Res. In
BKL 082 L	"	"	"		x	x		x			"
BKL 084 R	"	"	"		x	x		x			"
BKL 093 R	"	"	"		x	x		x			"
BKL 122 R	"	"	"		x	x		x			"
BKL 116 R	"	"	"		x	x		x			"
BKL 124 R	"	"	"		x	x		x			"
BKL 124 L	"	"	"		x	x		x			"
BKL 123 R	"	"	"		x	x		x			"
RYS 066 R	"	"	"		x	x		x			"
RYS 066 L	"	"	"		x	x		x			"
JCN 014 R	"	"	"		x	x		x			"
JCN 012 L	"	"	"		x	x		x			"
JCN 017 R	"	"	"		x	x		x			"
JCN 013 R	"	"	"		x	x		x			"
JCN 002 R	Phocoena phocoena	Harbor porpoise	"		x	x		x			"
JGM 273 R	"	"	"		x	x		x			Smithsonian
JGM 273 L	"	"	"		x	x		x			"
JGM 274 R	"	"	"		x	x		x			"
Delphinidae											
JCN 003 R	Delphinus delphis	Common dolphin	"		x	x		x			Hubbs/Sea World Res. In
JCN 003 L	"	"	"		x	x		x			"

TABLE 15-1. (CONTINUED)

Specimen Number	Scientific Name	Common Name	Description of Materials	Preservation Dried	Preservation Formalin	Examination a	b	c	d	e	Lending Institution
JCN 004 R	Delphinus delphis	Common dolphin	Periotic with ossicles		x	x		x			Hubbs/Sea World Res. In
JCN 005 L	"	"	"		x	x		x			"
JCN 001 R	Grampus griseus	Risso's dolphin	"		x	x		x			"
JCN 001 L	"	"	"		x	x		x			"
JCN 018 L	Tursiops truncatus	Bottlenosed dolphin	"		x	x		x			"
JCN 019 L	"	"	"		x	x		x			"
JCN 020 R	Orcinus orca	Killer whale	Ossicles		x	x					"

a Ossicular mass

b Tympano-periotic mass

c Basilar membrane dimensions

d Spiral laminae cross sections

e Spiral laminae scanning electron micrographs

TABLE 15-2. WEIGHTS AND MASS RATIOS FOR ELEMENTS OF THE OSSICULAR CHAINS OF 6 ODONTOCETE SPECIES AND FOR 8 BOWHEAD WHALES. (ODONTOCETE VALUES ARE MEANS CALCULATED FROM VALUES PRESENTED BY AWBREY et al. 1979).

	Weight (mgms)		
Specimen #	Malleus	Incus	Stapes
FED 4391		471	
FED 4319	939		
FED 4347		470	
FED 4296	1368		169
LACM 54471		508	
LACM 44005	886		
FED 4383		553	
FED 4403R	1349	641	
FED 4403L	1375		

	Mean Weights (mgms)			Mean Mass Ratios		
Species	Malleus	Incus	Stapes	M/S:I/S:S/S	(M+I)/S:S/S	# spec.
Balaena mysticetus	1183	529	169	8.1:3.1:1[(1)]	10.1:1	9
Phocoenoides dalli	71.7	18.4	9.8	7.3:1.8:1	9.2:1	16
Phocoena phocoena	64.9	15.9	8.6	7.5:1.8:1	9.4:1	4
Tursiops truncatus	135.4	32.6	8.9	15.2:3.7:1	18.9:1	2
Delphinus delphis	81.1	19.7	5.2	15.5:3.8:1	19.4:1	4
Grampus griseus	207.5	50.0	18.4	11.3:2.7:1	14.0:1	2
Orcinus orca	772.9		49.8	15.5: :1		1

(1) These figures are ratios of means for the values reported, not means of ratios.

Figure 15-1a. Lateral views of the tympano-periotic complexes from bowhead, gray and Bryde's whales. The middle ear is housed inside the tympanic bone(T). The inner ear is found in the periotic bone(P). The malleus is fused to the tympanic bone at the sigmoid process(→). The bowhead tympano-periotic complex is on the left.

Figure 15-1b. Medial view of the tympano-periotic complexes from bowhead, gray and Bryde's whales. The cochlea(C), part of the periotic bone(P) contains the inner ear apparatus. The tympanic bone(T) is a cowrie shaped bone carved by the Eskimos. The bowhead whale tympano-periotic complex is on the left.


15-1a
T
P
P
T
P
T

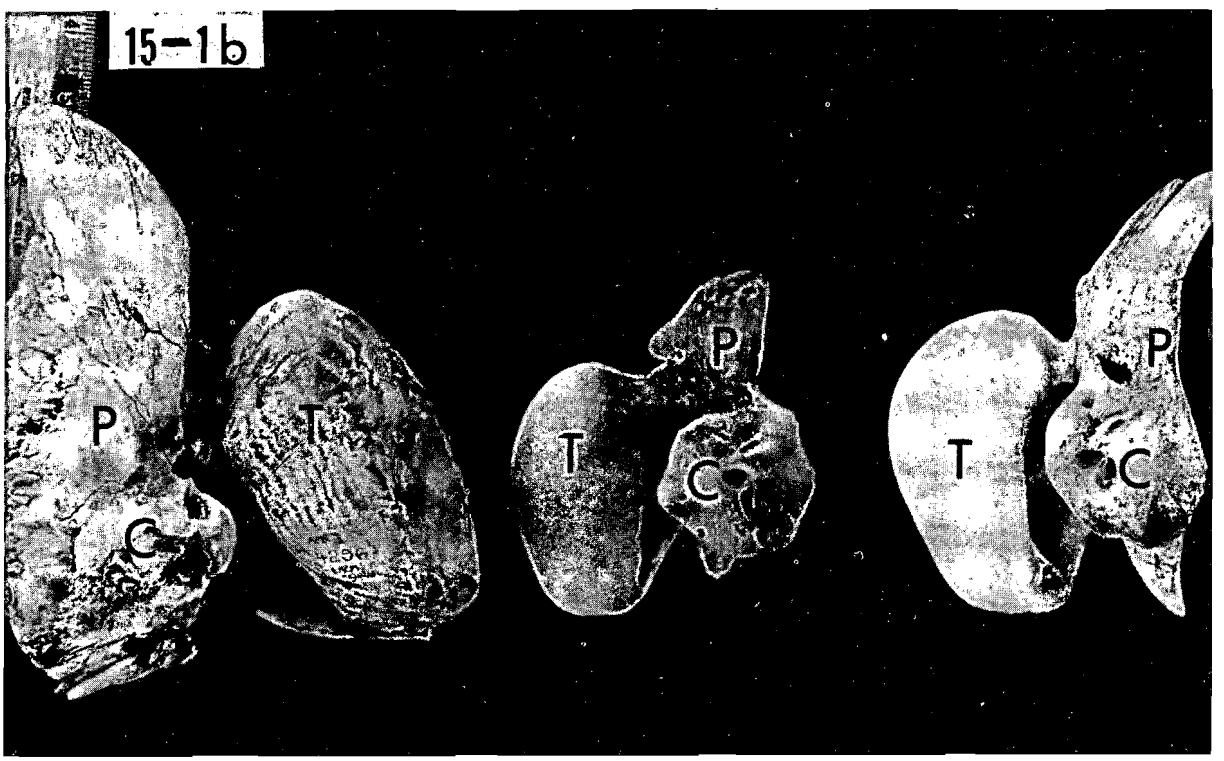
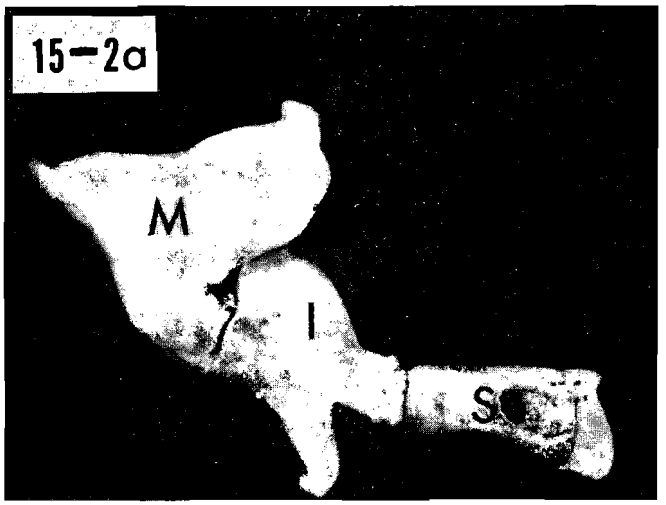

15-1b
P
C
T
P
T
C
P
T
C

Figure 15-2a. The ossicular chain of a bowhead whale containing the malleus(M), the incus(I) and the stapes(S). Note the angles of attachment of the ossicles and the morphology of the stapes footplate. The hole in the stapes is characteristic of mysticete stapes which are similar to the typical terrestrial form and different from that of the odontocete where the stapes is solid.

Figure 15-2b. The bowhead ossicular chain compared (top to bottom) to those of the bottlenose dolphin, common dolphin, harbor porpoise, Dall porpoise, killer whale and the Risso's dolphin. A segment of the sigmoid process is still attached to the malleus in the Risso's dolphin specimen. The scale on the right is in inches.


15-2a
M
I
S

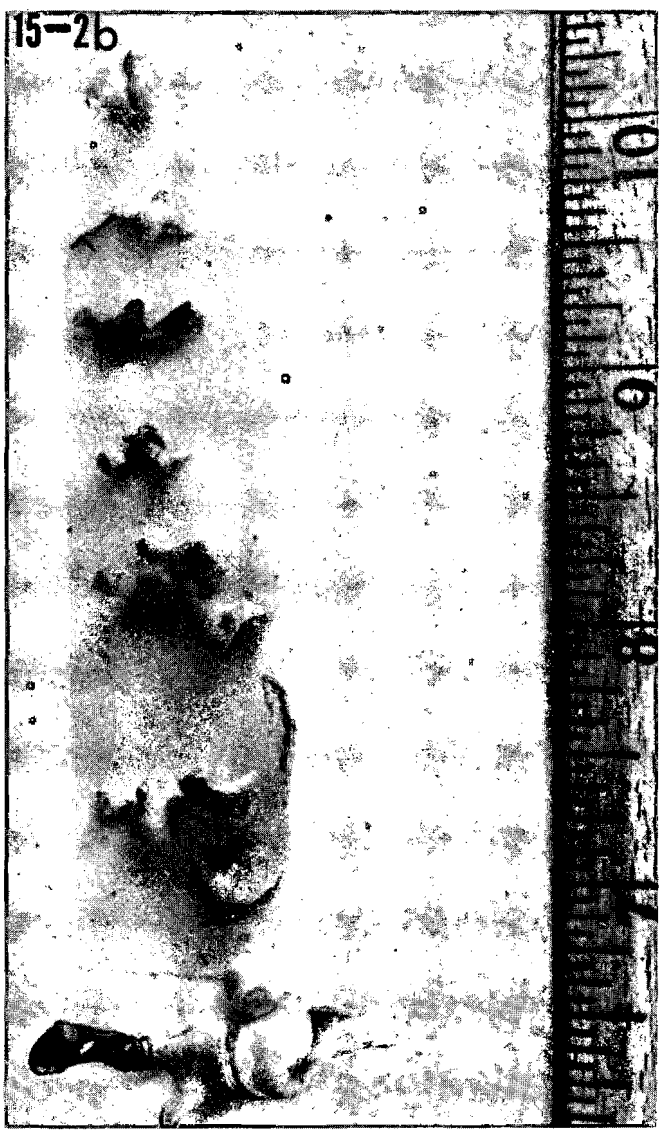
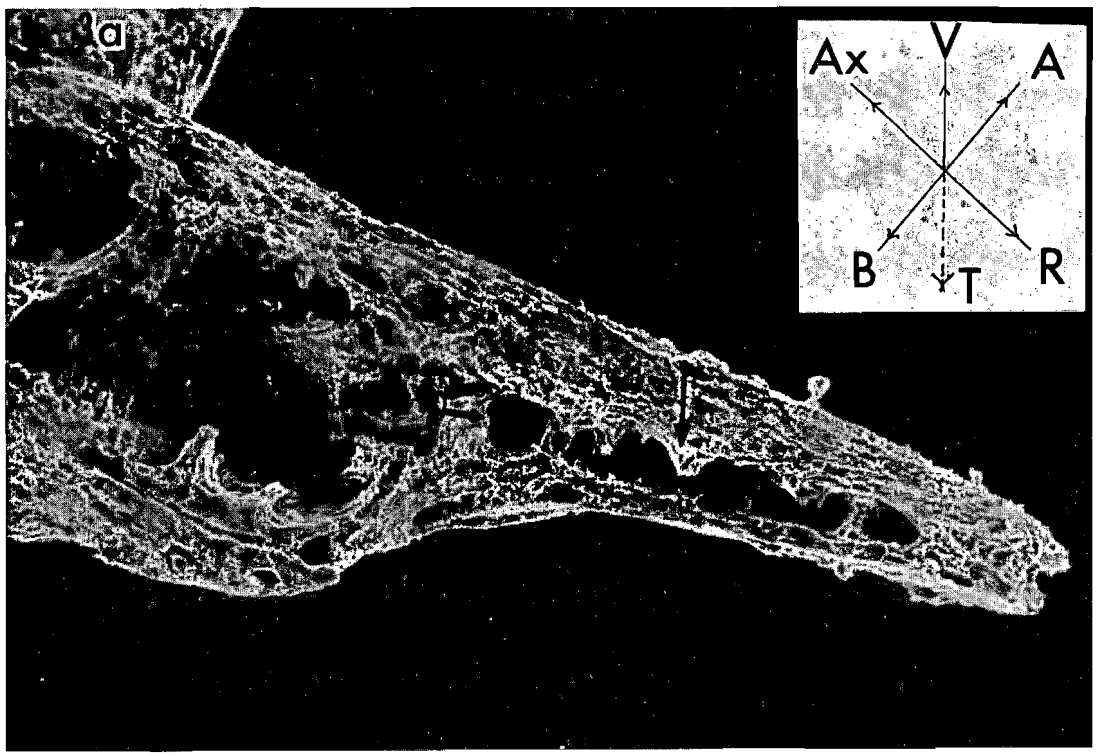

15-2b

Figure 15-3a. The primary spiral lamina from a minke whale giving the orientation to its morphology: Ax-axial, R-radial, V-vestibular, T-tympanal, B-basal, A-apical, VF-vestibular faceplate, TF-tympanal faceplate, ⟶ -core partitioning and → -lumen. 42X

Figure 15-3b. The cochlea of a minke whale opened to expose the cochlear turns with the primary spiral laminae(PSL) and the secondary spiral laminae(ssl) in place. The apical turn is above the basal turn. Note the differences in morphology of the apical and basal primary spiral lamina. The secondary spiral lamina is not present in this species in the apical turn. Scanning electron micrographs (SEM) of the basal primary and secondary spiral lamina from this specimen can be seen in Figs 15-19 and 15-24, respectively.


a
Ax
V
A
B
T
R

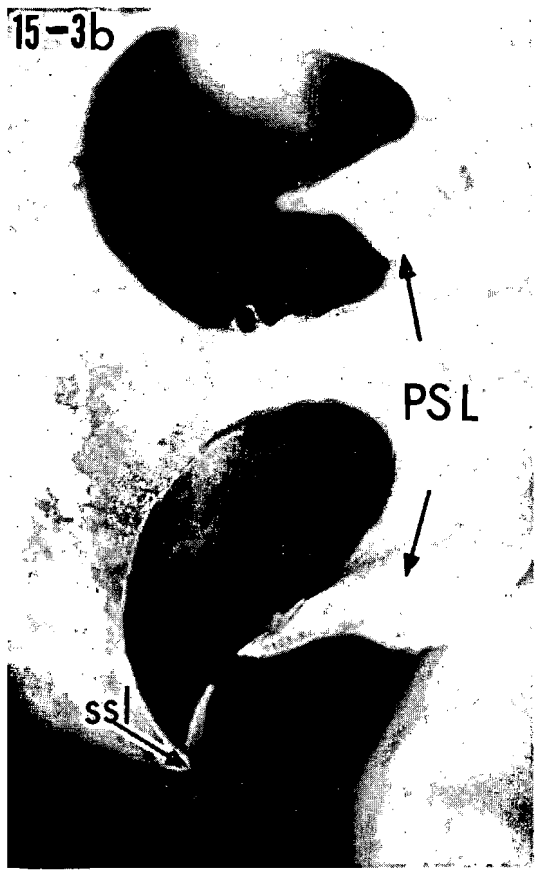

15-3b
PSL
ssl

Figure 15-4. Ventral view of the basal turn of a bowhead whale cochlea. The basilar membrane(→) coils from apical to basal (right to left). The cochlear duct continues apically for another 1 1/2 turns. Note the smooth increase in basilar membrane width apically.

6.6X

Figure 15-5. Closeup of the ventral aspect of the extreme basal end of a bowhead whale cochlea. Note the size and morphology of the primary(⟶) and secondary(⟶) spiral laminae, which lie adjacent to the basilar membrane(→). The hook region, left, even further basally is broken off in this specimen.

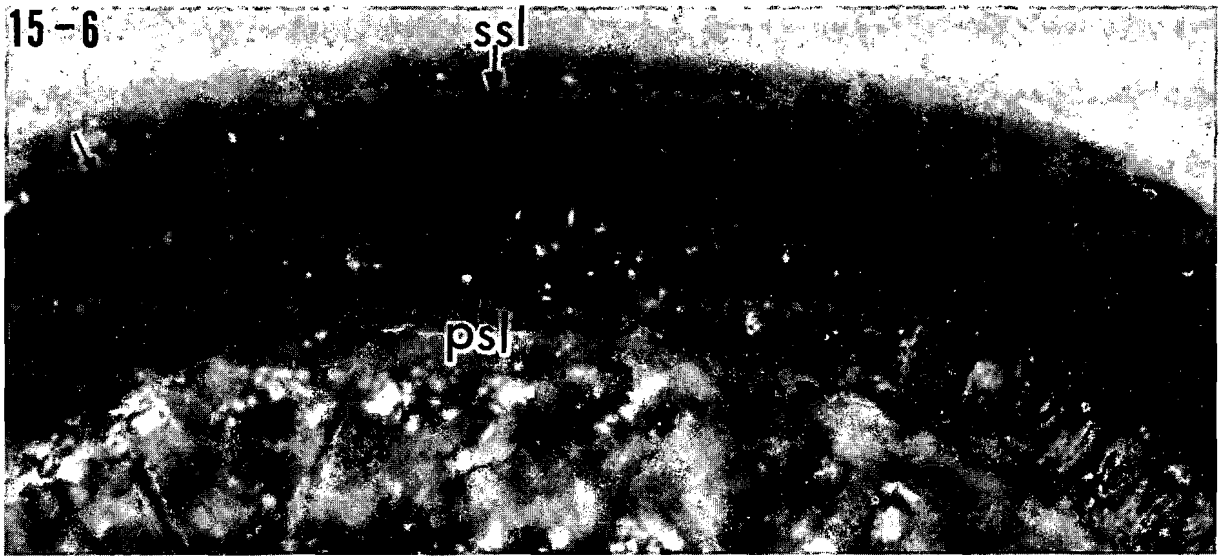
20X

15—4

15—5

Figure 15-6. Ventral view, approximately 1/4 turn apically from Fig 15-5, of the bowhead whale cochlea showing the basilar membrane(→) and the primary(psl) and secondary(ssl) construction. Note the wide basilar membrane and the lack of crisp definition at the margin between the basilar membrane and the primary spiral lamina. 20X

Figure 15-7. Ventral view of the bowhead whale cochlea 1/4 turn apically from Fig 15-6. Note the increased width of the basilar membrane(→) and the much reduced secondary spiral lamina (ssl). 20X


15-6
ssl
psl

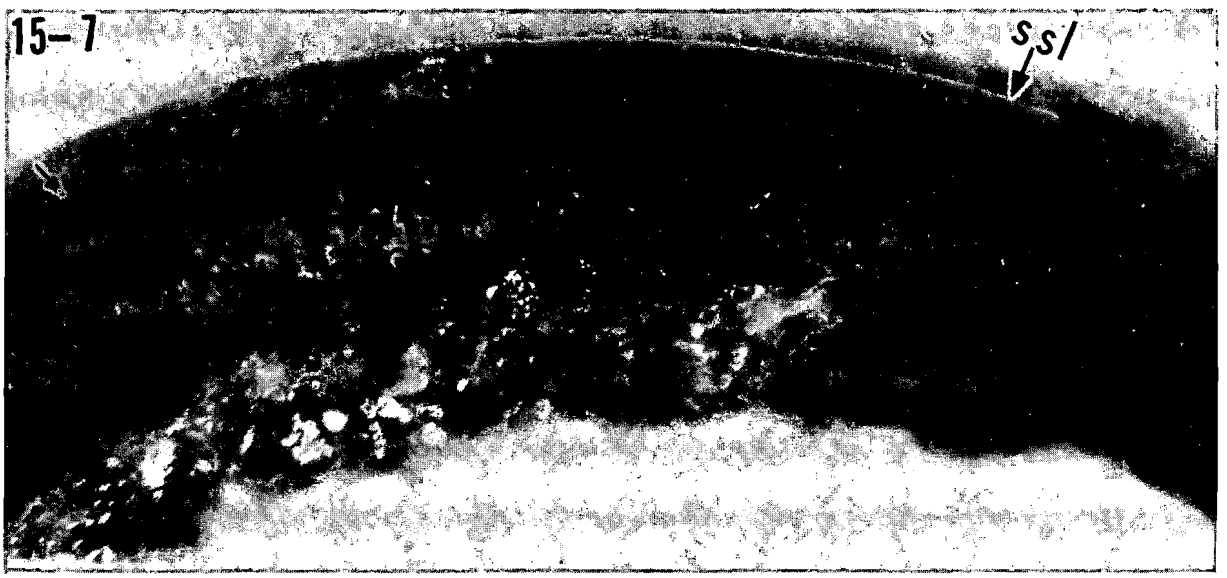
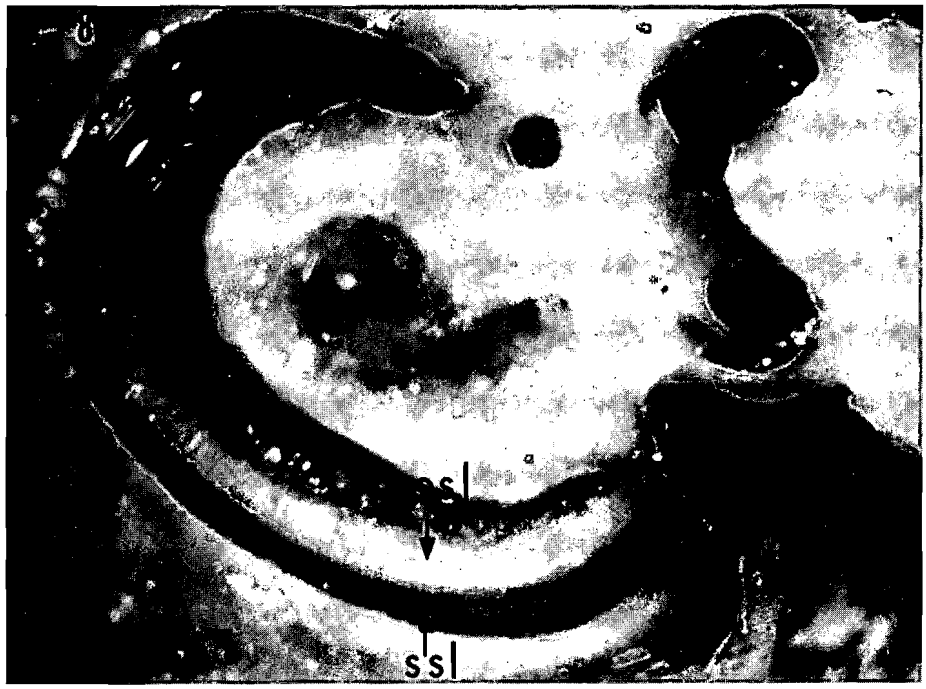

15-7
ssl

Figure 15-8. Ventral view of the Dall porpoise cochlea showing the basilar membrane (→) and the primary(psl) and secondary(ssl) spiral lamina. As in Fig 15-4, note the smooth increase in the basilar membrane width from basal to apical(right to left). The hook, lower right, is very pronounced in this species. Note the differences between coiling patterns of Dall porpoise and those of the bowhead whale(Fig 15-4). 10X

Figure 15-9. Ventral view of a basilar membrane of a Dall porpoise at the basal end just apical to the hook. (Similar in perspective to that of Fig 15-5). Note that the basilar membrane(→) is very narrow, the secondary spiral lamina (——→) very robust and the basilar membrane cleanly connected to the secondary and primary(—|→) spiral lamina. 30X

Figure 15-10. Ventral view of the basilar membrane of the Dall porpoise, 1/2 turn apically from the view in Fig 15-9. Note that the basilar membrane(→) has not increased measurably in width and remains distinctly connected to both the primary(—|→) and secondary spiral lamina(——→). 30X


ss
ss


t=10

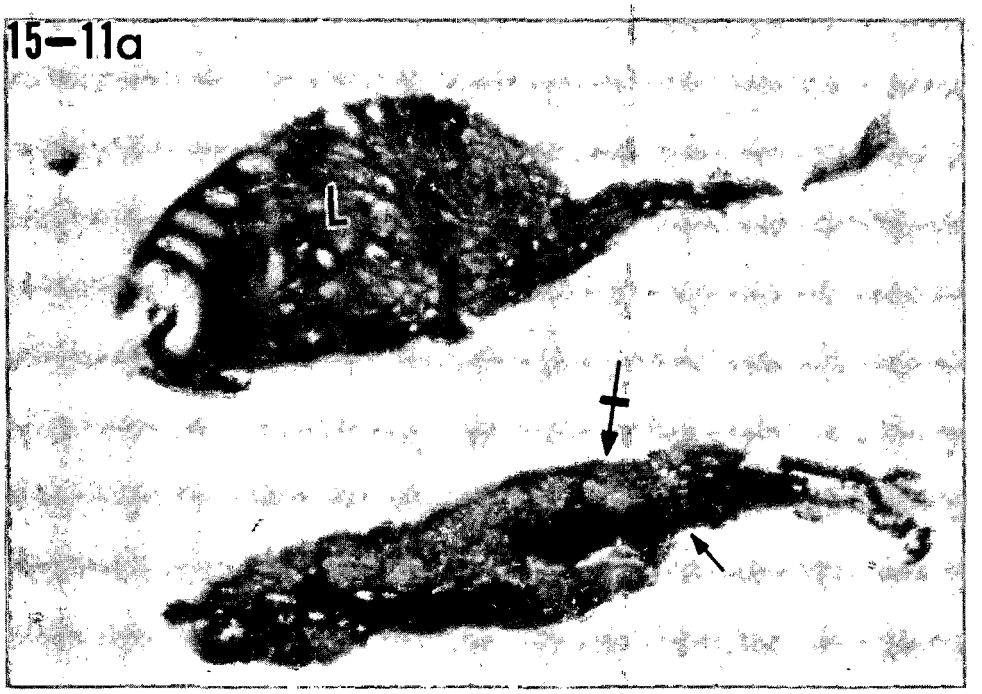


Figure 15-11a. Radial cross section of the primary spiral lamina(⟷) of a bowhead whale at approximately 16% of its apical to basal length. The limbus(L) is approximately 100 μm thick here. At the radial edge the faceplates are separated by 8 μm. Note the nerve bundle(→) on its path towards the habenular openings and the Organ of Corti. Also note how much smaller is lamina here than the view illustrated in Fig 15-13a. 100X

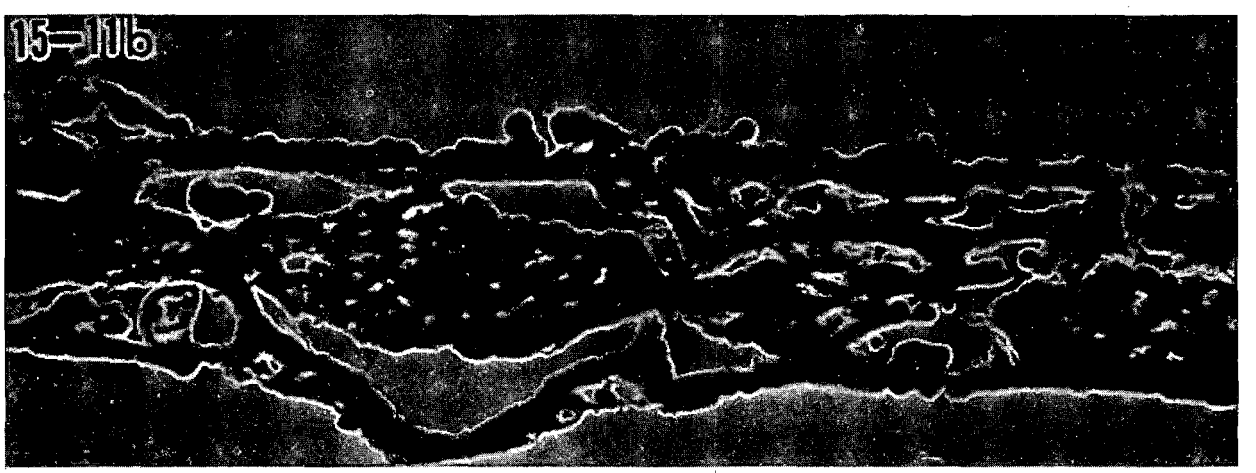


Figure 15-11b. Basal cross section of the primary spiral lamina at the same location as in 15-11a. Note how thin the laminar faceplates appear. 200X

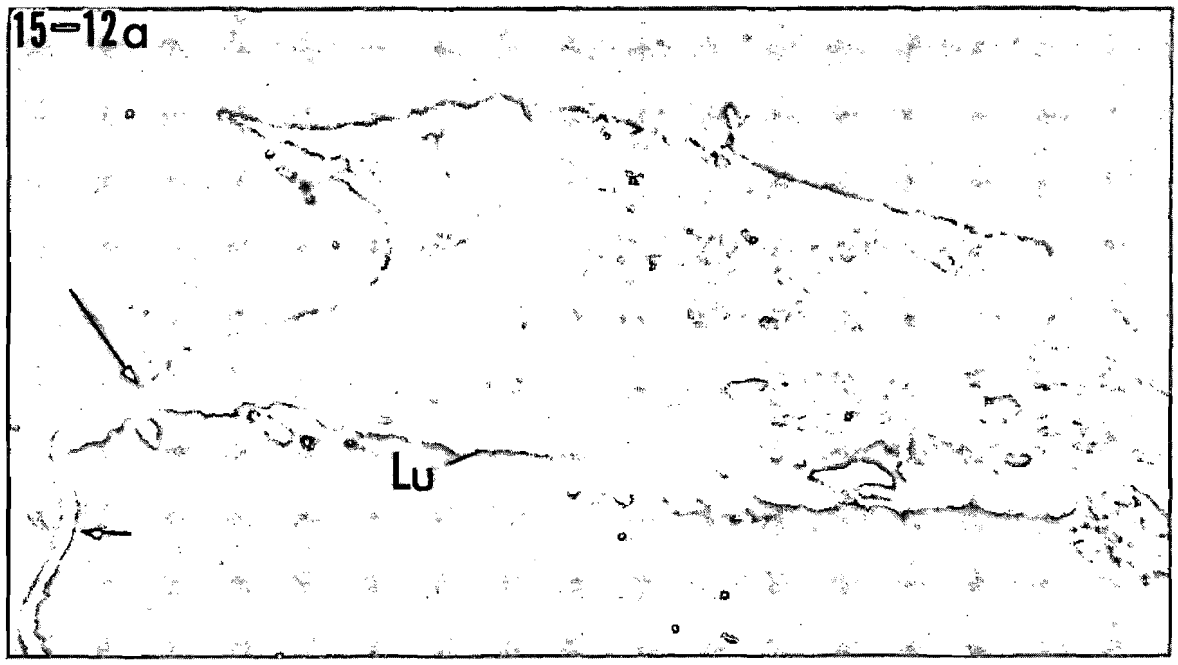


Figure 15-12a. Radial cross sections of the primary spiral lamina, limbus (L), and basilar membrane(→) of a bowhead whale 44% of its basilar membrane length from the apex. Note that the lumen (Lu) carrying nerves to the Organ of Corti point directly towards the radial margin. The limbus is 120 μm thick. The basilar membrane is 2.5-5 μm thick. 100X

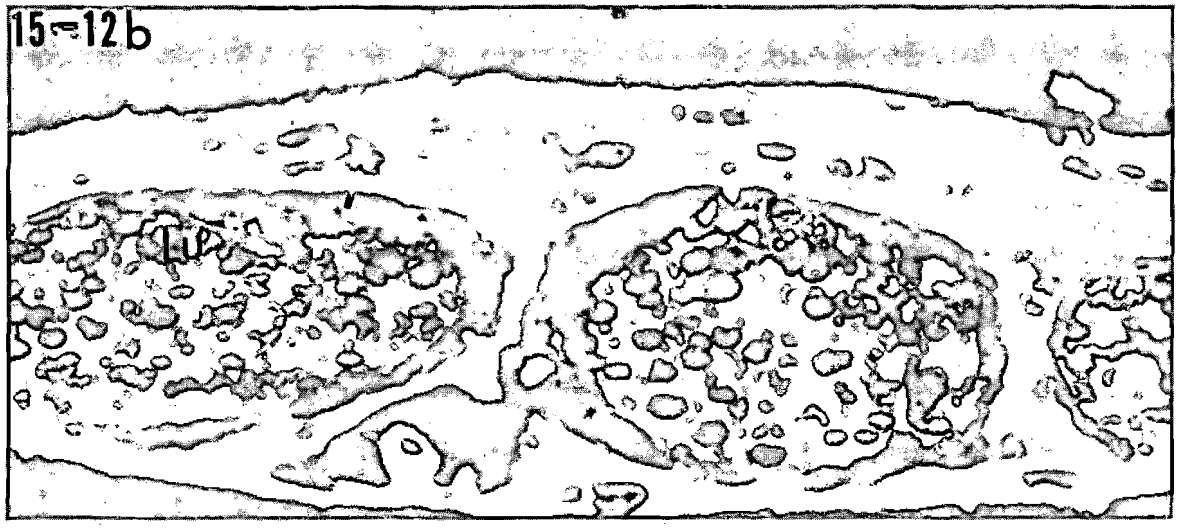


Figure 15-12b. Basal cross section of the primary spiral lamina at 65% of the basilar membrane length. Note increased thickness of the vestibular faceplate(→) and partitions(P) among the lumen(Lu). 200X

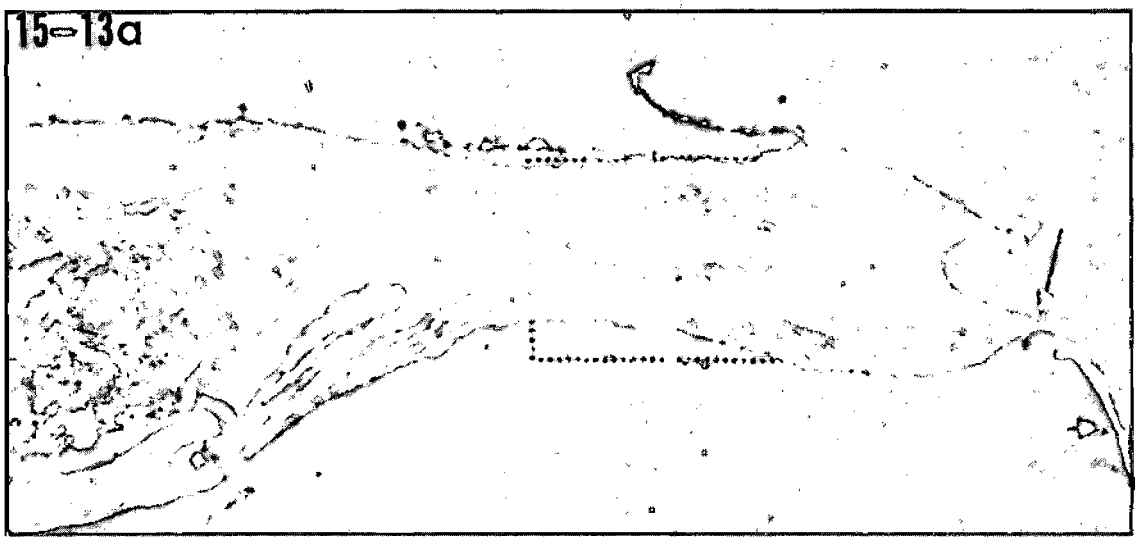


Figure 15-13a. Radial cross section of the primary spiral lamina of a bowhead whale at 77% of the basilar membrane length. The limbus(L) is 125 μm thick. Both faceplates are connected at the radial edge(⟶). The basilar membrane is 3-7 μm thick(⟶). 100X

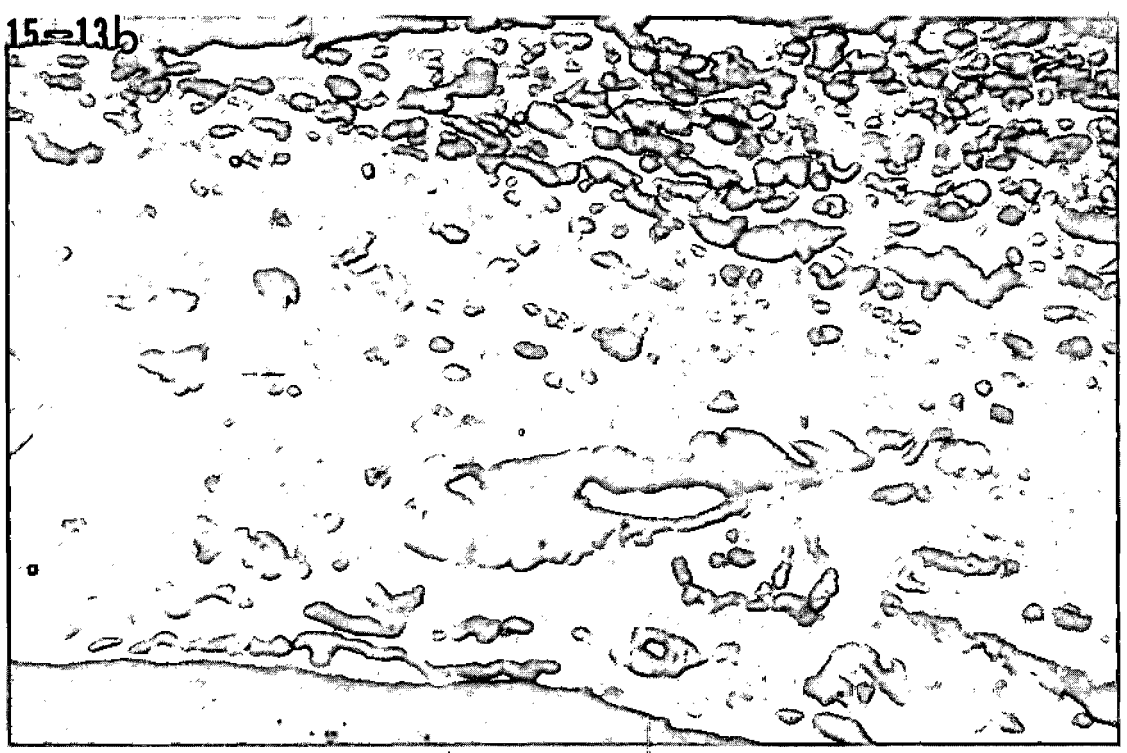


Figure 15-13b. Detailed view at the location indicated in Fig 15-13a. Note the density of the trabeculae and the occurrence of secondary lumen(⟶). 400X

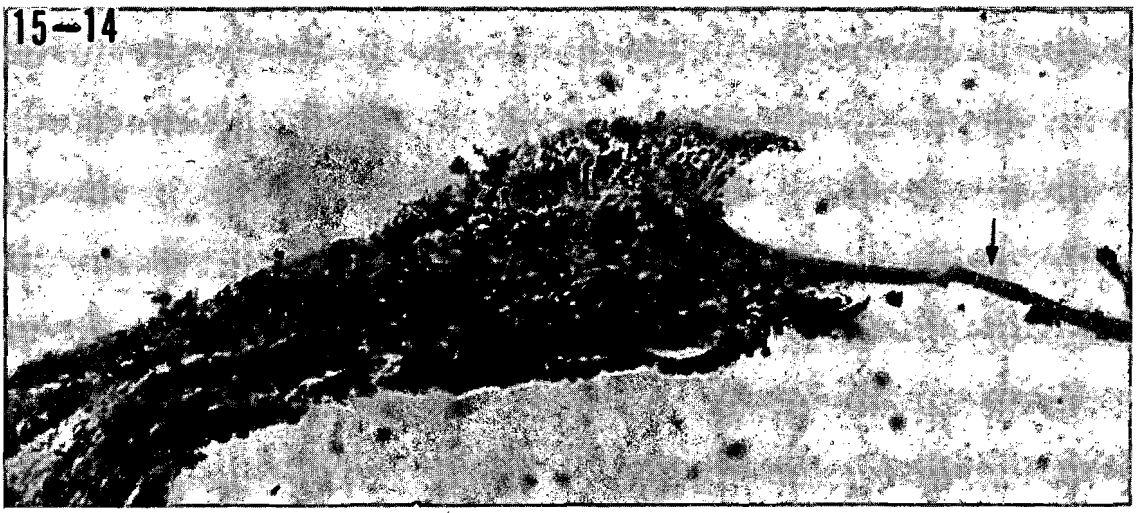


Figure 15-14. Radial cross section of the cochlea of a Dall porpoise at the extreme apical end, near the helicotrema. The limbus(L) is 158 μm thick, basilar membrane(→) 5 μm thick. The faceplates are separated at the radial edge. At the axial edge the vestibular faceplate is 112 μm thick, the tympanal faceplate 88 μm thick. 100X

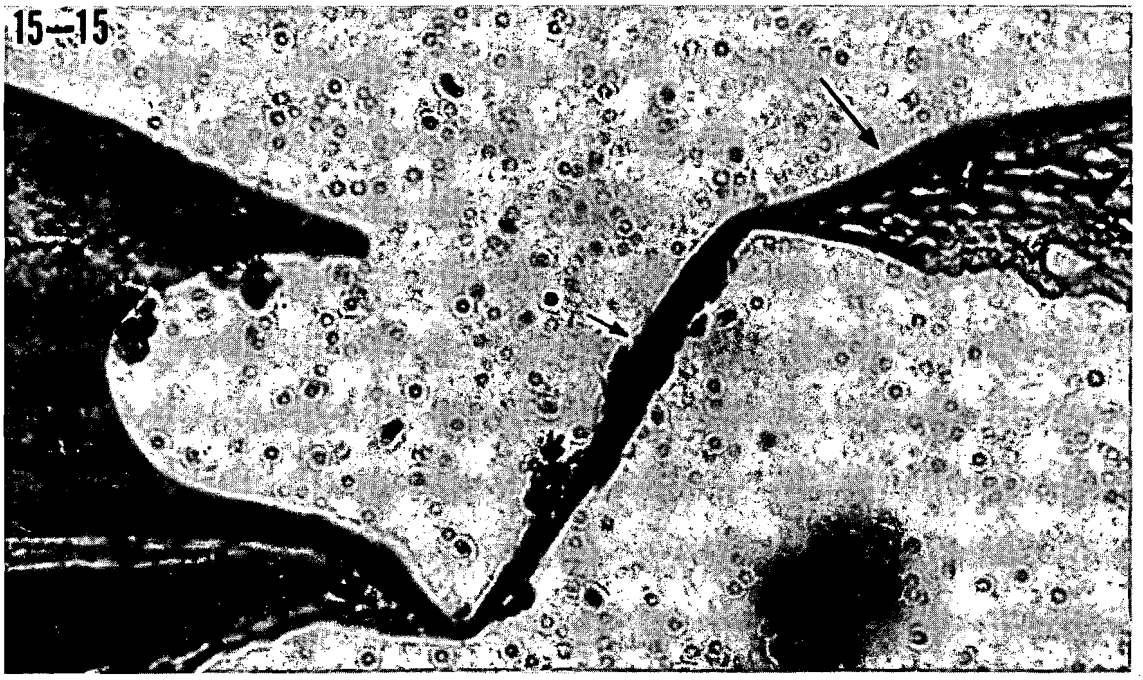
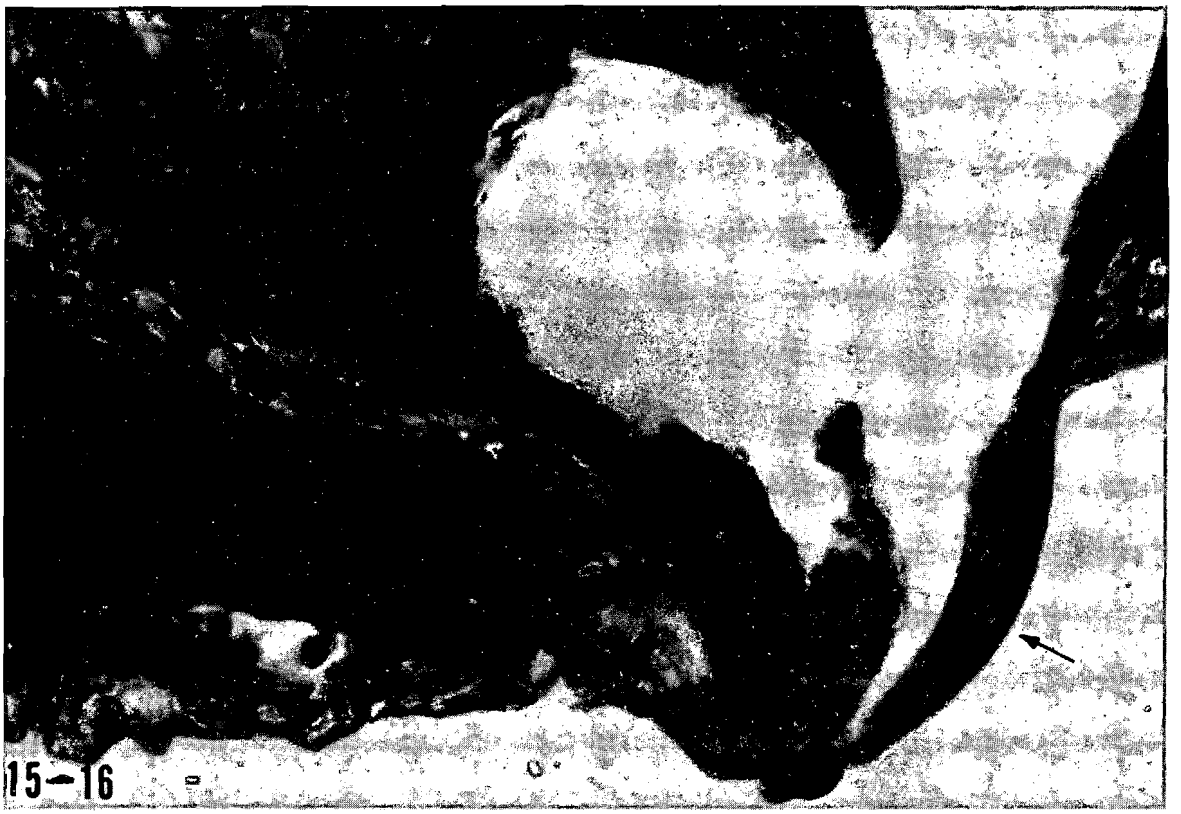
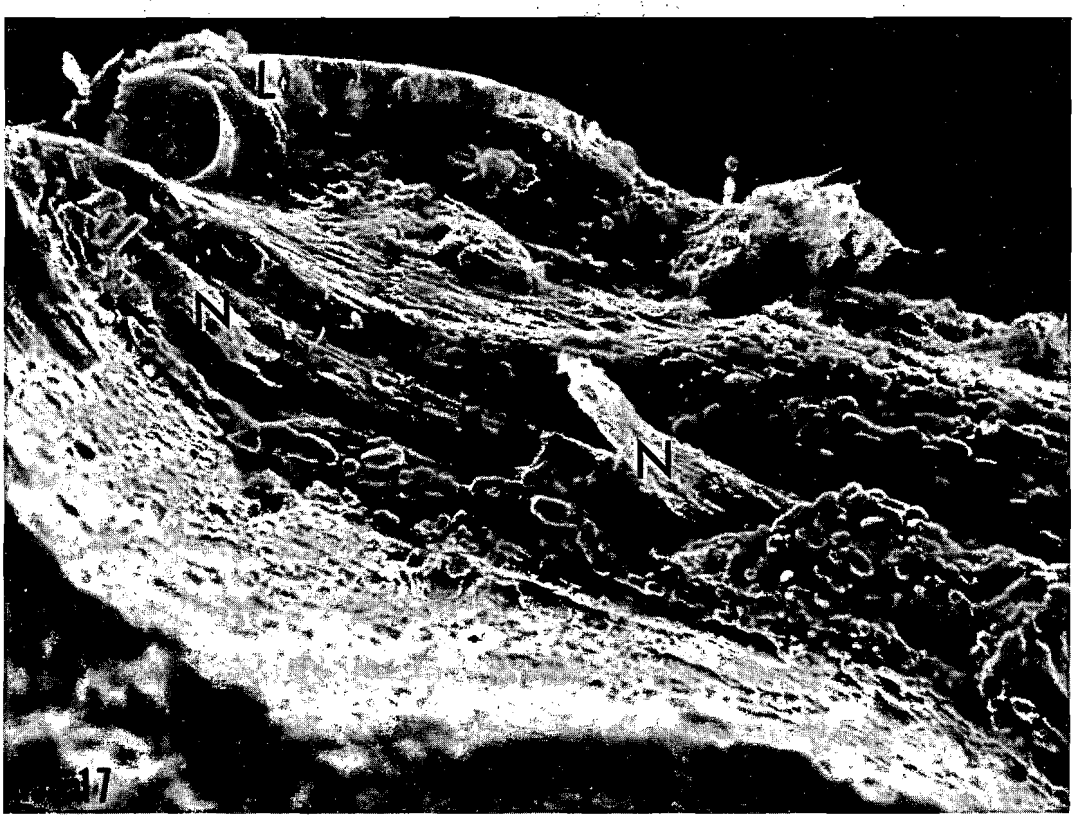


Figure 15-15. Radial cross section from midlength of the basilar membrane of a Dall porpoise. In this area the basilar membrane(→) is 98 μm wide and 2-6 μm thick. Note the dense structure (and thereby increased stiffness) of the secondary spiral lamina(——→). 400X

Figure 15-16. Radial cross section of the basilar membrane of a Dall porpoise at the basal end. Note the basilar membrane(→) shape, unique among cetaceans examined to date. In this area the basilar membrane is 45 μm wide, 2 μm thick at its thinnest section, and 9 μm thick near the secondary spiral lamina. The limbus(L) is 100 μm thick. Note that the faceplates are connected radially. 400X

Figure 15-17. An SEM of the primary spiral lamina of a right whale at the apical 1/2 turn. Note the nerves(N) oriented radially towards the habenular openings. The limbus(L) rests atop the lamina. The Organ of Corti would normally rest radially to the limbus. 170X


15–16


L
N
N

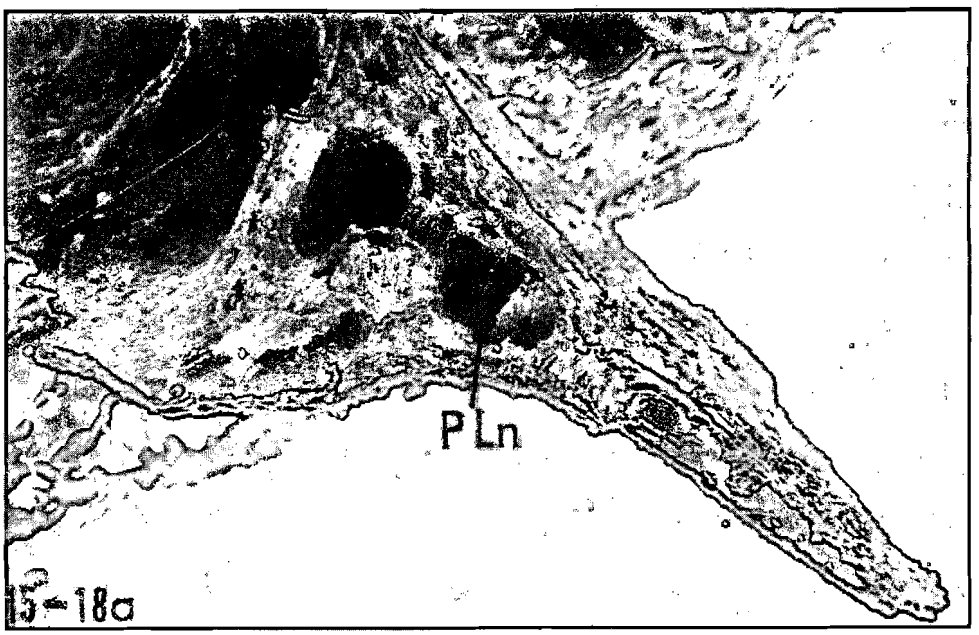


Figure 15-18a. An SEM of the primary spiral lamina of a bowhead whale at the basal end. The primary lumen(PLn) are plainly visible, appearing to be offset basally. 49X

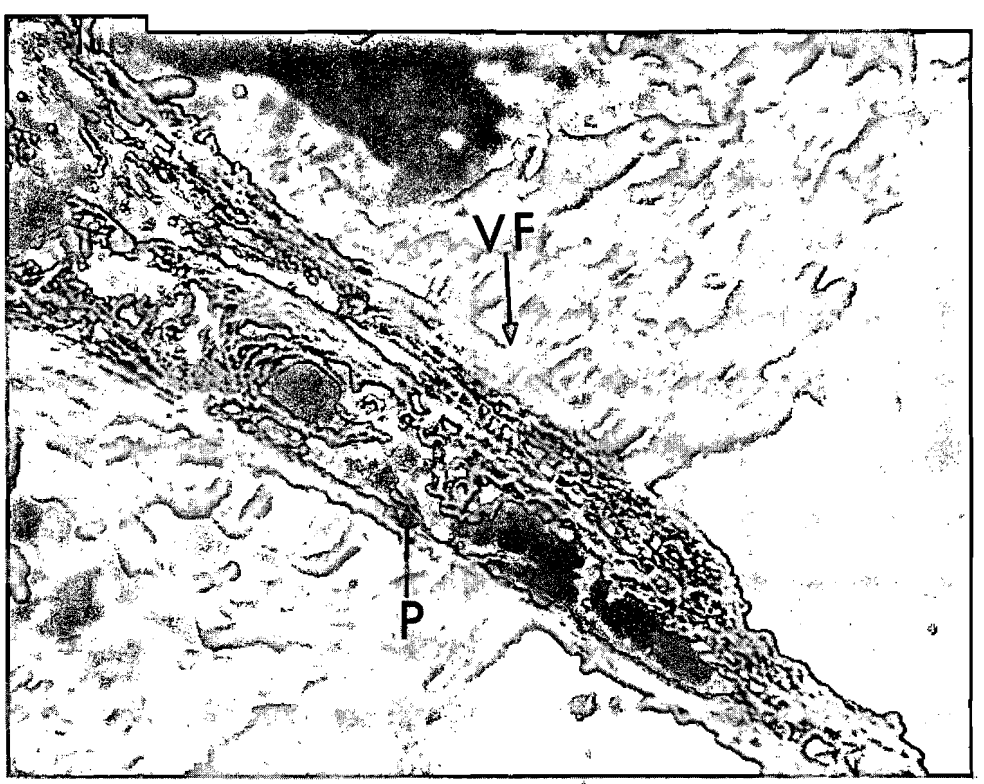


Figure 15-18b. Detail from the primary spiral lamina of the bowhead whale shown in Fig 15-18a illustrating the partitioning(P) and thickness of the vestibular faceplate(VF). 96X

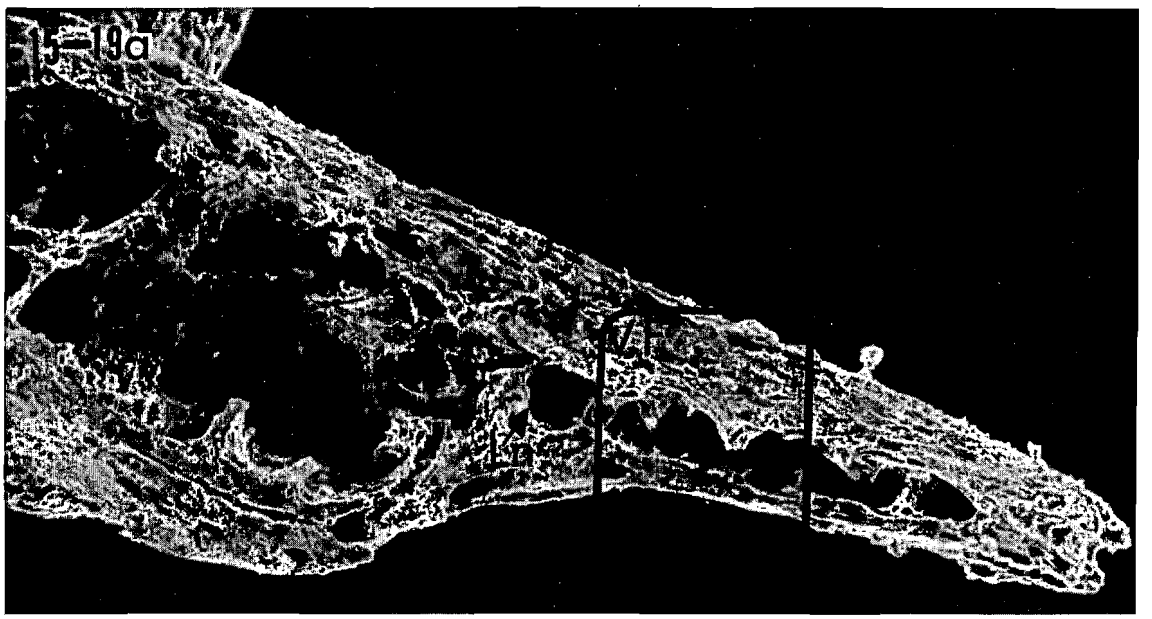


Figure 15-19a. An SEM of the primary lamina of a Minke whale at the basal end. Note the thickness of the vestibular faceplate (VF) and the diameter of the lumen(Ln). As in the bowhead whale(Fig 15-18a) the lumen appear offset from the radial direction. 42X

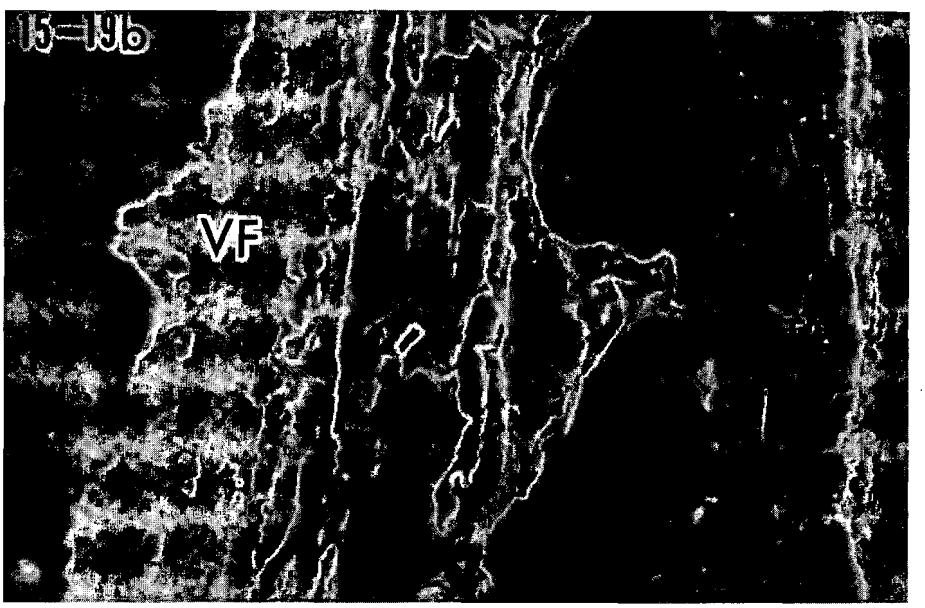
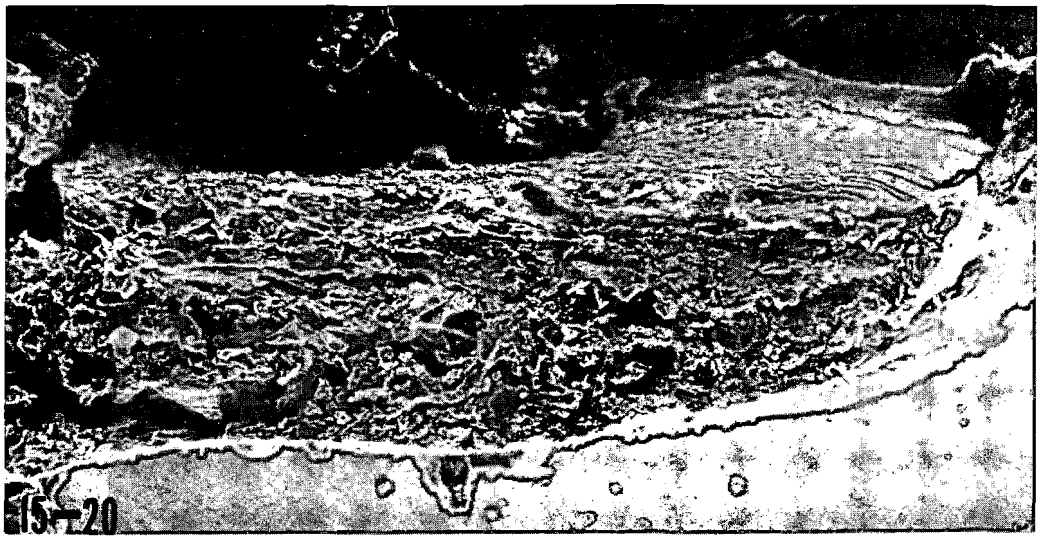


Figure 15-19b. Detailed view as indicated in Fig 15-19a. Note the thickness and density of the trabeculated inner meshwork. In this area the vestibular faceplate(VF) is approximately twice as thick as the tympanal faceplate(TF). 520X

Figure 15-20. A SEM of the primary spiral lamina of a bowhead whale at the hook region of the basal end. Both faceplates and internal partitioning have thickened such that by this location the lamina is now almost solid bone. (This view is from the same area and perspective as the view of the secondary spiral lamina seen in Fig 15-23). The spiral lamina is probably stiffest at this location. 87X

Figure 15-21. Radial cross section of the secondary spiral lamina of a bowhead whale at 50% of the basilar membrane length. Note the even meshwork leading towards the basilar membrane connection(top right). 200X


15-20

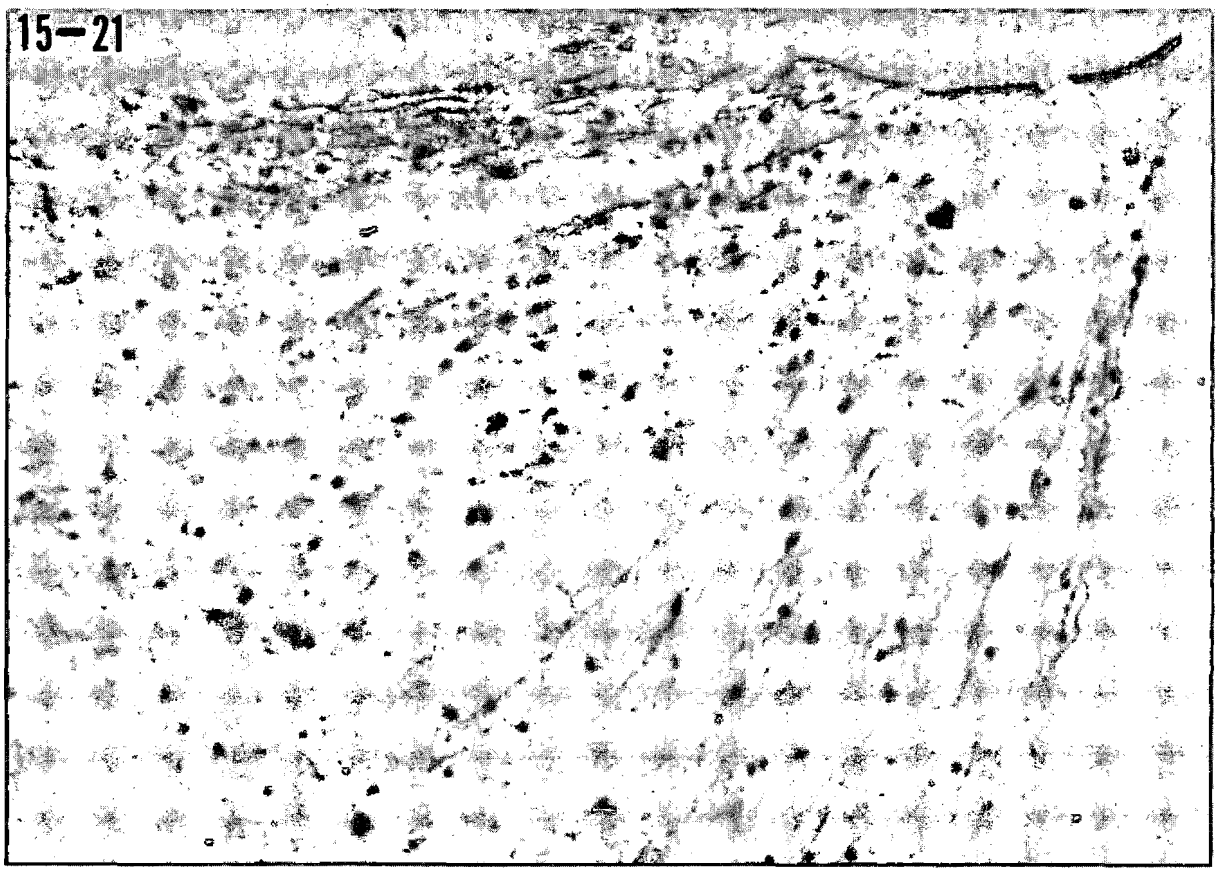
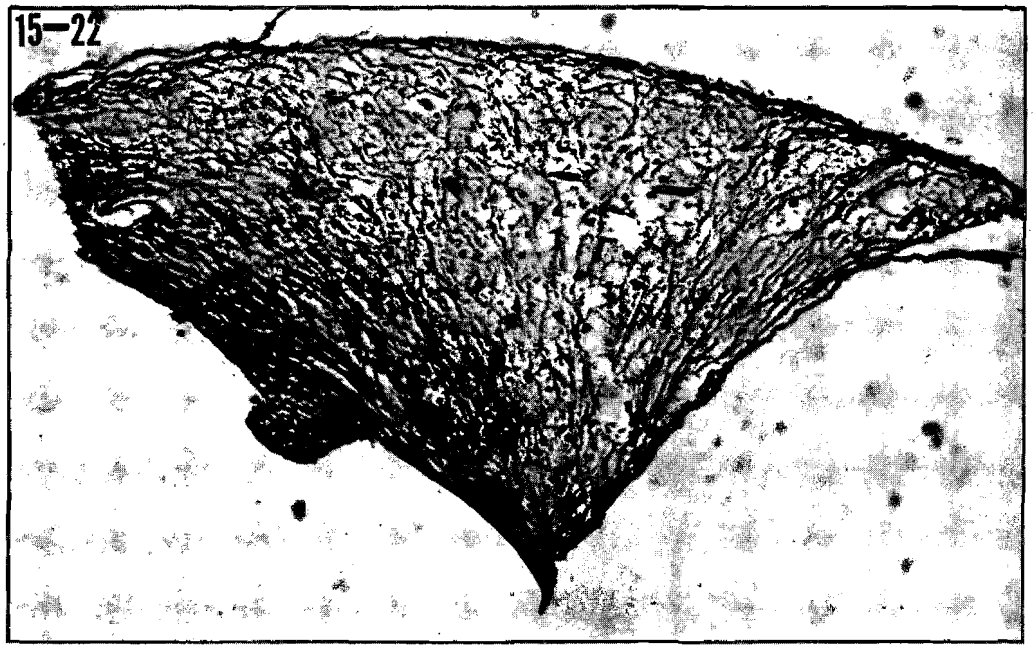
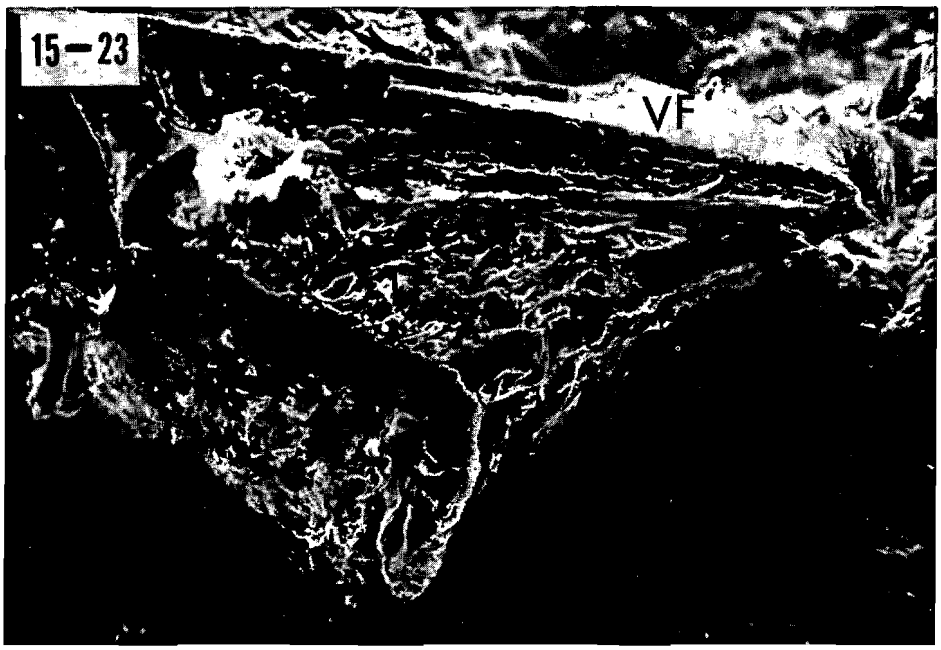

15-21

Figure 15-22. Radial cross section of the secondary spiral lamina of a bowhead whale at 94% of the basilar membrane length. Compared with a more apical view(Fig 15-21) the meshwork is thicker and has more lumen and the basilar membrane connection is more stout. 100X

Figure 15-23. A SEM of the secondary spiral lamina of a bowhead whale at the hook region of the extreme basal end of the cochlea. At this location the lamina is made up of two sections. The vestibular faceplate(VF) has long trabeculae, similar in structure to those at the apical end of the primary spiral lamina(Fig 15-17). The tympanal faceplate(TF) contains the familiar radial meshwork seen in cross section in Fig 15-22. This construction, while atypical of cetaceans, may nonetheless result in high stiffness values. 95X

Figure 15-24. A SEM of the secondary spiral lamina at the hook region of a minke whale. By this location the meshwork has increased in density to the point that the lamina is now nearly solid bone. See Fig 15-23 for comparison with a similar view of a bowhead whale. 95X


15-22


15-23
VF

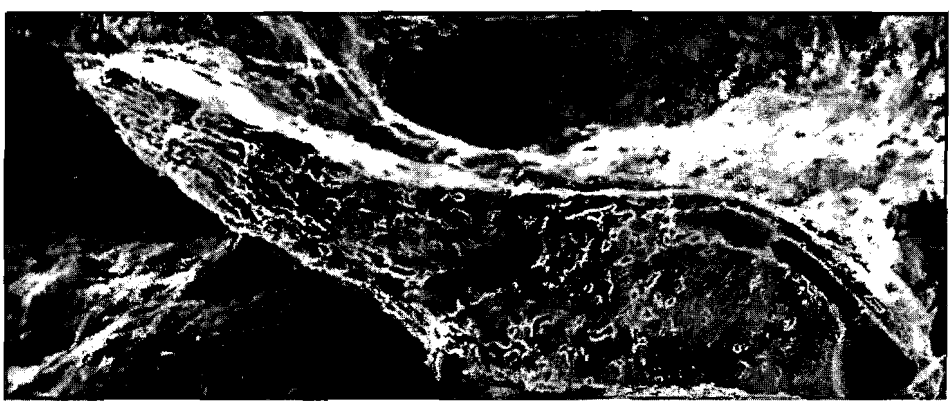


TABLE 15-3. NUMBER OF TURNS IN THE COCHLEA AND DIMENSIONS OF THE BASILAR MEMBRANE OF 28 INDIVIDUALS OF 5 ODONTOCETE SPECIES AND 1 BOWHEAD WHALE. (ODONTOCETE VALUES ARE MEANS CALCULATED FROM VALUES PRESENTED IN AWBREY et al. 1979).

Species	# of Turns	Basilar Membrane Length (mm)	Basilar Membrane Width (mm)	Increase in Width	# spec.
Balaena mysticetus	2 1/2	61.3	120-1,670	13.9	1
Phocoenoides dalli	2	29.1	49-404	8.2	17
Phocoena phocoena	2	32.2	49-457	9.3	4
Tursiops truncatus	2	43.3	40-453	11.6	2
Delphinus delphis	2	30.7	52-294	5.7	4
Grampus griseus	2	40.2	44-300	6.8	2

Photomicrographs from SEM views of spiral laminae of the cochlea of several mysticetes, arranged in the same apical to basal format, are shown in Figs 15-17 through 15-20. At the apical end of a right whale cochlea, (USNM 269161) (Fig 15-17), nerves can be seen running in a radial direction towards the habenular openings. As in the bowhead, the lumen for these nerves in the right whale are located tympanally in a dense meshwork. This meshwork is thickest in the vestibular faceplate at the apical end, in contrast with the situation in the basal laminae, where both faceplates are more similar in thickness. Basally, in the primary spiral laminae of the bowhead, (FED 4403) (Fig 15-18), and the minke whale, (USNM 314 874) (Fig 15-19), the nerve lumen lie at approximately 45° angles to the long axis. These lumen are roughly perpendicular to the long axis throughout the laminae in bottlenose dolphins (Fleischer 1976b; Fig 3b, p. 171). They are similarly perpendicular apically in bowhead whales (see cross section, Fig 15-12). By the hook, at the extreme basal end of the spiral lamina of the bowhead whale's cochlea, both faceplates and the partitions among the lumen have thickened to become almost solid bone, thereby imparting to the lamina its maximum stiffness (Fig 15-20).

Figures 15-21 and 15-22 are views of radial cross sections of the bowhead (FED 4403) secondary spiral laminae in the middle and the basal segments of the cochlea. In both of these locations there is a radial meshwork leading to basilar membrane point of contact. This meshwork is thickest basally, where the elements making it up are 13 μm in diameter. In the bowheads examined to date, the secondary spiral lamina has degenerated by the first cochlear turn.

Photomicrographs of an SEM view of the bowhead secondary spiral lamina at the hook (Fig 15-23) illustrate clear and important differences in structure of the laminae among bowhead and minke whales (Fig 15-24)[2] and bottlenose dolphins (Fleischer 1976b, Fig. 11, p. 184). Unlike these latter two species, in which the hook is almost

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[2]To minimize effects of individual variability in detailed descriptions of structure, and to facilitate comparisons with previous work, the SEM electron photomicrographs of spiral laminae of minke whales were taken of opposing primary (Fig 15-19) and secondary (Fig 15-24) laminae of the same specimen studied by Fleischer (1976a, J.G. Mead pers. comm.). These structures are seen in situ in Fig 15-3a in a photographic perspective matching identically the perspective illustrated by Fleischer (1976a, Fig 7, p. 138).

solid bone, the bowhead whale's secondary spiral lamina at this location is composed of 2 distinct zones. The tympanal faceplate contains the familiar radial meshwork (see Figs 15-21 and 22). However, the vestibular faceplate is characterized by long trabaculae, similar in appearance to the primary spiral laminae more apically.

DISCUSSION

Middle Ear Morphology Fleischer (1978) discusses the relationships between stapedial velocity and the overall frequency capacity of the ear. Because the piston motion of the stapes in the oval window is that of a mass loaded spring, the relative masses of the ossicles relate directly to their vibrational capacities to input sound. Since the malleus and incus act together to drive the stapes, the ratio $\frac{M + I}{S} : S/S$ is most indicative of that relationship. This being the case, one would logically expect, as did Fleischer (1978), that higher values of this ratio would indicate higher frequency hearing capabilities. Awbrey et al (1979), summarized in Table 15-2, illustrate class differences between delphinid and phocoenid ossicular mass ratios (and basilar membrane morphology). Bowhead whale ossicular mass ratios are intermediate between these two odontocete families, both of which have been demonstrated by various methods to hear high frequencies (Norris and White 1978). From additional evidence presented in this paper, however (see Discussion below), it is unlikely that bowhead whales hear at comparably high frequencies. Therefore, pending further evidence one must suspect that there are functional elements of the hearing mechanisms of cetaceans which obviate the validity for using high ossicular mass ratios solely as evidence of high frequency hearing capability. The principal additional factor influencing the relationship between stapedial velocity and hearing capability has been theorized to be the stiffness of the stapedial-oval window connection (Fleischer 1978). However, because of the difficulties of extracting

undamaged stapes from bowhead whales, resulting from their fragility and their morphology - more typical of terrestrial mammals than are odontocetes - we were unable to corroborate Fleischer's (1978) theory.

Inner Ear Morphology The very complicated mechanics of inner ear physiology (eg. Steele 1974, Wever 1971) will not be addressed in detail here. However, because the dynamic interactions of the basilar membrane and its support system are fundamental to the ear's mechanics, and because their morphologies are relatively accessible for investigation, the comparative morphologies among species can be used to infer auditory capabilities. For example, Bruns (1976a and b) demonstrated significant correlations between auditory structures and auditory response capabilities in bats. In particular, he noted discontinuities in the morphology of scalae, spiral laminae and basilar membrane of Rhinolophus ferrumequinum. These discontinuities produced variations in basilar membrane stiffness and, thereby, in its vibrational characteristics. Subsequent behavioral audiograms and frequency maps along the basilar membrane showed that these discontinuities resulted in localized specializations for frequency and pitch discrimination. Awbrey et al (1979) and Norris (1979) utilized similar approaches to assess hearing abilities of Dall porpoises and Risso's dolphins, Grampus griseus, respectively. The same logical framework utilized in the above studies can be used to interpret results of this investigation.

The number of turns observed in the cochlea of bowhead whales, 2 1/2 (Fleischer 1976a and this study - see Table 15-3), is typical of mysticetes (Yamada 1948, Fleischer 1976a) but greater than that observed for odontocetes, 1 3/4 to 2 (Wever et al 1971b, Fleischer 1976a. Awbrey et al 1979). This feature alone has not been correlated with hearing ability. However, Fleischer (1976a, Fig 19, p. 144) illustrates that the relationship between width of the basilar membrane and number of turns of the cochlea differentiates mysticetes from odontocetes. (By this criterion some archeocetes are intermediate in these values.) Fleischer (1976a) interprets this differentiation of form to indicate presence of low (mysticete) and high (odontocete) auditory thresholds.

Yamada and Yoshizaki (1959) described the cochlear coiling patterns and undiminished size of the semicircular canals of a right whale as features which are "rather terrestrial and strikingly non-cetacean." In this sense, they considered the right whales, family Balenidae, as "living fossils." Based principally on differences in the relative lengths of the secondary spiral laminae, Fleischer (1976a) distinguished the Balaenidae from the rorqual whales, Family Balaenopteridae.

Bowhead whale basilar membrane morphologies observed during our study (Table 15-3) are nearly identical to those previously reported for this species (Fleischer 1976a). Stiffness gradients along the inner ear have been related to hearing abilities, with highest stiffness occurring in species with known high frequency sensitivity (Bekesy 1960). Stiffness gradients, of unquantified magnitude, have been demonstrated by this study to exist in bowhead, right and minke whales. The morphological features comprising this gradient parallel some features producing a similar gradient in bottlenose dolphins (Fleischer 1976b).

Notable similarities are evident in bowhead whale and bottlenose dolphin spiral laminae construction. For example, the laminar faceplates are separated apically and joined basally in both species. Fleischer (1976b) ascribed special significance to this characteristic and to the progressive apical to basal solidification of the laminae as they affect their resilience and vibrational characteristics.

In general, however, the basilar membrane of the bowhead whale is relatively wider and the lamine are weaker and thinner, with less crisply defined radial edges, than those of bottlenose dolphins and Dall porpoises. Based on these differences, alone, it is tempting to conclude that the bowhead ear (and that of other mysticetes studied) is specialized for purely low frequency hearing while that of odontocetes is capable of responding at broader ranges, including ultrasonic frequencies. However, comparisons among several morphological characteristics of mysticetes (notably bowhead and minke whales) and odontocetes (notably bottlenose dolphins) argue for caution in such interpretations. For example, the basal hook of the bowhead whale has structural features indicative of high stiffness and therefore of high frequency vibrational

ability. Similar ability has been taken as indicative of high frequency hearing in odontocetes (Fleischer 1976a, b; Wever et al 1971a, b). Further, though the morphologies are strikingly different, the ossicular mass ratios of bowheads are similar to those of odontocetes with known high frequency hearing. The relationships of the above features to hearing are not completely understood.

The helicotrema functions to equilibrate pressure differences across the cochlear partition at the extreme apical end of the cochlea (Dallos 1970). Since greater equilibrations can take place through a larger helicotrema, with the result that less energy is available to drive the basilar membrane, the larger the helicotrema the greater the pressure shunt. This being the case, a large helicotrema would allow for greater pressure loss at the area of low frequency hearing and thus a loss in low frequency audition. Conversely, a small helicotrema is indicative of a system capable of low frequency hearing. Scalar values of the bowhead helicotrema would offer little basis for comparing them with the small mammals investigated by Dallos (1970). Comparisons of the bowhead helicotrema to that of other cetaceans may, however, clarify the bowheads' low frequency hearing capabilities. The helicotrema of the bowhead whale is small relative to the overall size of its basilar membrane. It is displaced to the inner margin of the basilar membrane, part of which wrapped around its opening. In the odontocetes previously examined (Awbrey et al 1979; Norris 1979), the helicotrema has been observed to be large relative to the basilar membrane. If the inverse relationship described above holds true (i.e. the smaller the area the lower the frequency) then bowhead whales have hearing abilities specialized for low frequencies.

Greenwood (1961) derived equations that predict auditory threshold based on the length of the basilar membrane and its elasticity. From that work, if the threshold is known the elasticity can be predicted. For example, if the elephant hears to 10.5 kHz (Heffner and Heffner 1980) an elasticity value of 0.0378 is predicted. The actual elasticity value derived from Bekesy (1960) for the elephant is 0.038. Since the elephant basilar membrane was approximately as long as the bowhead whales, its basilar membrane elasticity value was used for the mysticetes in a

sample calculation. This procedure predicted an upper hearing threshold of approximately 12 kHz for the bowhead whale.

It is widely held that the auditory response capabilities of a species, like its other features, evolve according to the biological pressures placed on it. In general, one might reasonably expect that an animal will be capable of hearing those sounds of biological importance to it. The majority of bowhead whale vocalizations center around 200 Hz, but some vocalizations extend perhaps as high 6 kHz (Ljungblad et al 1980). The acoustic environment inhabited by the bowhead whale contains a still wider variety and spectrum of both biological and non-biological sources. The Arctic marine spectral levels and sources have been summarized (ASA 1981). However, the tabular summary of the spectra presented based as it was on preconceptions about bowhead and gray whale hearing, did not consider sounds above 8 kHz. Such biological sounds as vocalizations by killer whales, belugas and the several species of Arctic seals may be important to the bowhead. Most such vocalizations are above 5 kHz (ASA 1981). Hunting sounds of the killer whale contain appreciable energies to 16 kHz and beyond (Awbrey, unpublished data). For all the reasons presented above, it would be imprudent to base an estimate of the bowhead whales' auditory capability strictly on the spectrum of its own vocalizations.

The evidence from this study suggests that bowhead hearing capabilities range from high infrasonic or low sonic to high sonic or low ultrasonic frequencies. But any estimate of bowhead whale hearing made at this time should be viewed cautiously. Actual behavioral or electrophysiological measurements are the only currently available means of conclusively determining auditory response capability.

SUMMARY

The auditory response capabilities of the bowhead whale were estimated based on examination of the middle and inner ear morphology of eight individuals. Observed ossicular mass ratios were intermediate between mean ratios for representative delphinids and phocoenids, both of which have been demonstrated to have high frequency hearing abilities. Basilar membrane length was 61.25 mm; width was 120 μm basally, widening to 1.67 mm apically. An apical to basal stiffness gradient was described

in the spiral laminae. These values and descriptions were compared to other cetaceans. This comparison indicated that the bowhead whale possesses several unique auditory morphological characteristics, particularly at the hook -- the area of the cochlea where highest frequency audition takes place -- and at the helicotrema, the area of lowest frequency audition. Whether or not other mysticetes possess similar morphologies has not been assessed. Available evidence supports the tentative conclusion that the auditory resonse capabilities of the bowhead whale range from high infrasonic or low sonic to high sonic or low ultrasonic frequencies.

ACKNOWLEDGMENTS

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REFERENCES

Acoustical Society of America (Coordinating Comm. on Environmental Acoustics, Subgroup). 1981. San Diego workshop on the interaction between man-made noise and vibration and Arctic marine wildlife.

Awbrey, F. T., J. C. Norris, A. B. Hubbard, and W. E. Evans. 1979. The bioacoustics of the Dall porpoise-salmon drift net interaction. Hubbs/Sea World Res. Inst. TR 79-120, 37 p.

Bekesy, G. V. 1960. Experiments in Hearing. McGraw-Hill Book Company, Inc., New York. 534 pp.

Bruns, V. 1976a. Peripheral auditory tuning for fine frequency analysis by the CF-FM Bat, Rhinolophus ferrumequinum. I. Mechanical Specializations of the Cochlea. J. Comp. Physiol. 106:77-86.

Bruns, V. 1976b. Peripheral auditory tuning for fine frequency analysis by the CF-FM bat, Rhinolophus ferrumequinum. II. Frequency Mapping in the Cochlea. J. Comp. Physiol. 106:87-97.

Dallos, P. 1970. Low-frequency auditory characteristics: species dependence. J. Acoust. Soc. Am. 48 (2):489-499.

Evans, W. E. (ed.). 1974. Gray Whale, Special Issue. Marine Fisheries Review. 36(4), 82 p.

Fleischer, G. 1976a. Hearing in extinct cetaceans as determined by cochlear structure. J. Paleont. 50 (1):133-152.

Fleischer, G. 1976b. On bony microstructures in the dolphin cochlea, related to hearing. N. Jb. Geol. Paleont. Abh. 151 (2):166-191.

Fleischer, G. 1978. Evolutionary Principles of the Mammalian Middle Ear. Advances in Anatomy, Embryology and Cell Biology 55:5-70.

Francis, R. L. 1975. Behavioral audiometry in mammals: review and evaluation of techniques. Symp. Zool. Soc. Lond. 37:237-289.

Greenwood, D.D. 1961. Critical bandwidth and the frequency coordinates of the basilar membrane. J. Acoust. Soc. Am. 33 (10):1344-1356.

Hawkins, J.E. and L.-G. Johnson. 1968. Microdissection and surface preparations of the inner ear. In: Handbook of Auditory and Vestibular Research Methods. M. Smith and T. Vernon (ed.).

Heffner, R. and H. Heffner. 1980. Hearing in the elephant (Elephas maximus). Science, 208:518-520.

Ljungblad, D. K., S. Leatherwood and M. Dahlheim. 1980. Sounds recorded in the presence of a bowhead whale, Balaena mysticetus, adult and calf. In: Bowhead Whale Special Issue. H. Braham, W. Marquette, T. Bray and S. Leatherwood (eds.). Marine Fisheries Review. December 1980.

Norris, J. C. 1979. Estimation of the auditory threshold of the Risso's dolphin, Grampus griseus. Hubbs/Sea World Res. Inst. TR 79-113, 15 pp.

Norris, J. C. and M. J. White. 1978. Review of Marine Mammal Auditory Threshold Literature. Hubbs/Sea World Res. Inst. Techn. Rep. 78-112, 11 pp.

Steele, C. R. 1974. Behavior of the basilar membrane with pure-tone excitation. J. Acoust. Soc. Am. 55(1):148-161.

Wever, E. G. 1971. The mechanics of hair cell stimulation. Ann. Otol. 80:786-804.

Wever, E. G., J. G. McCormick, J. Palin and S. H. Ridgway. 1971a. The cochlea of the dolphin, Tursiops truncatus: general morphology. Proc. Natl. Acad. Sci. 68 (10):2381-2385.

Wever, E. G., J. G. McCormick, J. Palin and S. H. Ridgway. 1971b. Cochlea of the dolphin, Tursiops truncatus: the basilar membrane. Proc. Natl. Acad. Sci. 68 (11):2708-2711.

Yamada, M. 1948. Auditory organ of the whalebone whales (Preliminary Report). Sci. Rep. Whales Res. Inst. 2:21-30.

Yamada, M. and F. Yoshizaki. 1959. Osseous labrinth of cetacea. Sci. Rep. Whales Res. Inst. 14:291-304.

APPENDIX I

CURRENT PROCEDURE FOR ALLOCATING THE BOWHEAD WHALE, BALAENA MYSTICETUS, BY THE ESKIMO WHALERS OF BARROW, ALASKA

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INTRODUCTION

It is generally believed that the modern day Eskimos originated from the peoples of Siberia. The period when they first set foot in North America is not clear, though it most likely occurred when Alaska was a geographic part of Asia and furthermore, within the time frame of 18,000-8,000 B.C. (Dumond 1977).

Once established on the North American continent these people differentiated into culturally and linguistically distinct factions (Dumond 1965, Dumond 1977). The first recorded use of marine mammals by Eskimo peoples was on the Alaskan peninsula at about 4,000 B.C. However, the use of bowhead whales as an important food source by the Inupiaq speaking Eskimos of the arctic coast may have begun as late as the Christian Era (Dumond 1977).

Whaling had become successful enough to contribute successfully to the support of several permanent communtiites along the arctic coast, the largest of which were at Barrow and Point Hope. These villages are located on promontories which provide ready access to near shore leads which are frequented by whales (Dumond 1977, Evans 1980). A conservative estimate for the pre-European contact population of the Inupiaq is 2,000 people (Jamison et al. 1978).

Since it is unlikely that the average harvest during that period was more than ten whales per year, it seems reasonable that there would develop an equitable system for distributing portions of the whales that were harvested. This paper deals specifically with the system of allocation in use today in the village of Barrow, as there are regional differences.

OBJECTIVE

To document by personal interview, observation and with photographs the procedure of butchering and allocating captured bowhead whales in the Eskimo community of Barrow, Alaska.

METHODS

The information contained herein was gathered through personal interviews with several whaling captains and their crews, and by firsthand observation of the hunt during 1978 and 1980. Also of importance was the knowledge assimilated while residing in the Barrow community for one year (1977-1978).

The numerous trips to the ice camps during the tissue collection process (RU-180) provided valuable exposure to the Eskimo whaling practices.

Photography was a valuable aid in documenting the anthropological aspects of whaling. The photographs taken graphically recorded the butchering process and served to clarify the information obtained during the interviews.

When doing the interviews, drawings were made to record the procedure for dividing the whale, as a verbal description alone would have been inadequate.

RESULTS AND DISCUSSION

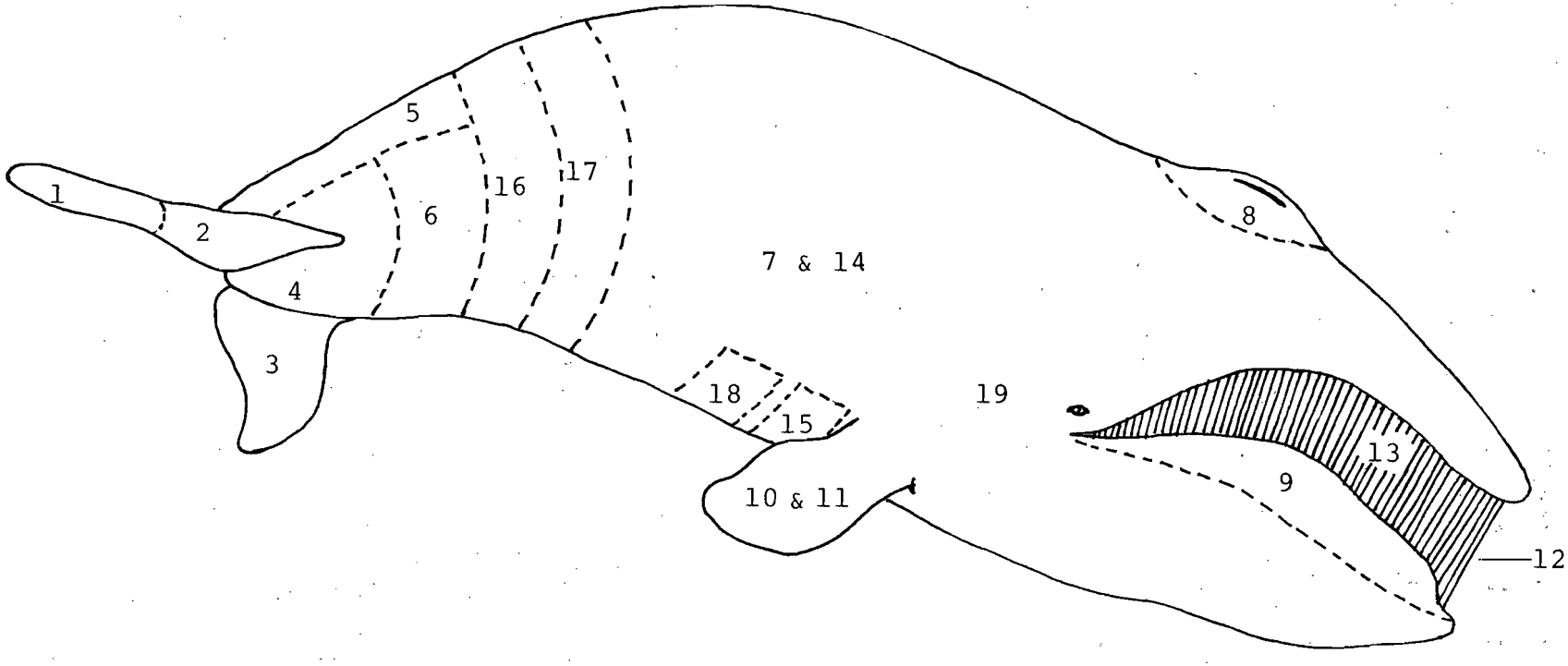
Twenty to forty people participate in the butchering process. The successful Captain directs the process. As can be seen in Figure 16-1, the various parts of the whale are allocated in a very specific manner. The items listed below pertain to the numbered areas seen in Figure 16-1.

Item 1. This section of the fluke is eaten at the Thanksgiving feast which originated under the influence of white missionaries and whalers. The feast takes place in the Presbyterian and Assembly of God churches in Barrow.

The flukes are considered by the Eskimo to be one of the most savory parts of the whale. During spring whaling the whales are struck and killed relatively close to the ice edge (within one kilometer). When the whale is killed, the flukes are removed and lifted, if possible, into the whaling boat or umiaq, a skin boat. This facilitates towing the animal to the ice edge. A heavy rope is then secured around the narrow portion of the body just anterior to the flukes and the whale is then towed to the butchering site on the ice margin.

Item 2. This section of the fluke is eaten at the Christmas celebration. This celebration is also conducted in the Barrow churches. Traditionally the Eskimos had a "winter gathering" during which they celebrated their summer and autumn bounty by dancing, feasting and competing in games. The games were similar to those performed during the Eskimo Olympics, December 26, and include the finger pull, arm pull and the double foot kick (jumping up with both feet to kick a bar).

16-1



Item 3. The other fluke is eaten at the Nalukataq, the post-whaling celebration. Nalukataq literally means "to be tossed into the air on a skin". At this feast the Eskimos perform the blanket toss. Some Eskimos believe that the blanket toss originated as a means of spotting whales far out in the leads. After a successful spring whaling season, the people have traditionally gathered on the beach to celebrate and feast on whale meat and maktak. Maktak is the skin and a portion of the attached blubber. When the maktak is eaten the blubber is trimmed to approximately 5 cm in thickness.

Item 4. This section is saved, if possible, to be eaten before the following spring whaling season in an "open house" setting. It may also be saved for the Nalukataq.

Item 5. This section is eaten during the Nalukataq celebration.

Item 6. This section is divided between the three feasts (Nalukataq, Thanksgiving and Christmas). (NOTE for Items 4, 5 and 6: Certain pieces of maktak are relished more than others, therefore, it is divided so that all receive portions of equal quality.)

Item 7. This portion which is anterior to the anus is divided among the crews in the following manner:

A. With the first whale taken all crews on the ice get an equal share whether or not they help to butcher the whale. The maktak is cut into strips (approximately 30 cm wide). Young boys are responsible for dragging the strips from the butchering site into nearby organized allotments.

B. With the second whale caught and those thereafter, each crew must send a representative to the butchering site in order to get a portion for their crew. A roll call is taken before the butchering begins.

C. If a crew is actively involved in processing their own whale, they do not need to send a crew member, however, they still receive their portion.

Item 8. The blowhole area is eaten during the Christmas feast.

Item 9. One side of the lower lip down to the ramus of the mandible is the Captains's personal share to help defray the expenses involved in supporting the crew. The other side is divided among the crews under the same constraints mentioned for the meat and maktak (see Item 7).

Item 10. The flippers are disarticulated at the scapulo-humeral joint. One is given to the harpooner who attaches the floats to the whale with the darting gun. The harpooner is a respected member of the Eskimo community.

Item 11. The other flipper is divided among the crews represented at the butchering site and the portions are taken back to the ice camps to be eaten only on the ice in accordance with an Eskimo tradition.

Item 12. The tongue is divided among the crews with the same constraints as the maktak (see Item 7).

Item 13. All of the baleen goes to the Captain unless more than one boat is involved in pulling in the whale, then the Captain gets one-half and the other half is divided equally among the other boats involved in pulling in the whale. Quite often several boats are involved in pulling in a whale, particularly during the fall season.

Item 14. The heart, small intestine and kidneys are divided in half. One half is prepared at the home of the Captain as part of an "open house" for the whole village. Food is provided until all attending are satisfied. The other half of these organs is saved for Nalukataq.

Item 15. A piece of maktak, approximately 50 x 50 x 40 cm , is cut off immediately, cooked and passed around to the workers by the women at the butchering site. Women traditionally do not go out onto the ice until after a whale has been caught. At one time they were responsible for the complete removal (and storing) of the whale from the butchering site, but this is no longer a custom today (Brower 1942).

Item 16. This section of maktak is used by the Captain to repay the other crews who fired bombs into the whale. They can choose between payment in maktak (or meat) or replacement bombs.

Item 17. This portion is cooked at the home of the Captain the day of the kill, along with section 14 at the open house ceremony. During the ceremony a flag is raised above the house of the Captain. Successful crews also put up a flag on the umiaq as they are towing in the whale. Another flag is raised at the butchering site to guide people coming from the village to the butchering site. Each whaling Captain has a separate flag design.

Item 18. This portion belongs to the owner and operator of the block and tackle used to raise the whale up onto the ice. The portion is a 30 cm cube and a similar sized piece of meat.

In earlier times when a whale was caught during the spring harvest, it could not be pulled up onto the ice, instead the Eskimo whalers used a walrus skin rope to roll the whale over and over along the ice margin while they cut off and removed strips of maktak. The meat and organs were pulled onto the ice in small pieces. The head could be immediately removed, anchored and allowed to float without danger of sinking because the tongue bouyed it up.

Item 19. The tympanic bullae are the property of the Captain. These are highly prized and very beautiful bones. They are very dense and grossly appear similar to ivory.

The meat is divided under the same stipulations as the maktak. When the whale has been completely butchered, the women (or anyone else who wants some) can glean meat scraps off the vertebrae. The skull and jaw bones are usually pushed from the ice back into the water. The Inupiaq believe that in this way the spirit of the whale never dies and future harvest are insured. This contrasts with Point Hope whalers who have a tradition of saving the lower jaw bones to document whale catch and as a contest to return with the largest jaw bones since their length is related to the length of the whale. In Point Hope they are placed at the Nalukataq grounds.

16-2

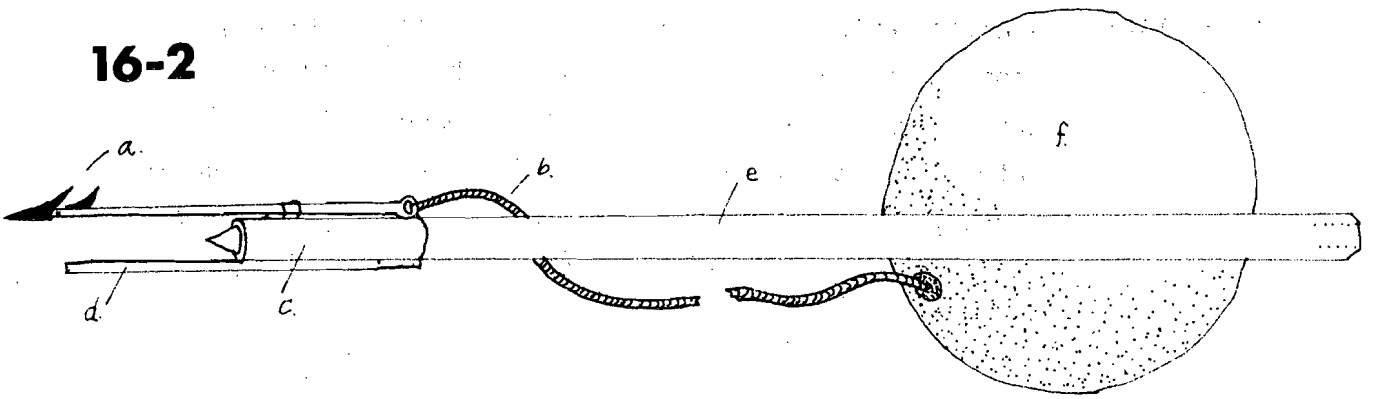


Figure 16-2. The darting gun is the primary whaling tool. It is used to simultaneously attach a line and float to the whale and kill it with explosives. These guns were developed by Yankee whalers in the nineteenth century and many of the originals are still in use today. Parts include the: harpoon tip (a), attachment line for floats (b), bomb in propelling case (c), trigger for bomb (d), shaft for manipulating weapon (e) and float used to mark and tire whale (f).

16-3

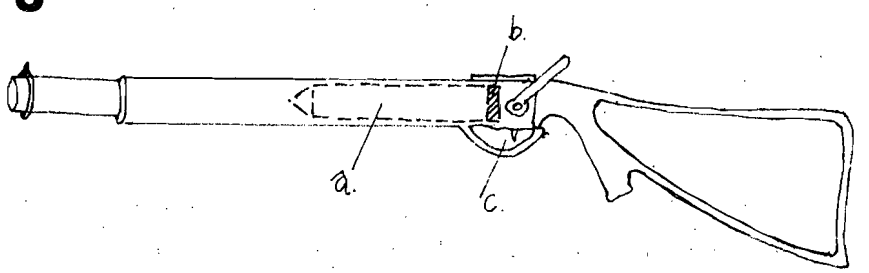


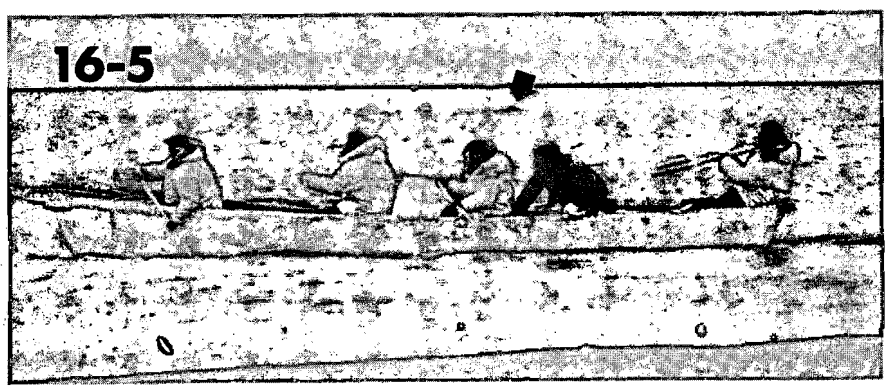
Figure 16-3. The shoulder gun is used in conjunction with the darting gun once the floats are attached. It is used to kill a wounded whale. Large whales may require many shots. Parts include the: bomb (a), charge to propel bomb into whale (b) and conventional trigger (c). The bombs have an internal fuse, which can be adjusted up to 8 seconds.

Figure 16-4. Whaling Captain Eugene Brower at his spring whaling camp, 8 km N.E. of Barrow, Alaska. He is holding a darting gun, the principle whaling weapon. It acts as both a harpoon and a bomb gun. The harpoon tip attaches a heavy rope and floats to the whale. The other function is to propel a timed bomb deep into the whale (see also Fig 16-2).

Figure 16-5. A crew in pursuit of a bowhead whale. They are paddling directly into the up-lead path of the whale where it is presumed to have limited vision. The whale being pursued is not included in this scene. Note the passing bowhead in the background (arrow), this whale is not within capture distance.

Figure 16-6. Five crews are seen aiding the successful whaling crew in towing a captured whale (80B7). It was harpooned very close to the ice margin, but was killed with the assistance of other crews approximately 2 km from where it was struck. The successful Captain (George Ahmaogak) has his traditional family flag raised (arrow). The assisting crews will divide one side or half of the baleen equally between themselves as part of the traditional process. If unassisted, the Captain would retain all of the baleen.


16-4


16-5


16-6

Figure 16-7. This whale is being hoisted with the aid of a powerful (high reduction) block and tackle onto the ice where it will be butchered. An ice ramp must be tediously chopped into the ice margin in order to facilitate hoisting the whale from the water. A radio call alerts members of the other active crews when a whale is killed who will then proceed to the butchering site to assist in dividing the whale. The assisting crews will get equal shares of meat and maktak and the owner of the block and tackle will get a special allocation (see also Fig 16-1). This whale (80B8) was 8.7 m in length.

Figure 16-8. The whale (80B8) has been pulled onto the ice and a crew member is marking the shares based on the number of crews represented at the butchering site. Harry Brower, Sr., the successful captain, is standing second from the left, in the foreground.

Figure 16-9. The strips of "maktak" or the skin and attached blubber, are organized into the allotted shares. Each crew will transport them back to Barrow to be stored in their ice cellars. Ice cellars are holes dug vertically into the permanently frozen ground accessed with ladders and a pully system, they maintain a -9^{o}C annual mean in Barrow (Metzner 1980). A typical pressure ridge is seen in the background. Such ice ridges are formidable obstacles over which paths must be chopped in order to gain access to the lead.


16-7


16-8


16-9

Figure 16-10. A sled loaded with a crew share ready for transport into the village. Muscle and organ tissue are carried in the black plastic bag on top of the blubber. The sled design is a modern counterpart to the dog sled for use with snow machines. The rough sea ice conditions can ruin a freight sled like this in two or three seasons.

Figure 16-11. A portion of the captain's share, here seen tied to a sled, includes heart (a), small intestine (b) and baleen (c). The heart and small intestine are used by the captain for the "open house" celebration the day of the whale capture and for Nalukataq.


16-10

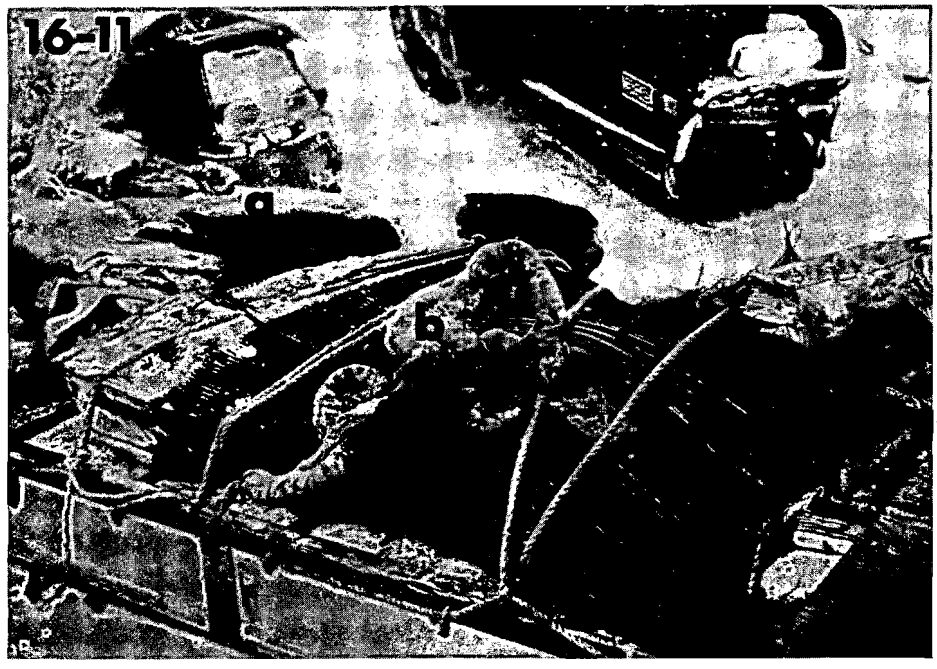

16-11
a
b

Figure 16-12. An additional portion of the Captain's share is seen to include a torso section anterior to flukes (a), lip (b) and flipper (c). By tradition, the crew member that attaches the floats to the whale (harpooner) gets one flipper. A section of the fluke (d) which is a prized food item will be saved for one or more of the celebrations.

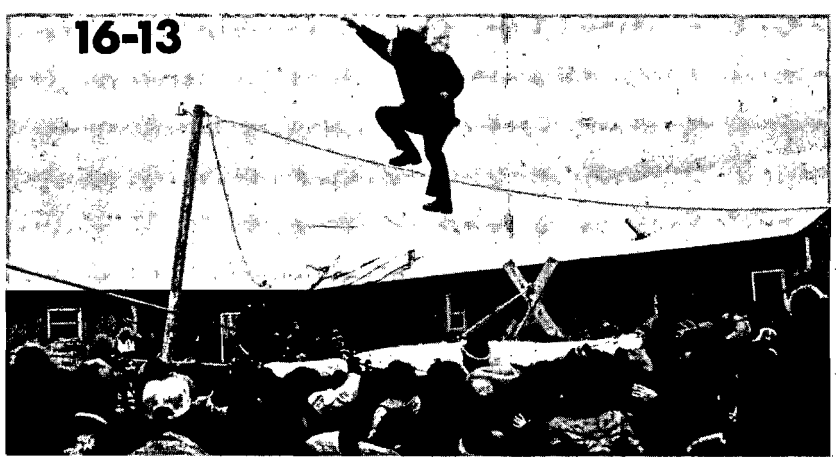


Figure 16-13. The Nalukatag or the catch of the whale celebration includes the blanket toss which it is named after. A large tarpaulin, made of ugruk skins (bearded seal) is manned by the participants who lift it rapidily throwing the jumper high in the air. Some Eskimos believe that this practice began as a technique to spot migrating whales. The Nalukataq celebration takes place on the village beach usually in June after Spring whaling has ended.

SUMMARY

In the Alaskan Arctic, bowhead whaling is and has been for thousands of years, central in the Inupiaq culture. These people have developed a strategy of collectively hunting and sharing a few large animals, finding it more efficient than hunting large numbers of small game during the whale migration.

When a whale is captured, it is divided equally among the active whaling crews which will further divide it among the community members. Thus, the successful crew will get essentially the same share as the others. In an eight week spring season, the chances for success were traditionally and are still not good, which necessitated a system of sharing, as a successful crew one year will most likely fail the next.

The Captain directs the butchering of the whale under precise traditional rules. He is also responsible for saving certain pieces for the three village festivals; Nalukataq, Thanksgiving and Christmas.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the cooperation of whaling Captains Harry Brower, Sr., his son, Eugene Brower, and Ralph Aveoganna who provided much of the information in this report. Their hospitality during my many visits to their homes and spring whaling camps is also greatly appreciated.

Thank are further due to Frankie Akpik, Pauline Adams, and Roy Nageak.

REFERENCES

Brower, C. 1942. Fifty Years Below Zero, a Lifetime in the Far North. Dodd, Mead and Co., New York.

Dumond, D.E. 1965. Eskaleutian linguistics, archaelogy and prehistory. American Anthropology. 67:1231-1257.

Dumond, D.E. 1977. The Eskimos and Aleuts. Thames and Hudson, Ltd. London.

Evans, C.D. and S. V. Cuccarese. 1980. The Bowhead Whale-Biological Basis for Decision. A Report to the Alaska Eskimo Whaling Commission from the Arctic Environmental Information and Data Center, University of Alaska, Anchorage, Alaska.

Jamison, P.L., S. Zegura and F.A. Milan. 1978. Eskimos of North Western Alaska: A Biological Perspective. Dowden, Hutchison and Ross, Inc., Stroudsburg, PA.

Metzner, R. 1980. Personal communication.

APPENDIX II

OBSERVATIONS ON THE HEART OF THE BOWHEAD WHALE

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INTRODUCTION

Structural studies on the heart of the great whales have been necessarily limited due to the many difficulties in obtaining specimens suitable for examination. Many times the sparsity of material has required, as in the present case, that descriptions be made on the basis of a single specimen. Even with this allowance, however, investigations have been few in number.

Knox (1838) was impressed by the great size of the heart in his examination of one adult and one fetal whale (Balaena borealis Knox). He also noted its broad conformation and blunt apex. Walmsley (1938) described the coronary vasculature of an adult and fetal fin whale (Balaenoptera physalus). The 250 lb heart of an adult male sperm whale (Physeter catodon) was examined by Race et al (1959). They noted that the basic design of the heart followed the general mammalian plan but that the marginal branches of the left and right coronary arteries supplying the ventricles were exceptionally large. One of the few studies based on a number of specimens was conducted by Truex et al (1961) in which observations were made on the hearts of the sei (Balaenoptera borealis), gray (Echrichtius gibbosus) and sperm (Physeter catodon) whales. They examined 10 hearts, ranging in size from 100 to 350 lbs. Their emphasis was on a description of coronary vascular patterns; however, they also noted certain pathological aspects (atherosclerotic plaques) in the hearts of 4 sperm whales and reported unidentified nematodes in the proximal veins on the dorsal surface of 2 sperm whale hearts. Slijper (1979) noted that the width of the heart exceeds its length in the mysticetes and sperm whale.

Because of its rarity as a species and its remote habitat on the globe, the bowhead whale (Balaena mysticetus) has been the subject of very little anatomic study. In the fall of 1979, the heart from a sexually mature male bowhead whale (79KK1) became available for study. The animal was taken off Kaktovik, Alaska by Eskimo hunters. Due to poor weather the beaching of the animal was delayed to the extent that the heart was no longer useful as a food item. The specimen was incomplete and had suffered partial decomposition. However, since the heart is a valued food item in the Eskimo harvest of the bowhead, further opportunities for examination of this organ seem particularly remote. For this reason we think it is of value to report our findings even of this limited specimen, allowing perhaps a preliminary comparison of the cardiac features of this species with those of other whales considered in the literature.

OBJECTIVE

1. To make gross anatomical observations on the heart of the bowhead whale.

METHODS

Studies were limited to the heart of one 12.7 m long, sexually mature male, Eskimo harvested bowhead whale (79KK1) which was supplied by Research Unit 180. The animal was captured off Kaktovik, Alaska September 20, 1979 but was lost due to a storm. It was located and beached September 22. Approximately 1/4 of the heart involving primarily the basilar portion was lost. There was decomposition of the specimen prior to fixation. This precluded histologic study. The specimen was preserved in aqueous formalin and examined in September 1980.

RESULTS

Prior to fixation the heart appeared as a large flaccid organ without a distinct apex (Fig 17-1).† After fixation, distortion limited observations on the normal shape and proportion of the heart (Fig 17-2). The gross preserved specimen weighed 80 kg. The cardiac muscle tissue and vessel walls were gray and the myocardial fat was grayish-yellow. The specimen was missing most of the right atrial (RA) free wall and all of the right auricular appendage. A V-shaped portion of the right ventricular (RV) free wall and a small section of the left atrial (LA) free wall were absent. The left ventricular (LV) free wall, left atrioventricular valve (mitral valve) and dorsal papillary muscle had been tran-

†Anatomical terms are based on usage in: Nomina Anatomica Veterinaria, 2nd Ed., Vienna, 1972 and Miller's Anatomy of the Dog by Evans and Christensen, 2nd Ed., W.B. Saunders, Philadelphia, 1979.

sected but the edges matched when reapposed, indicating the LV mass and A-V valve were present in entirety. Only a small portion of the septal cusp, papillary muscle and remnants of chordae tendineae of the right atrioventricular valve (tricuspid valve) remained. The pulmonic and aortic semilunar valves were intact and the pulmonary artery was present to the level of bifurcation into right and left pulmonary arteries. The aorta had been severed a few inches above the aortic valve. Figure 17-3 demonstrates the orientation of the valves in this specimen.

Right Atrium — The right atrial free wall was 4 mm thick at a point 17 cm above the tricuspid valve in an area free of pectinate muscles. The coronary sinus was visible but the margins were severely decomposed.

Right Atrioventricular Valve — Only a portion of the septal cusp and the papillary muscle remained near the septal end of the trabecula septomarginalis (Fig 17-4). The thickness at the free edge of the cusp was 1 mm. At a location 1/3 of the way from the free edge the cusp thickness was 2.5 mm.

Right Ventricle — The right ventricular free wall thickness was 4.2 cm at the atrioventricular junction. As in other species the inflow portion of the ventricle was more heavily trabeculated than the infundibulum. The moderator band was intact (Fig 17-5). It measured 10.5 cm in length, 3.5 cm in width and 1.5 cm in thickness in the middle of the band. The moderator band had a cavernosus-like appearance similar to erectile tissue. Histologically this appeared to be a decomposition artifact due to gas formation.

Pulmonic Valve — The valve was flattened and distorted due to fixation artifact (Fig 17-6). The approximate circumference was 15 cm. The measurements of the leaflets are shown in Table 17-1. The leaflets were thinnest at the free edge, thicker toward the center and thin at the base. The left and right cusps had a scalloped free margin. Behind each cusp was a sinus of Valsalva.

Left Atrium — The wall thickness of the anterior free wall varied between 2-10 mm due to well developed pectinate musculature. Near the junction of the pulmonary veins the dorsal free wall was 1.4 cm thick. At the junction of the auricular appendage the free wall was 5 mm thick.

Mitral Valve — The mitral valve circumference was 72 cm. The valve consisted of a septal (Fig 17-7) and parietal cusp (Fig 17-8)

with two small commissural cusps. The thickness of the cusps is given in Table 17-2. There were first and second order chordae tendineae. Primary chordae were approximately 7-10 cm long and and 1-2 mm thick at the attachment to the valve free edge. The secondary chordae were longest with an average length of approximately 11 cm. The average thickness was 4 mm at the point of attachment on the ventral aspect 3.5-4 cm from the free margin of the cusps.

There were 3 firm laminar thickenings involving single chordae of the mitral valve apparatus (Fig 17-9). The lesions were nodular to cylindrical in appearance. They did not incorporate the papillary muscles or valve cusps. One nodule 7.5 mm in diameter originated next to the ventral papillary muscle on a chorda which inserted on the septal cusp (Fig 17-10). A dumbbell shaped nodule 2 cm long and 7.5-12.5 mm in diameter originated from the dorsal papillary muscle on the lower half of a chorda which inserted on the septal cusp (Fig 17-11). A third cylindrical lesion 4 cm long and 7.5-10 mm in diameter was located above the dorsal papillary muscle on the lower half of a chorda inserting on the septal cusp (Fig 17-12). The lesions did not appear likely to restrict the movement of the mitral valve or to affect valve competence.

The chordae lesions were sectioned for histochemical evaluation. Masson's trichrome stain indicated the tissue was composed primarily of fibrous connective tissue and Von Kossa stain revealed foci of calcification (Fig 17-13).

Left Ventricle The left ventricular free wall was 5 cm thick at the A-V junction, 4 cm thick just below the origin of the dorsal papillary muscle and 3 cm thick at the apex. The trabeculae carneae were coarser and more impressively developed in the left ventricle than in the right. The trabeculae were more numerous and dense on the apical left ventricular free wall than along the basilar LV wall or septum (Fig 17-14). The LV septum was muscular along its entire length.

The papillary muscles appeared short, broad and flattened (Fig 17-15). The ventral papillary muscle was 10 cm wide. The dorsal papillary had been transected through its long axis. The wall thickness including the dorsal papillary muscle was 9 cm at the level of origin of the chordae.

Aortic Valve: The aortic valve had an approximate circumference of 42 cm (Fig 17-16). There were no noduli valvularum semilunarium (Arantii) in the center of the cusp margins. There were distinct sinuses of Valsalva in the aortic wall behind each cusp. Each cusp had numerous short

half-moon shaped striations (lunulae valvularum semilunarium) parallel to the valve edge on the superior surface. The cusps were thinner at the margin and thicker towards the center of the cusp (Table 17-3).

The right coronary ostium was flattened during fixation. The distorted orifice was 6 cm long and 2 cm wide. The right and left edges of the ostium were each 5 cm from the respective commissure of the right cusp. From the free cusp margin to the dorsal aspect of the ostium was 4.75 cm.

The left coronary ostium had a diameter of 4.5-4.75 cm (Fig 17-17). The left border of the ostium was 9 cm from the left commissure with the right cusp. The right border of the ostium was located 3.25 cm from the right commissure with the septal cusp. The dorsal edge of the ostium was 3.25 cm above the cusp margin.

The left cusp had two fenestrated lesions near the margin of the cusp in the area of the lunulae. The smaller fenestration was a 7 mm long, 2 mm wide slit located over the left coronary ostium 3 cm from the right commissure of the cusp and 5 mm from the cusp margin (Fig 17-18). The larger fenestration had web-like interdigitating strands of cusp tissue giving it the appearance of a 3-lobed clover leaf (Fig 17-19). The lesion was 1.2 cm in length and width and was located 2.5 cm from the left commissure of the cusp and 5 mm from the cusp margin.

Coronary Vasculature The coronary vasculature was embedded in large fat deposits in the A-V sulcus and interventricular grooves. The left coronary ostium opened into the circumflex coronary artery (1.5 cm diameter) and into the paraconal interventricular coronary artery (ventral interventricular c.a.) (Fig 17-20). Septal branches from the paraconal interventricular c.a. penetrated deep into the septum. A left ventricular c.a. and left marginal c.a. branched off the circumflex c.a. The right coronary artery (2.0 cm diameter) originated from the right coronary orifice. The artery wall thickness was 2.5 mm. Due to loss of right atrial and ventricular tissue, the presence or lack of branches other than a right ventricular c.a. from the right c.a. could not be determined. A subsinuosal interventricular c.a. (dorsal interventricular c.a.) communicated with both the circumflex and right coronary artery (Fig 17-21).

The coronary venous pattern consisted of a great cardiac vein which paralleled the paraconal interventricular and circumflex c.a. (Fig 17-22). A left marginal vein coursed beside the corresponding artery. The great cardiac vein, middle cardiac vein (dorsal interventricular v.) and right cardiac v. all

TABLE 17-1. MEASUREMENTS (mm) OF THE PULMONIC VALVE FROM WHALE 79KK1

Cusp	Width at midpoint	Length	Thickness at free edge*	Thickness 5.5 cm from free edge*	Thickness at base*
Left cusp	80	140	1.5	4	2.5
Intermediate cusp	110	185	2.5	3	3.5
Right cusp	75	170	1.5	3	1.5

*Measurements taken at middle of cusp length

TABLE 17-2. MEASUREMENTS (mm) OF THE MITRAL VALVE FROM WHALE 79KK1

Cusp	Thickness free edge	Thickness 2 cm from free edge	Thickness 5 cm from free edge	Thickness at base
Septal cusp	2	5	1.5	--
Parietal cusp	1 - 2	--	--	3

TABLE 17-3. MEASUREMENTS (mm) OF THE AORTIC VALVE FROM WHALE 79KK1

Cusp	Length	Width	Thickness at free edge*	Thickness 4.5 cm from free edge*	Base
Septal cusp	200	100	1 - 2	5	2
Left cusp	170	95	2	3.5	3
Right cusp	200	80	1.5	4	4

*Measurements taken at middle of cusp length

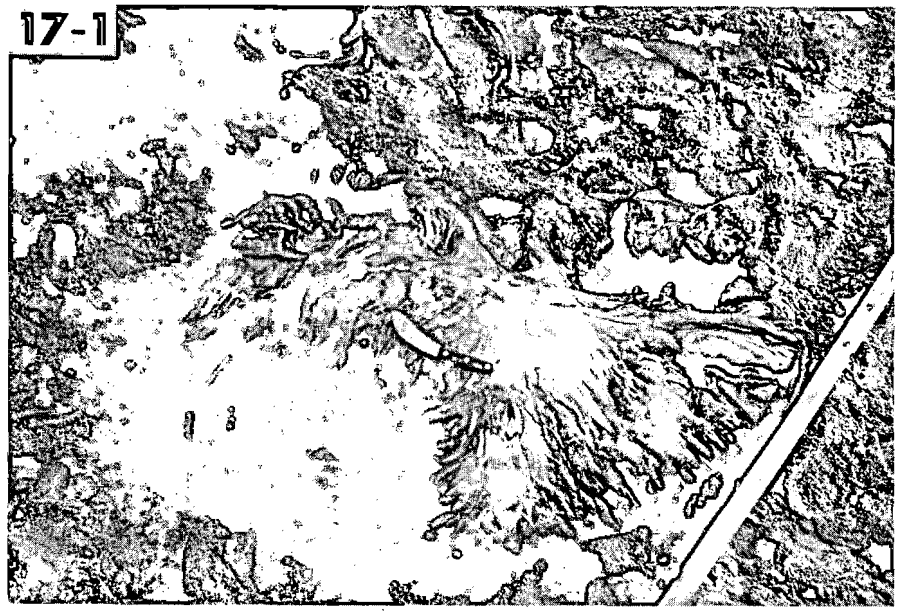
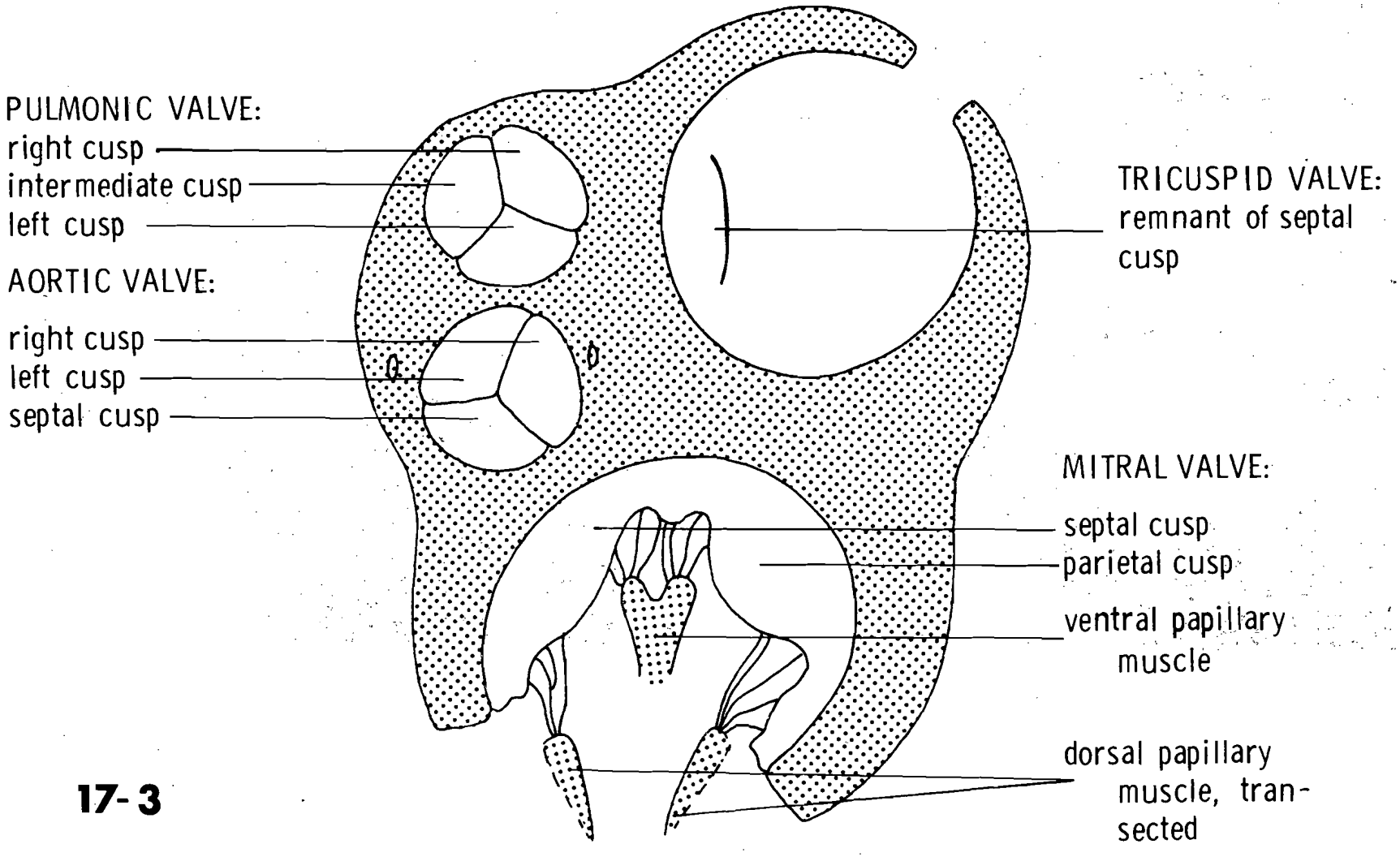
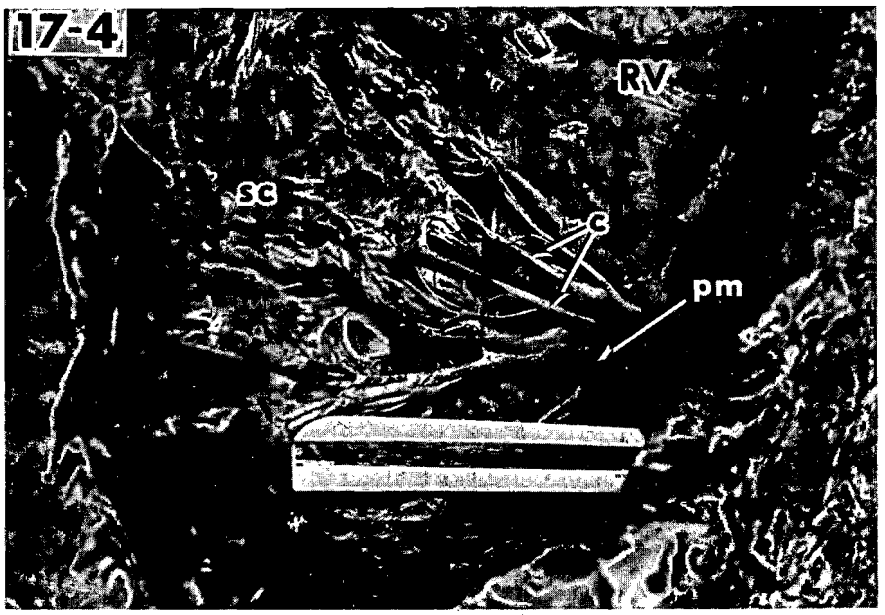


Figure 17-1. The large globular heart of a bowhead whale 79KK1 at the butchering site. The knife is approximately 24 cm long.

Figure 17-2. The preserved heart (79KK1) being dissected by Dr. Ray Tarpley. The specimen weighed 80 kg.; however, approximately 1/4 of the heart was missing (primarily from the basilar area).

Figure 17-3 A craniodorsal view illustrating the orientation of the valves. Note that the aortic valve is situated with the right cusp nearest the septum as in pigs. Only a portion of the septal cusp of the tricuspid valve remained.





Firgure 17-4 Remnants of the septal cusp (sc), chordae tendineae (c) and papillary muscle (pm) of the tricuspid valve. The septal wall of the right ventricle is indicated (RV).

Figure 17-5 The trabecula septomarginalis (moderator band) (m) of the right ventricle. This large cord of cardiac muscle joined the septal and free walls of the right ventricle and was 10.5 cm in length Note remnants of chordae tendineae (c) on the septum adjacent to the band.

Figure 17-6. The pulmonic valve, consisting of 3 cusps, was distorted as a result of fixation. A clamp in each sinus of Valsalva identifies the 3 cusps (p).

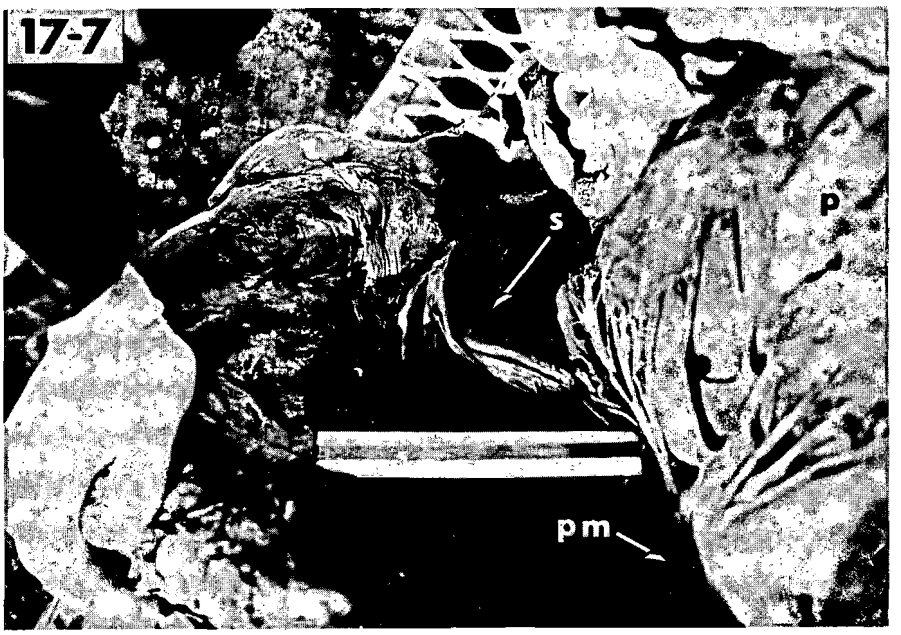


Figure 17-7. The septal cusp (s) of the mitral valve had been transected through the left ventricular free wall and dorsal papillary muscle. A portion of the ventral papillary muscle (pm) and parietal cusp (p) are seen on the right of the photo. The ruler is 15 cm long.

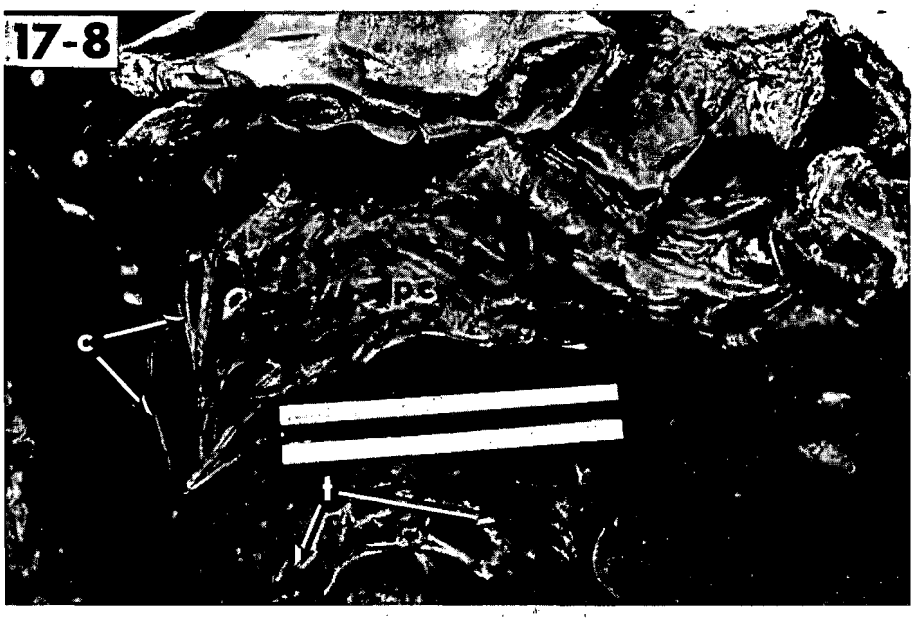


Figure 17-8 The parietal cusp (pc) of the mitral valve and its chordae tendineae (c) overlying the septum. Well developed trabeculae carneae (t) in the left septal wall can be seen. The ruler is 15 cm long.

Figure 17-9 Three laminar firm lesions removed from chordae tendineae of the mitral valve. These were shown histochemically to consist of fiborous connective tissue and calcium deposits. No other portions of the mitral apparatus were involved.

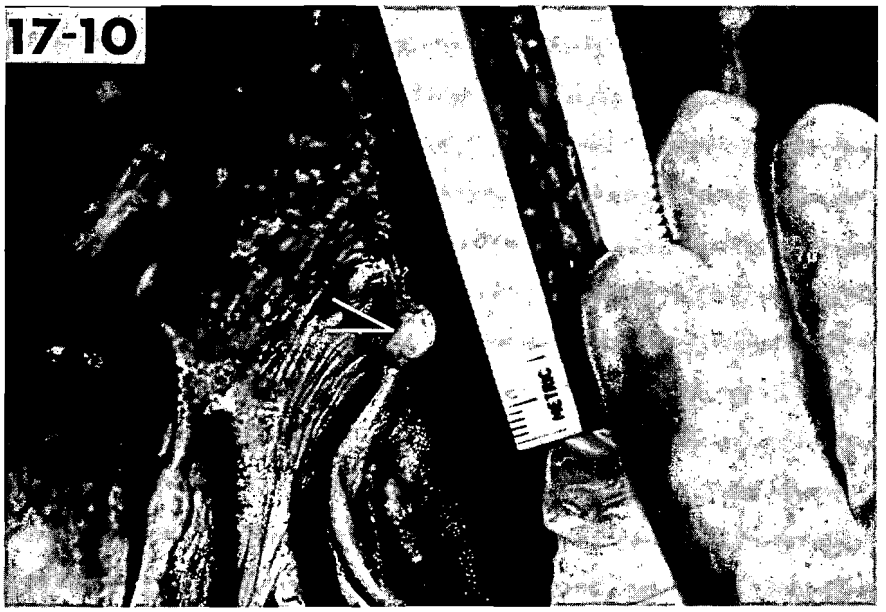


Figure 17-10 Nodular lesion (arrowhead) on a chorda tendineae originating on the ventral papillary muscle and inserting on the septal cusp. This lesion is approximately 7.5 mm in diameter and is shown on the left in Fig 17-9.

Figure 17-11 Dumbbell shaped lesion (arrowheads) on a chorda tendineae originating from the dorsal papillary muscle and inserting on the septal cusp (c). This lesion is shown in the center in Fig 17-9. The ruler is 15 cm long.

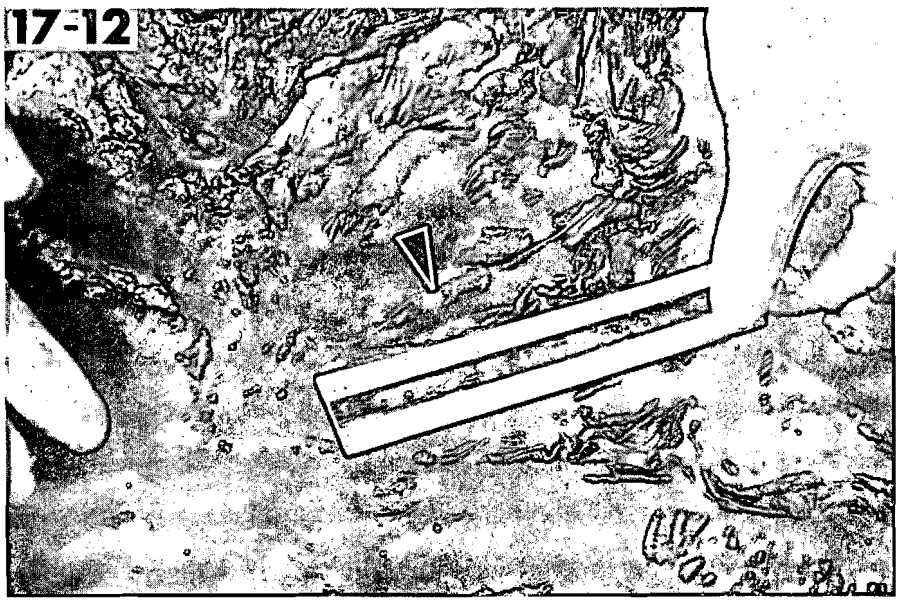


Figure 17-12 Cylindrical lesion (arrowhead) on a chorda tendineae originating from the dorsal papillary muscle and inserting on the septal cusp. This lesion is shown on the right in Fig 17-9. The ruler is 15 cm long.

Figure 17-13 Photomicrograph illustrating Von Kossa stained black foci of calcification (arrowheads) in a lesion from a chorda tendineae of the mitral valve. Objective magnification - 10X.

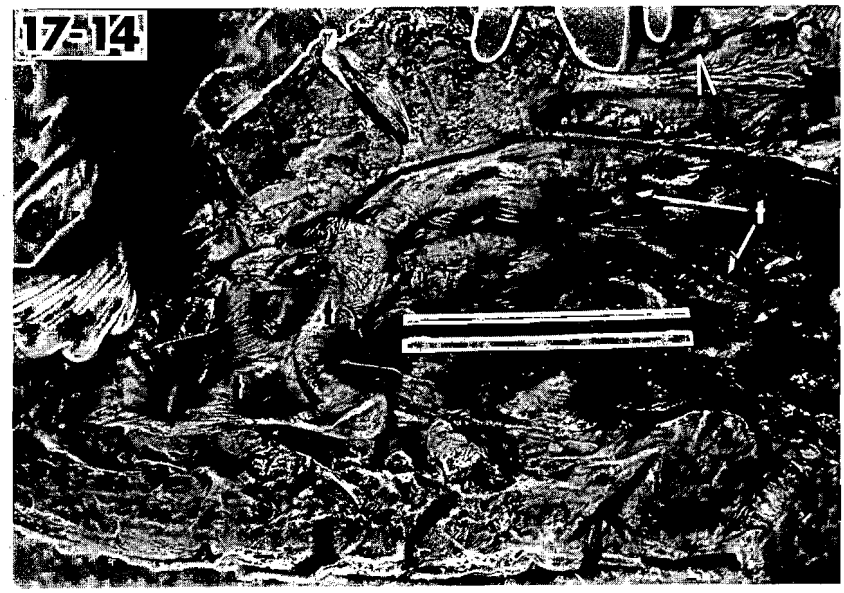


Figure 17-14. Cross section of the left ventricular free wall distinguished by prominent branching trabeculae carneae (t). The apex of the ventricle is at the left on the photo. In the upper right hand corner, a cylindrical lesion (arrowhead) on a chorda tendineae of the septal cusp of the mitral can be seen. This lesion is also pictured in Figs 17-9 & 17-12. The ruler is 15 cm long.

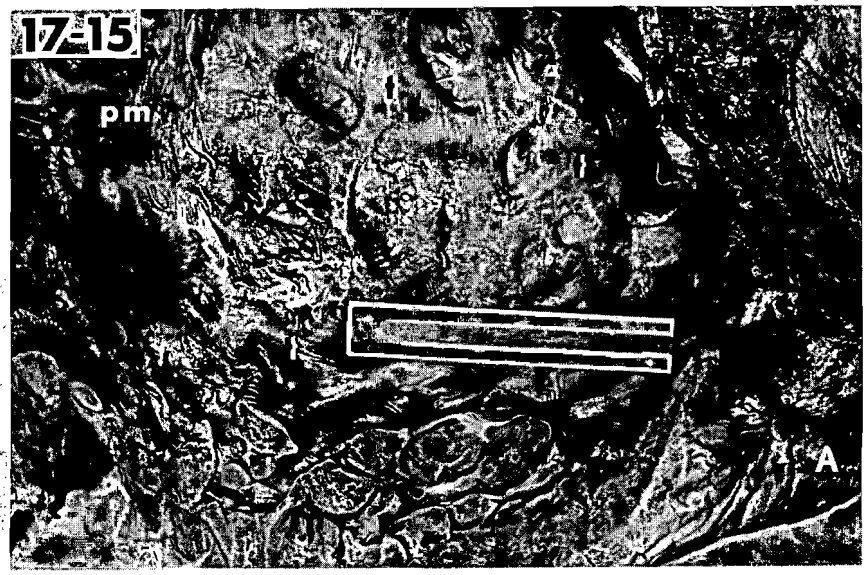


Figure 17-15. The left ventricular septum with trabeculae carneae (t). The ventral papillary muscle (pm) is a flattened, broad structure in the upper left quadrant of the photo. The apex (A) of the ventricle curls up to the right end of the 15 cm ruler.

Figure 17-16. Aortic valve with three cusps (c). Clamps were placed through the left and right coronary ostia. Note the fenestration at the margin of the left cusp (f).

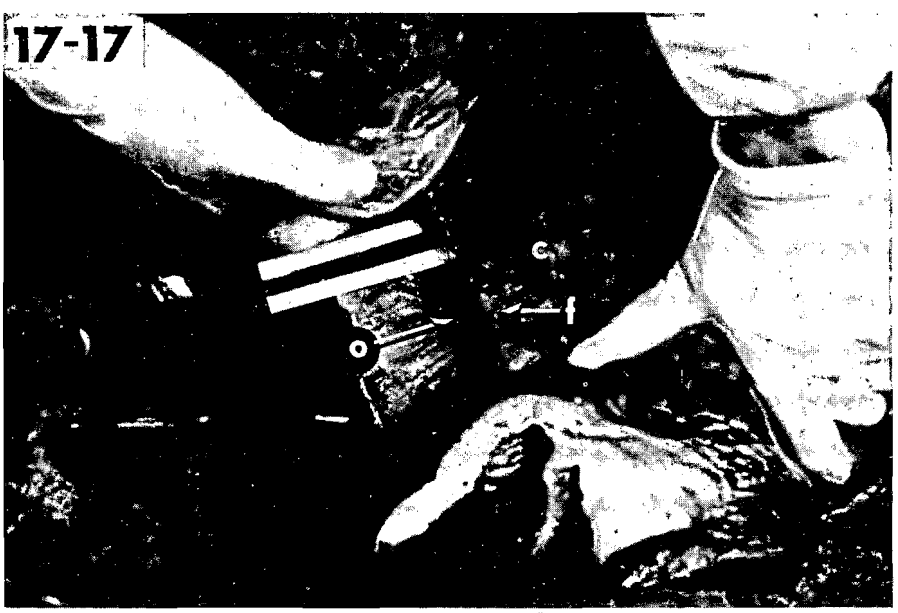


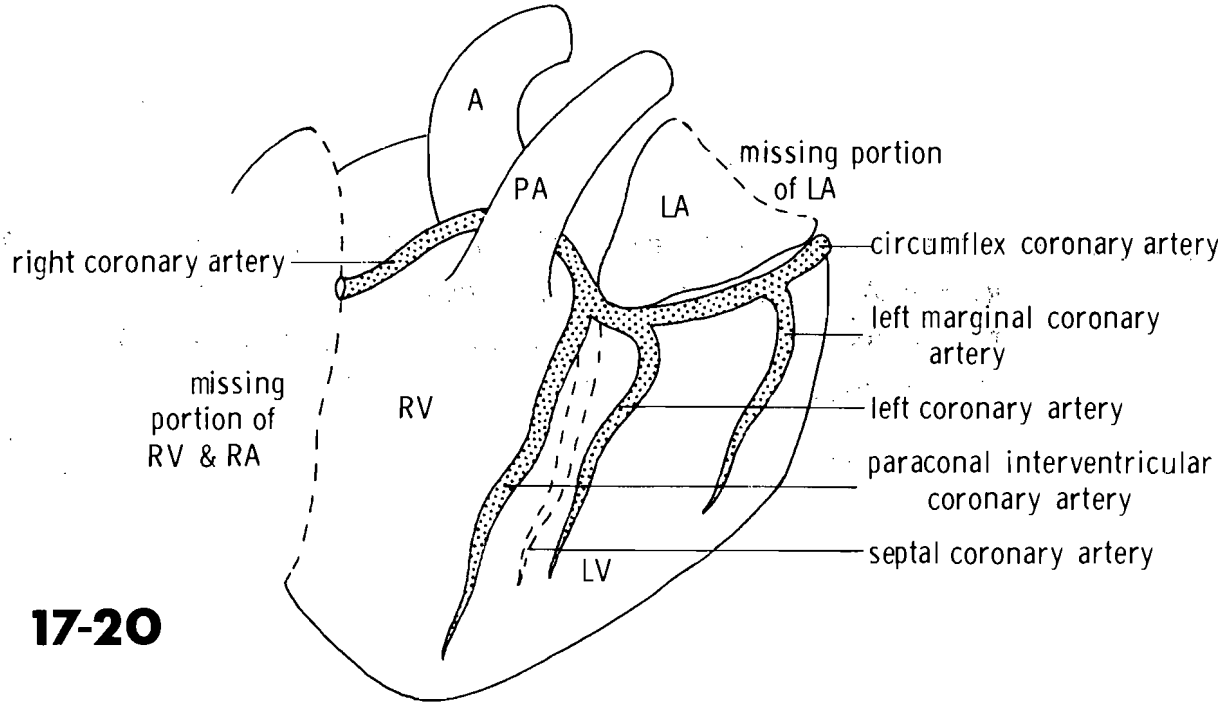
Figure 17-17. Left cusp (c) of the aortic valve with left coronary ostium (o) behind the cusp. Note the fenestration (f) near the margin of the valve cusp overlying the ostium.

Figure 17-18 Enlargement of the slit-like fenestration (arrowhead) 5 mm from the left cusp (c) margin of the aortic valve overlying the left coronary ostium (o). The fenestration is 7 mm long and 2 mm wide.

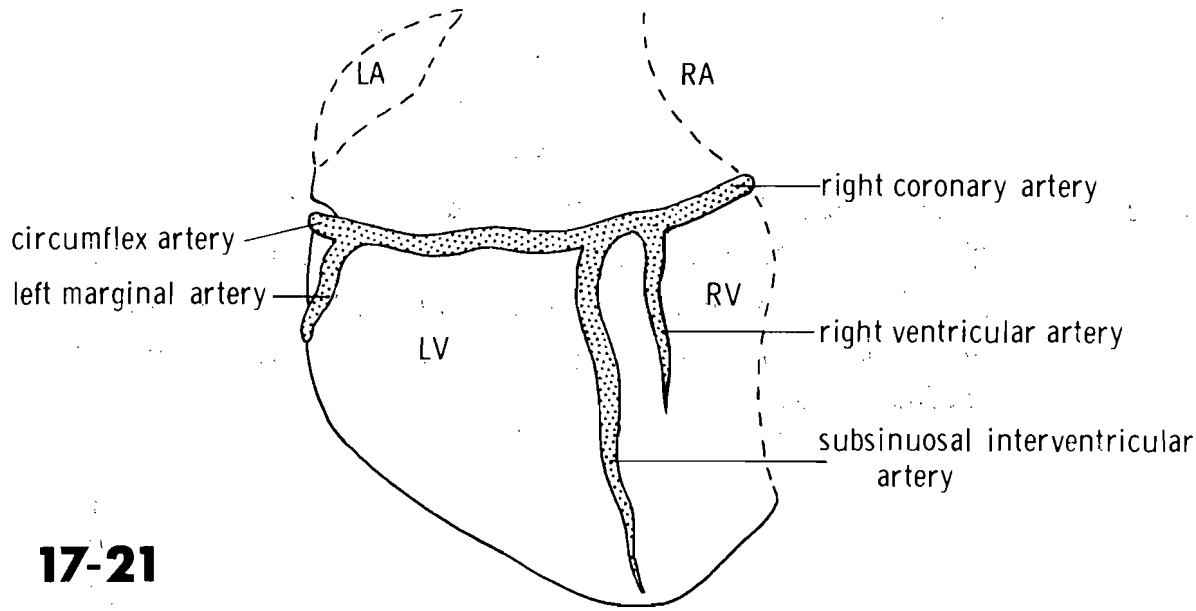
Figure 17-19 Another fenestration (1.2 cm in length and width) (f) in the left cusp (c) of the aortic valve. The fenestration had interdigitating, weblike strands giving it the shape of a 3-lobed cloverleaf. Left coronary ostium indicated (o).

Figure 17-20 Illustration of the cranioventral coronary arteries in whale heart 79KK1. Part of the right ventricle (RV) and atrium (RA) and left atrium (LA) were missing. Branches off the cirumflex artery supplied the septum and left ventricle (LV). The aorta (A) and pulmonary artery (PA) are indicated.

Figure 17-21 Illustration of the caudodorsal coronary arteries in whale heart 79KK1. Note the anastomosis of the circumflex and light coronary arteries. The left (LV) and right (RV) ventricles and position of left (LA) and right (RA) atria are indicated. The dashed lines delineate tissue missing from the specimen.


A
PA
LA
missing portion of LA
right coronary artery
circumflex coronary artery
left marginal coronary artery
missing portion of RV & RA
RV
left coronary artery
paraconal interventricular coronary artery
septal coronary artery
LV

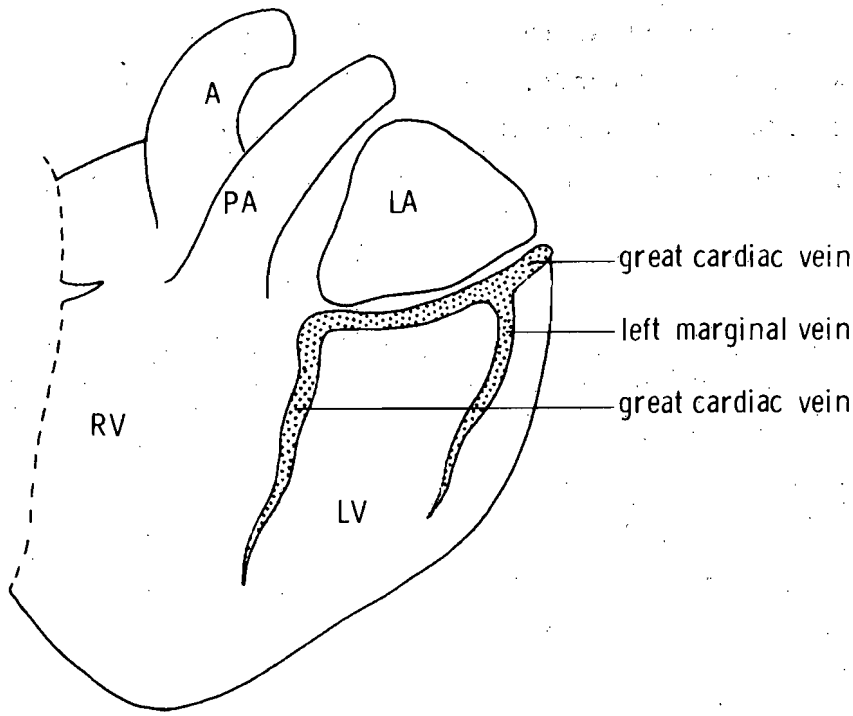
17-20


LA
RA
right coronary artery
circumflex artery
left marginal artery
RV
LV
right ventricular artery
subsinuosal interventricular artery

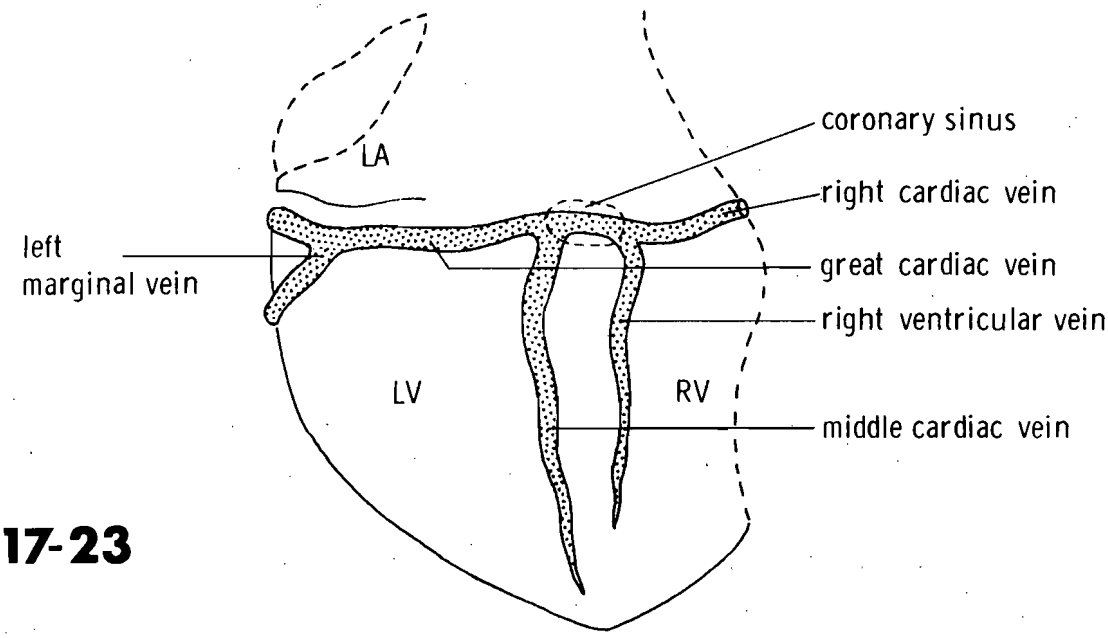
17-21

Figure 17-22 Illustration of cranioventral coronary veins in whale heart 79KK1. RV = right ventricle, LV = left ventricle, LA = left atrium, PA = pulmonary artery, A = aorta. The dashed lines delineate missing tissue.

Figure 17-23 Illustration of the caudodorsal coronary veins in whale heart 79KK1. LA = left atrium, LV = left ventricle, RV = right ventricle. The great cardiac, right cardiac and middle cardiac veins opened into the coronary sinus. The dashed lines delineate missing tissue.


A
PA
LA
great cardiac vein
left marginal vein
great cardiac vein
RV
LV

17-22


LA
coronary sinus
right cardiac vein
left
marginal vein
great cardiac vein
right ventricular vein
LV
RV
middle cardiac vein

17-23

communicated with the coronary sinus (Fig 17-23). A right ventricular vein was adjacent to the middle cardiac vein over the RV. The cardiac veins were larger in diameter and thinner walled than the corresponding arteries. The great cardiac vein and right cardiac vein were ventral to the coronary arteries. There were numerous anastomotic vessels and sinuses communicating with coronary arteries and veins which were most apparent in the interventricular sulci and A-V sulcus.

DISCUSSION

The exact measurements of various tissues in this specimen may not be realistic because of the effects of fixation and therefore may be of less value than those from a fresh specimen. However, due to the void of information pertaining to the cardiovascular system of the bowhead whale these observations are recorded as a basis of gross anatomical information on which to build and compare any future observations derived from study of more desirable specimens.

Although the specimen weighed 80 kg, the heart would have probably weighed in excess of 91 kg if the missing tissues were taken into account. It was a large globular specimen in which both the left and right ventricle contributed to the apex as has been noted in other species of whales by Knox (1838) and Truex et al (1961). The rough comparison of left to right ventricular free wall thickness ratio was less than in most other species of mammals. The trabecular and papillary muscles of the ventricles resembled those seen in large domestic mammals, i.e., horses and cattle, but in proportionately larger dimensions. The trabeculae carneae were prominent and branched while the papillary muscles were broad and flattened.

The orientation of the cardiac valves was similar to other mammalian hearts except that the aortic valve was situated with the right cusp adjacent to the septum as is seen in porcine hearts. The mitral valve was bicuspid. Three lesions consisting of fibrous connective tissue and calcium deposits were found on the chordae tendineae of this valve. The lesions did not appear likely to have impaired valve function but are interesting in that they involved only a portion of each chordae and not other parts of the mitral apparatus. This is a very unusual finding which is not characteristic of normal ischemic or infectious phenomena. An A-V valve from another bowhead whale (79KK4) (Albert 1979, Fetter and Everitt 1979) did not have lesions involving the chordae. Benign aberrant tissue growth or scar formation and calcification secondary to thrombi or parasitic migration would be considered as possible causes.

Fenestrations on the aortic valve similar to the ones observed in this study have been described in other species, including man (Netter 1969) and horses (Stunzi and Tuescher 1970), as an infrequent but normal finding. The semilunar valve from whale 79KK4 (Albert 1979, Fetter and Everitt 1979) did not show any fenestrations in the cusps. The fenestrations are typically located at the site of the lunulae near the margin of the cusp and within the contact zone with other valve cusps. Hence they do not result in valvular insufficiency. Such lesions are more common on the aortic valve but either or both semilunar valves may be affected.

The coronary vascular pattern was similar to that described by Truex et al (1961) as the basic coronary pattern observed in gray and sei whales. Race et al (1959) described large left and right marginal coronary arteries without left or right ventricular artery branches in the heart of an adult sperm whale. Both studies noted in all specimens an anastomosis between the distal right coronary artery and circumflex coronary artery as was observed in this specimen. The left and right coronary arteries appeared to contribute equally in distribution to the cardiac tissue. There were large anastomotic vessels and sinuses between coronary arteries and veins of this specimen which were larger and more numerous than those observed in other non-marine mammals. Truex et al (1961) observed anastomotic vessels between arteries and veins in ten hearts from sei, gray and sperm whales. Although no atherosclerotic plaques were noted in the vessels of this specimen, the advanced state of decomposition would have made such an observation difficult if not impossible.

It is hoped that future acquisition of fresher specimens will allow more detailed study of the anatomy of the heart of the bowhead whale. Areas of particular interest would include conduction tissues, myocardial fiber dimensions, coronary vasculature, the cardiac valves, cardiac chamber volumes and observation for vascular parasites.

SUMMARY

Gross anatomical observation of the preserved heart of harvested bowhead whale 79KK1 revealed a large globular shaped heart with similar structure to other large mammalian species. The aortic valve orientation was similar to that of the pig heart. Two fenestrative lesions near the margin of the left cusp of the aortic valve were similar to normal fenestrations reported in semilunar valves of man and horses. Three firm nodular to cylindrical thickenings on each of three chordae tendineae of the mitral valve were composed of fibrous connec-

tive tissue with foci of calcification. Similar chordae lesions have not been described in other cetacean hearts or in hearts of other mammals. The coronary vascular pattern resembled that which has been described in hearts from sei and gray whales. Histologic studies were not possible due to decomposition of the specimen prior to fixation.

REFERENCES

Albert, T. F. 1979. Tissues (Structure/Function) (RU-280) In: Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of the Beaufort Sea Lease Area, J. Kelley and G. Laursen (eds.), pp. 297-329. Final Report to the Bureau of Land Management from the Naval Arctic Research Laboratory, Barrow, Alaska.

Evans, H. E. and G. C. Christensen. 1979. Miller's Anatomy of the Dog, 2nd Ed., pp. 632-651. W. B. Saunders, Philadelphia.

Fetter, A. W. and J. I. Everitt. 1979. Tissues (Structure/Function) (RU-280a) In: Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of the Beaufort Sea Lease Area, J. Kelley and G. Laursen (eds.), pp. 331-358. Final Report to the Bureau of Land Management from the Naval Arctic Research Laboratory, Barrow, Alaska.

Knox, F. J. 1838. Catalogue of Anatomical Preparations of the Whale, pp. 1-38. Neill and Co., Edinburgh.

Netter, F. H. 1969. Anatomy. In: Heart, The Ciba Collection of Medical Illustrations, Vol. 5, pp 1-33. CIBA, Summit, N. J.

Race, G. J., W. L. J. Edwards, E. R. Halden, H. E. Wilson and F. J. Luibel. 1959. A large whale heart. Circulation 19:928-932.

Slijper, E. J. 1979. Whales, p. 159. Cornell University Press, Ithaca, N.Y. Second English edition. First English edition published in 1962.

Stunzi, H. and E. Tuescher. 1970. Endocardium. In: Handbuch der Speziellen Pathologischen Anatomie der Haustiere, E. Joest (ed), pp. 201-240. Paul Parey, Berlin, Germany.

Truex, R. C., F. G. Nolan, R. C. Truex, Jr., H. P. Schneider and H. I. Perlmutter. 1961. Anatomy and pathology of the whale heart with special references to the coronary circulation. Anat. Rec. 141:325-353.

Walmsley, R. 1938. Some observations on the vascular system of a female finback. Contr. Embryol. Carneg. Instn., 37:109-192.

APPENDIX III

RESEARCH MEETING

Tissue Structural Studies of the Bowhead Whale, *Balaena mysticetus*

Dates:	December 18, 19, 20, 1980
Location:	Howard Johnson's Motor Lodge Washington National Airport 2650 Jefferson Davis Highway Arlington, Virginia 22202
Sponsored By:	Department of Veterinary Science University of Maryland College Park, Maryland 20742

AGENDA

Thursday Evening, December 18, 1980

6:20 P.M. Introduction, Objectives of Meeting. T. Albert

6:30 P.M. Overview of BLM Whale Research. T. Sullivan

7:00 P.M. Distribution of Whale Tissue among Eskimo Hunters at the Butchering Site. C. George

7:30 P.M. Project Management, Tissue Collection Procedures, Strandings, Toxic Substances. T. Albert; RU 180, 280, 380

Friday, December 19, 1980

8:00 A.M. Observations on the Structure of the Lymphoimmune System and Bone of the Bowhead Whale. A. Fetter, J. Everitt; RU 480

9:00 A.M. Observations on the Structure of the Reproductive System of the Bowhead Whale. M. Garcia; RU 580

9:30 A.M. Observations on the Structure of the Visual Apparatus of the Bowhead Whale. R. Dubielzig; RU 680

10:00 A.M. Break

10:30 A.M. Observations on the Composition of the Blood and Urine of the Bowhead Whale. W. Medway; RU 880

11:00 A.M. Studies on the Cytogenetics of the Bowhead Whale. G. Jarrell; RU 980

11:30 A.M. Lunch

1:00 P.M. Observations on the Structure of the Lung of the Bowhead Whale. J. Haldiman, R. Henry, W. Henk; RU 1380

1:30 P.M. Observations on the Structure of the Skin of the Bowhead Whale. F. Al-Bagdadi; RU 1380

2:00 P.M. Observations on the Structure of the Kidney of the Bowhead Whale. Y. Abdelbaki, W. Henk; RU 1380

2:30 P.M. Observations on the Structure of the Brain of the Bowhead Whale. D. Duffield; RU 1380

3:00 P.M. Break

3:30 P.M. Observations on the Structure of the Stomach and Intestines of the Bowhead Whale. R. Sis, R. Tarpley; RU 1480

4:00 P.M. Studies on the Serology and the Viral Flora of the Bowhead Whale. A. Smith; RU 1080

4:30 P.M. Studies on the Bacterial Flora of the Bowhead Whale.
D. Johnston; RU 1180

5:00 P.M. Observations on the Parasites of the Bowhead Whale.
R. Heckmann; RU 1280

5:30 P.M. Dinner

7:00 P.M. Pathological Findings Noted During the Post Mortem Examination of Bowhead Whales. G. Migaki; RU 780

7:30 P.M. Studies on the Auditory Apparatus of the Bowhead Whale.
J. Norris; RU 1580

8:00 P.M. Observations on the Structure of the Heart of the Bowhead Whale.
C. Jones, R. Tarpley

Saturday, December 20, 1980

8:30 A.M. General Discussion and Assessment of Findings.
- How far have we come towards achieving stated objectives of project?
- General review of findings
- Integration of findings
- Areas requiring further study
- Any areas overlooked?

11:30 A.M. Lunch

1:00 P.M. (continuation of Discussion and Assessment)

2:30 P.M. Aspects of Report Preparation (Closed Session: investigators and consultants)

4:00 P.M. Adjourn

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APPENDIX IV

SOME BRAIN MORPHOMETRICS OF THE BOWHEAD WHALE

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INTRODUCTION

The gross and microscopic anatomy of various mysticete brains have previously been examined (Breathnach 1955, Jacobs and Jensen 1964, Morgane et al 1980, Pilleri 1964). Perhaps the best comparison that can be made for bowhead material is the work of Pilleri (Pilleri 1964) on the southern right whale Eubalaena.

I was interested in studying the relative cephalization of the bowhead as compared with other cetacean species and especially to compare various odontocetes of similar brain size with the bowhead, a mysticete. In relating brain size to body weight mysticete whales come off rather poorly compared with other mammals. But, as Von Bonin (Von Bonin 1937) has pointed out, "whales have an enormous amount of subcutaneous fat, a special adaptation to life in cold ocean waters, which enters into their body weight." I wished, therefore, to compare the bowhead to some odontocete whales for which material was available.

I have been interested in cephalization (Jerison 1973) and in how convoluted is the cerebral cortex in various small cetaceans (Elias and Schwartz 1969). Data had been obtained through postmortem examination of oceanarium specimens and beached or stranded cetaceans (Ridgway and Brownson 1979, Ridgway and Dailey 1972). A standard procedure had been developed for examination of such brains and this procedure was followed with the bowhead material.

OBJECTIVE

To study the relative cephalization of the bowhead whale as compared with other cetaceans.

METHODS

Brains were removed from Eskimo harvested bowhead whales through the efforts of RU 180. Each brain was placed in formalin after removal and allowed to fix for 2 to 4 weeks before shipment to San Diego for analysis.

On arrival in the laboratory, the formalin was changed and the brain in formalin was placed on a shaker bath for about one week to assure more uniform penetration of the fixitive before examination.

After it was thoroughly hardened each brain was bisected by a mid-sagittal cut through the interhemispheric cleft, and septum, exposing the median walls of the cerebral hemispheres. The corpus callosum was severed between the hemispheres and the cut continued along the raphe of the brain-stem finally bisecting the cerebellum.

Each half brain was rinsed with tap water, dried and weighed separately. The total weight recorded was the sum of the two halves. The brainstem and cerebellum were removed by a cut from the anterior margin of the superior colliculus down to the posterior margin of the infundibulum. The cerebellum was separated from the brainstem and all these parts were weighed.

The cerebral hemispheres were placed in a guillotine device and cut into 1 cm slices for gross examination and analysis by stereology (Elias and Schwartz 1969). Stereology makes possible a three dimensional analysis like surface area of the cerebral cortex by examination of two dimensional surface such as a brain slice. Using a clear lined lucite plate each brain slice was counted according to published stereology methods (Elias and Schwartz 1969) and the available formulae were employed to calculate cortical surface area and index of folding of the cerebral cortex.

RESULTS

Results obtained from six bowhead brains examined during the past two years are presented in Table 19-1. No gross pathology was observed in any of the brains (Fig 19-1). The mean brain weight for the six animals was 2,738 grams. The brain labeled as "Ingutuk" was not grossly different in any way that could be determined from this examination. The cerebellum (Fig 19-2)

TABLE 19-1. SOME BRAIN MORPHOMETRICS OF THE BOWHEAD WHALE

Animal Number	Length (m)	Total Brain Wt. (Gm)	Cerebellum Wt. (Gm)	Percent of Cerebellum	Cortex Surface Area (cm^2)	Index of Folding
79B1	8.71	2717	676	24.8	4219	3.37
79KK2	--	2560	552	21.6	3989	3.02
79KK3	10.3	3133	575	18.4	4734	2.76
79KK4	9.14	2500	609	24.3	4121	2.84
80B2	10.8	2740	656	23.9	3934	2.62
80B8	8.7	2781	510	18.3	5251	2.94
$\bar{X}$	9.53	2738	596	21.8	4374	2.93
S.D.	0.85	198.2	57.6	2.69	470.2	.58

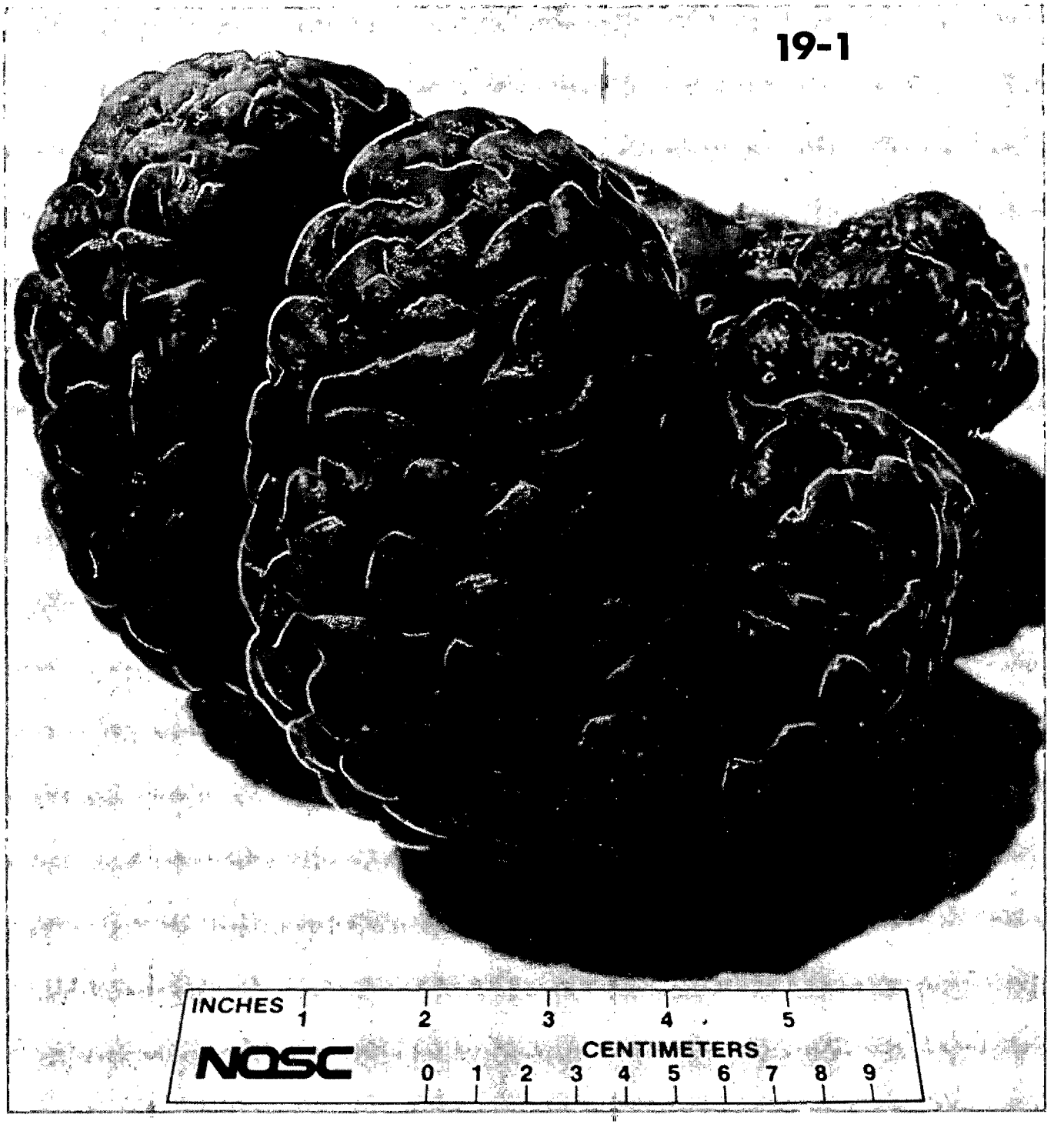

Figure 19-1. A bowhead brain viewed from the left anterior aspect. The dorsum of the brain is resting on the table.

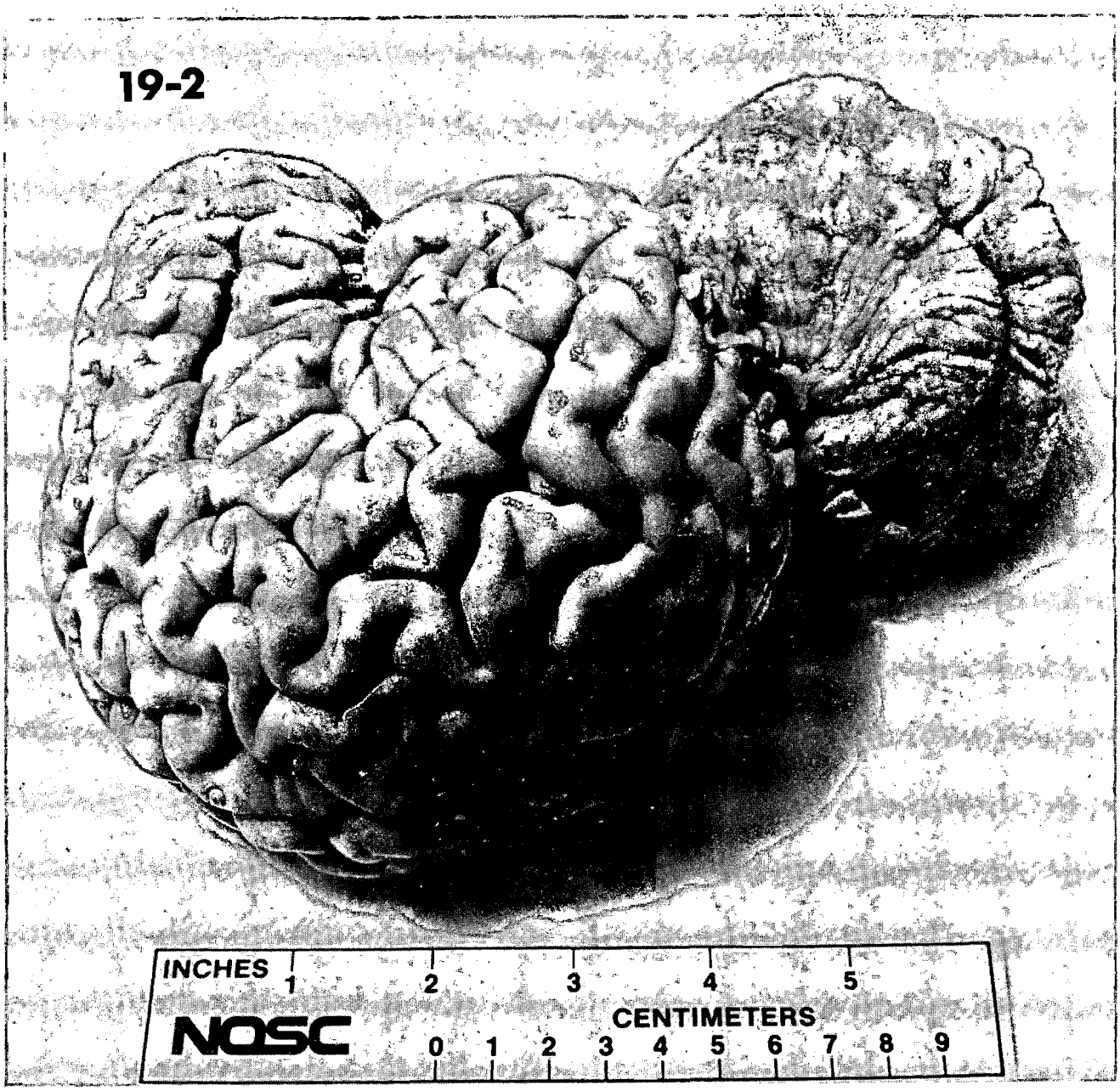

Figure 19-2. Lateral view of bowhead cerebrum and cerebellum. Note that the cerebellum makes up a large percentage of total brain weight averaging 21.8% in our six specimens.

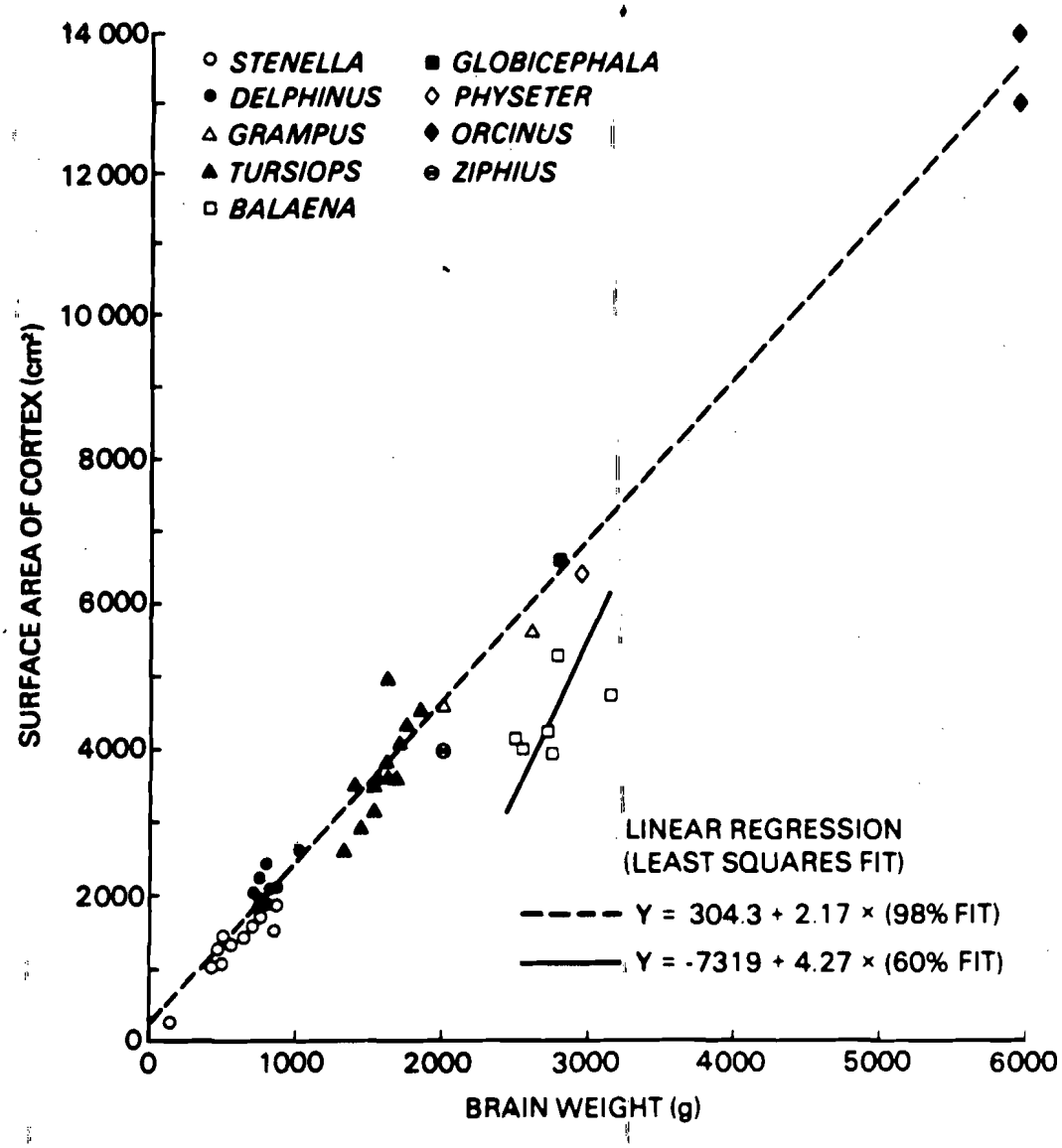

Figure 19-3. Plot of brain weight and surface area of cerebral cortex comparing various odontocetes and the bowhead. The one Physeter brain plotted was from a neonate.

averaged about 21.8% of the total brain weight among the six specimens. Surface area of the cerebral cortex averaged 4,374 cm^2 and index of folding averaged 2.93.

The bowhead brains were smaller than those of fin, humpback and sei whales reported in the literature (Jacobs and Jensen 1964) and the cerebellum of the bowhead makes up a greater percentage of total brain weight.

Comparisons were made with odontocete brains by plotting weight of each brain against surface area of the cerebral cortex. The results are shown in Fig 19-3. The regression line for odontocetes shows a 98% fit for brains of all genera used from Inia to Physeter. The regression for bowheads shows a 60% fit but all bowhead points are to the right of odontocete values. Clearly the bowhead brains are less convoluted than are odontocete brains. The bowhead brains are the same size range as much smaller odontocetes such as Grampus, Globicephala, and Delphinapterus.

DISCUSSION

Although the bowhead brains are in the same general size range as Grampus, Globicephala, and Delphinapterus, bowhead body weight is roughly fifty times greater. The odontocetes just mentioned have cortical-surface-area-to-volume-ratios about one-third greater than bowhead. The following question arises: Why does Delphinapterus require ten times more cerebral cortex per kg of body weight to make a living in the same environment occupied by the bowhead? It would appear that differences in body fat could not account for such a large difference in relative brain size between these two species. Wood and Evans (1980) have considered various factors, including echolocation and variability of zoogeographic range, that might account for the large brains in odontocetes. There is as yet no answer, but such analyses comparing the beluga and the bowhead might be useful.

ACKNOWLEDGMENTS

I thank Rick Van Schoik for technical assistance.

REFERENCES

Breathnach, A.S. 1955. Surface features of the brain of the humpback whale (Megaptera novaeangliae), J. Anat. Lond. 89:343-354.

Elias, H. and D. Schwartz. 1969. Surface areas of the cerebral cortex of mammals determined by stereological methods. Science 166:11-113.

Jacobs, M.S. and A.V. Jensen. 1964. Gross aspects of the brain and a fiber analysis of cranial nerves in the great whale. J. Comp. Neur. 123:55-72.

Jerison, H.J. 1973. Evolution of Brain and Intelligence. Academic Press, New York.

Morgane, P.J., M.S. Jacobs and W.L. McFarland. 1980. The anatomy of the brain of the Bottlenosed Dolphin (Tursiops truncatus). Surface configurations of the telencephalon of the Bottlenosed Dolphin with comparative anatomical observations on four other species, Brain Res. Bull. 5:Suppl. 3,1-102.

Pilleri, G. 1964. Morphologie des Gehirnes des "Southern Right Whale" Eubalaena australis Desmoulins 1822 (Cetacea, Mysticeti, Balaenidae) Acta Zoologica. 46:245-272.

Ridgway, S.H. and R.H. Brownson. 1979. Brain size and symmetry in three dolphin genera. Anat. Rec. 193:664.

Ridgway, S.H. and M.D. Dailey. 1972. Cerebral and cerebellar involvement of trematode parasites and their possible role in stranding. J. Wildlife Dis. 8:33-43.

Von Bonin, G. 1937. Brain-weight and body-weight of mammals. J. Gen. Psychol. 16:379-389.

Wood, F.G. and W.E. Evans. 1980. Adaptiveness and ecology of echolocation in toothed whales. In: Animal Sonar Systems Ed. by R.G. Busnell and J.F. Fish. Plenum, New York. pp 381-425.

APPENDIX V

LISTING OF COLLECTED BOWHEAD WHALE SPECIMENS WITH OBSERVATIONS MADE DURING INITIAL EXAMINATION

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During the spring 1980 whaling season nine bowhead whales were taken by Eskimo hunters in Barrow, Alaska. A wide range of samples (over 550 specimens) were collected with the bulk of the specimens coming from five animals (80B1, 80B2, 80B7, 80B8 and 80B9).

At the butchering site the sampling procedure was always subordinated to the food gathering process (APPENDIX I) which limited the availability of certian items. Specimens were labeled at the butchering site and various initial observations recorded using hand held tape recorders. Many photographs were taken to provide for proper anatomical information. As mentioned earlier (RU 180) the samples were returned to the logistical base for subsampling, further description and subsequent distribution (Fig 1-6).

On the following pages is a listing of collected specimens by animal. Also included is the Research Unit to which each sample was sent as well as a brief description for most of the specimens. The included Figures serve to further orient the specimens.

Listing of Tissue Specimens From Bowhead Whale 80B1 With Related Observations

Taken by: Arnold Brower, Sr. at Barrow, Alaska, May 24, 1980
Length: 10.9 meters
Sex: female
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen descriptions made at time of collection and/or shipment.

Small Specimens in 10% Buffered Formalin (80B1)

Digestive system

Tag 101, (RU 1480): Jacobson's organ "groove" on right side of anterior part of roof of mouth. Tag on anterior end. This "groove" runs from "right to left", that is, it is at a right angle to long axis of hard palate. The groove is about 4 cm long. There are 2, one on each side of the midline of the anterior part of the hard palate about 10-15 cm from anterior tip of hard palate.

Tag 102, (RU 1380): Hard palate mucosa, 1/3 of way from anterior tip (about 110 cm) is cut at right angle to hard palate long axis and shows thin epithelium(1 mm)of hard palate mucosa and underlying fat. Also includes some of the small baleen structures on each side. Site of specimen removal can be seen in Fig 20-7. Note "junctional area" where hard palate mucosa meets medial side of baleen. Also note that the hard palate, although very long,is very narrow, being only 5-10 cm wide.

Tag 61, (RU 1380): Hard palate mucosa about 1 cm from where mucosa of hard palate ends posteriorly (just before the 2 rows of baleen unite in the rear of mouth, Fig 20-9). The mucosa of hard palate in this section is about 2 cm wide but tapers toward the posterior of this section, with about 2 cm of small baleen hairs on each side. Note what looks like fatty tissue extending to 1 mm or so below the epithelial surface in the middle of this section.

Tag 50, (RU 1380): Rear of hard palate, this section is about 10 cm long with 8 cm being small baleen hairs. The most caudal 2 cm or so is 1 mm thick mucosa that is caudal to the baleen. In the rear of the roof of the mouth, both rows of baleen come together so that hard palate mucosa ends (Fig 20-9). The next 15 cm posteriorly the palate is covered by a mat of small baleen hairs. The hairs then end and the roof of mouth mucosa (now 1 mm thick) continues caudally as pharynx. This sample's long axis is parallel to hard palate long axis and was taken from hard palate midline.

Tag 100, (RU 1380): Small baleen, approximately 10 cm from anterior end of baleen row, sample long axis is at right angle to hard palate long axis. Hard palate mucosa is tagged, note groove between it and medial side of baleen row. Skin of upper lip (also tagged) is lateral to the baleen.

Tag 41, (RU 780): Mouth lesions in rear of mouth, this sample has 1 grayish white area with irregular margin.

Tag 103, (RU 780): Mouth lesions in rear of mouth, (baleen trauma??), has 3 smooth grayish white areas.

Tag 8, (RU 1480): Stomach, 15 x 2 cm, white area is nonglandular portion of stomach mucosa and red is glandular mucosa of stomach. This sample is at the "junction" of white and red areas of mucosa.

Tag 12, (RU 1480): Stomach, mucosa of nonglandular portion, full thickness.

Tag 3, (RU 1480): Colon, green fecal material on mucosa.

Tag 62, (RU 1480): Colon-anal canal junction, sample 20 x 20 x 2 cm, shows red glandular colon mucosa meeting gray colored mucosa of anal canal.

Tag 52, (RU 1480): Liver, includes capsule.

Tag 72, (RU 1480): Liver, internal.

Tag 13, (RU 1480): Pancreas.

Lung

Tag 17, (RU 1380): Lung, includes pleura.

Tag 19, (RU 1380): Lung, with 2 cm diameter bronchus, section from dorsal margin 30 cm from caudal edge, small piece of pleura present.

Kidney

Tag 104, (RU 1380): Kidney, 5 x 5 x 5 cm sample.

Tag 105, (RU 1380): Kidney, 20 x 15 x 10 cm, smooth surface of this sample is surface of kidney.

Reproductive system

Tag 49, (RU 580): Vagina, mucosa strip 1 x 5 cm.

Tag 51, (RU 580): Cervix, note small (1 mm) gland like "spots" on free surface.

Tag 67, (RU 580): Cervix.

Tag 55, (RU 580): Uterus, 5 cm above cervix.

Tag 74, (RU 580): Uterus, mid part of a horn.

Tag 59, (RU 580): Uterus, cross section of horn.

Tag 47, (RU 580): Ovary, left, sliced transversely.

Tag 75, (RU 580): Right ovary with piece of uterine horn attached.

Skin

Tag 43, (RU 1380): Skin, lower jaw, anterior-most part of ventral midline, includes inner and outer surface of lip, tags are on outer (thicker) skin.

Tag 66, (RU 1380): Skin, right lower lip margin, 1.2 m from anterior end, note thicker skin on outer surface of lip (similar to that seen in Fig 20-11).

Tag 53, (RU 1380): Skin, right lower jaw margin, about 1/2 way from anterior tip to posterior end of lower lip, thick skin is outer surface and thin skin is inner surface of lip. Tag and notch on anterior edge of outer surface.

Tag 42, (RU 1380): Skin, 10 x 10 cm from lower jaw and includes dozen or so tactile hairs.

Tag 44, (RU 1380): Skin, 10 x 10 cm, from lower jaw, includes 6-8 tactile hairs, near ventral midline, was adjacent to Tag 42.

Tag 45, (RU 1380): Skin, lower jaw ventral midline 30 cm from anterior tip, tag and notch on anterior edge.

Tag 54, (RU 1380): Skin, ventral midline of lower jaw about 60 cm from anterior tip, tag and notch on anterior edge.

Tag 58, (RU 780): Blowhole scar, 4 scars on blowhole, photos taken, 2 scars are about 10 x 2 cm, took section of one scar, piece is from right side of middle and has black on each end of section and one end of section extends into right nostril (Fig 20-18).

Tag 68, (RU 1380): Skin, core sample of flipper near tip, skin tag in dorsal surface.

Tag 64, (RU 1380): Skin, flipper cranial margin 30 cm from tip, tag and notch in skin of dorsal surface.

Tag 71, (RU 1380): Skin, from cranial margin of flipper about 60 cm from tip, skin tag on dorsal end.

Tag 73, (RU 1380): Skin, flipper cranial margin 90 cm from tip, tag and notch in skin of dorsal surface.

Tag 57, (RU 1380): Skin, flipper caudal margin 30 cm from tip, tag and notch in dorsal skin.

Tag 70, (RU 1380): Skin, flipper caudal margin 60 cm from tip, tag in skin of dorsal surface.

Tag 60, (RU 1380): Skin, flipper caudal margin 90 cm from tip, tag in skin of dorsal surface.

Blubber core

Tag 76, (RU 480): Blubber core, full thickness and includes underlying muscle, site on animal not known as sample taken from larger piece removed by Eskimos during butchering.

Lymph nodes and spleen

Tag 63, (RU 480): Lymph nodes, location not indicated.

Tag 1, (RU 480): Lymph node, from colon mesentery.

Tag 5, (RU 480): Lymph nodes, colon area.

Tag 20, (RU 480): Spleen, full width sample.

Cardiovascular system

Tag 112, (RU 480): Heart, section of wall of an atrium, about 20 x 20 x 1 cm.

Tag 6, (RU 480): Heart, seems like ventricular wall full thickness sample, but not sure.

Tag 7, (RU 480): Heart, full thickness of ventricular wall.

Tag 10,(RU 480): Heart, from outer surface of ventricle, about 20 cm below coronary groove and parallel to coronary groove. Not a full wall thickness. Can see a couple 1 mm diameter vessels.

Tag 46, (RU 480): AV valve leaflet with piece of papillary muscle and chordae tendineae.

Tag 16, (RU 480): Valve, semilunar, from aorta or pulmonary artery, this section is about 2 cm wide and extends from free margin of leaflet to and including some of vessel wall at base of heart.

Tag 9, (RU 480): Aortic bulb, full thickness of wall. The aortic bulb is the enlargement of the aorta just after it leaves the heart seen in diving mammals. Distal to it, the aorta returns to its "normal" diameter.

Tag 4, (RU 480): Vascular rete immediately around pituitary, vessels very small, pituitary has been removed.

Tag 15, (RU 1380): Vascular rete surrounding spinal cord meninges. This mass filled the foramen magnum.

Other tissues

Tag 48, (RU 580): Pituitary left half (right half is frozen), vascular rete attached.

Unnumbered sample, (RU 480): Bone, 2 cm "slab" cross section of a transverse process of a lumbar vertebra.

Unnumbered sample, (RU 480): Bone, 1 cm thick "slab" cross section of a spinous process of a lumbar vertebra.

Tag 65, (RU 1380): Intervertebral disc, (taken from same vertebra as bone sections), section about 2 cm wide x 1/2 cm thick (down to bone), includes circularly arranged connective tissue and then the more or less jelly-like

nucleus pulposus in center. Section runs just about to center of disc (see also tag 69) (Fig 20-37).

Tag 69, (RU 1380): Intervertebral disc, piece taken (similar to that tagged 65) from the other side of the disc. This disc was cut through as the vertebra was removed. The disc was about 2 cm in anterior to posterior direction.

Tag 56, (RU 1380): Skeletal muscle, at proximal end of lower jaw.

Tissues for Electron Microscopy (80B1)

- Tissues in fixative for about 6 hours, except blood which was in fixative for 20 hours.
- Fixative (2% Formaldehyde, 1.25% glutaraldehyde, 0.1 M cacodylate buffer.)
- Buffer (5% sucrose in 0.1 M cacodylate buffer, pH=7.4, 4-11-80)
- Tissues in vials of buffer
  - Kidney and skin to RU 1380, Blood to RU 480.
  - Kidney: The white part of the sample is what seems to be the tip of the medulla, above this is red tissue which is medulla and cortex.
  - Kidney: As above.
  - Kidney: "
  - Skin: The black tissue is epidermis with the fine vertical "striations" being dermal indentations into the epidermis. The white tissue is dermis (1 mm or less) and the rest is blubber.
  - Skin: As above.
  - Skin: As above.
  - Skin: As above.
  - Skin: As above.
  - Blood: Blood cells that were centrifuged out (during serum/plasma separation) were put into fixative and then buffer.

Blood Samples (80B1)

- Blood smears
  - for cytological evaluation (RU 880)
  - for parasitological evaluation (RU 1280)
- Serum (or plasma), frozen
  - for antibody level determination (RU 1080)
  - for hormone level determination (RU 580)
  - for clinical chemistry (RU 880)

Stomach Contents (80B1)

- Smears (on glass slides) (RU 880)
- Vials, (RU 880) contain some of stomach contents in formalin. Stomach contained 12-17 l of dark red watery fluid and several "chunks" (5 x 1 cm) of what seem to be matted baleen hairs. Also found 6 or 8 1-2 cm long by 3-5 mm wide yellowish white, "smooth objects" in the fluid. They are easily crushed and are somewhat "mushy", were found in nonglandular portion of stomach. One vial contains "hairs" and "smooth objects".

Tissues for Toxic Substance Analysis (80B1)

- Spleen
- Liver
- Blubber
- Skeletal muscle
- 2 samples of each (one to be archived)
- all to RU 380

Swabs Taken for Bacterial Isolation (80B1)

"80B1 LUNG #1": taken from 1 cm diameter bronchus approximately 20 cm from anterior tip of lung. Samples: 3 swabs in transport medium, 1 anaerobic swab, 1 swab in thioglycollate broth.

"80B1 BRONCHUS": taken from 7 cm diameter main bronchus at entrance into lung. Samples: 3 swabs in transport medium, 1 anaerobic swab, 1 swab in thioglycollate broth.

- all to RU 1180.

Swabs Taken for Viral Isolation (80B1)

- Bronchus
- Colon
- Blowhole
- all to RU 1080

Tissue Samples (1 gram) Taken for Viral Isolation (80B1)

- Lung (lung was engorged with blood, traumatized from bomb.)
- Liver
- Spinal cord (within 5 cm of brain)
- Brain (cerebral cortex)
- Colon mucosa
- Kidney
- Spleen
- all to RU 1080

Tissue Samples Taken for Tissue Culture (80B1)

- Skin
- Kidney
- Lung
- all to RU 1080

Bone Samples (80B1)

- Humerus and proximal radius, 2 cm thick slab.
- Head of humerus, 2 cm thick slab.
- Elbow joint, 5 cm thick slab, includes distal 2 cm of humerus and proximal 2 cm of ulna.
- Body of vertebra, 1 cm thick slab (Fig 20-38), cut in half.
- Body of vertebra, 2 cm slab, cut in half and this one also has 3 full width sections (2 x 1 cm) cut out of center for better fixation (therefore this slab is in 5 pieces.)
- Total 10 pieces, all in 10% buffered formalin.
- all to RU 480.

Radiographs Taken (80B1)

- Proximal end of humerus, includes proximal epiphyseal plate.
- "Slab" of body of vertebra, includes both epiphyseal plates.
- Proximal end of humerus with that of 80B8 (the Ingutuk) on the same film.

- "slab of body of vertebra with that of 80B8 (the Ingutuk) on the same film.
- all specimens approximately 2 cm thick.
- radiographs taken June 6, 1980.

Large Specimens (80B1)

- Trachea with bifurcation (no lungs attached) (RU 1380)
- Lung (RU 1380)
- Most of vagina, cervix, and most of uterus (RU 580)
  - 43 cm of vagina to cervix. (This is not entire vagina, does not include vulva).
  - cervix and its folds, about 30 cm long.
  - 30 cm from inner end of cervix to what outwardly seems to be a bifurcation.
  - 86 cm from inner end of cervix to tip of one of the uterine horns.
  - horns are about 4 cm in diameter.
- Intestine segments (RU 1280)
- Spleen (RU 1380)
- Brain (damaged during removal)
  - sent to Dr. S. Ridgway, Naval Ocean Systems Center, San Diego, CA for initial examination and then to RU 1380.
- Stomach with esophageal entrance and 30 cm of duodenum (RU 1480).
- all above in 10% formalin.
- Blubber chunk, approximately 30 x 30 x 15 cm, frozen.
  - sent to Larry Hobbs, National Marine Mammal Laboratory, NMFS, Seattle, Washington.

Listing of Tissue Specimens From Bowhead Whale 80B2 With Related Observations

Taken by: Marchie Nageak at Barrow, Alaska, May 25, 1980
Length: 10.8 meters
Sex: male
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen descriptions made at time of collection and/or shipment.

Small Specimens in 10% Buffered Formalin (80B2)

Digestive system

Tag 10, (RU 1480): Stomach, mucosa of nonglandular part (similar to that in Fig 20-21).

Tag 37, (RU 780): Stomach lesion, nodule in mucosa of nonglandular part of stomach mucosa (similar to that in Fig 1-34)2 x 1 cm and raised 1 cm nodule, cut surface shows cheesey greenish yellow material, bacterial cultures taken.

Tag 39, (RU 780): Stomach lesion, nodule in mucosa of nonglandular part of stomach mucosa, 1 cm diameter, rather firm (similar to that in Fig 20-21).

Tag 26, (RU 1480): Stomach, mucosa of "red" (glandular) part of stomach.

Tag 36, (RU 780): Liver tumor (?), 2 x 1 cm pinkish white area on diaphragmatic surface of liver, was raised about 1 mm, on cut surface it extends into liver about 1½ cm, looks like circumscribed tumor (Fig 20-22) took piece. for EM.

Tag 21, (RU 1480): Pancreas.

Lung

Tag 11, (RU 1380): Lung, dorsal margin, 15 cm from posterior, EM samples taken.

Kidney

Unnumbered Specimen, (RU 1380): Kidney, 20 x 8 x 8 cm sample.

Skin

Unnumbered Specimen, (RU 1380): Eyelids, intact.

Tag 32, (RU 1380): Skin, "core sample" all the way through fluke, taken about 5-8 cm from tip, skin on one side just barely full thickness.

Tag 38, (RU 1380): Skin, fluke, 30 cm from tip, anterior margin, tag in dorsal surface skin.

Tag 30, (RU 1380): Skin, fluke, 30 cm from tip on rear margin. Fluke about 1.2 m from midline to tip. Fluke samples taken at 30 cm intervals starting at tip.

Tag 17, (RU 1380): Skin, fluke, 60 cm from tip on cranial margin, tag in dorsal skin.

Tag 35, (RU 1380): Skin, fluke, 60 cm from tip on rear margin, tag on dorsal surface skin.

Tag 34, (RU 1380): Skin, fluke, 90 cm from tip on rear margin, tag on dorsal skin.

Tag 40, (RU 1380): Skin, fluke, 90 cm from tip on cranial margin, tag in dorsal skin.

Lymph nodes and spleen

Tag 25, (RU 480): Lymph node that was attached to glandular material (thymus?) that was attached to the rete around vessel tagged as 14.

Tag LLN, (RU 480): Lymph nodes near lung.

Tag LLN-2, (RU 480): Lymph nodes, near lung.

Tag LLN-1, (RU 480): Lymph nodes near lung.

Tag 15, (RU 480): Spleen.

Cardiovascular system

Tag 14, (RU 1380): Blood vessel, yellow color, 5 cm diameter, wall 1 mm thick, taken from area of aortic bulb, inside vessel can see small openings (1 mm) which seem to lead to rete material which covers one side of this vessel.

Tag 104, (RU 1380): Vascular rete surrounding meninges of first part of spinal cord, entirely fills foramen magnum.

Other tissues

Eye, (RU 680): Globe incised for formalin penetration.

Tag 13, (RU 1380): Adrenal, entire, about 18 x 5 x 2 cm, can see "wavey indentations" on cut surface, picture taken (roll 131), sliced transversely. A piece taken for EM that extended from surface inward about 1 cm. Another EM sample taken that was "full thickness", piece about 2 mm thick, it extends across the width of the adrenal and this piece is about 4 cm long. The other adrenal is frozen.

Tag 27, (RU 480): Thymus (?), may be fat, not sure.

Tag 100, (RU 480): Bone, spinous process of lumbar vertebra, 1 cm wide "slab", cross section.

Tag 101, (RU 480): Bone, 1 cm "slab" cross section of transverse process of a lumbar vertebra.

Tag 3, (RU 480): Bone, cross section, 1 cm slab, of transverse process.

Unnumbered Specimen, (RU 480): Bone

Tissues for Electron Microscopy (80B2)

- Tissues in fixative for 5 to 6 hours.
- Tissues in vials of buffer
  - Liver (RU 1480)
  - Liver tumor?? (suspect this is neoplasm) (RU 1480)
  - Pancreas (RU-1480)
  - Lung (RU 1380)
  - Lung (RU 1380)
  - Adrenal: Full thickness sample across width of gland (sample is about 2 mm thick and 4 cm long). (RU 1380)
  - Adrenal: From outer surface inward about 1 cm. (RU 1380)
  - Stomach: Forestomach (white mucosa) (RU 1480)
  - Stomach: Glandular (red mucosa) (RU 1480)

Blood Samples (80B2)

- Blood smears
  - for cytological evaluation (RU 880)
  - for parasitological evaluation (RU 1280)

- Serum (or plasma), frozen
  - for antibody level determination (RU 1080)
  - for hormone level determination (RU 580)
  - for clinical chemistry (RU 880)

Other Frozen Items(80B2)

- Adrenal (piece of) for hormone analysis (RU 580)

Tissues for Toxic Substance Analysis (80B2)

- skeletal muscle
- liver
- spleen
- blubber
- 2 samples of each (one to be archived)
- all to RU 380

Swabs Taken for Bacterial Isolation (80B2)

- "80B2 #37", taken from 1 cm diameter abscess in first portion of stomach. Samples: 3 swabs in transport medium, 1 anaerobic swab, 1 swab in thioglycollate broth.
- "80B2 BRONCHUS", taken from 5 cm diameter main bronchus near entrance into lung. Samples: 3 swabs in transport medium, 1 anaerobic swab, 1 swab in thioglycollate broth.
- all to RU 1180.

Swabs Taken for Viral Isolation (80B2)

- Bronchus (RU 1080)

Tissue Samples (1 gram) Taken for Viral Isolation (80B2)

- Lung (margin, midway from both ends)
- L.L.N. (lymph node in close association with lung)
- Possible thymus (very questionable; may be adipose tissue)
- Liver
- Spleen
- Kidney
- Large bowel mucosa (exact location uncertain)
- Brain (cerebral cortex)
- Spinal cord (within 5 cm of brain)
- All to RU 1080

Tissue Samples Taken for Tissue Culture (80B2)

- Skin
- Kidney
- Lung
- All to RU 1080

Bone Samples (80B2)

- all in 10% buffered formalin
- Vertebral body, intact slab (similar to that in Fig 20-38).
- Vertebral body, slab, cut in half, note 2 cm diameter "soft spot" in center (fat?).
- Humerus and proximal radius, slab (similar to that in Fig 21-1).
- Radius and ulna together, slab, cross section, (taken about ¼ way from elbow toward carpus.)
- all "slabs", approximately 2 cm thick.
- total of 5 pieces (note additional pieces mentioned with "Small Specimens").
- all to RU 480.

Radiographs Taken (80B2)

- Proximal humerus, includes proximal epiphyseal plate.
- "Slab" of body of vertebra, includes both epiphyseal plates.
- Proximal end of humerus with that of 80B8 (the Ingutuk) on the same film (Fig 21-2).
- "Slab" of body of vertebra with that of 80B8 (the Ingutuk) on the same film.
- all specimens approximately 2 cm thick.
- radiographs taken June 6, 1980.

Large Specimens (80B2)

- Blowhole "cross section" from about 10-15 cm beneath skin surface (Fig 20-19) shows both air passages and cartilaginous. septum. (RU 1380)
- Lung (RU 1380)
- Intestine segments (4) (RU 1280).
- Liver chunk (10 x 10 x 10 cm) (RU 1280).
- Lung, section (30 x 15 x 45 cm), seems like piece of pulmonary artery visible (RU 1380).

- Brain
  - sent to Dr. S. Ridgway, Naval Ocean Systems Center, San Diego, CA for initial examination and then to RU 1380.
- Spleen (RU 1480).
- Stomach (good specimen), has esophageal entrance. (RU 1480)
- all above in 10% formalin
- Flipper bone "remnant", includes distal radius and ulna, carpus and some metacarpal and phalangeal parts. (RU 480)
- Flipper bone "remnant", includes humerus and proximal radius and ulna. (RU 1480)
- Blubber chunk, approximately 30 x 30 x 15 cm, frozen.
  - sent to Larry Hobbs, National Marine Mammal Laboratory, NMFS, Seattle, Washington.

Listing of Tissue Specimens From Bowhead Whale 80B3 With Related Observations

Taken by: Percy Nusunginya at Barrow, Alaska, May 25, 1980
Length: approximately 8.5 meters
Sex: male
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen descriptions made at time of collection and/or shipment.

Specimens in 10% Buffered Formalin (80B3)

- Epididymis, sample about 30 cm long
- Testicle (right), sliced transversely, (24 x 5½ x 3 cm thick)
- Testicle (left), sliced transversely and longitudinally (22½ x 7 x 2½ cm thick)
- Both testicles have several ½ to 1 mm diameter vessels visible on surface (Fig 20-27).
- all sent to RU 580

Tissue Sample Taken for Tissue Culture (80B3)

- Testis (RU 1080)

Listing of Tissue Specimens From Bowhead Whale 80B4 With Related Observations

Taken by: Ralph Aveoganna at Barrow, Alaska, May 25, 1980
Length: 10.4 meters
Sex: male
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen descriptions made at time of collection and/or shipment.

Bone Samples (80B4)

- Vertebral body, slab, intact (similar to that in Fig 20-38).
- Vertebral body, slab, intact.
- Humerus, longitudinal slab (similar to that in Fig 21-1).
- Radius and ulna together, slab, cross section.
- Spinous process of lumbar vertebra, slab, cross section.
- Transverse process of lumbar vertebra, slab, cross section.
- Other transverse process of same lumbar vertebra, slab, cross section.
- all 2 cm thick "slabs"
- 7 pieces, all in 10% buffered formalin
- all sent to RU 480

Baleen

- long piece obtained for National Marine Fisheries Service

Radiographs Taken (80B4)

- Proximal humerus, includes proximal epiphyseal plate.
- "Slab" of body of vertebra, includes both epiphyseal plates.
- Proximal end of humerus with that of 80B8 (the Ingutuk) on the same film
- "Slab" of body of vertebra with that of 80B8 (the Ingutuk) on the same film.
- specimens approximately 2 cm thick.
- radiographs taken June 6, 1980

Listing of Tissue Specimens From Bowhead Whale 80B5 With Related Observations

Taken by: Ben Itta at Barrow, Alaska, May 25, 1980
Length: 10.4 meters
Sex: male
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen descriptions made at time of collection and/or shipment.

Specimens in 10% Buffered Formalin (80B5)

- Testicle, split longitudinally (20 x 8 x 2½ cm)
  - epididymis attached
- Testicle (Fig 20-28), not split, (18 x 8 x 3 cm).
  - epididymis attached
- both sent to RU 580

Tissue Sample Taken for Tissue Culture (80B5)

- Testis (RU 1080)

Listing of Tissue Specimens From Bowhead Whale 80B6 With Related Observations

Taken by: Simeon Patkotak at Barrow, Alaska, May 25, 1980
Length: approximately 8.5 meters
Sex: male

No tissues were obtained from this animal.

Listing of Tissue Specimens From Bowhead Whale 80B7 With Related Observations

Taken by: George Ahmaogak at Barrow, Alaska, May 26, 1980
Length: 10.0 meters
Sex: female
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen descriptions made at time of collection and/or shipment.

Small Specimens in 10% Buffered Formalin (80B7)

Digestive system

Tag 22, (RU 1380): Midline, anterior most part of upper jaw, numbered tag on outer surface, note skin small bumps ("pinhead" size), white mucosa from hard palate, dark skin between white and "bumps" area is groove between lip and hard palate mucosa (similar to that seen in Fig 20-8).

Tag 12, (RU 1380): Tag 12 on outer end, 20 cm long piece that includes entire left Jacobson's groove as well as groove between hard palate mucosa and upper lip skin and also includes some of the 1 mm or less diameter "bumps" on upper lip (similar to that seen in Fig 20-8).

Tag 16, (RU 1380): On hard palate mucosa, groove between hard palate and small baleen hair (similar to that seen in Fig 20-7 and Fig 20-8) and another groove between baleen and skin on outer side of upper lip (similar to that seen in Fig 20-8). Includes anterior most baleen.

Tag 32, (RU 1380): 10 cm long section where mucosa of hard palate ends as 2 rows of baleen (small "hairs") come together at rear of the roof of the mouth (Fig 20-9). This section (cut surface) has gingiva about 2 cm thick with the baleen in it and tapers down to where the baleen ends medially. The epithelium of the hard palate is about 1 mm thick. A big "plug" of fat is under this epithelium as seen on cross section.

Tag 4, (RU 780): Stomach, nonglandular portion of stomach mucosa (Fig 20-21). Note that in nonglandular portion of stomach, found several 1 cm diameter, raised nodules which seem to be well circumscribed abscesses. Cut into one (cultured for bacteria) and has tag 37 about 10 cm away on same mucosa. Smaller nodule has tag 4 next to it and was not cultured.

Tag 11, (RU 780): Mucosa of nonglandular portion of stomach with nodule under mucosal surface (Fig 20-21).

Tag 25, (RU 780): Stomach mucosa, nonglandular portion, nodule in mucosa (Fig 20-21).

Tag 33, (RU 780): Nonglandular portion of stomach, note nodule projecting up 3-4 mm in mucosa (Fig 20-21).

Tag 26, (RU 1480): Small intestine, full thickness, about 10 cm proximal to junction with colon (Fig 20-23), muscular wall seems about 2 cm thick.

Tag 20, (RU 1480): Colon, full thickness, about 15 cm distal to junction of small intestine and colon (Fig 20-23). Mucosa covered with green pasty feces.

Tag 18, (RU 1480): Colon mucosa, green slimy fecal material attached, full thickness.

Kidney

Tag "Left Kidney Margin", (RU 1380): Margin of left kidney (outer surface, piece is about 10 cm in diameter).

Unnumbered specimen (RU 1380): Kidney, 15 cm diameter sample, one side is on outer surface of kidney and is covered by membrane like "sheet".

Tag 2, (RU 1380): Round ligament of the bladder, 2 cm long section, about 15 cm from where connects with urinary bladder (Fig 20-25).

Tag 29, (RU 1380): Urinary bladder, full thickness of wall (Bladder seen in Fig 20-25).

Reproductive system

Tag 30, (RU 580): Ovary (a piece has been removed and frozen for hormone analysis). This ovary has been sliced transversely and has some uterine horn attached.

Tag 101, (RU 580): Ovary and attached 25 cm or so of opened uterine horn.

Tag 21, (RU 580): Nipple and surrounding skin, subcutaneous tissue (10-15 cm) may have some mammary tissue.

Skin

Tag 15, (RU 1380): Skin of upper lip just where it rolls under into mouth, note "pinhead" sized "bumps". This is a good section to illustrate these "bumps" (similar to that seen in Fig 20-7).

Tag 13, (RU 1380): Skin, upper jaw, midline, 30 cm from anterior tip, tagged anterior edge (similar to that seen in Fig 20-11).

Tag 1, (RU 1380): Skin, about 90 cm from anterior end of upper jaw (similar to that seen in Fig 20-11).

Tag 14, (RU 780): Skin with lesion, from lateral aspect of upper lip on right side. Is a groove in skin 2 cm long, 2 mm at maximum width and tapers inward as a "V shaped" crevice.

Tag 34, (RU 1380): Skin with tactile hairs (8) from anterior end of upper jaw (similar to that seen in Fig 20-11).

Tag 35, (RU 780): Skin, lesion, about 20 cm above "gum line", ½ way between jaw tip and blowhole. EM sample taken from this piece. Outer 1 mm or so is the mushy "fungus-like" tissue that tends to break up.

Tag 17, (RU 780): Skin with lesion on left approximately 30 cm anterior to and 30 cm ventral to blowhole. Sample is 25 cm long and 5 cm wide and includes lesions on skin. Has a groove in skin which is about 22 cm long, 2 cm wide and tapers to depth of 4-5 mm.

Tag 9, (RU 780): Skin, upper jaw, left side, about 15 cm outward from baleen and includes part of 2 large skin lesions (Fig 20-23). Figure 20-12 shows site after removal of sample.

Tag 11A, (RU 1380): Skin with tactile hair from anterior area of chin on left side.

Tag 9A, (RU 1380): Skin with tactile hair 30 cm from tip of lower jaw on right side in row of tactile hairs; this sample has tactile hair (similar to that seen in Fig 20-11).

Tag 15A, (RU 1380): Skin, lower jaw on left, 60 cm from anterior tip, includes skin lesion (about 8 cm long), includes tactile hair, numbered tag on anterior end. This sample provides a good view of the lesion on gross cut surface.

Tag 38, (RU 1380): Skin, margin of left lower lip, about 60 cm before posterior end of lip, includes outer surface (thick) and inner surface (thin).

Tag 5, (RU 1380): Skin, margin of lower lip on left side, 90 cm from tip of lower jaw, thick skin is outer surface, thin skin is inner surface (Fig 20-11) shows similar area on right side of lower lip on another whale).

Tag "LUEL", (RU 1380): Strip of left upper eyelid from edge to an area about 2 cm beyond eyelid, includes conjunctiva, numbered tag is on edge of lid.

Tag "Lower Left Eyelid", (RU 1380): Skin, strip from margin of lid to about 2 cm beyond eyelid, includes conjunctiva, numbered tag on edge of eyelid.

Tag 1/3D, (RU 1380): Skin, dorsal midline, 1/3 distance from flipper to flukes, numbered tag in skin and notch on anterior edge.

Tag 2/3 D, (RU 1380): Skin, dorsal midline, 2/3 of distance from flipper to beginning of flukes, tag in skin is on anterior margin.

Tag 1/3 L, (RU 1380): Skin, left lateral midline, 1/3 distance from flipper to flukes, anterior end has notch and numbered tag.

Tag 2/3 L, (RU 1380): Skin, left lateral midline, 2/3 distance from flipper to fluke, numbered tag and cut on anterior edge.

Tag 14A, (RU 780): Skin, tip of chin, ventral midline, appears to include an old lesion.

Tag 12A, (RU 1380): Skin, chin, 15 cm from anterior end, ventral midline, white skin.

Tag 8A, (RU 1380): Skin, 30 cm caudal from tip of lower jaw, ventral midline; numbered tag on anterior surface.

Tag 13A, (RU 1380): Skin, ventral midline, 90 cm from tip of lower jaw.

Tag 1/3 V, (RU 1380): Skin, ventral midline, 1/3 distance from flipper to fluke, anterior end has notch and numbered tag.

Tag 2/3 V, (RU 1380): Skin, ventral midline, 2/3 distance from flipper to fluke, numbered tag and notch on anterior end.

Tag "Tip of right flipper, tag dorsal edge", (RU 1380): Skin from tip of right flipper, shows dorsal and ventral surface, tag on dorsal surface, (don't know if cranial or caudal margin).

Tag 5A, (RU 1380): Skin, right flipper at widest spot, cranial edge and includes dorsal and ventral surface, numbered tag on dorsal surface.

Tag "Rt. flipper, 30 cm on caudal edge", (RU 1380): Skin sample from caudal border of flipper 30 cm from tip. "Numbered" tag on dorsal surface.

Tag 7A, (RU 1380): Skin, full thickness sample of flipper 20 cm from tip.

Tag 1A, (RU 1380): Skin, right flipper, ventral surface at base of attachment of flipper to body.

Tag 10A, (RU 1380): Skin, flipper, ventral surface, full skin thickness, (exact location not known).

Tag "Rt. flipper, 90 cm on caudal edge, widest point of flipper", (RU 1380): Skin sample on caudal border of flipper 90 cm from tip, tag on dorsal surface.

Tag 4A, (RU 1380): Skin, tip of left fluke, numbered tag on cranio-dorsal edge.

Tag 3A, (RU 1380): Skin, fluke, numbered tag on dorsal surface, shows dorsal and ventral surface along cranial margin near tip.

Tag X-19, (RU 1380): Right fluke full thickness, 30 cm from tip. Note 2 cm diameter skin lesion on one of the skin surfaces -

it is raised 2 mm.

Tag 2A, (RU 1380): Skin, left fluke, skin of dorsal and ventral surfaces, exact location not known, surfaces not indicated.

Blubber core

Tag ½ M B H, (RU 480): Blubber core, ½ meter behind blowhole, skin tag on anterior, this core is not a full depth sample.

Tag ½ V, (RU 480): Blubber core sample, ventral midline ½ way from flipper to fluke, tag on skin is on anterior surface (cut in skin is on anterior). Note that this specimen has 20 cm or so of "dense" blubber and then what looks like a couple mm of muscle and then less dense adipose tissue of 10-15 cm and then underlying muscle.

Tag X-15, (RU 480): Blubber core, midline ventral, near umbilicus.

Tag 39, (RU 480): Blubber core sample from 1/3 way between flipper and end of flukes.

Tag mid lateral Blubber core, (RU 480): Lateral midline, probably at about ½ body length.

Lymph nodes and spleen

Tag "Mediastinal fat with lymph nodes", (RU 480): 25 cm loose chunk of tissue (fat?) with several lymph nodes, from mediastinum.

Tag "Lymph nodes by stomach", (RU 480): Nodes in mesentery near stomach.

Tag 7, (RU 480): Lymph nodes (4 or 5), cut open, from near kidney.

Tag 36, (RU 480): Spleen, full thickness cross section, about 1 cm thick.

Other tissue

Unnumbered specimen, (RU 680): Left eye with eyelids.

Tissue for Electron Microscopy (80B7)

- Tissue in fixative for about 6 hours.
- Tissue in vial of buffer
  - Skin lesion from upper jaw, full thickness of skin. (This is a part of a larger piece in formalin tagged #35 and is from site 20 cm above gum line and about ½ way between tip of rostrum and blowhole).

Note that this piece of tissue is of a skin lesion, which grossly seems to affect the outer 1-2 mm of the skin.
  - sent to RU 1380.

Blood Samples (80B7)

- Serum (or Plasma), frozen
  - for antibody level determination (RU 1080).
  - for hormone level determination (RU 580).
  - for clinical chemistry (RU 880).
- Blood smears
  - for cytological evaluation (RU 880).
  - for parasitological evaluation (RU 1280).

Other Frozen Samples (80B7)

- Urine - about 25 cc collected from urinary bladder by syringe (bladder contained approximately 1 liter of urine).
  - 2 vials kept frozen since collected
  - 6 vials inadvertently left at room temperature from day of collection (May 26) until "found" on June 6, then put into freezer.
  - all to RU 880.
- Ovary (section) for hormone analysis, (RU 580).

Tissues for Toxic Substance Analysis (80B7)

- Liver
- Spleen
- Kidney
- Blubber
- Skeletal muscle
- 2 samples of each (one to be archived)
- all to RU 380

Swabs Taken for Bacterial Isolation (80B7)

- "80B7 STOMACH ABSCESS": Taken from 1 cm diameter abscess in non-glandular portion of stomach. Samples: 3 swabs in transport medium, 1 anaerobic swab, 1 swab in thioglycollate broth (Fig 20-21).
- "80B7 BRONCHUS #1": Taken from 5 cm diameter main bronchus near its entrance into the lung. Samples: 4 swabs in transport medium, 1 anaerobic swab, 1 swab in thioglycollate broth.

- "80B7 BRONCHUS #2": Taken from 1 cm diameter bronchus about 20 cm from tip of lung. Samples: 3 swabs in transport medium, 1 anaerobic swab; no thioglycollate culture (supply of medium exhausted).
- all to RU 1180

Swabs Taken for Viral Isolation (80B7)

- Stomach abscess (1 cm diameter, in mucosa of nonglandular portion of stomach; swab taken of contents of abscess, Fig 20-21).
- Uterus
- Large bowel (exact location uncertain)
- Colon at colon-small intestine junction
- Blowhole
- Lower left eyelid (conjunctiva)
- all to RU 1080

Tissue Samples (1 gram) Taken for Viral Isolation (80B7)

- Lung
- Possible thymus
- Liver
- Left kidney
- Spleen
- Large bowel mucosa (exact location uncertain)
- Colon at colon-small intestine junction, mucosa
- all to RU 1080

Tissue Samples Taken for Tissue Culture (80B7)

- Skin
- Left kidney
- Lung
- Ovary
- Liver
- all to RU 1080

Bone Samples (80B7)

- Body of vertebra, 2 cm slab, intact (similar to that seen in Fig 20-38).
- Body of vertebra, 2 cm slab, cut in half.
- Transverse process of a lumbar vertebra, 2 slabs, each 2 cm wide.

- total 5 pieces, all in 10% buffered formalin
- all to RU 480

Radiographs Taken (80B7)

- "Slab" (2 cm) of body of vertebra, includes both epiphyseal plates.
- "Slab" (2 cm) of body of vertebra with that of 80B8 (the Ingutuk) on the same film.
- radiographs taken June 6, 1980.

Large Specimens (80B7)

- all in 10% formalin
- Lung (RU 1380)
- Intestine segments (3) (RU 1280)
- Liver chunk (10 x 10 x 10 cm) (RU 1280)
- Diaphragm chunk (10 x 10 x 10 cm) (RU 1280)
- Stomach (fair specimen) has 30 cm duodenum attached, esophageal entrance missing (RU 1480).
- Junction of small intestine and large intestine (RU 1480). Approximately 30 cm of each represented. Small intestine about 8 cm diameter where meets large intestine and diameter then goes rather abruptly to about 23 cm (as seen with specimen lying flat on ice, Fig 20-23). Colon contained greenish-black pasty material (some collected in formalin) while small intestine at this site was nearly empty.
- Colon contents (RU 1280).
- Part of uterus and attached urinary bladder (RU 580). Round ligaments of bladder are very prominent, approximately 2 cm in diameter (Fig 20-25).

Listing of Tissue Specimens From Bowhead Whale 80B8 With Related Observations

Taken By: Harry Brower, Senior, at Barrow, Alaska, May 27, 1980
Length: 8.7 meters
Sex: male
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen descriptions made at time of collection and/or shipment.

Small Specimens in 10% Buffered Formalin (80B8)

Digestive system

Tag 3A,(RU 1380): Upper lip and hard palate mucosa with part of Jacobson's groove (similar to that seen in Figs 20-7 and 20-8). Long axis of sample is same as long axis of body. Skin of lip is black and thick (2 cm) (also note 1 cm diameter depressed skin lesion). Lip skin becomes quite thin (1 mm) and gray color where it meets mucosa of hard palate (note groove that separates upper lip and mucosa of hard palate). Also note "bumps" on skin of upper lip just before "groove". Distance from groove (lip-hard palate junction) to part of left groove of Jacobson's organ is 4½ cm. Note tag at groove between lip and hard palate mucosa. Also tag marks part of left groove of Jacobson's organ. The mucosa of the hard palate is 13 cm long in this tissue specimen.

Tag 9, (RU 1380): Anterior most baleen on left side, note size (1-2 cm). Sample taken from upper jaw at right angle to long axis of body. Extends from skin of upper lip medially to include baleen (note groove between lip skin and baleen) and then medially again to mucosa of hard palate, note groove between medial side of baleen and mucosa of hard palate (similar to that seen in Figs 20-7 and 20-8). Note how skin thickness of upper lip decreases from about 2 cm to about

1 mm as it approaches baleen. Can also see some "bumps" (less than 1 mm diameter) on skin of lip where lip skin goes from black to gray color.

Tags 60, 41, 44, 51 and 59 (RU 1480): Tongue samples. Tongue at junction of anterior and middle thirds, on what seems to be left side, extending from floor of mouth, across more or less "groove" where floor of mouth and tongue meet, then on up to dorsal surface of tongue. Put 5 tags in a line along the "route" just described and took picture (Fig 20-10, to show sample locations and tag numbers at those sites). Each tongue sample is 1 x 3 cm. Tag 60 is on floor of mouth, tag 41 is about 5 cm up on tongue from "floor of mouth and tongue junction," tag 44 is about 1/3 of way up the side of the tongue, tag 51 is near dorsal surface but still on side of tongue, tag 59 on dorsal surface of tongue. All these are over a distance of about 90 cm.

Tag 2, (RU 780): Lesion in mouth; mucosa of back of mouth on right side, 5 x 5 cm. The 2 "white dots" (2 mm or so) are probably healed lesions probably due to baleen trauma, the lesions (now healed) extend through epidermis (1 mm).

Tag 80, (RU 1480): Stomach mucosa, tag 80 in nonglandular part of stomach. Tag 81 is in glandular (red) mucosa of stomach. This 10 x 2 cm specimen cuts across border of white(nonglandular part of stomach mucosa) and red (glandular mucosa) part of stomach.

Tag 16, (RU 1480): Stomach, mucosa of nonglandular portion (similar to that seen in Fig 20-21).

Tag 46, (RU 1480): Stomach, from glandular area with red mucosa.

Tag 24, (RU 1480): Liver, with capsule.

Tag 12, (RU 1480): Pancreas, 5 x 6 cm specimen, also took EM sample from this.

Lung

Tag 53, (RU 1380): Lung including pleura, from anterior margin. When view lung lying on ice, the lung seems rather rectangular

and the anterior seems a bit thinner (dorso-ventrally) than the posterior. Also the anterior seems thicker (medial-laterally) than the posterior.

Tag 58, (RU 1380): Lung, from dorsal margin, about 1/4 way from anterior end, sample extends from lateral surface over dorsal margin to medial surface, tags on medial "end".

Tag 56, (RU 1380): Lung, 2/3 way back on dorsal border, extends from lateral to medial surface, tag on medial surface.

Tag 10, (RU 1380): Lung including pleura, from edge where lateral surface meets diaphragmatic surface. EM pieces taken from this sample.

Tag 52, (RU 1380): Lung, from center of caudal margin (Fig 20-4). Took picture of the intact lung (with ruler) laying on ice, lung seems rather rectangular in shape.

Tag 3B,(RU 1380): Main bronchus, just before enters lung, eliptical shape.

Tag 89, (RU 1380): Lung, bronchi near main bronchus.

Tag 82, (RU 1380): Lung, 8 cm diameter specimen, with 2 cm diameter bronchus.

Tag 91, (RU 1380): Lung with bronchus (about 2 cm diameter).

Kidney

Tag 95, (RU 1380): Kidney, from surface, membranous material covers kidney surface.

Tag 92, (RU 1380): Kidney, 15 x 10 x 10 cm sample, sliced nearly through, uncut side is surface.

Reproductive system

Tag 15, (RU 580): Testicle with epididymis, only ½ here. (Both testicles collected, tube leading from each testicle seem to meet on midline at bladder. Collected urinary bladder and attached piece of each testicle).

Tags 18, 7 (RU580): Testicle, Tag 18 is in testicle and tag 7 in epididymis.

Skin

Tag 34, (RU 1380): Skin, 10 x 1 cm, upper lip left margin, 3/4 way from anterior to posterior end of lip. The 1 cm gray structure at one end is the tissue that separates upper lip from lateral aspect of baleen, this thing looks like a "gasket".

Tag 45, (RU 1380): Skin from lateral surface of upper lip (black skin). Note "gasket" like structure (tag) that seems to separate skin of upper lip from lateral aspect of baleen. The white smooth tissue which is continuous with the "gasket" is part of the "gum" of the baleen (Fig 20-14).

Tag 37, (RU 1380): Skin, margin of lower lip, at about 1/5 of way from anterior to posterior along length of lip (is about 60 cm from anterior tip). On outer surface is ½ of a skin lesion (1 cm wide and 1 cm deep). Note how skin is much thicker on outer surface of lip.

Tag 35, (RU 1380): Skin, half way along left margin of lower lip, thicker skin is outer skin of lip while thinner skin is inner aspect of lower lip.

Tag 42, (RU 1380): Skin, left margin of lower lip, about 3/4 of way from anterior tip.

Tag 4, (RU 780): Skin, lesion from left side of face, lesion part of epidermis is starting to peel off.

Tag 20, (RU 1380): Skin, from most anterior aspect of lower lip on midline where curls inward into mouth, tag is on anterior end, the thicker white skin is on outer surface and the thinner black skin is on inner aspect of lower lip.

Tag 22, (RU 1380): Skin, white, on ventral midline of lower jaw, 60 cm from tip, tag on anterior edge, note 1 cm diameter lesion on skin surface.

Tag 30, (RU 1380): Skin, white, note 2 x 1 cm lesion depressed 3 mm, from lower jaw on midline about 1.2 m from tip, tag is toward anterior.

Tag 28, (RU 1380): Skin, with 1 cm diameter lesion, from midline lower jaw, about 1.8 m from anterior tip.

Tag 26, (RU 1380): Skin, about 3 m from anterior tip of lower jaw, on ventral midline, is in line with anterior aspect of flipper insertion. Tag on anterior.

Tag 27, (RU 1380): Skin, about 4.5 m from anterior tip on ventral midline, on line with point 60 cm behind posterior aspect of flipper insertion.

Tag 25, (RU 1380): Skin, white, about 5.2 m from anterior tip of lower jaw on ventral midline, tag on anterior edge. (Figure 1-15 shows this sample being taken, abdomen cut open and can see liver at this site).

Tag 88, (RU 1380): Skin, ventral midline, 1/3 distance from flipper to fluke, tag and cut on anterior surface, sample 8 x 10 cm.

Tag 98, (RU 1380): Skin, from about 6.4 m from anterior tip and about 30 cm to right of ventral midline (just to right of middle of genital slit, Fig 20-1).

Tag 84, (RU 1380): Skin, ventral midline about 2/3 distance from flipper to fluke, tag and cut on anterior edge, 8 x 10 cm size sample. Note 2 depressed (2 mm) lesions on skin surface, each 1 cm diameter.

Tag 87, (RU 1380): Skin, dorsal midline, 1/3 distance from flipper to fluke, tag and notch on anterior edge.

Tag 85, (RU 1380): Skin, 8 x 10 cm sample, from dorsal midline, 2/3 distance from flipper to fluke, tag and notch on anterior edge.

Tag 86, (RU 1380): Skin, 8 x 10 cm sample, from left lateral midline, 1/3 distance from flipper to fluke, tag and notch on anterior edge.

Tag 93, (RU 1380): Skin, 10 x 5 cm, left lateral midline, 2/3 distance from flipper to fluke, tag and cut on anterior edge, also 5 mm diameter skin lesion.

Tag 11, (RU 1380): Intact eyelids, numbered tag is on lateral canthus of left eyelids, also a notch cut into skin lateral to lateral canthus.

Blubber cores

Tag 97, 1/3 V, (RU 480): Blubber core, from ventral midline at 1/3 distance from flipper to flukes, skin tag on anterior surface as is a cut in skin, a full thickness sample from skin to muscle. Note outer dense layer of blubber and inner "mushy" layer of fat.

Tag 14, (RU 480): Blubber core, taken from close to ventral midline, 30 cm in front of anus, sample about 20 cm long, probably not full thickness.

Tag 38, (RU 480): Blubber core, tag 38 in outer layer and tag 36 in inner layer of tissue. Note muscle layer separating 2 layers. From behind flipper on left side.

Tags 33,31, (RU480): Blubber core, full thickness, location of core about 1.2 m behind left flipper on lateral midline, tag 33 in outer layer and tag 31 in inner layer of tissue good view of muscle layer separating 2 adipose layers (Fig 20-3). Photo on roll 133.

Tag 29, (RU 480): Blubber core location at about level of liver, 4.5 m behind tip of lower jaw, taken at about midpoint of body on mid lateral line.

Tag 8, (RU 480): Blubber core, shows both adipose layers, from about 4.5 cm above left eye.

Tag 96, (RU 480): Blubber core, 1 meter caudal to blowhole, not full thickness, tag and notch on anterior edge, note 2 cm diameter skin lesion on surface.

Tags 55,57, (RU480): Blubber core, outer dense blubber layer is tagged 55 and inner mushy tissue layer is tagged 57. Note that the 2 adipose layers are separated by a 2 mm or so thick discontinuous layer of muscle. Note 2 or 3 small (5 mm) diameter lesions on skin surface. This is not a full thickness section as some of inner adipose layer is missing as this piece was collected from larger piece that had been removed during butchering. Photo is last on roll 133.

Tag 1, (RU 480): Blubber core, full thickness, tag 1 is in outer blubber, tag 19 is in inner adipose layer, note prominent muscle layer separating the 2 layers of tissue Location on body not specified.

Spleen

Tag 23, (RU 480): Spleen, 5 x 3 cm, includes surface (Fig 20-24).

Cardiovascular system

Tag 43, (RU 480): Blood vessel, seems to be aorta, cross section, about 8 cm diameter, was seen on midline just below body of a vertebra at about level of diaphragm. (Photos on roll 133).

Other tissues

Tag 90, (RU 680): Eye, with some surrounding muscles, is left eye.

Tag 94, (RU 580): Adrenal, (intact with a 15 mm section removed).

Tag 99, (RU 1380): Adrenal, a 15 mm cross section (transverse section) from the above mentioned adrenal (tagged 94).

Tags 105,100, (RU580): Pituitary, ½ of pituitary, other half (tagged 100) is frozen for hormone analysis. Pituitary split longitudinally (Fig 20-29). Pituitary was removed intact and this sample has dura above pituitary (tagged) then pituitary and then vascular rete below pituitary. This vascular rete seems to surround much of pituitary and seems to underlie much of brain and seems continuous with the vascular rete that fills the foramen magnum.

Tag 5, (RU 480): Thymus, glandular tissue ("pancreas like") was attached to aortic bulb, suspect is thymus. Some taken for tissue culture and some for EM.

Tag 83, (RU 480): Thymus (?), 13 cm diameter, fatty material, may be thymus, also has some of what seem to be lymph nodes.

Tissue for Electron Microscopy (80B8)

- Tissues in fixative for approximately 6 hours.
- Tissues in vials of buffer
  - Skin: Full thickness plus blubber. (RU 1380)
  - Skin: As above. (RU 1380)
  - Liver: (RU 1480)

- Pancreas: Taken from tissue tagged #12. (RU 1480)
- Thymus: ?? Am not sure, but tissue was in right location to be thymus. (RU 1380)
- Thymus: (As above) taken from tissue tagged #5. (RU 480)
- Lung: Taken from sample tagged #10. (RU 1380)
- Lung: Taken from sample tagged #10. (RU 1380)
- Spleen: (RU 480)
- Spleen: (RU 480)
- Kidney: The larger of the 2 pieces has whitish tissue at one end which is medulla. (RU 1380)
- Testicle: Taken from testicle tagged #15. (RU 580)
- Testicle: Taken from testicle tagged #15. (RU 580)
- Testicle: Taken from testicle tagged #15. (RU 580)

Blood Samples (80B8)

- Blood Smears
  - for cytological evaluation (RU 880)
  - for parasitological evaluation (RU 1280)
- Serum (or plasma), frozen
  - for antibody level determination (RU 1080)
  - for hormone level determination (RU 580)
  - for clinical chemistry (RU 880)

Other Frozen Items (80B8)

- Testicle (section) for hormone analysis (RU 580)
- Pituitary (½ of) for hormone analysis (has tag 100) (RU 580)

Tissues for Toxic Substance Analysis (80B8)

- Blubber
- Kidney
- Skeletal muscle
- Diaphragm
- Spleen
- Liver
- 2 samples of each (one to be archived)
- all to RU 380

Swabs Taken for Bacterial Isolation (80B8)

- "80B8 BRONCHUS-B": taken from main bronchus immediately distal to tracheal bifurcation.
- "80B8 BRONCHUS #1": taken from main bronchus where it enters the lung; bronchus was 5 cm diameter; swabs taken approximately 45 cm from those marked "BRONCHUS-B."
- "80B8 BRONCHUS #2": taken from 1½-2 cm diameter bronchus approximately 20 cm from caudal tip of lung.
- all 3 sets of swabs include:
  - 4 in transport medium
  - 1 anaerobic
  - 1 in thioglycollate broth
- NOTE: Anaerobic swab from "BRONCHUS #2" is sealed with tape. The plastic wrapper became brittle in the cold and tore.
- all to RU 1180.

Swabs Taken for Viral Isolation (80B8)

- Blowhole
- Left eye (conjunctiva)
- Prepuce (Fig 20-1)
- Large bowel (exact location uncertain)
- Rectum
- all to RU 1080

Tissue Samples (1 gram) Taken for Viral Isolation (80B8)

- Liver
- Kidney
- Spleen
- Large bowel mucosa (exact location uncertain)
- Testis
- Spinal cord within 5 cm of brain
- Brain (cerebral cortex; brain severely traumatized from bomb)
- Thymus ? (very questionable, may only be adipose tissue)
- Thymus (probable thymus)
- Lung (This sample was not taken from fresh tissue. It was taken from a section of lung tissue which had been stored in tissue culture medium in a refrigerator for 4 days.)
- all to RU 1080

Tissue Samples Taken for Tissue Culture (80B8)

- Skin
- Kidney
- Lung
- Testis
- all to RU 1080

Bone Samples (80B8)

- 2 cm thick slab of humerus with proximal radius
- 2 cm thick slab of humerus with proximal radius
- 2 cm thick slab of cross section of radius and ulna together
- 2 cm thick slab of cross section of radius and ulna together
- Body of vertebra, 1 cm thick slab, intact
- Body of vertebra, 1 cm thick slab, intact
- Body of vertebra, 1 cm thick slab, cut in half
- Body of vertebra, 2 cm thick slab, cut in half
- Transverse section through olecranon, shows ulna with olecranon growth plate visible on proximal side of the slab.
- Transverse section through olecranon, just proximal to above section, shows olecranon growth plate on both sides and large olecranon cartilage.
- 2 cm slab across spinous process of a vertebra.
- 2 cm slab across transverse process of a lumbar vertebra (2 samples)
- total 13 pieces, all in 10% buffered formalin
- all to RU 480

Radiographs Taken (80B8)

- Proximal humerus including proximal epiphyseal plate.
- "Slab" of body of vertebra, includes both epiphyseal plates.
- all specimens approximately 2 cm thick.
- radiographs taken June 6, 1980

Large Specimens (80B8)

- Lung, left (Fig 20-20), weight 13.2 kg (RU 1380)
- Most of testicle, ½ of other testicle and spermatic cords, attached urinary bladder (RU 480)

- Intestine segment (1) (RU 1280)
- Diaphragm chunk (10 x 10 x 10 cm), tag 103, (RU 1280)
- Brain (sent to Dr. S. Ridgway, Naval Ocean Systems Center, San Diego, CA for initial examination and then to RU 1380)
- Stomach, about 2/3 is present, esophageal entrance and duodenal exit areas missing (RU 1480)
- Atrium piece (25 x 25 cm) (RU 480)
- all above in 10% formalin
- Baleen, 2 intact gum segments, including 81 plates. (sent to Dr. Lee Braithwaite, Brigham Young University, Provo, Utah, for use in other BLM funded research).

Listing of Tissue Specimens From Bowhead Whale 80B9 With Related Observations

Taken by: Patsy Tukle at Barrow, Alaska, May 27, 1980
Length: 13.6 meters
Sex: female
NOTE: Associated with the description for each specimen is an "RU" designation, that is, the Research Unit to which the specimen was sent. Specimen description made at time of collection and/or shipment.

Small Specimens in 10% Buffered Formalin (80B9)

Digestive system

Tag 10, (RU 1480): Tongue, surface, note many irregularly round white "spots" on the black surface of tongue, "spots" are 1-10 mm in diameter, not raised.

Tag "Colon-Anal Canal Junction",(RU 1480): Piece of tissue 30 cm long, 15 cm thick), terminal part of colon and first part of anal canal (white mucosa). The white mucosa (anal canal) has 3 eroded areas; 2 are 1 cm diameter, 1 is 2 mm diameter (are these ulcers?) Note: one of the erosions (tagged 100) has been removed. Note attached lymph nodes.

Tag 100, (RU 780): Anal canal "ulcer", one of 3 erosions of mucosa mentioned in large specimen above.

Reproductive system

Tag 23, (RU 580): Vagina, mucosa, has 2 x 1 cm roughened area, just barely raised (¼ mm or so), looks like area of heavily cornified vaginal epithelium.

Tag 25, (RU 580): Vagina, mucosa, sample is 15 cm long x 2 cm wide, long axis of sample same as vaginal long axis.

Tag 6, (RU 580): Cervix, mucosa between 3rd and 4th ring of cervix, not part of a ring.

Tag 17, (RU 580): Cervix, piece of one of the rings of cervix, from 2nd ring from anterior end (the 6th ring going inward).

Tag 19, (RU 580): Uterus, body, full thickness, about half way between anterior end of cervix and uterine bifurcation.

Tag 20, (RU 580): Uterus, horn, 15 cm after horn begins at the bifurcation (Fig 20-14).

Tag 16, (RU 580): Uterus, horn, full thickness, from same horn as Tag 20. This sample is from 30 cm cranial to the "outwardly seen" bifurcation.

Ovary, (RU 580): Sliced transversely, 8 cm segment removed and frozen for hormone analysis.

Ovary, (RU 580): Sliced transversely, piece of oviduct attached.

Tag 101, (RU 580): Nipple, with surrounding skin, nipple incised longitudinally.

Blubber core

Tag 13, (RU 480): Blubber core, full thickness, about 61 cm behind blowhole.

Spleen

Tag 54, (RU 480): Spleen sample. The spleen as lying on ice was approximately 48 cm long, 25 cm at greatest width, 9 cm at greatest thickness and weighed approximately 5 kg.

Other tissue

Tag 12, (RU 480): Cartilage, from dorsal margin of scapula, this 8 cm long sample is from long axis of scapula.

External parasite

Unnumbered specimen (RU 1280): LOUSE, found on baleen.

Frozen Item (80B9)

- Ovary (section) for hormone analysis (RU 580)

Bone Samples (80B9)

- Body of vertebra, slab, intact, note 1 cm diameter "soft spot" in center, seems like 1 mm vessel there.
- Body of vertebra, slab, cut in half.
- Transverse process, lumbar vertebra, slab, cross section.
- Other transverse process, lumbar vertebra, slab, cross section.
- all specimens approximately 2 cm thick.
- total 5 pieces, all in 10% buffered formalin.
- all to RU 480

Radiographs Taken (80B9)

- "slab" of body of vertebra, includes both epiphyseal plates.
- "slab" of body of vertebra with that of 80B8 (the Ingutuk) on the same film.
- all specimens approximately 2 cm thick.
- radiographs taken June 6, 1980.

Large Specimens (80B9)

- Cervix and most of uterus (RU 580)
- vulva and nipple (RU 580). Approximately 20 cm lateral to the vulvar opening is a recessed nipple and near it another recessed structure (??) and about 15 cm further laterally seems to be another nipple (?) not nearly as recessed.
- intestine segment (RU 1280)
- blubber chunk (10 x 10 x 10 cm) (RU 1280)
- liver chunk (10 x 10 x 10 cm) (RU 1280)
- all above in 10% formalin
- colon contents in vial with formalin (RU 1280)

General Comments (80B9)

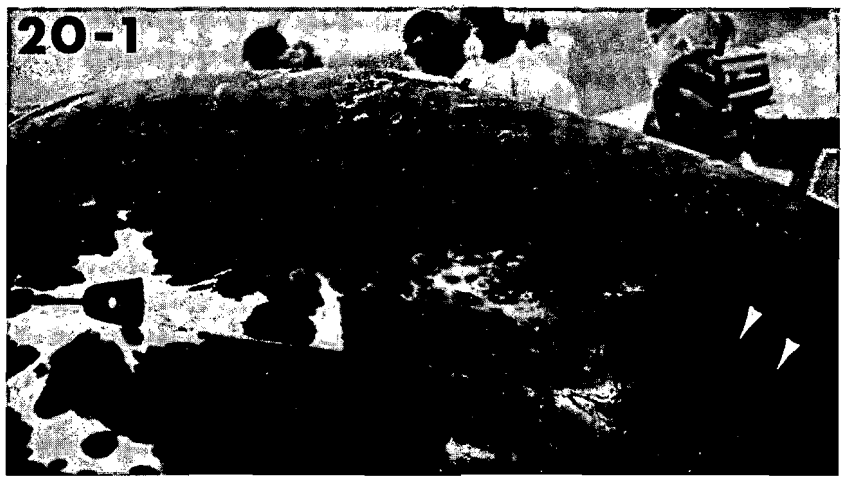
- With cervix and uterus on the ice (Fig 20-26) could note that cervical area seemed approximately 4 times thicker than horns. Large "fat pad" (approximately 10 cm thick) associated with horn and body on each side (Fig 20-26). The "outward" site of bifurcation of uterus was 48 cm from anterior most part of cervix. On opening the uterus could see bifurcation was sooner than that seen externally and that body was approximately 25 cm long. The uterine mucosa had longitudinal folds, each approximately 2 cm high. When opened the cervix seemed to have 7 separate rings with the outermost ring the largest and the others seemed to decrease in size moving anteriorly. The cervix was approximately 110 cm long. Each cervical ring had 7-10 separate "folds" (each approximately 1 cm thick) around its orifice.
- What appeared to be an old wound was seen on a large section of skin lying on the ice. This section of damaged skin apparently originated from somewhere on the upper jaw. The injury (Fig 20-20), consisted of a 7 cm wide depressed area which sloped.

down gradually to 4 cm diameter then tapered further for another 4 cm to its narrowest point as seen from above. The lining of this conical shaped "hole" in the skin was mostly white with some black skin. We were not able to obtain samples of this damaged tissue. It seemed to be some sort of penetrating wound. On the inner aspect of this 20 cm thick piece of skin and blubber was some grayish slimy material which seemed like pus, leading one to suspect a fistulous tract.

Figure 20-1. Whale (80B8, male) lying on right side. Flensing tool can be seen being positioned at anterior end of genital groove. Note dozens of small irregularly circular skin lesions (white arrowheads) on the caudo-ventral aspect of the animal.

Figure 20-2. Whale (80B8) lying on right side. A strip of skin and underlying tissue has been removed, opening the peritoneal cavity revealing the liver (L) and small intestines (I). Dr. L. M. Philo (P) is removing a skin sample (Tag 25) from the ventral midline. Flensing tools are indicated by white arrows.

Figure 20-3. The very thick black epidermis characteristic of the bowhead is readily seen in this animal (80B8). The solid triangles indicate the discontinuous muscle layer which seems to separate the outer firm blubber from the inner layer of much softer fatty tissue. The proximal aspect of the left flipper is barely visible (arrows).


20-1


20-2
P
L

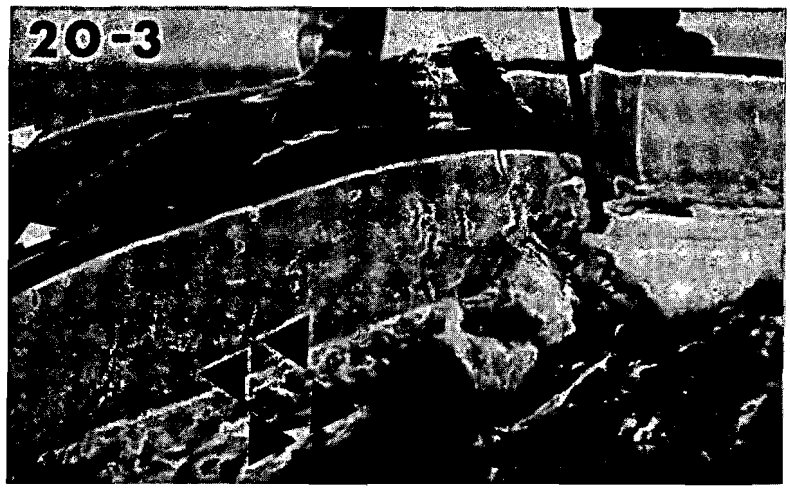
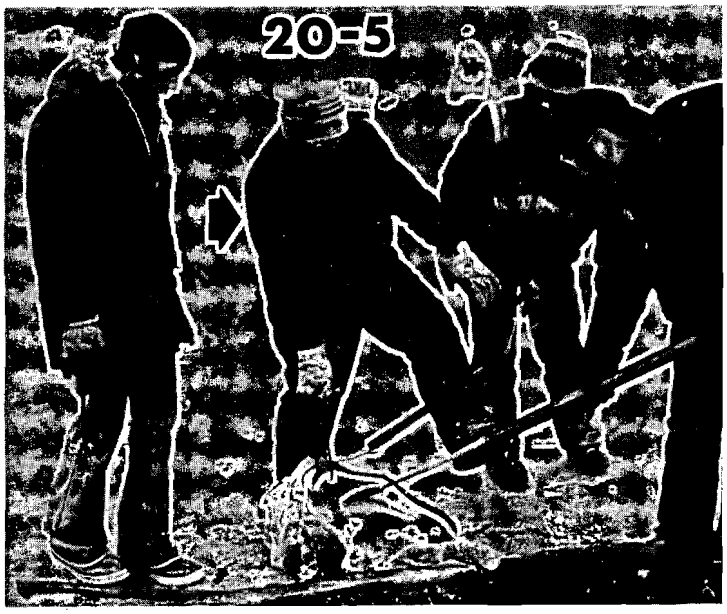

20-3

Figure 20-4. Opened thorax (80B8) showing both lungs (L). Also note body of vertebra (V) and large vertebral foramen (white arrows).

Figure 20-5. Maktak (skin and underlying blubber) being removed from boney remnant of flipper (80B2) under the direction of Nate Elavgak (arrow). Entire specimen collected. See also TABLE 21-1.

Figure 20-6. Note prominent genital groove just anterior to anus (white arrow) in female bowhead whale (80B7). On either side of the genital groove is a groove (black arrows) containing nipple of mammary gland. Compare with similar area of male animal seen in Fig 20-1. (Photo by G. Jarrell).


20-4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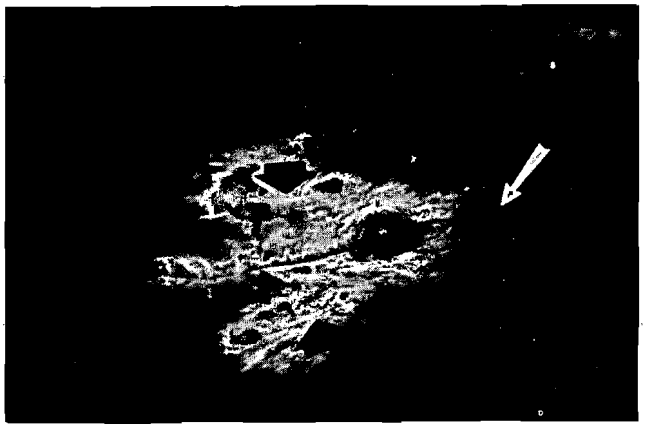
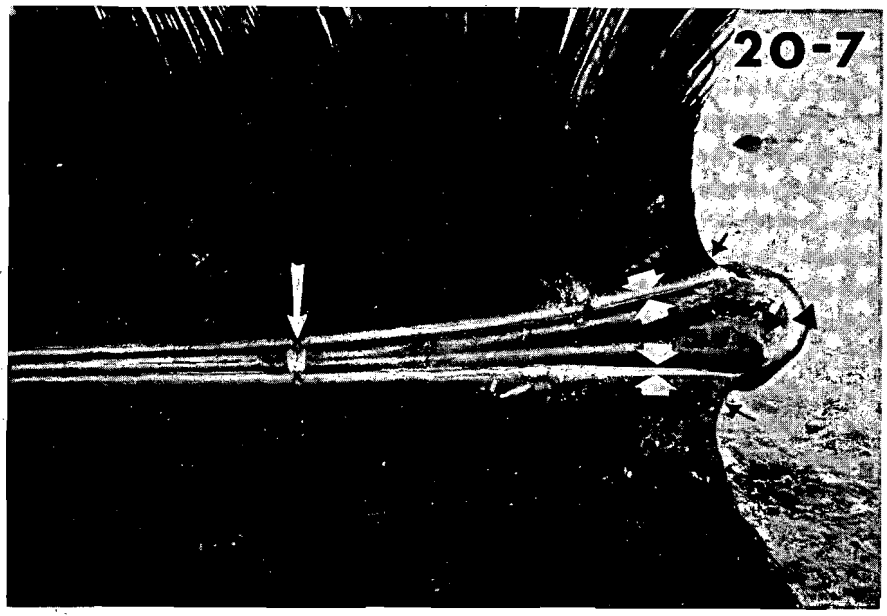


Figure 20-7. Internal view of disarticulated upper jaw of bowhead whale 80B1. Lateral surface of left row of baleen in contact with ice. A portion of the medial (inner) surface of the right and left rows of baleen is visible. The hard palate is very long and quite narrow. A full width sample (Tag 102) of the hard palate mucosa was removed at the site indicated by the long white arrow. Note the two shallow grooves (approximately 2 mm deep) which run longitudinally and seem to separate the most medial aspect of the baleen from the mucosa of hard palate. In this Figure these grooves appear as a longitudinal white line (between small white arrows) on either side of the hard palate mucosa. Anteriorly the hard palate mucosa is separated by a distinct groove (between solid black triangles) from the innermost aspect of the skin of the upper lip. Note that the most anterior baleen structures on either side are very short (black arrows, see also Fig 20-8).

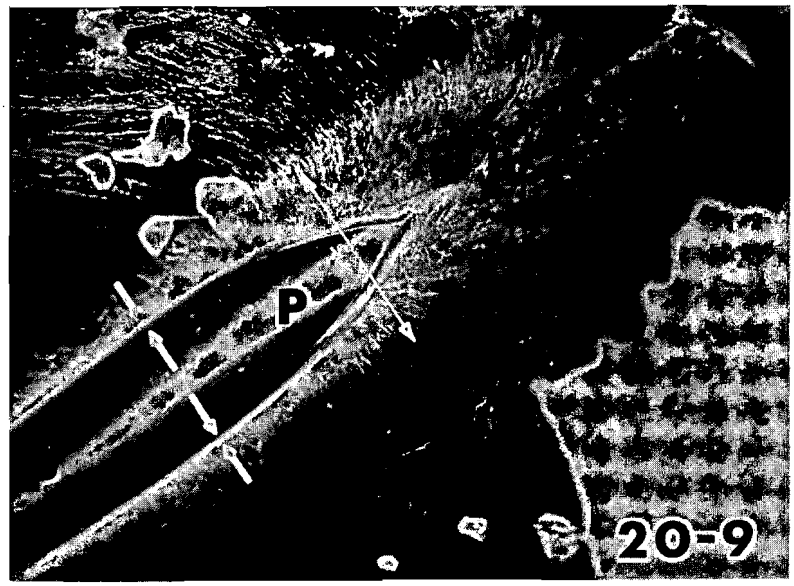
Figure 20-8. Anterior portion of upper jaw (79B3) illustrating junctional groove (small black and small white arrows) where mucosa of hard palate (P) meets skin of upper lip (UL). Also visible near the anterior tip of the hard palate are the two grooves (white arrows) of the Jacobson's organ. The medial surface of a portion of the right row of baleen (B) is visible as is the lateral surface of a portion of the left row of baleen. Note that the most anterior baleen structures in both rows (large white arrows) are very small (a few cm in length). The "gasket-like" structure (G) which separates the lateral surface of the baleen tissue from the skin of the upper lip is delineated by open white arrows (see also Fig 20-14.


20-7


20-8
B

Figure 20-9. Caudal aspect of roof of mouth (80B7) showing the most caudal portion of hard palate mucosa (P). Note that the fine baleen structures (B) on either side of the hard palate mucosa come together posterior to the hard palate mucosa. In the rear of the roof of the mouth, both rows of baleen (B) come together so that the bare hard palate mucosa (P) ends. The next 15 cm posteriorly the hard palate is covered by a mat of baleen "filaments". Posterior to this mat of small baleen structures the mucosa of the roof of the mouth continues, however, such a continuation is not visible in this Figure. The two sets of small white arrows locate the two shallow grooves (one groove on either side of the hard palate mucosa) which run longitudinally and seem to separate the most medial aspect of the baleen from the hard palate mucosa (see Fig 20-7). The double tipped white arrow shows the location where sample Tag 61 was taken from whale 80B1. This Figure also provides information pertaining to sample Tag 50 (whale 80B1) and sample Tag 32 (whale 80B7).

Figure 20-10. Portion of tongue lying on ice from whale 80B8. Five samples were taken (arrows) in a line (at right angle to long axis of tongue) extending from the floor of the mouth (arrow at right) up the side of the tongue to the dorsal surface (arrow at left). The sampling site was approximately at the junction of the anterior and middle thirds of the tongue.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20-9

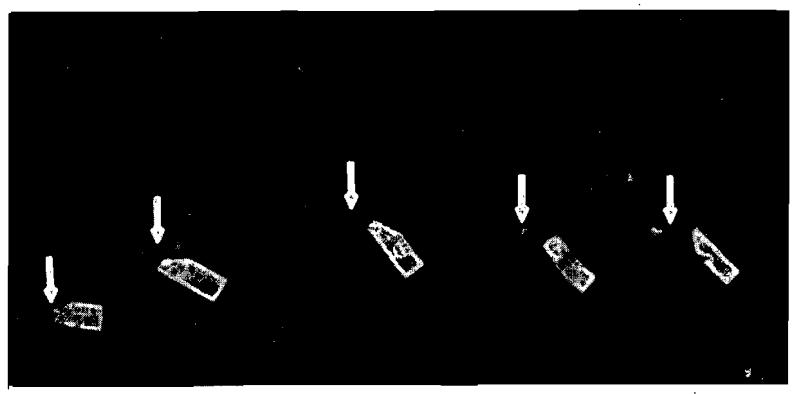
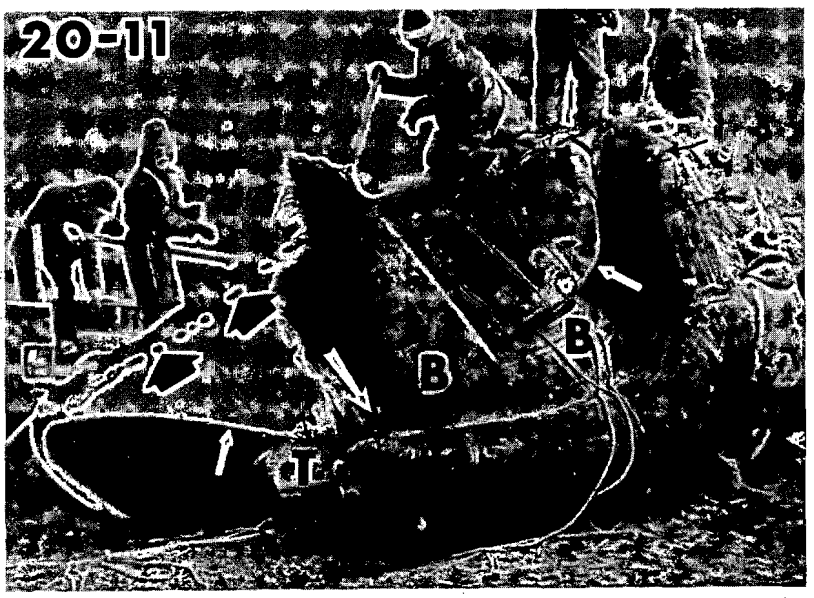


Figure 20-11. Bowhead whale (79KK1) lying on left side on beach. This Figure serves to illustrate the sites from which many samples were taken from the head region of several whales. Note the strong arch of the upper jaw and how narrow it is anteriorly in relation to the lower jaw. Many of the baleen plates (B) of the right side are visible. The large white arrow indicates the region of very short baleen structures at the anterior end. The large black arrows locate the row of tactile hairs in pigmented epidermis on the right side of the lower jaw. Several samples were taken along the margin of the lower lip (small white arrows) in various animals. The right eye (small black arrow) is visible, as is a portion of the tongue (T).

Figure 20-12. Portion of head visible with animal (80B7) lying on right side. Blowhole area barely visible (black arrow) resting on ice. Note knife (approximately 25 cm) on the ice just to right of black arrow for scale. Note large number of lesions (white arrowheads) on the skin. A section of skin including part of 2 large lesions was removed from the area between the 2 large white arrows. The indicated site is approximately 15 cm outward from the baleen (B). A close up view of the skin lesions prior to their removal can be seen in Fig 20-13.


20-11
B
B

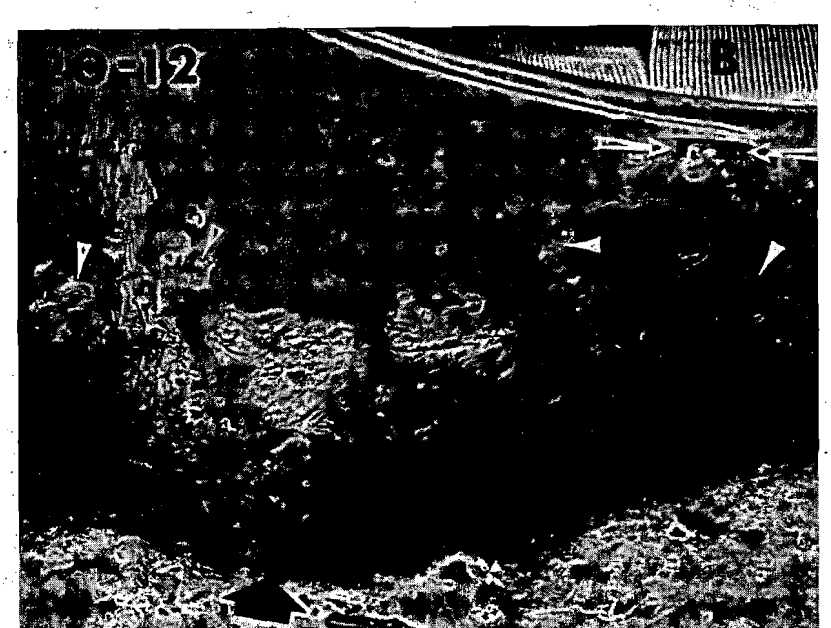
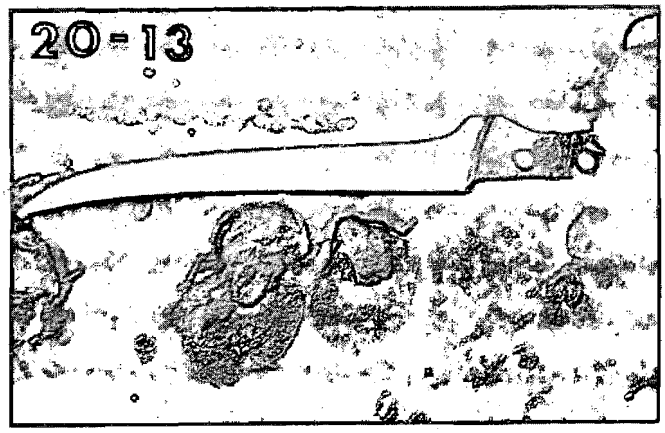

B

Figure 20-13. Skin of upper jaw (80B7) approximately 15 cm outward from the baleen showing several skin lesions prior to their sampling (sample Tag 9). Note the partially visible gloved hand holding knife (knife blade is 20 cm long). This is a close up view of an area seen in Fig 20-12. As can be seen, the lesions are irregularly circumscribed roughened areas of the epidermis.

Figure 20-14. A portion of the lateral aspect of the upper jaw (80B8), showing the "gasket-like" tissue (G) which separates the skin (S) of the upper jaw from the lateral aspect of the baleen (B). The large white arrow indicates the site from which has been removed the tissue sample indicated by the 2 small white arrows. This indicated specimen is sample Tag 45 from whale 80B8. Note that the white smooth tissue (indicated by small white arrow on right) of the removed specimen is continuous with the "gasket" and seems to be part of the "gum" of the baleen.

Figure 20-15. Close up view of a section of skin (79B3) showing several skin lesions. Note the variation in size (1-6 cm) and shape of lesions. Several of the roughened areas (arrows) seem to have 1 mm long "thread-like" projections on their surface. See also Figs 20-1, 10-12, 20-13, 20-16 and 20-17.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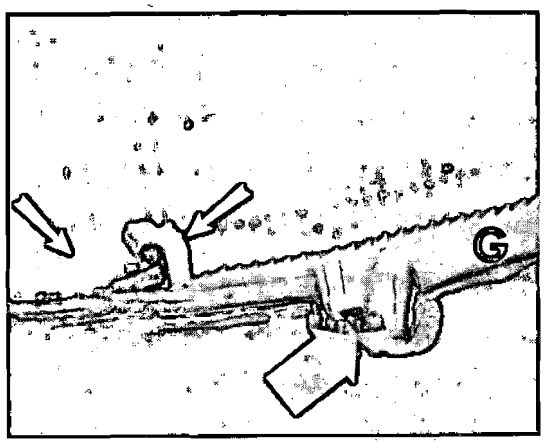
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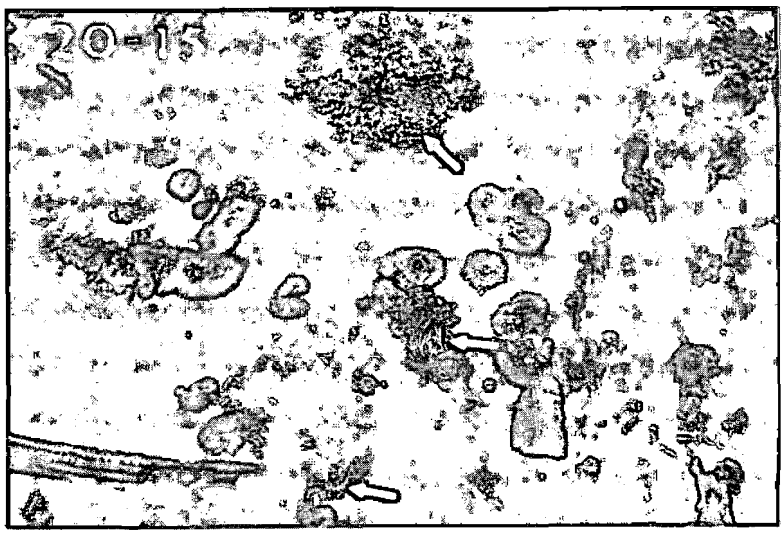
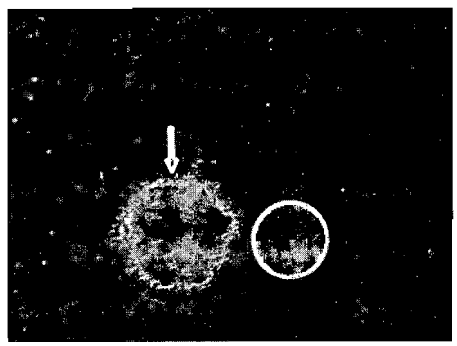

20-13

Figure 20-16. Skin lesions (solid arrows) from whale 79KK1. Lesion diameters here range from approximately 1 cm to 4 cm. Note that the roughened areas in this instance are elevated 1-2 mm with a central depressed area (best seen in the largest lesion). The opened white arrow indicates an area of white epidermis (a scar).

Figure 20-17. Skin lesion (arrow) from the fluke of whale 79KK1. The 25 cent coin gives an indication of lesion size. In this instance the lesion is just barely elevated (less than 1/2 mm) with a "crusty" surface. Outwardly this lesion differs markedly from those in Figs 20-13, 20-15 and 20-16.

Figure 20-18. Blowhole area lying on ice, from whale 80B1. Ruler (30 cm) lies on skin between closed external nares. The approximate lengths of the closed external nares are indicated by the double headed arrows. The irregular areas of white epidermis in the blowhole area probably represent scars resulting from earlier damage, possibly due to breaking through ice in order to breathe. The small black line cutting across the area of white epidermis just above the ruler represents the location from which a specimen (Tag 58) was taken. The specimen included the scarred area and also extended into the nostril. Beneath the skin just lateral to each nostril is a complex arrangement of muscle bundles (M) embedded in connective tissue. The muscle bundles at this location are 1-3 mm in cross sectional diameter and are likely concerned with opening the nostril. See also Fig 20-19.


20-16



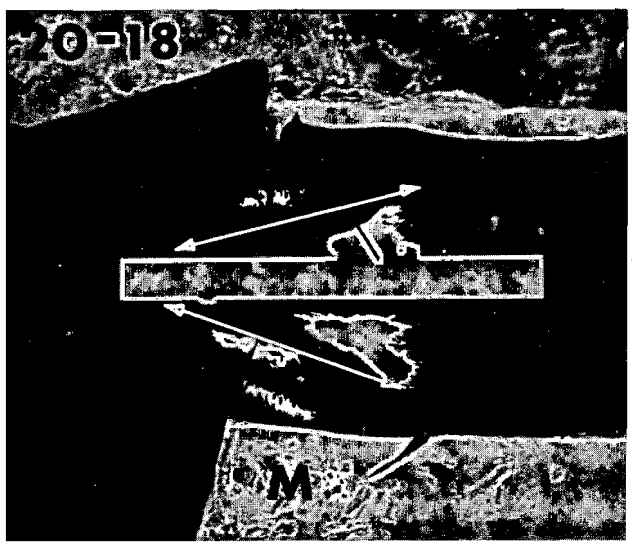
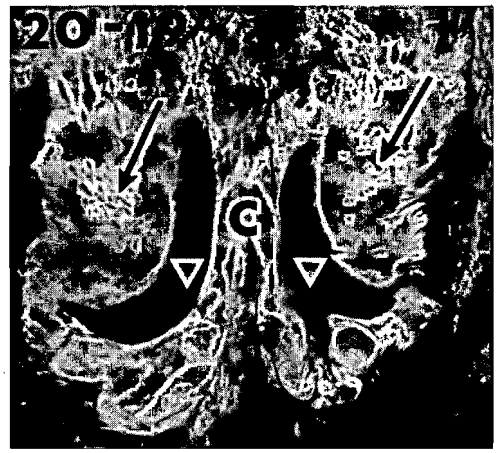

20-18

Figure 20-19. Transverse section of blowhole area 10-15 cm beneath skin surface of whale 80B2. This is similar to what would be seen if the blowhole area seen in Fig 20-18 were viewed from beneath. In this instance the airpassages, lined by pigmented epidermis, are indicated by solid white triangles. The small muscle bundles (seen earlier in Fig 20-18) are also seen here (arrows). Cartilage (C) separates the two nasal passages at this level.

Figure 20-20. Weighing left lung (solid white triangle) at butchering site of bowhead whale 80B8. The lung weighed 33.2 kg and was collected intact. Note various materials pertaining to collection of specimens; wooden box (B) for cutting instruments, insulated boxes for microbiological samples (M) and samples for electron microscopy (E), and containers (F) of formalin. Note 3 m high pressure ridge in background.

Figure 20-21. Small nodule (between solid black triangles) in mucosa of esophageal portion of the stomach (E) of bowhead whale 80B7. Several such nodules were found in whales 80B2 and 80B7. Note the rugous nature of the white mucosa (E) of the esophageal portion of the stomach and the thickness of the wall (between white arrows).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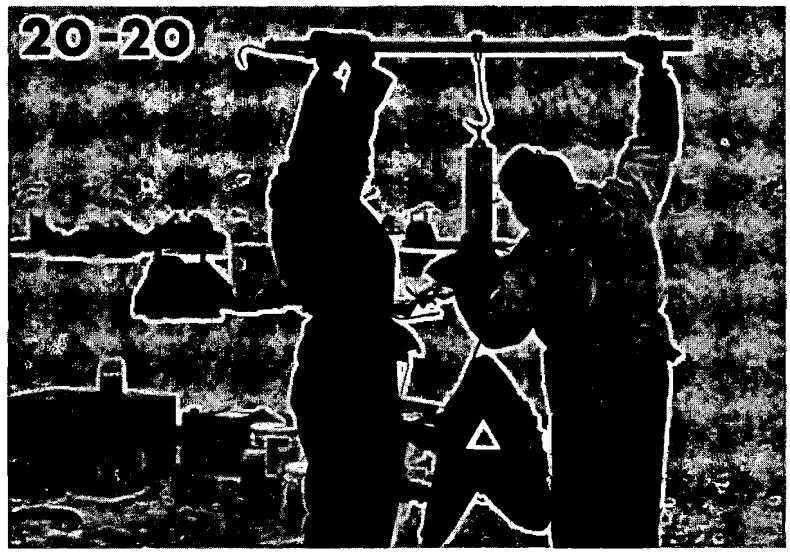
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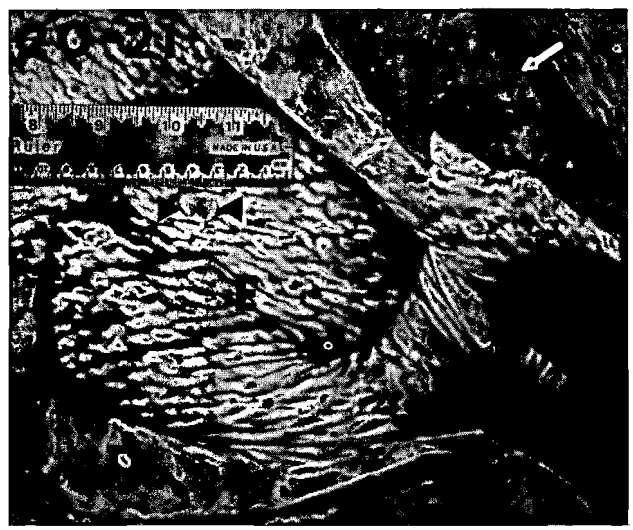
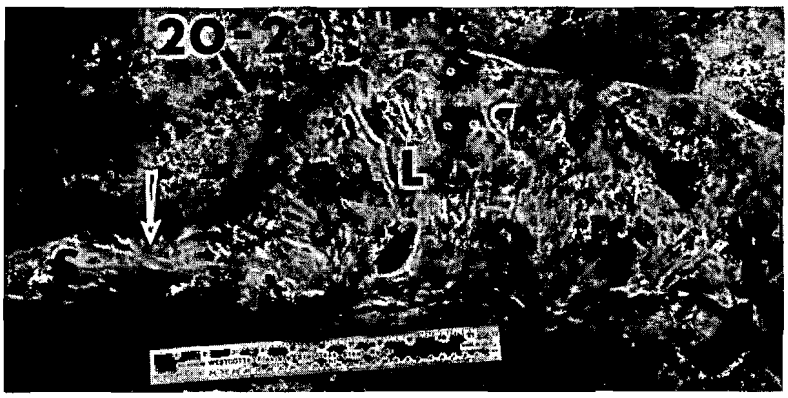


Figure 20-22. Tumor in substance of liver of bowhead whale 80B2. The tumor (between solid black triangles) was noted as a 2 x 1 cm pinkish white colored area on the diaphragmatic surface of the liver (L). It was raised slightly (1 mm) and on cut surface was white in color and extended approximately 1 1/2 cm into the parenchyma. It seemed well demarcated from the surrounding liver.

Figure 20-23. Junction of small intestine (S) and large intestine (L) in bowhead whale 80B7. This specimen was collected in its entirety. While lying on the ice the diameter of the specimen changed abruptly from 8 cm (S) to 23 cm (L). A small full thickness sample (Tag 26) was taken at the indicated site (arrow).

Figure 20-24. Spleen from bowhead whale (80B8) lying on ice. The spleen was shaped like a rather flattened triangle, weighed 3.5 kg, was 38 cm in greatest length, 20 cm at widest and 8 cm in greatest thickness. A small specimen (Tag 23) was collected. Note the numerous vessels (arrowheads) visible on the surface.


20-22
L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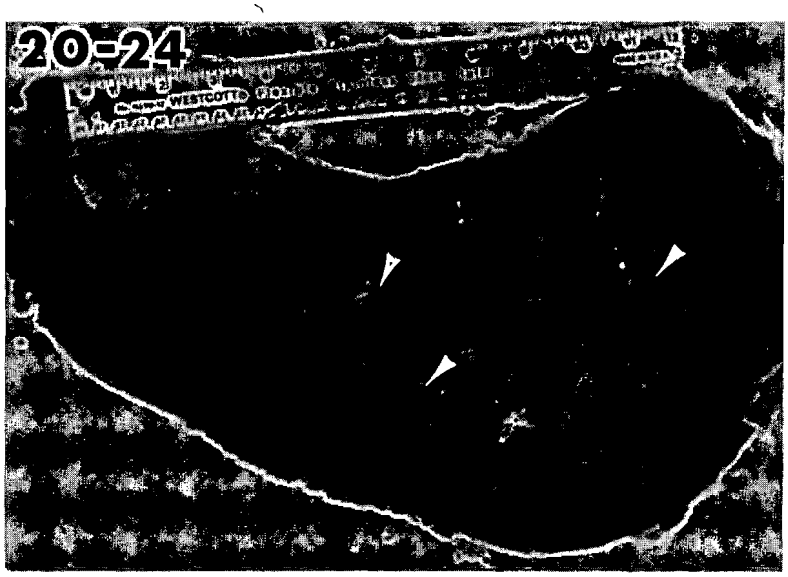

20-24

Figure 20-25. Urinary bladder (B) lying on ice from bowhead whale 80B7. Note prominent round ligament of bladder (remnant of umbilical artery) ("small" u) with sample (Tag 2) removed at site (black arrow) approximately 15 cm before attaching to bladder. Section of uterus ("large" U) attached. Entire specimen collected. Bladder contained approximately 1 l of urine (sample collected). White arrow indicates scalpel.

Figure 20-26. Uterus from bowhead whale 80B9 lying on ice. Note the cervical area (C), body (U) and uterine horns (U) with large amount of attached fat (F) and urinary bladder (B). Note 30 cm ruler (arrow).


20-25
B

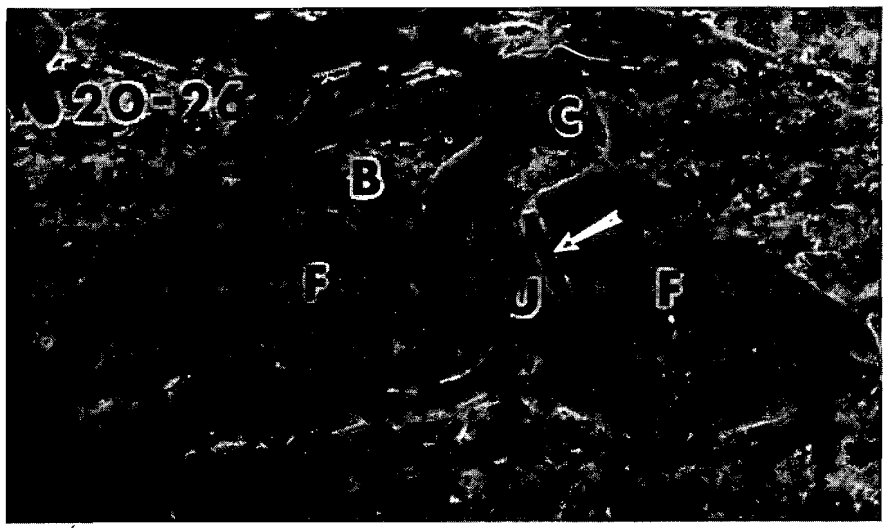
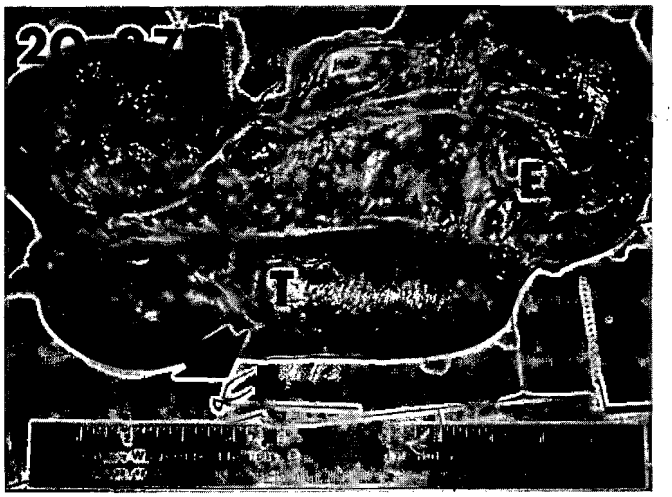

20-26
B
C
F
J
F

Figure 20-27. Testicle (T) and epididymis (E) from bowhead whale 80B3. Note the paper tag with metal clasp (arrow) used to identify nearly all specimens collected.

Figure 20-28. Testicle (T) with prominent epididymis (E) from bowhead whale 80B5. The ruler is 30 cm (12 inches) in length.

Figure 20-29. Pituitary halved longitudinally (small arrow) from bowhead whale 80B8. Note vascular rete like tissue (large arrow) which seems to surround much of pituitary. Entire structure collected (Tag 100, Tag 105).

Figure 20-30. Section of damaged skin from bowhead whale 80B9 lying on ice. A depressed area (between arrowheads) sloped inward creating a conical shaped "hole" in the skin lined by black and white epidermis which appeared to be a fistulous tract (large white arrow). Unfortunately we were not able to sample this area.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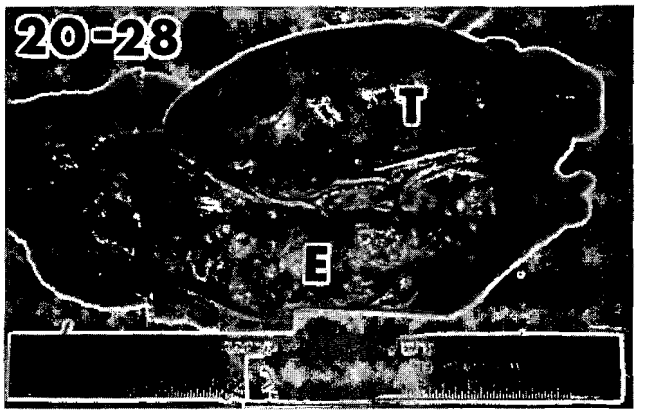
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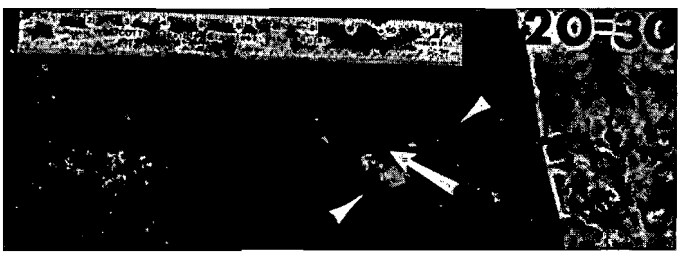


Figure 20-31. Whaling Captains Harry Brower, Sr. (1) and Eugene Brower (2) examining flesh of bowhead whale 80B8 during butchering process. Note food items being loaded onto sled (3), flensing tool (4) lying on ice, pile of whale meat (5) and holes in ice (H) used to anchor block and tackle during hauling of whale up onto ice. Open water of lead can be seen beyond ice edge.

Figure 20-32. Whaling Captain Arnold Brower, Sr. seated next to Ralph Ahkivak, who is holding damaged shoulder gun. In this instance the projectile ("bomb") exploded while it was still in the barrel just after the gun was fired. Shrapnel from the projectile and damaged barrel (arrow) flew forward and no one was injured. Note open water (L) of lead just beyond ice edge. The shotgun partially visible in the extreme lower left is used for occasional hunting of ducks while at whaling camp.

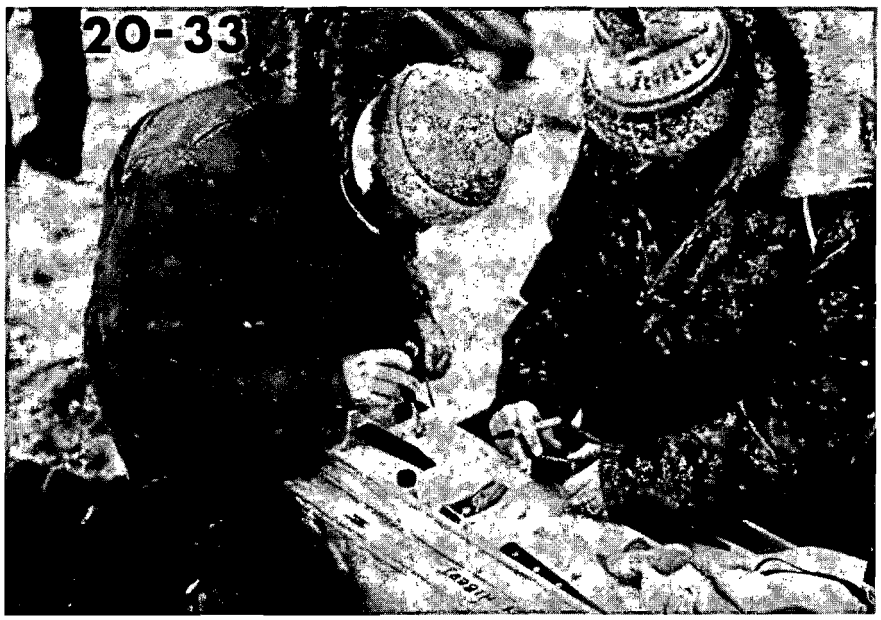

20-31
3
1
2
5
4


20-32
L

Figure 20-33. Skin samples being finely cut and placed into flask of nutrient medium for subsequent chromosomal studies (RU 980) and viral isolation studies (RU 1080). Severe environmental conditions limited what could be done at the collection site. (Photo by G. Selby).

Figure 20-34. Specimen collection sled in foreground with insulated boxes and containers of tissue preservative. Flag of successful whaling Captain (Harry Brower, Sr.) atop pressure ridge served as a guide for those traveling back and forth from butchering site (80B8) to village. Note CB radio antenna at tent and snow-machine with sled about to go up trail over pressure ridge.

Figure 20-35. General view of butchering site (80B8) at ice edge with process nearly completed. Arrow locates skin boat (umiaq) up on ice. Note specimen collection sled (with large box) in center foreground and lead in background. The specimen sled and tent at left are seen from a different angle in Fig 20-34.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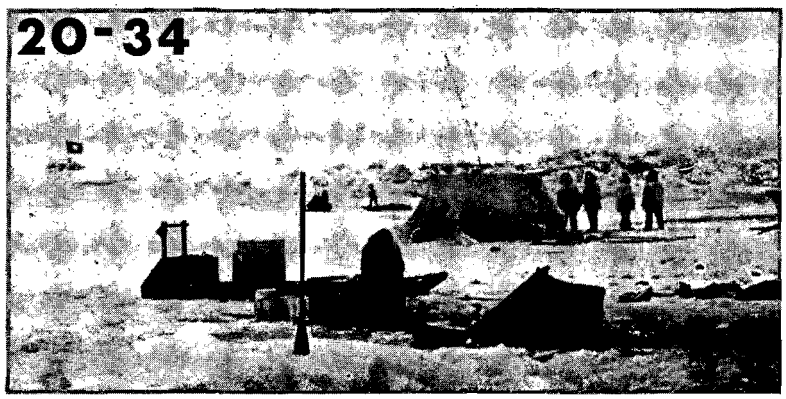
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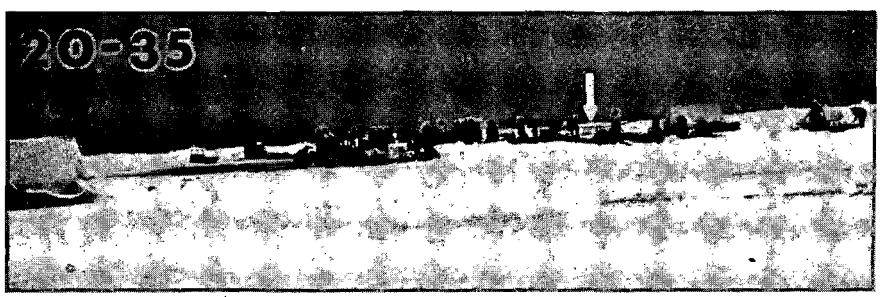
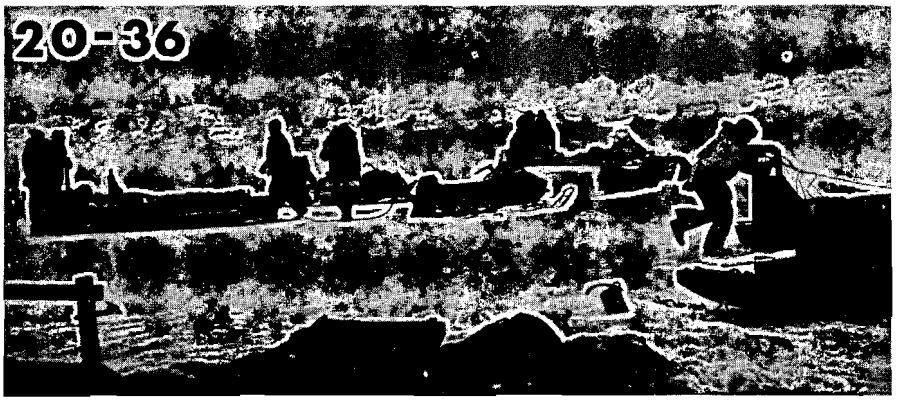

20-35

Figure 20-36. Sleds loaded with flesh at conclusion of butchering of bowhead whale 80B8.

Figure 20-37. Vertebra from bowhead whale 80B1 illustrating large vertebral body and prominent transverse processes. The black line across the body of the vertebra indicates how it was cut in order to obtain a 1 cm thick slab such as seen in Fig 20-38. Note also the prominent area of fibrous connective tissue (C) and the area of the nucleus pulposus (N) of the intervertebral disc. A 2 cm wide section of the intervertebral disc (including C and N) was collected (Tag 65, Tag 69).

Figure 20-38. Slab (1 cm thick) cut through body of vertebra of bowhead whale 80B1. Note the prominent cranial and caudal epiphyseal plates (between white arrows). The black solid triangles locate a portion of the adhered intervertebral disc seen on the cranial and caudal articular surfaces of the vertebral body.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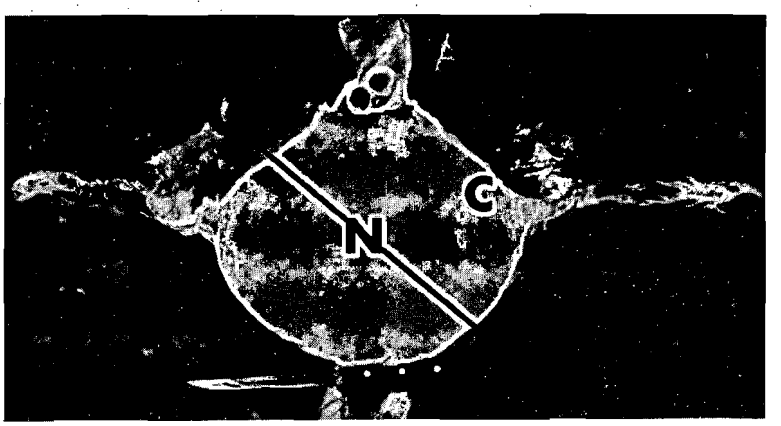
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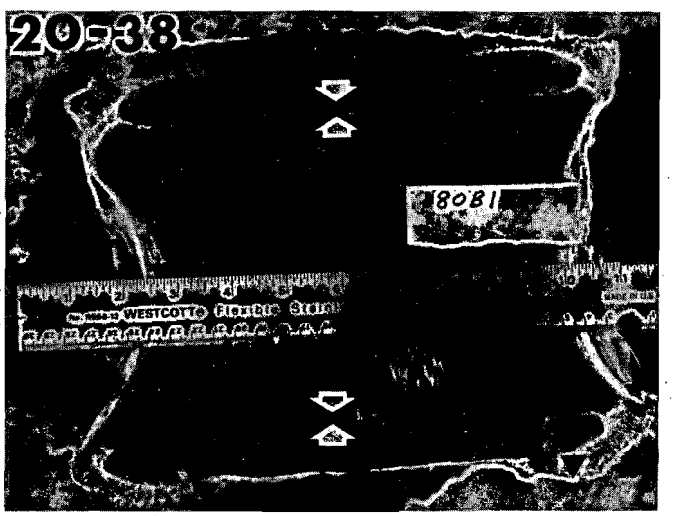
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Figure 20-39 Radius (R) and ulna (U) from bowhead whale 78KK2 cut tranversely in order to show entry site of bomb fragment. The two cut sections of the radius and ulna which were longitudinally continuous are now positioned one above the other. The brass fragment (large arrows) was found embedded in the radius (R) at the end of entry wound (small arrows). Note the heel print (H) in snow for indication of scale.

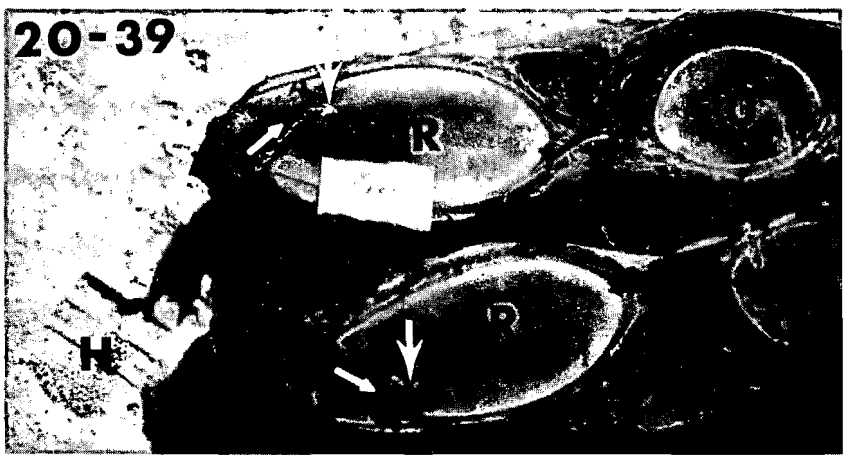

Figure 20-40 Heart from bowhead whale 79KK1 being placed into container for shipment back to NARL and storage (Fig 1-2) until examined during the summer of 1980 (see also APPENDIX II). (Photo by G. Selby)

APPENDIX VI

OBSERVATIONS ON THE RADIOGRAPHIC ANATOMY OF THE PECTORAL LIMB* OF THE BOWHEAD WHALE

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INTRODUCTION

The subsistence harvesting of bowhead whales by Alaskan Eskimos provides a unique opportunity to study many aspects of the morphology of the whale. During the butchering process each pectoral limb* (flipper) is removed from the body at the scapulo-humoral joint. One flipper is usually cut up on the ice (APPENDIX I) while the other is taken ashore intact. The intact flipper can be "borrowed" for a short period and radiographed.

OBJECTIVE

To define the boney structure of the pectoral limb (distal to the scapula) of the bowhead whale by means of radiographic examination as an aid in assessing extent of physical maturity.

METHODS

Flippers removed from subsistence harvested bowhead whales were taken to the Naval Arctic Research Laboratory for radiographic examination (Fig 1-3).

RESULTS AND DISCUSSION

As can be seen in TABLE 21-1, all or part of a flipper was examined radiographically (Fig 1-3) for nine bowhead whales and one gray whale. Figures

* Pectoral limb here does not include the scapula as only those structures distal to the scapula are removed as a unit.

21-1 through 21-14 illustrates findings from the radiographic and gross observations made on tissues of the various flippers examined. In addition to radiographic examination, a series of gross measurements were made on two bowhead flippers (TABLES 21-2 and 21-3).

The total number of bones in each of the bowhead flippers examined ranged from 19-24, due to variation in the number of carpals and metacarpals. (TABLE 21-1).

The humerus had well marked proximal and distal epiphyseal plates in physically immature animals (Fig 21-1). When such a whale is butchered and the humerus from each flipper subsequently discarded, each humerus will deteriorate into three sections (proximal epiphysis, shaft and distal epiphysis). While examining areas of beach during the ice free period one can occasionally locate the prominent shaft of a humerus. The proximal epiphysis (Figs 21-3 and 21-4) and distal epiphysis are seldom located.

The radius and ulna each had a well marked proximal epiphyseal plate in physically immature animals.

The carpal number ranged from zero to four with two carpals being seen most often. On animal (80B8) possessed four distinct carpals and one less distinct structute possibly a fifth carpal (Figs 21-10 and 21-11). The significance of such variability must be interpreted with caution as most of these animals were likely quite young and carpal ossification may not have been completed. The finding of two carpal bones in each of the two largest whales examined may indicate that at least for them this was to be the carpal number. There were no carpal bones reported from a small (6.4 m) Greenland right whale (bowhead) captured at Osaka Bay, Japan (Nishiwaki and Kasuya 1970). In a large (13.6 m) Greenland right whale (bowhead) there were five carpal bones (Eschricht and Reinhardt 1866).

The number of metacarpal bones seen was either four or five with the variation due to the presence or absence of the first metacarpal. The shape of the first metacarpal also seemed to differ markedly from that of the other metacarpals (Figs 21-10 and 21-14) and to even vary in shape between individual bowheads (Albert and Philo 1979). Previous reports describe the number of metacarpals as being four (Nishiwaki and Kasuya 1970) or five (Eschricht and Reinhardt 1866, Nishiwaki 1972).

The number of digits present in the examined bowhead material was clearly four, with digits two through five present (Fig 21-14 and TABLE 21-1). The second digit had three phalanges, the third digit four phalanges, the fourth digit three phalanges and the fifth digit two phalanges. The same phalangeal

TABLE 21-1. BONES OF THE FLIPPER AS EXAMINED RADIOGRAPHICALLY IN NINE BOWHEAD WHALES AND ONE GRAY WHALE

Whale Identification	Sex	Whale Length (m)	Carpal Bones	Metacarpal Bones	Digit Two Phalanges	Digit Three Phalanges	Digit Four Phalanges	Digit Five Phalanges	Total Bones in Flipper[a]
78KK2	M	13.3	2	4	3	4	3	2	21
79B1	M	8.7	2	5	3	4	3	2	22
79B2[b]	M	10.2	3	5	-	-	-	2	-
79B3[c]	M	8.3	0	4	3	4	3	2	19
79B4[b]	M	15.2	2	5	3	4	3	2	22
80B1	F	10.9	2	5	3	4	3	2	22
80B2[b,d]	M	10.8	2	-	-	-	-	-	-
80B4[b,d]	M	10.4	1	-	-	-	-	-	-
80B8[e]	M	8.7	4	5	3	4	3	2	24
Gray	F	7.8	5	4	3	5	4	2	26

[a] also includes humerus, radius and ulna in addition to carpal, metacarpal and phalangeal bones

[b] entire flipper not radiographed

[c] no carpal bones were seen radiographically, however, this does not necessarily mean that ossification would not have become evident in the future

[d] only boney remnant of flipper available after flensing (see Fig 20-5)

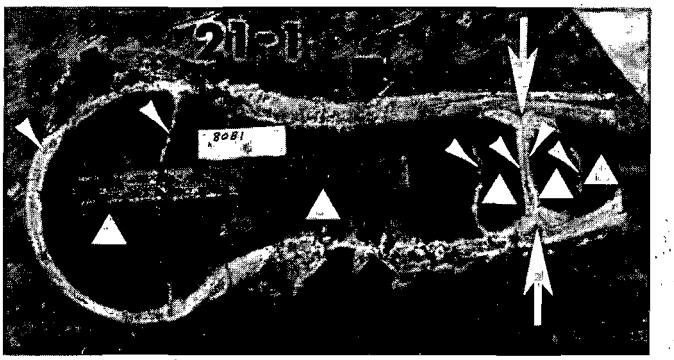
[e] as can be seen in Figs 21-10 & 21-11 there is some evidence that a fifth carpal bone may be forming

Figure 21-1. Humerus of bowhead whale 80B1 cut longitudinally and lying upon piece of plywood. The six small white arrowheads (from left to right) locate the articular cartilage of the head of the humerus, the proximal epiphyseal cartilage of the humerus, the distal epiphyseal cartilage of the humerus, the articular cartilage of the distal surface of the humerus, the articular cartilage of the proximal surface of the radius and the proximal epiphyseal cartilage of the radius. The five white solid triangles locate the proximal epiphysis of the humerus, the diaphysis (shaft) of the humerus, the distal epiphysis of the humerus, the proximal epiphysis of the radius and a portion of the remainder of the radius. The large arrows locate the elbow joint. Note the thick layer of fibrous connective tissue (black arrows) adhered to the shaft of the humerus. Ruler is 30 cm (12 inches). See also Figs 21-2 to 21-4.

Figure 21-2. Radiograph of 1 cm thick longitudinal slab of proximal portion of humerus from bowhead whales 80B2 (on left) and 80B8 (on right). Note that the bone from 80B8 (an Ingutuk) is much denser than that of 80B2. The proximal epiphysis (P) is separated from the metaphysis by the radiographically prominent epiphyseal cartilage or "growth plate" (between solid triangles). The white arrow locates the metal clasp of an identity tag. Note that part of the humeral head (upper left) of 80B2 had been damaged during butchering. See also Figs 21-2, 21-3 and 21-4.

Figure 21-3. Carving utilizing naturally smooth convex articular surface of proximal epiphysis of humerus from an unidentified bowhead whale. Ruler is 30 cm (12 inches). See also Figs 21-1, 21-2 and 21-4.

Figure 21-4. Opposite surface of bone carving from that seen in Fig 21-3. This surface is concave, roughened and was in contact with proximal epiphyseal cartilage of humerus. The specimen was purchased in Point Hope, Alaska. Arrow indicates string used to hang carving.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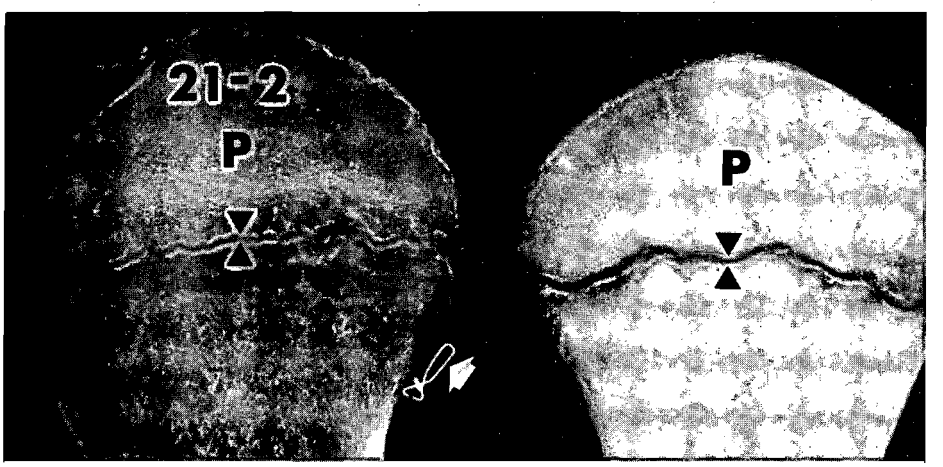
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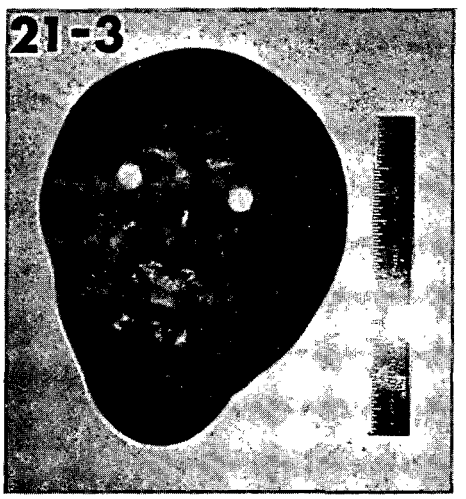
P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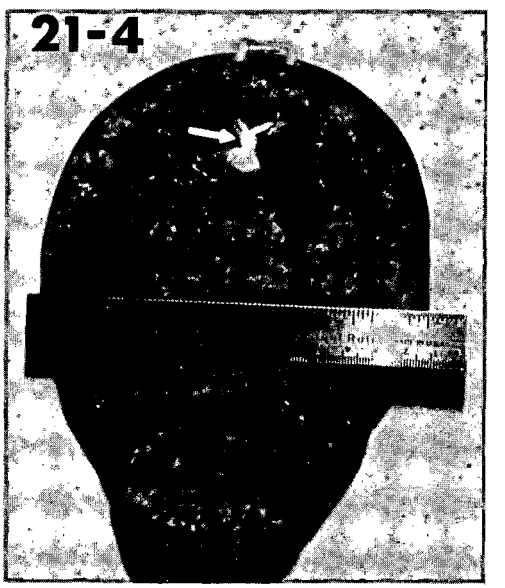
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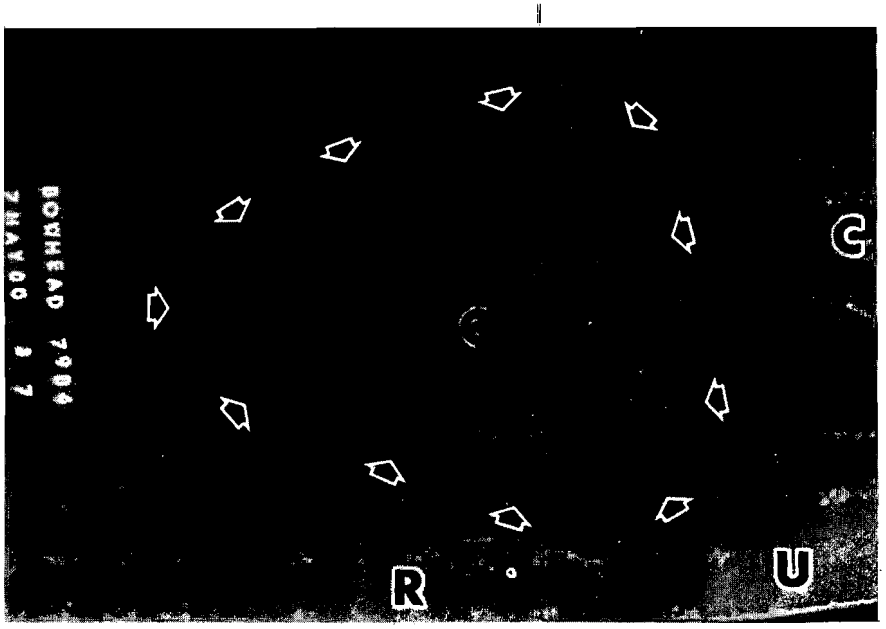


Figure 21-5. Radiograph of a portion of the carpal region of a flipper from bowhead whale 79B4. The bones visible here are a portion of the distal aspect of the radius (R) and ulna (U), an entire carpal bone (C) and a portion of another carpal bone (C). The white arrows delineate cartilage surrounding the carpal bone. The cartilage surrounding this carpal bone is seen to be separate from the cartilage at the distal end of the radius, at the distal end of the ulna (See Fig 21-6) and around the other carpal bone. There are two carpal bones (C) present in this flipper (See TABLE 21-1).

TABLE 21-2. GROSS MEASUREMENTS (cm) OF A FLIPPER OF BOWHEAD WHALE 80B1

Location Along Long Axis[a,b,c]	Thickness[d]	Width [e]
61	21	53
91	18	72
102	-	76*
107	16	75
122	14	70
137	12	58
152	9	38
168	6	20

a distance from most proximal aspect of head of humerus

b total length, 177 cm

c greatest diameter of head of humerus, 25 cm

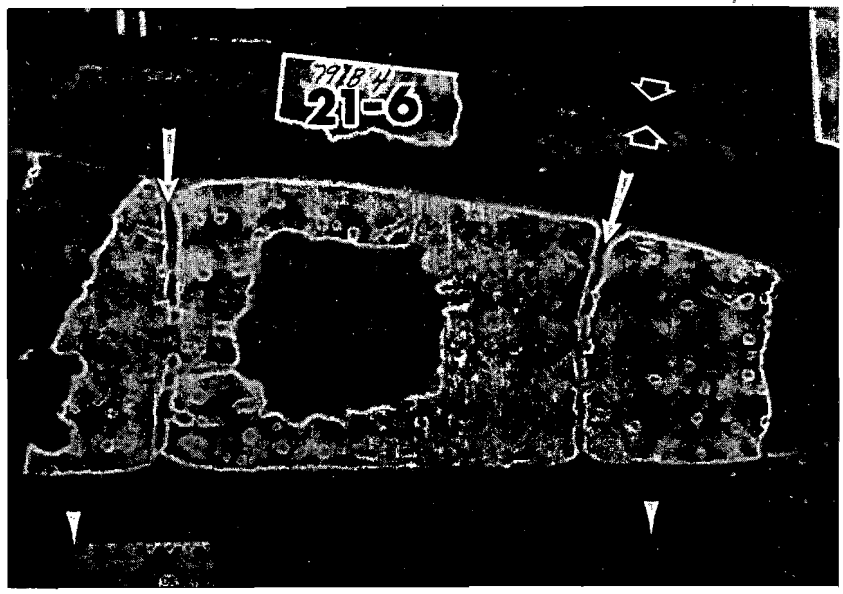
d greatest thickness at indicated site on long axis

e from anterior to posterior surface

* greatest width along entire length

Figure 21-6. Slab of carpal region of flipper of bowhead whale 79B4. The bones visible here are the distal aspect of the ulna (U), a carpal bone (C) and the proximal portion of a metacarpal bone (M). The carpal bone is surrounded by white colored cartilage which seems separated by what appear to be vascular channels (large arrows) from the cartilage on the distal end of the ulna (U) and that on the proximal end of the metacarpal bone (M). The cartilage itself seems penetrated in numerous areas by these channels. The epidermis is located by the open arrows. The ruler (30 cm) is delineated below by the small white arrowheads.

Figure 21-7. Radiograph of slab of carpal region of bowhead whale 79B4 (similar to that seen in Fig 21-6). The bones visible here are the distal aspect of the ulna (U), a carpal bone (C) and the proximal portion of a metacarpal bone (large arrow). The open arrows delineate the cartilage surrounding the carpal bone.


21-6

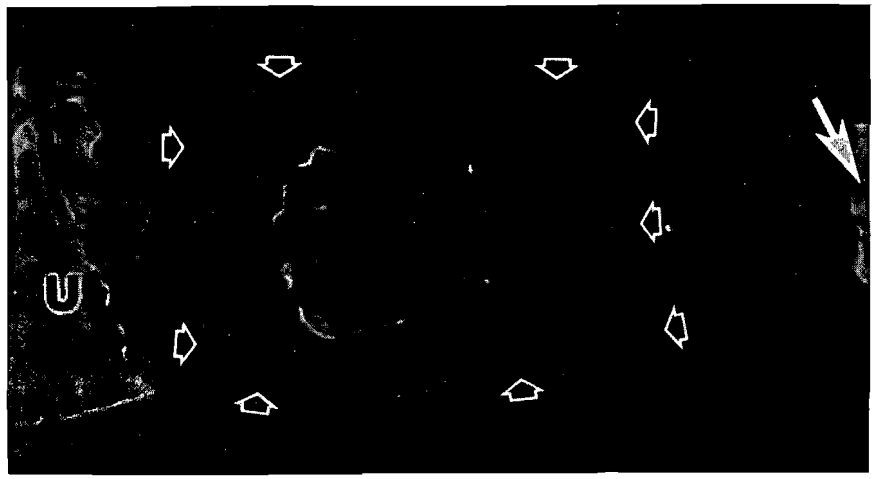
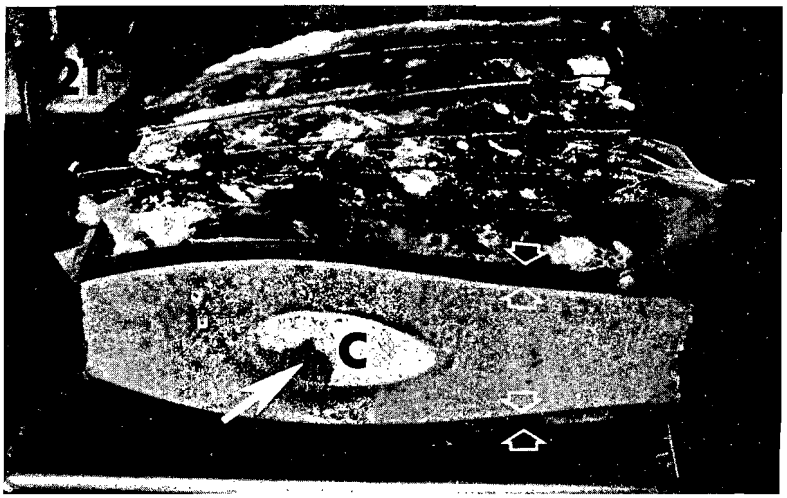


Figure 21-8. A portion of the carpal region of bowhead whale 79B4 cut into six slabs. The nearest slab shows a portion of the first metacarpal bone (large arrow) surrounded by cartilage (C). The epidermis is delineated (open arrows) on dorsal and ventral surfaces.

Figure 21-9. Slab of a portion of phalangeal area of flipper of bowhead whale 79B4. The most distal phalangeal bone (two solid triangles) of this digit has cartilage on distal (1) and proximal (2) surfaces. The more proximal phalangeal bone (single solid triangle) also has a prominent amount of cartilage on its distal surface (3). The cartilages (2, 3) of the phalangeal bones are separated here by a cleft (large arrow). There are numerous channels (black arrows) in the cartilages. The open arrows delineate the epidermis on the dorsal and ventral surfaces of this portion of the flipper. The small arrowheads delineate the ruler (30 cm) beneath the distal phalangeal bone.


C

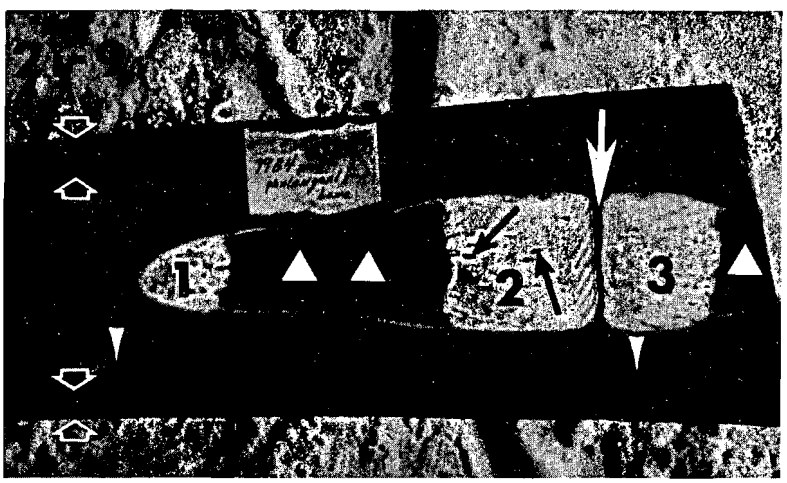
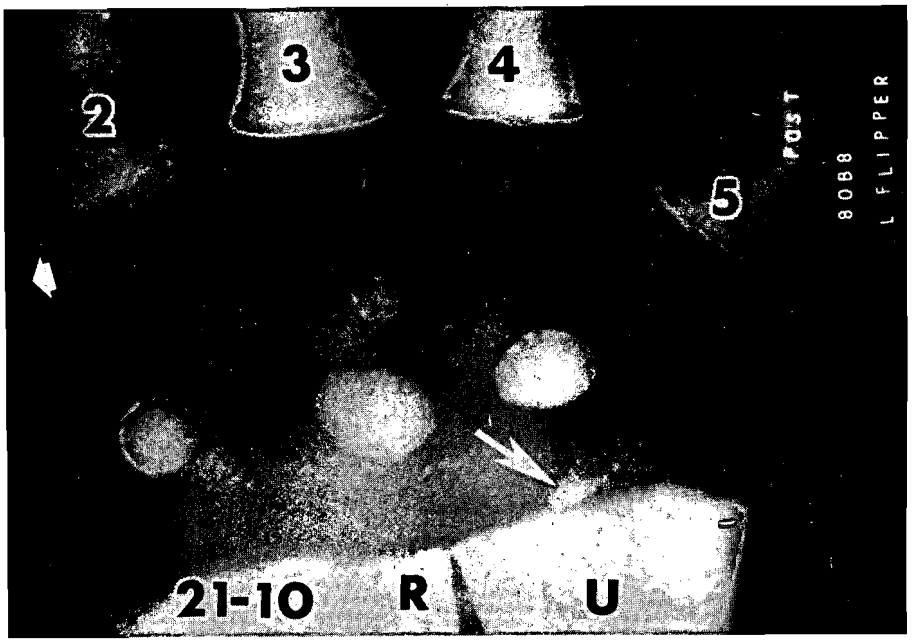

1
2
3

Figure 21-10. Radiograph of carpal region of left flipper from bowhead whale 80B8. The distal portion of the radius (R) and ulna (U) are visible as is a portion of the first metacarpal bone (small arrow) and metacarpal bones two through five (2-5). In the center are four carpal bones, each with a clearly defined border. The large arrow indicates another osseous structure which has a very irregular outline and seems in contact with the distal surface of the ulna.

Figure 21-11. Closer view of a portion of the carpal area seen in Fig 21-10. The radius (R), ulna (U) and carpal bones (C) are indicated. The small (3 cm long) boney structure seen between the arrows has a very irregular outline.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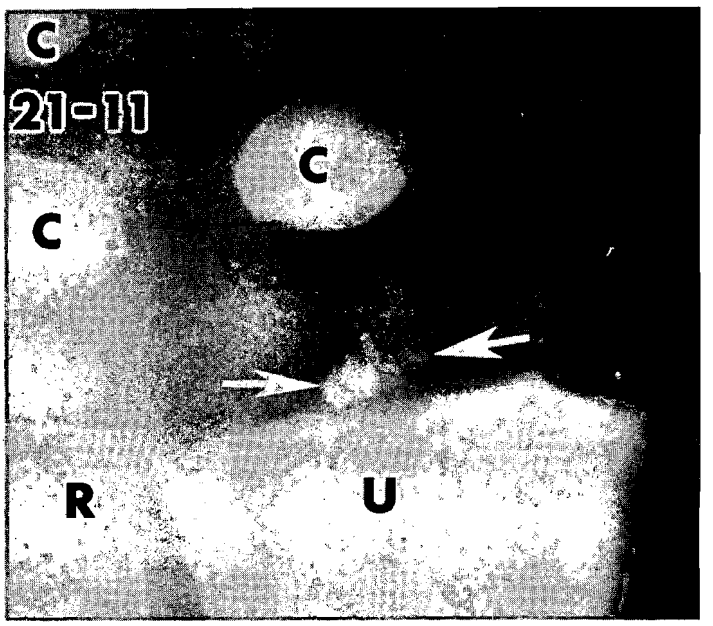
C
21-11
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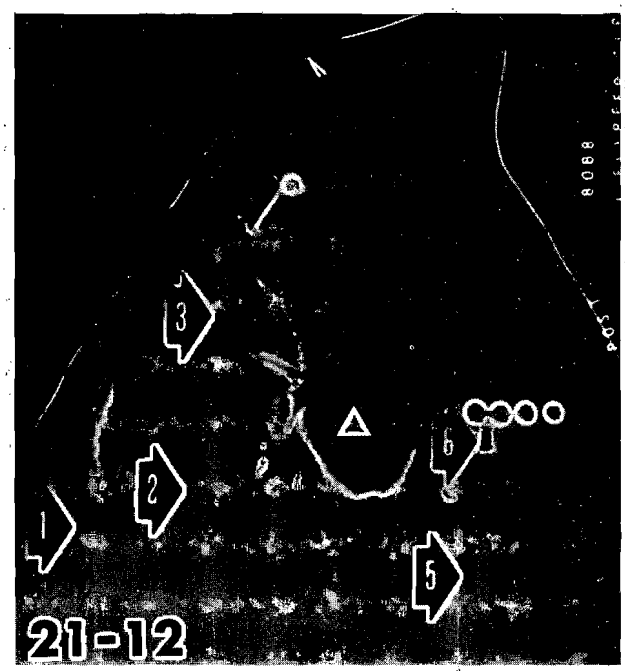
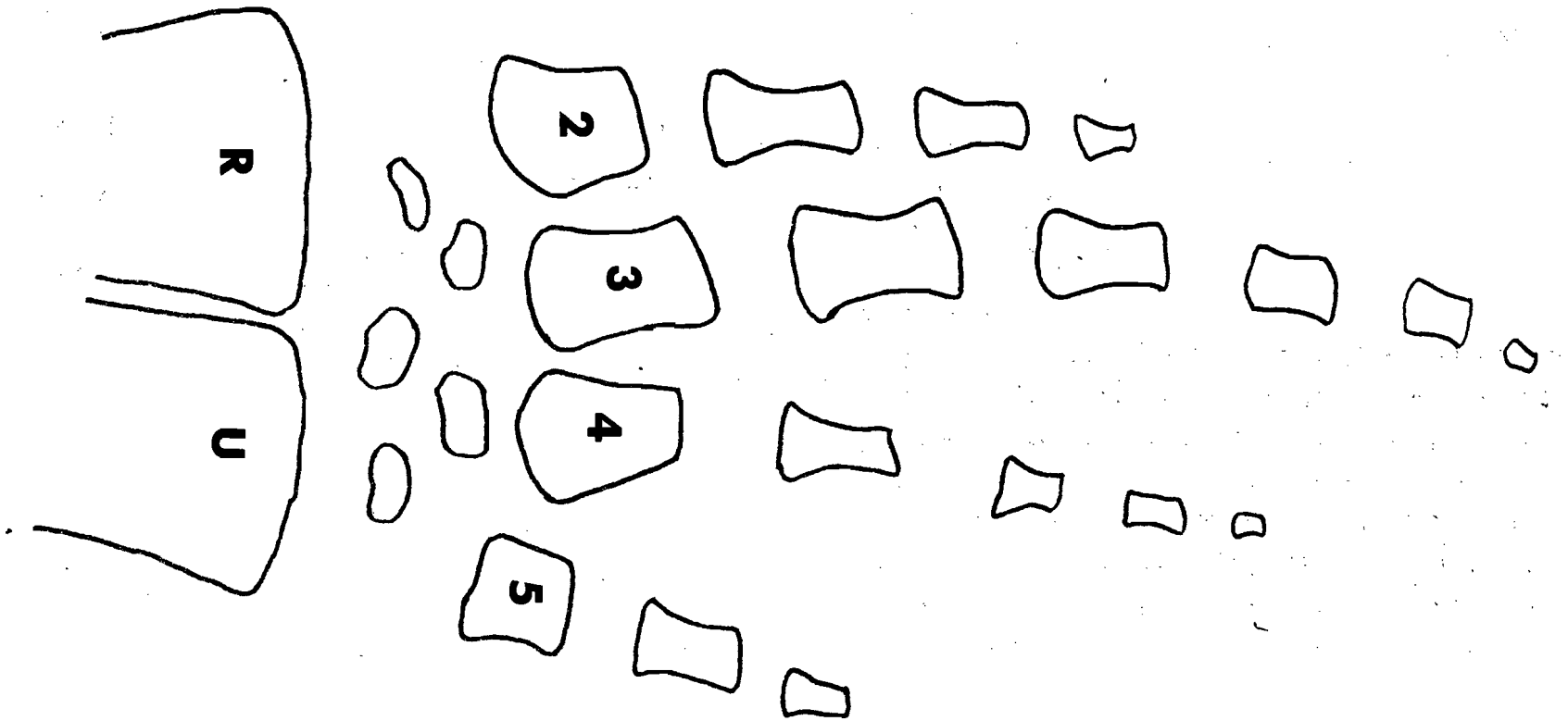


Figure 21-12. Radiograph of the distal portion of the left flipper from bowhead whale 80B8. The border of the flipper is outlined by wire placed there prior to taking radiograph. The phalangeal bones visible are: the third (1) in digit two. the second (2), third (3) and fourth (4) in digit three and the second (5) and third (6) in digit four. The solid white triangle marks the hole cut through the distal part of the flipper for attachment of a rope (see also Figs 1-3 and 1-11). Note the cartilage (radiographically less dense than bone) which is clearly seen (see also Fig 21-9). The four adjacent white circular areas are thumbtacks used as radiographic markers and indicate a site approximately 122 cm distal to the most proximal aspect of the humerus.

Figure 21-13. Representation of bones seen radiographically in the distal portion of a flipper from a stranded gray whale (7.8 m). Note the five carpal bones between the four metacarpal bones (2-5) and the distal portion of the radius (R) and ulna (U). The number of phalangeal bones were three in digit two, five in digit three, four in digit four and two in digit five. Approximate scale 1 cm = 3.5 cm. See also Table 21-1. (Drawing by J. C. George).



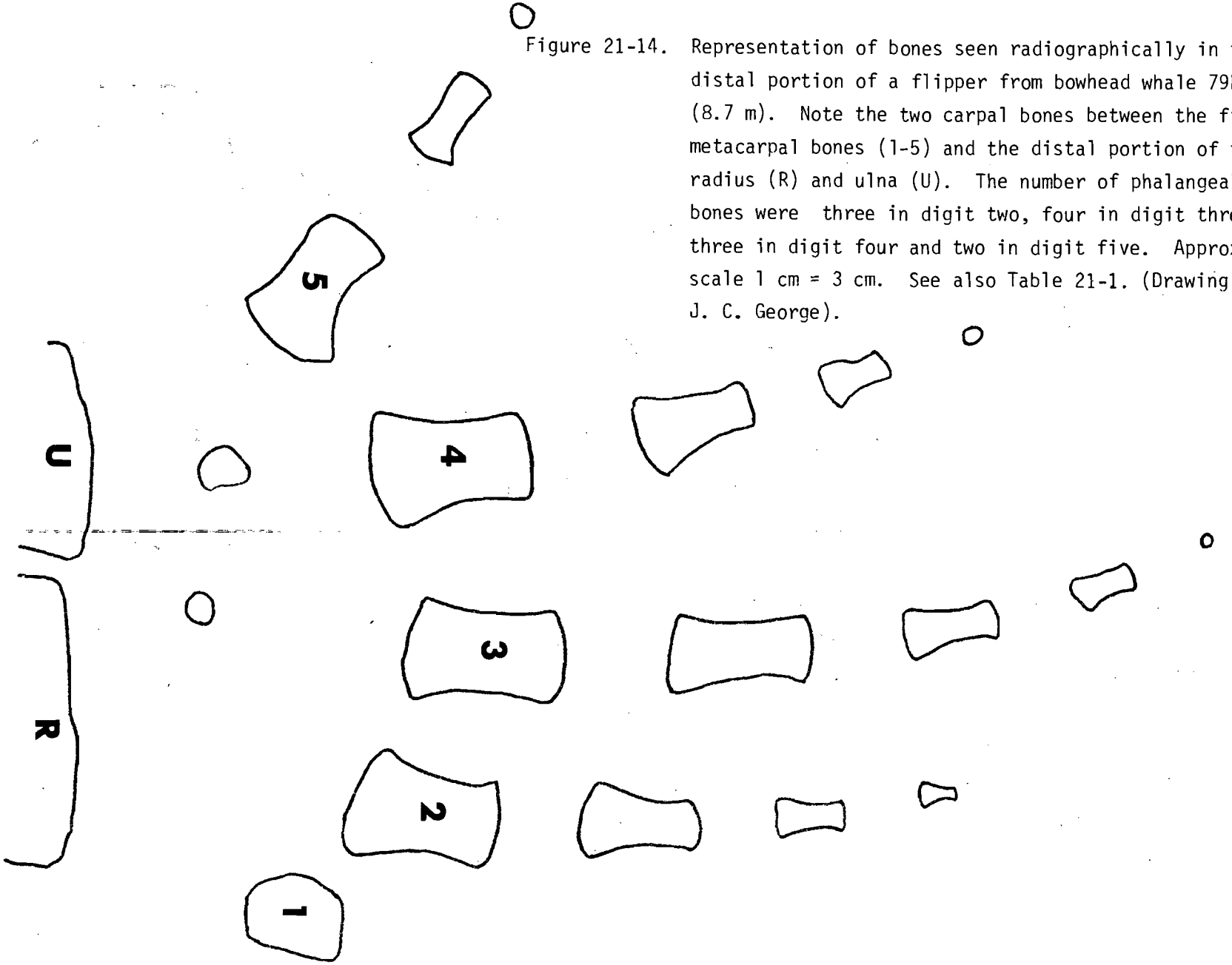


Figure 21-14. Representation of bones seen radiographically in the distal portion of a flipper from bowhead whale 79B1 (8.7 m). Note the two carpal bones between the five metacarpal bones (1-5) and the distal portion of the radius (R) and ulna (U). The number of phalangeal bones were three in digit two, four in digit three, three in digit four and two in digit five. Approximate scale 1 cm = 3 cm. See also Table 21-1. (Drawing by J. C. George).

TABLE 21-3. GROSS MEASUREMENTS (cm) OF A FLIPPER OF BOWHEAD WHALE 80B8

Location Along Long Axis[a,b,c]	Thickness [d]	Circumference
44	-	104
46	19	-
61	17	107
76	16	116
81*	-	121
91	14	119
107	12	95
122	9	69
137	5	-

a distance from most proximal aspect of head of humerus

b total length - approximately 145 cm

c greatest diameter of head of humerus, 20 cm

d greatest thickness at indicated site on long axis

* location on long axis with greatest width (anterior-posterior)

structure of the digits had been reported earlier for a single animal (Eschricht and Reinhardt 1866). In another instance (Nishiwaki and Kasuya 1970) the number of illustrated phalanges was one less for the fourth digit (possibly due to loss of the tiny bone during collection). It was interesting to note that the North Pacific black right whale, Eubalaena glacialis, (Omura et al 1971) has five digits (compared to the bowhead's four) with usually one more phalangeal bone per digit that the bowhead material of the present study. Eschricht and Reinhardt (1866) reported that the Cape whale (apparently Eubalaena glacialis) had one more phalangeal bone per digit than the Greenland right whale they examined.

In an earlier radiographic examination of whale flippers (Albert and Philo 1979) a tissue somewhat less dense (radiographically) than bone was clearly seen between bones within the same digit (similar to that seen in Fig 21-12). In that instance it was not possible to section the flipper to determine the exact nature of the tissue. From the present study (79B4) this tissue was clearly cartilage. The cartilage was white in color, firm and contained what seemed to be numerous vascular channels (Fig 21-6). The channels in the cartilage seemed to be up to 1 mm diameter. The carpal bones in 79B4 are seen to be surrounded by cartilage (Figs 21-5 through 21-7). The metacarpal and phalangeal bones have cartilage on their proximal and distal surfaces (Figs 21-6 through 21-9).

In large bowheads (over 15 m) the intact flipper is so large as to not lend itself to ready examination by radiographic means. In such instances it would be simpler to remove the humerus, cut it and radiograph longitudinal slabs in order to examine the bone for epiphyseal closure.

SUMMARY

Flippers (intact or partial) from nine bowhead whales and one gray whale were examined radiographically. In the bowhead material examined there was variability in the number of carpals and metacarpals and stability of the boney structure of the digits (Fig 21-14). The total number of bones in each of the bowhead flippers ranged from 19-24.

REFERENCES

Albert, T. F. and L. M. Philo. 1979. Tissues (structure/function) (RU-579). In: Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of the Beaufort Sea Lease Area, J. Kelley and G. Laursen (eds.), pp 187-212. Final Report to the Bureau of Land Management from the Naval Arctic Research Laboratory, Barrow, Alaska.

Eschricht, D. F. and J. Reinhardt. 1866. On greenland right whale. In: Recent Memoirs on the Cetacea, W. H. Flower (ed.), pp 1-143. The Ray Society, London.

Nishiwaki, M. 1972. General Biology. In: Mammals of the Sea, Biology and Medicine, S. Ridgway (ed.), pp 3-204. Charles C. Thomas Co.

Nishiwaki, M. and T. Kasuya. 1970. A greenland right whale caught at Osaka Bay. Sci. Rep. Whales Res. Inst. No. 22:45-62.

Omura, H., M. Nishiwaki and T. Kasuya. 1971. Further studies on two skeletons of the black right whale in the North Pacific. Sci. Rep. Whales Res. Inst. No. 23:71-81.

APPENDIX VII

STATEMENT OF WORK
TISSUE ANALYSIS OF
ENDANGERED WHALES IN THE BEAUFORT SEA

I. Background

In 1953 the Outer Continental Shelf (OCS) Lands Act (67 Stat. 462) was passed establishing Federal Jurisdiction over the submerged lands of the continental shelf seaward of state boundaries. The Act charged the Secretary of the Interior with the responsibility of the administration of the mineral exploration and development of the OCS. It also empowered the Secretary to formulate regulations so that the provisions of the Act might be met.

Subsequent to the passage of the OCS Lands Act of 1953, the Secretary of the Interior designated the Bureau of Land Management (BLM) as the administrative agency for leasing submerged Federal lands, and the Geological Survey for supervising production.

The National Environmental Policy Act of 1969 requires that all Federal agencies shall utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences in any planning and decisionmaking which may have an impact on man's environment. The BLM efforts in this direction are Environmental Impact Statements (EIS), Environmental Assessment teams, marine environmental data acquisition and analysis studies, literature surveys, socioeconomic analysis studies, public conferences, and special studies (toxicity studies, spill trajectory analysis, etc.).

The Marine Mammal Protection Act (MMPA) of 1972 (16 U.S.C. 1361-1407) recognized that certain species and populations of marine mammals are, or may be, in danger of extinction or depletion as a result of man's activities and establishes a national policy that marine mammal populations should be protected and encouraged to develop to the greatest extent feasible, commensurate with sound policies of resource management. The Secretaries of Interior and Commerce are charged with all responsibility, authority, funding, and duties under the Act.

The Endangered Species Act of 1973 as amended in 1978, provides for the conservation of all animal and plant species that are determined to be endangered or threatened. The Act required that all major Federal actions do not jeopardize the continued existence of endangered species and threatened species or result in the destruction or modification of their habitats determined to be critical.

OCS Lands Act Amendments of 1978 (92 Stat. 629) were passed establishing "a policy for the management of oil and natural gas in the Outer Continental Shelf," and for protecting "the marine and coastal environment." The Amendments authorize the Secretary of the Interior to conduct studies in areas or regions of lease sales to ascertain the "environmental impacts on the marine, and coastal environments of the Outer Continental Shelf and the coastal areas which may be affected by oil and gas development" (43 U.S.C. 1346).

The BLM has four priority goals for OCS leasing; these are 1) orderly resource development to meet the Nation's energy needs; 2) protection of the marine and coastal environments; 3) receipt of fair market value; and 4) preservation of free enterprise competition.

II. Purpose of the Procurement

The purpose of this procurement is to acquire information that can be used as a basis for detecting physical or physiological changes in bowhead or gray whales that may be caused by activities or events associated with oil and gas development in the Beaufort Sea.

III. Objectives of the Procurement

1. Determine the morphology of the bowhead, Ingutuk and gray whales and to the extent possible the function of tissues and organs that have a high probability of being affected by oil or other contaminants to provide a basis for detecting and monitoring changes that may occur and be caused by activities and events associated with offshore oil and gas development in the Beaufort Sea.

2. Identify present microbiological (viruses, bacteria, and antibodies in the blood) and parasitological burdens, tissue pollutant levels,

dietary habits (from ingested material) and incidence of pathology to provide a basis for detecting and monitoring changes in whales that may occur as a result of OCS oil and gas activities.

3. Gather biologic information which may resolve the question of whether the Ingutuk whale is a separate species or morphological variant of the bowhead whale.

4. Determine the incidence of whales stranded on shores in the vicinity of the proposed Beaufort Sea lease area to provide a basis for detecting and monitoring changes that may occur and be caused by activities and events associated with OCS oil and gas activities.

5. Satisfy the requirements of the Endangered Species Act, Section 7 consultation (June 1978) between BLM and the National Marine Fisheries Service.

6. Implement BLM's multi-year whale research plan for the Beaufort Sea which was developed during an interagency workshop in August 1979.

IV. Description of the Work

Task 1: The contractor shall obtain tissue samples from individual bowhead and gray whales. The tissue samples shall be from whales that have been harvested by Eskimo hunters or whales that have been stranded. At a minimum the contractor shall obtain samples of the following tissues: visual apparatus, digestive tract, reproductive tract, skin, respiratory structures and blood.

Task 2: Establish a mechanism (in cooperation with NMFS) for obtaining required whale tissue from Eskimo hunters. The coordination shall take place under an existing memorandum of understanding between BLM and NMFS.

Task 3: Examine the tissues and organs collected so as to achieve the objectives listed above.

Task 4: Store, or make arrangements for storing, tissue samples for future analysis, should it ever be suggested that tissue levels of pollutants are changing because of activities or events associated with offshore oil and gas development.

Task 5: Collect and deliver samples of baleen to other investigators as directed by BLM.

Task 6: BLM has an existing interagency agreement with the Naval Ocean Systems Center (NOSC) for aircraft support. The contractor shall coordinate the use of this aircraft for sighting stranded whales.

Task 7: The contractor shall conduct this study under the provisions and restrictions set forth in the BLM permit to study endangered whales in Alaskan waters.

V. Period of Performance

The period of performance for this study is from April 1, 1980 to March 1, 1981.

VI. Delivery Schedule

1. The Contractor shall deliver the following products:
   - A progress report discussing the results of the spring whale migration. The progress report shall be delivered to BLM on or before August 15, 1980.
   - A draft final report for the entire study. This report shall be delivered to BLM by January 16, 1981. BLM shall review the draft final report and submit comments to the contractor by February 28, 1981.
   - A final report for the entire study incorporating the BLM review comments when appropriate. The final report shall be delivered to BLM by March 31, 1981.

2. The contractor shall deliver five (5) copies of all reports to:

   Mr. Robert Hansen
   Contracting Officer
   Bureau of Land Management
   Code 851
   18th & C Streets, NW
   Washington, D. C. 20240

VII. Contract Administration

Contracting Officer's Authorized Representative (COAR). Dr. Byron Morris, Alaska OCS is designated as the Contracting Officer's Authorized Representative for the purpose of administering the technical aspects of this contract and inspecting the Contractor's work for compliance with the work statement, delivery requirements, and specifications. The COAR is authorized to clarify technical requirements, and to review and approve work which is clearly within the scope of work. He is not authorized to issue changes pursuant to the changes clause or to in any other way modify the scope of work.

APPENDIX VIII

Publications as of August 1981

Migaki, G. and T. F. Albert. Lipoma in the liver of a bowhead whale. Vet. Path. In Press.

Papers Presented at National and International Meetings as of August 1981

Abdelbaki, Y., W. Henk, J. Haldiman, R. Henry, D. Duffield, F. Al-Bagdadi and T. F. Albert. Observations on the kidney of the bowhead whale.
Presented at: Annual Meeting of The American Veterinary Medical Association (July 1981).
Abstract: Zbl. Vet. Med. C. Anot. Histol. Embryol. In Press.

Al-Bagdadi, F., W. Henk, J. Haldiman, R. Henry, Y. Abdelbaki, D. Duffield and T. F. Albert. Regional observations on bowhead whale skin.
Presented at: Annual Meeting of The American Veterinary Medicine Association (July 1981).
Abstract: Zbl. Vet. Med. C. Anot. Histol. Embryol. In Press.

Albert, T. F. Collection of tissue specimens from Eskimo harvested bowhead whales, Balaena mysticetus.
Presented at: Twelfth Annual Conference of the International Association for Aquatic Animal Medicine (May 1981).

Duffield, D., Y, Abdelbaki, F. Al-Bagdadi, J. Haldiman, W. Henk, and T. F. Albert. Gross anatomy of the brain of bowhead whales.
Presented at: Annual Meeting of The American Veterinary Medical Association (July 1981).
Abstract: Zbl. Vet. Med. C. Anot. Histol. Embryol. In Press.

Haldiman, J., R. Henry, W. Henk, Y. Abdelbaki, F. Al-Bagdadi, D. Duffield and T. F. Albert. Microanatomy of the respiratory system of the bowhead whale.
Presented at: Annual Meeting of The American Veterinary Medical Association (July 1981).
Abstract: Zbl. Vet. Med. C. Anot. Histo,. Embryol. In Press.

Henry, R., J. Haldiman, Y Abdelbaki, F. Al-Bagdadi, D. Duffield, W. Henk, and T. F. Albert. Gross anatomy of the respiratory system of the bowhead whale.
Presented at: Annaul Meeting of The American Veterinary Medical Association (July 1981).
Abstract: Zbl. Vet. Med. C. Anat. Histol. Embryol. In Press.

Tarpley, R., R. Sis and T. F. Albert. Stomach structure of the bowhead whale. Presented at: Twelfth Annual Conference of the International Association for Aquatic Animal Medicine (May 1981).

APPENDIX IX

SOME THOUGHTS REGARDING THE POSSIBLE EFFECTS OF OIL CONTAMINATION ON BOWHEAD WHALES, BALAENA MYSTICETUS*

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Bowhead whales, during much of the northward migration, utilize leads (open water areas) existing within the shifting ice pack. This use of the lead system is particularly important to the bowhead at least as far north as Point Barrow (Braham et al. 1980). If a segment of a typical lead were contaminated over much of its surface with spilled oil, the bowheads utilizing such a lead would be at high risk of oil contact.

Let us consider a scenario with the following assumptions. These assumptions are formulated to describe a situation which may lead to high probability of contact between bowhead whales and oil.

ASSUMPTIONS

1. Bowhead whales will be moving north in a nearshore lead during spring.
2. The lead will range from 1-3 km in width.
3. Recently spilled oil will cover much of the water surface for several km. Some dispersed oil is in the water column.

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*Please note that the thoughts presented here represent the views of the author based upon our studies of the bowhead. The views presented do not necessarily reflect those of the Bureau of Land Management or of any other agency of the U.S. Government. Literature reviewed through June 1981.

PROBABLE RESULTS

When faced with such a scenario the most likely options available to the whales would include: 1) turn back (where would they go?); 2) try to find another lead or attempt to utilize the small irregularly spaced open areas within the ice cover (they may also be contaminated, or may be too far away); 3) continue up the lead in a more or less normal manner until they have passed the slick; 4) continue up the lead but staying submerged for as long as possible.

If either option 3 or 4 are chosen, there will be contamination of the animals. The effects will obviously depend upon: 1) the extent of contact, 2) the duration of contact, 3) the composition of the oil (as influenced by how much "weathering" of the oil has occurred).

It is likely that those areas of the skin which come above the surface during breathing will be repeatedly contaminated. The remainder of the skin and the eyes are likely to be contacted by dissolved components (and "globules") in the water column.

Whether or not the bowhead would maneuver to avoid the oil is an open question. It is well known that odontocetes (toothed whales) possess an echolocating ability (Norris 1969) while mysticetes (baleen whales) apparently do not (Beamish 1977). There is no evidence that odontocetes are able to use their echolocating ability to detect oil fouled waters.

On the other hand there is evidence that some marine animals do not necessarily avoid oil fouled water (seals, Spooner 1967; sea otter, Williams 1978; polar bear, Oritsland et al. 1981; whales, Goodale et al. 1981).

Possible Effects on Eyes. There is little doubt that irritation will occur. Ocular irritation was noted in a laboratory study involving ringed seals, Phoca hispida, immersed in crude oil covered water (Geraci and Smith 1976).

The fact that the bowhead cornea is thinnest at its center, and is in essentially direct contact with the water (and whatever is dissolved in it) makes it of particular interest. A corneal irritant can result in corneal inflammation with opacity (and therefore reduced vision) and/or corneal ulceration with possible

perforation (and thereby blindness). Conjunctival irritation in animals commonly leads to "squinting" and thereby reduced vision. Since the conjunctival sac is so extensive in the bowhead, a conjunctivitis would also likely reduce eye mobility as the animal seeks to reduce the pain associated with moving inflammed conjunctival surfaces which are in contact with each other.

Possible Effects of Oil Contact on Skin. There is as yet no experimental evidence of the effect of spilled oil upon cetacean skin. There is evidence however of the ability of petroleum products to irritate the skin of laboratory animals (Am. Pet. Inst. 1980) Since the skin of cetaceans does not possess the thick layer of cornified epithelial cells (RU 1380 this report) which is common to the skin of other mammals it seems reasonable to speculate that cetacean skin may respond to irritants such as crude oil in a manner approaching sensitive mucous membranes (Geraci and St. Aubin 1980).

It is not known whether spilled oil will adhere to the skin of a free ranging cetacean. In a preliminary study (RU 1380 this report) it was shown that crude oil will adhere to preserved bowhead whale skin, particularly roughened areas of skin. Although cetacean skin is generally regarded as being very smooth there are at least three exceptions to this. Much of the skin surface of the gray whale is covered with barnacles, the right whale has prominent rostral callosities, and the bowhead has many small eroded areas on its skin surface. Therefore, the skin of at least these three whales does exhibit localized areas of roughness.

In all of the bowhead whales (13) examined by me, there have been dozens to hundreds of small (1-3 cm diameter) eroded areas on the skin surface, particularly the head (RU 1380 this report). These skin lesions have been described as (RU 780, RU 1380 this report) localized areas of epidermatitis and are characterized by a very rough surface, usually some erosion, and by the presence of large numbers of bacteria and diatoms. In many of these eroded areas, blood vessels (capillaries) are just beneath the surface (RU 1380 this report). These eroded areas provide a microhabitat

for many bacteria and diatoms (RU 1380 this report). As the whale swims oil might adhere to this rough surface (as it did on preserved skin, RU 1380 this report) or it might just be "washed away" by the water. If the oil were to stick to these rough areas the following consequences are possible: 1) resident bacteria could be negatively affected by the oil and possibly die, 2) resident bacteria could remain unaffected and maintain present numbers, 3) the bacterial microhabitat could be affected so as to lead to an increase in numbers! Under normal circumstances the water rushing by may serve to help limit the numbers of bacteria in these lesions. With an "oil cover", the microhabitat may be protected and allow for great increases in bacterial numbers. If any of the bacteria present in these lesions are pathogenic or potentially pathogenic and flourish as a result of oil contact, then the stage is set for increased skin irritation. This could lead to further skin damage and possible ulcer formation, with associated localized inflammation. The direct action of the oil as an irritant could also lead to additional damage to the areas of eroded epithelium. Either instance might result in bacteria entering the blood at this site and/or enhanced absorption of petroleum components. If such a sequence were to occur so that these hundreds of sites were to become areas of acute inflammation the whale might develop (over a period of days or even weeks) a severe inflammation of the skin.

What would be the effect of this on the control of skin blood flow associated with thermoregulation? A partial answer to this question may be provided by a study involving polar bears exposed to crude oil in which case the affected areas of the bears' skin underwent vasodilation (apparently due to irritant effect of oil) with the subsequent loss of much body heat (Oritsland et al. 1981).

Possible Behavioral Effects Related to Oil Contact with Tactile Hairs. The bowhead has tactile hairs around the blowhole, distal area of upper jaw, and on either side of the lower jaw. These hairs are clearly sensory structures (RU 1380 this report). In a preliminary trial (RU 1380 this report) spilled oil did adhere to them. If oil initially adheres to the hairs, it may be washed away by the passing water. If the oil is not washed away,

then one might expect their function to be altered. The hairs near the blowhole may provide a sensory means for the whale to detect when the blowhole area is above the water surface. If this were their role and if no parallel sensory capacity exists their unaltered function is indeed critical to survival. The functions of the tactile hairs on the upper and lower jaws are not known, however, such functions could include prey item detection and/or detection of rate of movement through the water. It is not unreasonable to speculate that, if oil adheres to the tactile hairs and/or fills the cone-shaped depressions in the skin from which they emerge, the sensory capability of the animal will be compromised.

Possible Physiological Effects on Respiratory System. If the whale were repeatedly coming up through oil to breathe, oil may adhere within the blowhole slits or around them. When the animal exhales it is likely that most if not all would be "blown away" by the forceful exhalation and it is not likely that oil would clog the blowhole (Geraci and St. Aubin 1980). When the animal inhales, the rush of air could dislodge any adhered oil droplets and carry them into the respiratory tract. Since the animal is inhaling air just above the oil covered water's surface it is reasonable to expect it to inhale some of the more volatile compounds as they evaporate. The repeated inhalation of oil droplets and/or oil fumes is likely at the very least, to lead to some lung irritation. Since there is very little lymphoimmune tissue associated with the lungs (RU 480, RU 1380 this report) and there are pathogenic and potentially pathogenic bacteria already in the respiratory tract (RU 1180 this report) any such respiratory irritation could prove to be a threat to the animal.

Possible Effects on Digestive System. In this scenario it is not likely that the whales will be feeding as there is no firm evidence that bowheads regularly feed when actively migrating northward along the northwest coast of Alaska. But let us digress from the initial assumptions and assume that a bowhead

is feeding in the summer or early fall in an area "lightly" fouled by oil. If the animal were taking in some oil along with prey items, some of the oil would surely be swallowed. In the mouth the oil would have the opportunity to foul the baleen and reduce its filtering efficiency (Braithwaite 1980). While in the mouth it would also be able to contact (possibly occlude) the mucosal extremity of Jacobson's organ, a structure whose function in the bowhead is not known but could possibly serve as a chemoreceptor for detection of concentrations of prey items or play a role in assessing the reproductive status of another bowhead (Johns 1980). The direct effect of ingested oil on the whale's digestive tract mucosa is not known, however, it is not likely to be a beneficial one. One effect might be the coating of the mucosal lining by insoluble emulsified oil fractions. Such a coating might block or retard the secretion of mucosal glands. With much of the bowhead's lymphoimmune tissue associated with the gut, any absorbed toxicant might be detrimental to this tissue. Any compromising of the lymphoimmune system will result in decreased disease resistance. Another "problem" could arise from the inadvertant engulfment of tar balls or large "blobs" of oil, along with prey items. If such globular material would not liquefy due to body heat and/or digestive acids and enzymes, it might well cause a mechanical blockage in the stomach at the connecting channel. The connecting channel (RU 1480 this report) is quite narrow and is that part of the stomach that serves to connect the fundic chamber with the pyloric chamber. Mechanical blockage could result from the swallowing of broken off baleen "hairs" which have matted together into small "balls" due to the oil.

SUMMARY

It is my opinion that a significant recent oil spill covering a significant area of a lead (or leads) through which bowheads are migrating may pose the gravest of threats to the bowhead whale. Widespread contamination of the near shore lead during the spring migration will put nearly the entire stock at risk, since it is felt that most bowheads utilize the same lead

system. Whales encountering a significant oil spill in a lead, will not be able to "swim around it" unless there are other nearby open areas in the ice cover. With the "call" to migrate drawing them northward it is not likely that they will turn back.

In the laboratory it was shown that oil will adhere to roughened areas of preserved bowhead skin. Such areas include: 1) the hundreds of small eroded areas particularly common on the head, 2) the tactile hairs, 3) the conical depressions in the skin from which the tactile hairs emerge.

The most likely immediate effect would be on the animal's senses, namely, vision and tactile information provided by hairs. Damage to the eyes is likely to include a conjunctivitis and an inflammation of the cornea.

Another effect might include irritation of the skin, particularly involving areas with existing erosions of the skin surface. Such sites might provide an avenue for entry of bacteria into the blood stream and such skin damage could have an effect on the animal's ability to manipulate skin blood flow in response to thermoregulatory needs.

Other significant effects could include: the development of a bronchitis or pneumonia from inhaled irritants (combined with resident pathogenic microbes), direct damage to gut associated lymphoimmune tissue (and thereby lowered resistance to disease), and the formation of a mechanical blockage in the stomach and/or small intestine due to ingestion of tar balls and/or matted baleen hairs.

REFERENCES

American Petroleum Institute. 1980. Acute toxicity test- #6 heavy fuel oil. American Petroleum Institute Report, No. 78-6.

Beamish, P. 1977. Evidence that a captive whale (Megaptera novaeangliae) does not use sonar. Deep Sea Res. 25: 469-472

Braham, H., M.Fraker and B. Krogman. 1980. Spring migration of the western arctic population of bowhead whales. Marine Fisheries Review, 42: 36-46.

Braithwaite, L. 1980. The effects of oil on feeding mechanism of the bowhead whale . In: Proceedings of Interagency Meeting to Review, Coordinate, and Plan Bowhead Whale Research, Other Cetacean Research, and Related Research Bearing Upon the Conservation and Protection of Endangered Marine Species in Alaska and Elsewhere. T. Sullivan (ed.) Meeting held at NMFS in Seattle, WA. Nov. 12-14, 1980.

Geraci, J. and T. Smith. 1976. Direct and indirect effects of oil on ringed seals (Phoca hispida) of the Beaufort Sea. J. Fish. Res. Board Can. 33: 1976-1984.

Geraci, J. and D. St. Aubin, 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Marine Fisheries Review. 42: 1-12.

Goodale, D., M. Hyman and H. Winn. 1981. Cetacean responses in association with the Regal Sword oil spill. In: A Charaterization of Marine Mammals and Turtles in the Mid- and North-Atlantic Areas of the U.S. Outer Continental Shelf. R. Edel, M. Hyman and M. Tyrrell (eds.). Report to Bureau of Land Management from the University of Rhode Island.

Johns, M. 1980. The role of the vomeronasal system in mammalian reproductive physiology. In: Chemical Signals. D. Muller-Schwarze and R. Silverstein (eds.) Plenum, New York.

Norris, K. 1969. The echolocation of marine animals. In: The Biology of Marine Mammals. H. Anderson (ed.) Academic Press, New York.

Oritsland, N., F. Engelhardt, D. Juck, R. Hurst and P. Watts. 1981. Effects of Crude Oil on Polar Bears. F. Engelhardt (ed.). Dept. of Indian Affairs and Northern Development. Canada Publ. No. QS-8283-020-EE-A1 (In Press).

Spooner, M. 1967. Biological effects of the "Torrey Canyon" disaster. J. Devon Trust Nat. Conser. 1967 Suppl: 12-19.

Williams, T. 1978. Chemical immobilization, baseline parameters and oil contamination in the sea otter. Marine Mammal Commission Rep. No. MMC-77/06. Washington, D.C.