1968

Comparative Gross and Histologic Anatomy of the Gastrointestinal Tract of Pronghorn Antelope and Domestic Sheep

James A. Raney

COMPARATIVE GROSS AND HISTOLOGIC ANATOMY OF THE GASTROINTESTINAL TRACT OF PRONGHORN ANTELOPE AND DOMESTIC SHEEP

BY

JAMES A. RANEY

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Zoology, South Dakota
State University

1968

COMPARATIVE GROSS AND HISTOLOGIC ANATOMY OF THE GASTROINTESTINAL TRACT OF PRONGHORN ANTELOPE AND DOMESTIC SHEEP

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser / Date

Head, Entomology-Zoology Department Date

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Miss Nelle A. Hartwig, Professor of Entomology-Zoology, for her invaluable advice and encouragement throughout the investigation and preparation of this thesis. To several other individuals who have graciously contributed to this study I wish to express my thanks:

To the Department of Entomology-Zoology, South Dakota State University, who provided the necessary funds and laboratory equipment.

To Gary A. Thibodeau, Instructor of Entomology-Zoology, for his suggestions throughout this study.

To Dr. W. Lee Tucker, College Statistician, for his technical counsel and assistance concerning statistical procedures.

To the John Morrell Meat Packing Company, Sioux Falls, South Dakota for their cooperation in supplying visceral samples used in this study.

To my wife, Joan, for her continued encouragement and confidence in my ability throughout the completion of this thesis.

JAR

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

INTRODUCTION

The relationship between the domesticated sheep, Ovis aries, and the pronghorn antelope, Antilocapra americana americana, is close enough to validate a comparative gastrointestinal tract analysis (Table 1). This analysis is intended to compare and describe the various parts of the gastrointestinal tract of each species in the order of their occurrence from the esophagus through the rectum.

Due to its deciduous horns the pronghorn antelope has been separated into a single family, Antilocapridae. The genus Antilocapra is the only living genus of the family Antilocapridae. The genus name Antilocapra was compounded by Ord, in 1815, out of Latin antilope, an Antelope, and Capra, a goat (Seton, 1929).

A total of four subspecies of antelope has been described. A brief description of each subspecie will be of assistance in understanding the particular subspecies used in this study. Of the four subspecies, two originated in the United States and two in Mexico. Antilocapra americana americana (Ord) 1815 is the most common subspecies in the United States and is the type found in South Dakota. Antilocapra americana americana was used in this study. Antilocapra americana oregona Bailey, 1932 is located in the Hart Mountains of Oregon (Hall, 1946). Antilocapra americana mexicana Merriam, 1901, a pole breed, is found in Chihuahua, Mexico (Seton, 1929). Antilocapra americana peninsularis (Nelsen, 1912) is much like the subspecies americana, but with darker face-markings and a dark band joining tail

Table 1. Outline showing the basic position of the domesticated sheep and the pronghorn antelope in the zoological scheme.

Kingdom - Animalia	
Phylum - Chordata	
Class - Mammalia	
Order - Artiodactyla	
Suborder - Ruminantia	
Family - Bovidae	
Genus - *Ovis*	
Species - *aries*	
Ovis aries - Domesticated sheep	
Kingdom - Animalia	
Phylum - Chordata	
Class - Mammalia	
Order - Artiodactyla	
Suborder - Ruminantia	
Family - Antilocapridae	
Genus - *Antilocapra*	
Species - *americana*	
Subspecies - *americana*	
Antilocapra americana americana - Pronghorn antelope	
Subspecies - *oregona*	
Subspecies - *mexicana*	
Subspecies - *peninsularis*	

and back. These subspecies are located 45 miles south of Calmalli, Mexico (Seton, 1929).

Throughout this study both species will be referred to by their common rather than scientific names.

The pronghorn antelope and the sheep are similar in that the family Antilocapridae and the family Bovidae both have the presence of a gall bladder and a completely developed four chambered stomach. The difference in the two families is distinguished by the fact that the family Antilocapridae is the family of ruminants containing a single species, the pronghorn antelope. Therefore the characteristics of the animal are the characteristics of the genus and of the family. Also this family includes branched horns, present in both sexes, that are shed annually. The unbranched horn cores are not shed; thus they are called pronghorn (Cockrum, 1962). In the family Bovidae the horns do not shed and are paired, unbranched, and composed of keratin which grows out slowly and continuously from the base of projecting bony corelike prolongations of the frontal bones (Pennak, 1964).

Very little work has been done or published on the anatomy, much less the histological anatomy, of our game species. With this in mind, and so that the gross and histologic anatomy of the gastro-intestinal tract can be better understood, a study of the gastro-intestinal tract was suggested to the author by Dr. R. N. Swanson, Department of Entomology-Zoology, South Dakota State University.

An attempt was made in this study to compare the gastrointestinal tract of the sheep and the pronghorn antelope, using the sheep as a guide because of its similarity and availability.

The purpose of this study is not to prove any anatomical differences, but to compare the gastrointestinal tract of the two species. This comparison is to show correlation between species, with emphasis on pronghorn antelope because of lack of information on wild game ruminants.

LITERATURE REVIEW

Limited material has been published on gross and histologic anatomy of the gastrointestinal tract of the sheep. A careful literature search has revealed a lack of work done on gross and histologic anatomy on either domestic or wild ruminants. Many references were found in regard to physiological and biochemical aspects of most of the studied segments of the gastrointestinal tract of domestic ruminants. No material was found on histologic anatomy, and very little on gross anatomy of wild ruminants gastrointestinal tracts.

Esophagus

The esophagus of sheep has a lumen of about 2.5 cm. when moderately distended (Sisson and Grossman, 1953). The wall is relatively thin, and both muscular layers are striped throughout. Muscular layers consist of two strata of spiral fibers, except near the stomach, where they are longitudinal and circular. These two muscular layers continue into the stomach wall. A glandular prominence is formed, in the mucous membrane, at the cranial end of the esophagus, whereas the remaining portion is non-glandular.

The esophagus of pronghorn antelope is about 30 cm. in length, with a diameter of $1\frac{1}{2}$ cm. in the female, and $2\frac{1}{2}$ cm. in the males (Wenzel, 1955).

Trautmann and Fiebiger (1952) described the esophagus of all domestic animals as consisting of a cutaneous mucous membrane and a muscular tunic, which, in the cervical region, is covered by a loose fibrous adventitia. In the thoracic region the adventitia is replaced by a serous membrane. At the mucosal base is a tunica propria made up of closely woven collagenous fibers. Its well developed papillary body is overlain by stratified squamous epithelium. The muscularis mucosa, made up of longitudinal fibers, in ruminants is incomplete in the cranial portion, but more of a continuous sheet in the caudal portion. In some domestic animals the loose submucosa contains mucous glands. In ruminants, however, glands are present only at the pharyngoesophageal junction. The tunica muscularis is made up of two layers of striated muscle. At first these layers cross each other obliquely, then take a spiral course.

May (1964) noted that the wall of the esophagus in sheep is composed of four layers: an outer areolar coat, a muscular coat contributing to the thickness of the tube, a loose submucous layer attached to the muscular coat, and an inner thick mucous membrane which forms longitudinal folds when the tube is distended.

Stomach

The stomach of sheep (Trautmann and Fiebiger, 1952) and pronghorn antelope (Wenzel, 1955) is divided into four compartments. The three non-glandular diverticula are: rumen, reticulum, and omasum. These comprise the forestomach. The fourth compartment is a true

glandular stomach, the abomasum (Trautmann and Fiebiger, 1952). The average stomach capacity of the sheep is about four gallons (Sisson and Grossman, 1953). Externally all parts of the stomach are separated by constrictions which correspond to internal ridges that partially differentiate the cavities. The rumen, reticulum, and omasum are termed sacculations of the esophagus because they are lined with stratified squamous epithelium and are non-glandular. The abomasum is comparable to the stomach of the horse and dog because it is lined with simple columnar epithelium and has a glandular mucous membrane (May, 1964).

Rumen

The rumen of sheep is partially divided into two sacs, dorsal and ventral, the line dividing these being the right and left longitudinal groove. The dorsal sac of the rumen is a little longer and extends further forward than the ventral sac. The ventral sac is larger than the dorsal and its posterior blind sac extends 6-8 cm. farther than that of the dorsal posterior blind sac (Sisson and Grossman, 1953). The cranial external demarcation of the dorsal sac is the rumino-reticular groove, which is well marked ventrally and laterally. May (1964) noted that from the caudal transverse groove on each side, coronary grooves extend both dorsally and ventrally. Sisson and Grossman (1953) suggested that there is no right dorsal coronary groove. Coronary grooves mark off the posterior dorsal and

ventral blind sacs from the main cavity. Cranially the anterior transverse groove divides anterior dorsal and ventral blind sacs.

Wenzel (1955) described the rumen of pronghorn antelope as divided into dorsal and ventral portions by the longitudinal groove. The anterior end of the dorsal rumen is rounded and its junction with the reticulum coincides with the rumino-reticular groove. The dorsal rumen does not extend as far posteriorly as the ventral rumen. The dorsal rumen measured 30 centimeters from the rumino-reticular groove to the most posterior part, and 15 centimeters in depth, whereas the ventral rumen measured 35 centimeters in length and 14 centimeters in depth. The ventral portion is 10 centimeters more posterior than the dorsal portion.

Histologically, the mucosa of the rumen forms large tongue-shaped papillae. The mucosa has neither glands nor lymph nodules. Squamous epithelium varies in thickness and is covered by stratum corneum, stratum granulosum and stratum lucidum. In places where the stratum corneum is under tension, as on the tops of papillae, cells undergo the usual flattending in the process of cornification. Similar phenomena also occur in reticulum and omasum. The submucosa is loose and thin and blends into the lamina propria. The muscularis mucosa is absent, but a deeply stained sheet of connective tissue, which extends into the papillae, may be mistaken for muscularis mucosa. The tunica muscularis is composed of two layers. The outer layer is directed essentially craniocaudally, but in many places both layers

take a more oblique or even a dorsoventral course (Andrew, 1959; Trautmann and Fiebiger, 1952).

Blasco (1932) noted that sheep have two muscular coats at right angles to each other, whereas in domestic goats there are three coats in some places. No glands were found in the rumen. Blasco recorded measurements of different layers of rumen and reticulum of sheep and domestic goats which are listed in Table 2.

Dozsa et al. (1965) observed that in yearling sheep a sample of mucosa taken from any area of the rumen satisfactorily reflects the character of the entire ruminal mucosa; also, samples of mucosa obtained by biopsy are equivalent to those taken after slaughter. It was noted that length of papillae varied within specific areas, but average length ranged from 1.9 - 2.2 mm. Papillary bodies were distinct in almost all papillae, ranging in length from 36.0 - 75.0 microns, whereas the width of papillary stratum corneum ranged from 11.8 - 27.2 microns. The stratum corneum was observed to be compact on the tips of papillae, but cells on the surface may be swollen. Total thickness of the rumen varied between 1.6 - 2.6 mm, the difference being noted only in muscle layers and serosa.

Reticulum

The reticulum of sheep is the most cranial part of the stomach and is somewhat piriform in shape. The parietal surface is convex, facing forward. The visceral surface faces the opposite direction and is related to the rumen, and to a small extent related to omasum

Table 2. Rumen and reticulum thickness per layer of sheep and goats in mm.[1]

	Sheep	Goats
Rumen:		
Serosa	0.170	0.023
External muscular layer	2.088	1.004
Internal muscular layer	0.680	0.027
Submucosa	0.259	0.421
Mucosa	0.111	0.185
Papillae	1.680	3.577
Reticulum:		
Serosa	0.259	0.122
External muscular layer	0.726	0.726
Internal muscular layer	0.908	1.044
Submucosa	0.167	0.555
Mucosa	0.078	0.078
Papillae	2.406	3.507

[1] A. Blasco, 1932, Structure of the digestive organs of Ruminants, Rev. Hig. y san. P cuar. 22(4/5):246-263.

and abomasum. The reticulum ends dorsally by joining the rumen at the rumino-reticular groove (May, 1964).

Wenzel (1955) described the reticulum of pronghorn antelope as being anterior to the rumen, oval in shape and 15 centimeters long with a maximum width of 14 centimeters. Thickness of the walls is about the same as that of the rumen walls. The reticulated pattern of the mucous membrane was also observed.

The mucous membrane is raised into folds about half an inch high and they enclose four to six-sided spaces. This peculiar arrangement suggests the popular name "honeycomb". These spaces grow continually smaller and gradually disappear near the reticular groove and at the edge of the rumino-reticular fold (Sisson and Grossman, 1953).

Detailed structure of the mucosa resembles that of the rumen. In most large folds there is a band of smooth muscle fibers which run in the same direction as the fold and is continuous with the muscularis mucosa of the esophagus. Otherwise, muscularis mucosa is absent. The muscular tunic consists of two layers at right angles, and is much thicker at the apex of the reticulum. This tunic runs an oblique course (Andrew, 1959; Trautmann and Fiebiger, 1952).

Omasum

The oval omasum of the sheep has the capacity of approximately one pint. Its cavity contains about a hundred longitudinal folds called laminae omasi. These laminae are arranged in five levels, and

have numerous rounded, horny papillae which stud the surface. A four inch groove, sulcus omasi, extends the reticulo-omasal opening to the omaso-abomasal opening (Sisson and Grossman, 1953). The lesser curvature faces left and dorsally. The greater curvature faces right and backwards (May, 1964).

The omasum of pronghorn antelope is globular in shape and is approximately ten centimeters long and six centimeters wide, with walls three millimeters thick. The omasum is connected to the abomasum and reticulum in the same manner as in sheep (Wenzel, 1955).

The cutaneous mucous membrane contains dense capillary nets immediately under the epithelium. Mucous membranes have a distinct muscularis mucosa with no glands or lymph nodules. The laminae omasi contain various layers depending on size of laminae. The tunica muscularis is composed of an outer, thin, longitudinal layer and an inner, thicker, circular layer whose innermost stratum is continued into the larger laminae (Trautmann and Fiebiger, 1952).

Abomasum

The abomasum is an elongated tubular structure wider at the omasal, or fundic region, than at the pyloric end (May, 1964). The fundic portion is lined with a soft glandular mucous membrane, with over twelve spiral folds. A small cardiac gland zone surrounds the omasal-abomasal orifice (Sisson and Grossman, 1953).

Walls of the abomasum in pronghorn antelope are thinner than walls of rumen or reticulum. It is a U-shaped structure with a total

length of 23 centimeters. Inside surfaces of proximal portions are characterized by longitudinal folds or rugae, which are much smaller at the distal portion (Wenzel, 1955).

The wall of the abomasum is composed of a mucosa, tunica muscularis, and serosa. The surface epithelium consists of a simple layer of high (20-30 μ) columnar cells. Epitheliial cells of ruminants have a striated border and continue into depressions, or gastris pits, which increases the amount of secreting surface area. The lamina propria contain gastric glands, supported by a delicate connective tissue framework. Fundic glands are not necessarily found in the fundus. They are less branched than other glands and have a neck distinct from the glandular body. Pyloric glands open into much deeper pits and are more branched and coiled into a ball. The body of the gland is usually short, the excretory duct usually enters deep into lamina propria. The muscularis mucosa lies under lamina propria and probably plays a part in emptyling the glands. Submucosa is composed of loose connective tissue and many elastic fibers. This layer is backed by tunica muscularis which consists of an outer longitudinal, an outer oblique layer occurring near the cardia, and an inner circular layer (Andrew, 1959; Trautmann and Fiebiger, 1952).

Small Intestine

The small intestine of sheep is about 80 feet long with a diameter of about an inch. Diameter increases at its terminal part, where very extensive Peyer's patches are found (Sisson and Grossman, 1953).

In sheep the duodenum extends from the pylorus of the abomasum for a distance of two feet or more. The duodenum is divided into three parts. The first part forms an S-shaped curve on the caudate lobe of the liver and at the cranial end of the right kidney. The second part passes back toward the tuber coxae then turns forward to form the iliac flexure. The third part passes forward over the medial side of the second part. Common bile and pancreatic ducts enter the duodenum about two inches behind the S-shaped curve in the second part (May, 1964). The duodenum of pronghorn antelope measured about 0.76 meters (2.5 feet) (Wenzel, 1955).

The remainder of the sheep's small intestine, jejunum and ileum, is arranged in numerous, very close coils (Sisson and Grossman, 1953). The jejunum was measured in pronghorn antelope at 22 feet and ileum at 17 feet. Total length was found to be about 44 feet (Wenzel, 1955).

Large Intestine

The caecum of sheep measures from ten to twelve inches (25-30 cm.) in length, two to three and a half inches wide, and has the capacity of one quart. The colon begins at the ileo-caecal opening and extends about fifteen feet. Its caliber is about the same as the caecum to begin with, but gradually diminishes to about the width of the small intestine (May, 1964; Sisson and Grossman, 1953).

Wenzel (1955) noted that the caecum of pronghorn antelope was a conspicuous blind pouch at the ileo-caecal junction, and was

35 centimeters long and six centimeters wide. The colon also varied greatly in width, and measured 18 feet in length.

The rectum is usually covered with peritoneum, whereas the retroperitoneal portion is surrounded by a large quantity of fat. The anus is not prominent.

Intestinal Histology

Literature cited on histological anatomy of the intestinal tract is not specific for sheep or pronghorn antelope, but is described as "histology of domestic animals", in which the sheep was mentioned.

All areas of the intestinal tract consist of a mucosa, submucosa, muscularis, and serosa. Surface epithelium consists of simple columnar and goblet cells, which reach their greatest height on villi. The lamina propria has a framework of reticular tissue with elastic fibers and smooth muscle bundles. Villi are projections of lamina propria and serve to increase surface area available for absorption. Ruminants have short and thick villi. Glands of Lieberkuhn are found in the lamina propria, from pylorus to anus. In the duodenum, excretory ducts of submucosal glands pass through the lamina propria. Generally, glands of the large intestine are farther apart than those of the small intestine, but are longer and straighter. The exception is found in domestic goats, in which all intestinal glands are tortuous (Hans, 1947).

The muscularis mucosa consists of budnles of smooth muscle fibers which are perpendicular to one another. In the duodenum, muscularis mucosa may be interrupted or absent, because it splits into separate strands which dip into the glandular layer.

The submucosa consists of loose connective tissue and elastic fibers. It contains fat cells, lymph nodules, autonomic ganglia, nerves and blood vessels. In the duodenum the submucosa contains Brunner's glands.

Lymph nodules, in large numbers, are commonly found in the ileo-caecal region. In the large intestine solitary nodules are more frequent than in the small intestine.

Tunica muscularis is arranged in two layers at right angles to one another. No evidence of taeniae is found in the longitudinal layer of ruminants (Trautmann and Fiebiger, 1952).

METHODS AND MATERIALS

Preparation and Collection of Tissues

Gastrointestinal visceral samples of pronghorn antelope and sheep were collected, by the author, on three different occasions. Visceral samples from six two-year old sheep were selected at random from the evisceration line at the John Morrell Meat Packing Company, Sioux Falls, South Dakota on September 5, 1967. Collection of one pronghorn antelope was made in Perkins county on May 30, 1967. The third collection, which consisted of seven pronghorn antelope, was made in Harding county on September 30, 1967. Age of pronghorn antelope ranted from yearlings to three-year olds. Sex was not considered relative, in either species, in this study. All specimens appeared to be in good health.

Shortly after death, each portion of the gastrointestinal tract was measured, then cut into four 2 x 4 cm. rectangular sections. Sections were washed in a physiological irrigating solution and placed in low jars containing 100 ml of FAA (40% formalin - 7 ml, glacial acetic acid - 3 ml, 70% ethyl alcohol - 90 ml). To insure complete fixation, tissue remained in FAA 48 hours before further processing was continued. A sharp razor was employed to minimize tissue trauma and/or compression.

Histological Technique

Embedding

Following fixation, tissues were trimmed to expose a cross-section surface. Tissues were transferred to a vial of 70% ethyl alcohol for washing. Procedures for washing, dehydration, clearing, infiltration and embedding tissues are summarized in Table 3.

Tissues were embedded in paraffin immediately after paraffin bath II. Paraffin blocks were placed in an ice water bath to harden, then refrigerated until ready for sectioning.

Sectioning and Mounting

Paraffin blocks containing tissue were trimmed, with a razor, to the desired shape. Blocks were placed on a Spencer 820 microtome.[1] Tissues were cut 11 microns thick in ribbon form. Each ribbon was labelled and refrigerated until mounting.

Tissue Mounting

Ribbons were cut from each block, with one to five sections per ribbon. Each section was placed in a water bath at 38° - 41°C. A drop of Mayer's albumen mounting medium (fresh egg white - 50 ml, glycerine - 50 ml and sodium salicylate - 1 gm) was placed on pre-cleaned microscopic slides (25 x 75 mm), then the excess was wiped off.

---

[1]Spencer Lens Company; Buffalo, New York.

Table 3. Procedure for preparing gastrointestinal tissue for sectioning.

Procedure	Time	Chemical
Washing	24-72 hours	70% ethyl alcohol
Dehydrating	60 minutes	80% ethyl alcohol
Dehydrating	60 minutes	90% ethyl alcohol
Dehydrating	30 minutes	Absolute ethyl alcohol
Clearing	30 minutes	Absolute ethyl alcohol and xylol (1:1 ratio)
Clearing	30 minutes	Xylol
Infiltrating	30 minutes	½ xylol and ½ paraffin (melted paraffin)
Infiltrating	120 minutes	Paraffin bath I
Infiltrating	120 minutes	Paraffin bath II
Embed tissue in storage box		

Slides were dipped in a water bath to facilitate placement of tissue sections, then placed on a drying plate and allowed to dry at room temperature for 24 hours. Slides were stained in accordance with Tables 4 and 5.

Slide Analysis

Four slides were prepared from each of eleven portions of the gastrointestinal tract of both species. Two of these four slides were selected at random and duplicate measurements were recorded in millimeters (mm) from areas listed below. An A-O Spencer Ortho-Illuminator, an A-O Spencer microscope, and a Bausch and Lomb micrometer were employed in slide analysis and measurement.

Esophagus - thickness of stratified squamous epithelium

Rumen - thickness of mucosa and width of villi

Reticulum - thickness of stratum corneum and stratified squamous epithelium

Omasum - thickness of stratum corneum and stratified squamous epithelium

Abomasum - thickness of mucosa

Duodenum - thickness of mucosa

Jejunum - thickness of mucosa

Ileum - thickness of mucosa

Caecum - thickness of mucosa

Colon - thickness of mucosa

Rectum - thickness of mucosa

Table 4. Staining procedures in preparing gastrointestinal slides.

Solution	Time	Effect
Xylol I	3-5 minutes	Dissolve paraffin
Xylol II	60 seconds	Dissolve remaining paraffin
Absolute ethyl alcohol	60 seconds	Remove xylol
90% ethyl alcohol	60 seconds	Remove xylol - hydration begins
80% ethyl alcohol	60 seconds	Hydration - remove xylol
70% ethyl alcohol	60 seconds	Hydration
Distilled water	60 seconds	Remove alcohol
Harris Hematoxylin	3-25 minutes	Stain nucli and cell membranes
Distilled water	5-6 seconds	Wash excess stain
50% acid alcohol	To effect	Remove stain
Tap water	To effect	Turn tissue bluish-copper
Distilled water	60 seconds	Prepare to dehydrate
70% ethyl alcohol	60 seconds	Dehydration
80% ethyl alcohol	60 seconds	Dehydration
Erythrosin B counter-stain	3-5 seconds	Cytoplasmic stain
90% ethyl alcohol	60 seconds	Dehydrate and remove excessive counter-stain
Absolute ethyl alcohol	60 seconds	Dehydration complete
Xylol II	60 seconds	Remove alcohol
Mount cover slip (Canada Balsam)		

Table 5. Stains and reagents used in staining gastrointestinal slides.

Harris Hematoxylin	
Hematoxylin	0.5 gm
Absolute ethyl alcohol	5.0 ml
Ammonium alum	10.0 gm
Distilled water	95.0 ml
Mercuric oxide	0.25 gm
Erythrosin B	
Distilled water	100.0 ml
Erythrosin B	1.0 gm
Acid Alcohol	
50% absolute ethyl alcohol	100.0 ml
Concentrated HCL	4-6 drops

Comparisons of gastrointestinal mucosa at varying sites of the alimentary canal of antelope and sheep presented an opportunity to discover histologic differences. These areas remain more constant in size in relation to the age of the two species, which is important because of the variation of age in the pronghorn antelope.

Photography

Photography was accomplished by utilizing a Leitz Ortholux 81164 microcamera equipped with an automatic Leitz 35mm Orthomat microcamera.[2] Fine grain color film[3] was used in microphotography.

---

[2]E. Leitz, Inc.; 468 Park Avenue, South; New York, 16, New York.

[3]Kodacolor-X; CX 135 20; AHA 80 DIN 20; Eastman Kodak Co., Rochester, New York.

RESULTS AND DISCUSSION

Figures 1 and 2 show the differences in the muscular thickness between two particular pronghorn antelope due to age differences. The reason for selecting the areas studied was that the mucosal lining varied in thickness to a lesser degree than any other layer of the gastrointestinal tract. Therefore, the results of age differences within animals of the same species, as well as between species would be less significant. In addition, this histologic and anatomic study would be useful to combine the physiological and biochemical information now available on the sheep and to correlate it with the information obtained from this study on the pronghorn antelope.

Throughout the discussion, the gastrointestinal tracts will be classed as a single unit. When a difference between species arises it will be discussed separately.

Esophagus

Sections of the esophagus were obtained 15 - 18 cm. anteriorly to the rumino-reticular orifice.

The mucous membrane was lined with stratified squamous epithelium which rested upon a fairly thick lamina propria consisting of loose areolar tissue and elastic fibers. In both sheep and pronghorn antelope the epithelium appeared cornified at its surface, Figure 3.

The muscularis mucosa appeared as isolated bundles in this region of the esophagus. An outstanding feature of the muscularis mucosa, found only in the esophagus, was that it was thicker than any other portion of the gastrointestinal tract, and also, the fibers ran only longitudinally.

The submucosa consisted of dense areolar tissue which contained blood vessels and nerves.

The tunica muscularis was composed of two striated muscle layers, an inner circular and outer longitudinal layer, which were obliquely arranged. This arrangement made it difficult to identify each layer.

Rumen

The rumen, largest of the four compartments, was partially subdivided internally by ridges and externally by grooves. The apex of the ridges were comparatively free from papilla. The lining was raised into visible papillae between ridges. Longitudinal external grooves divided the rumen into dorsal and ventral areas. The ventral portion was the more posterior. Coronary grooves, arising from the posterior end of the longitudinal grooves dorsally and ventrally, divided the dorsal and ventral rumen into posterior blind sacs on both right and left sides. The right dorsal coronary groove was less apparent than the left. Samples were obtained from the mid-left lateral portion of the dorsal rumen.

The mucous membrane consisted of two superficial strata, an outer stratum corneum and an inner stratum granulosum, Figure 4. Immediately beneath the mucosa, in the lamina propria, a connective tissue band, which appeared to be the muscularis mucosa, was observed. This band, however, was part of the lamina propria. The lamina propria and the submucosa appeared to be the same layer. Between the submucosa and the tunica muscularis, Meissner's plexuses were observed throughout all portions of the stomach.

The tunica muscularis was composed of two perpendicular layers, an inner circular and outer longitudinal layer. Auerbach's plexuses occurred frequently in this area, Figure 5. The serosa was a coat of areolar tissue containing blood vessels and adipose tissue.

Reticulum

The reticulum, most anterior compartment of the stomach, was separated externally from the rumen by the rumino-reticular groove and internally by the rumino-reticular orifice. Ventral to the rumino-reticular orifice the rumino-reticular fold also separated rumen from reticulum. The reticulum was oval in shape, with the long axis running dorso-ventrally. Sections were acquired from the mid-left lateral portion of the reticulum.

The reticulated pattern of the mucous membrane was characterized by a five to six-sided network of vertical ridges. Ridges and the spaces between them were covered with stratified squamous epithelum which, like the rumen, had a stratum corneum and a stratum

granulosum, Figures 6 and 7. Macroscopic papillary structures were observed covering the entire internal surface of the reticulum.

A muscularis mucosa was present in larger ridges and appeared to run parallel with the long axis, while the lamina propria and submucosa were in close proximity to one another. The two muscular layers were at right angles to one another and backed by serosa.

Omasum

The omasum was the smallest stomach compartment. Ingesta enters the omasum from the reticulo-omasal orifice, and leaves via the omaso-abomasal orifice. Between these two openings was a groove, the sulcus omasi. Samples were obtained from the mid-left lateral portion of the omasum.

The omasum possessed a large number of leaves, laminae omasi, extending from dorsal and lateral areas, and occupied a large percentage of the lumen surface. Macroscopic horny papillae covered the entire surface of the leaves.

The entire omasum was covered with cornified stratified squamous epithelium. Each omasal leaf contained a centrally located area of smooth muscle. This muscle, part of the inner circular muscle layer, exhibited long fibers in cross section. A muscle layer, cut transversely, was observed between mucosa and central muscle area in each leaf. This was the muscularis mucosa. An outer longitudinal muscular tunic and serosa were also present.

Abomasum

The abomasu, last compartment of the stomach, is often referred to as the true or glandular stomach. It was divided into two main areas, fundic and pyloric. Tissues were taken 5 - 7 cm. from the omaso-abomasal orifice in the fundic region. The fundic region consisted of spiral folds or rugae, whereas, the pyloric region was relatively smooth.

The abomasum, lined with simple columnar epithelium, was backed by a sparsely supported connective tissue framework containing fundic glands, Figure 8. Mucosal arrangement was characterized by gastric furrows and gastric pits, Figure 9. A muscularis mucosa was observed to contain two perpendicular muscular layers, an inner circular and outer longitudinal layer. The submucosa consisted of connective tissue, adipose tissue, and elastic fibers which contained blood vessels and nerve plexuses. The muscular tunic had two complete layers, an inner circular, and outer longitudinal layer. The circular layer was by far the thickest. Also observed was what appeared to be a third oblique muscular tunic. This tunic was thin and located between submucosa and the circular muscle layer.

Small Intestine

The small intestine extended from the pyloric portion of the abomasum to the ileo-caecal junction. The small intestine varied in length between species. In the sheep it averaged 82 feet, whereas, in pronghorn antelope it averaged 52 feet.

The inner surface was marked with circular folds that projected into the lumen throughout the small intestine. These are called plicae circularis. Microscopically, each plica appeared to consist of a projection of the mucosa and submucosa.

The mucosa of the small intestine consisted of microscopic villi, which were composed of lamina propria and simple columnar epithelium. Villi occurred in all parts of the small intestine and were its most characteristic feature, Figure 10.

Intestinal glands or crypts of Lieberkuhn were a common occurrence at the base of the villi and throughout the intestinal tract. These crypts were lined with columnar epithelium resembling that which covered the villi.

Lymphoid tissue was observed throughout the mucosa of the small intestine. Aggregated lymph nodules, Peyer's patches, were common in the ileal mucosa, Figure 11. The muscularis mucosa contained two thin smooth muscle layers, circular and longitudinal.

The intestinal wall submucosa varied in the duodenum, jejunum, and ileum. Brunner's glands were in the duodenal submucosa. Apparently sheep and pronghorn antelope differed in this area. It appeared that the Brunner's glands were larger in the sheep than in the pronghorn antelope, Figures 12 and 13. Hans (1947) compared the duodenal glands of domestic animals and found those in the sheep among the largest of the domestic animals. Lymph nodules were also found in the submucosa of the ileum. These nodules were large enough to be

visible macroscopically. With the exception of solitary lymph nodules, which appeared throughout the small intestine, the jejunum was free of glands. The submucosa, in both species, contained blood vessels and Meissner's plexuses in proportionate numbers.

An inner circular and outer longitudinal layer of smooth muscle characterized the tunica muscularis. Between these layers Auerbach's plexuses were frequently observed.

The serosa was the outer layer of the stomach, small, and large intestine.

Tissue samples from the intestine were taken from the following locations: the duodenum, 12 inches from the pyloric junction; the jejunum, 4 feet from the pyloric junction and the ileum, 4 feet from the ileo-caecal junction.

Large Intestine

The epithelium was simple columnar, and the lamina propria contained numerous crypts of Lieberkuhn. Solitary lymph nodules were observed throughout the large intestine. The muscularis mucosa was composed of an inner circular and outer longitudinal layer, as in the small intestine.

No glands were present in the submucosa. A species difference was evident in submucosal caecal fat. There appeared to be more caecal fat in the pronghorn antelope than in the sheep, Figures 14 and 15. In the colon the submucosal fat was similar between species.

Gross measurements also showed species differences, Tables 6 and 7. The sheep caecum averaged 12 inches in length, whereas, the pronghorn antelope caecum averaged 18 inches in length. The colon of the sheep and pronghorn antelope averaged 16 feet, and 20 and a half feet respectively.

The tunica muscularis was arranged in two perpendicular layers, as in the small intestine. The serosa contained large deposits of adipose tissue, especially in the rectum.

Tissue samples of the caecum were obtained 8 inches from the ileo-caecal junction; the colon, 3 feet from the ileo-caecal junction; and of the rectum, 2 inches from the anus.

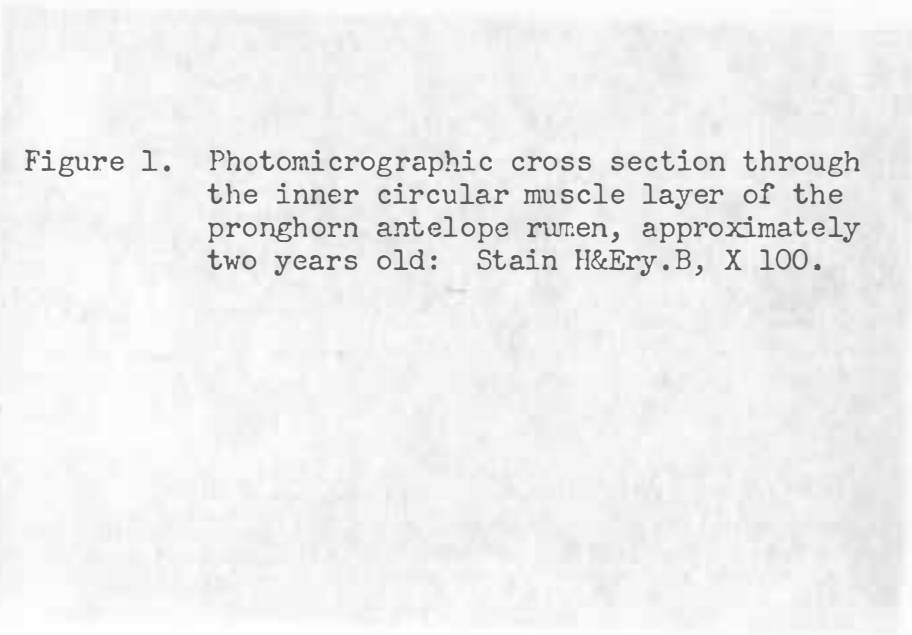

Figure 1. Photomicrographic cross section through the inner circular muscle layer of the pronghorn antelope rumen, approximately two years old: Stain H&Ery.B, X 100.

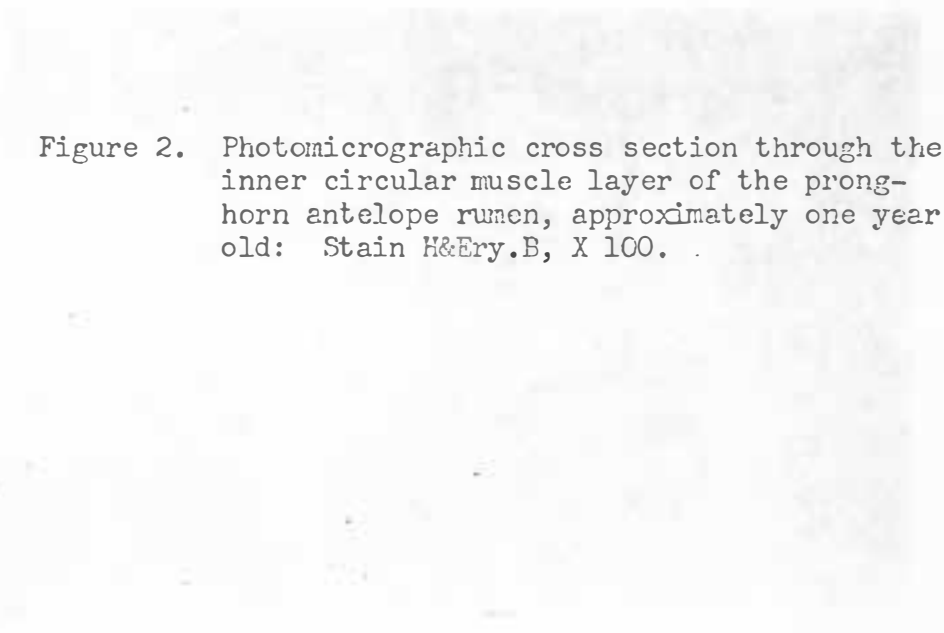

Figure 2. Photomicrographic cross section through the inner circular muscle layer of the pronghorn antelope rumen, approximately one year old: Stain H&Ery.B, X 100.

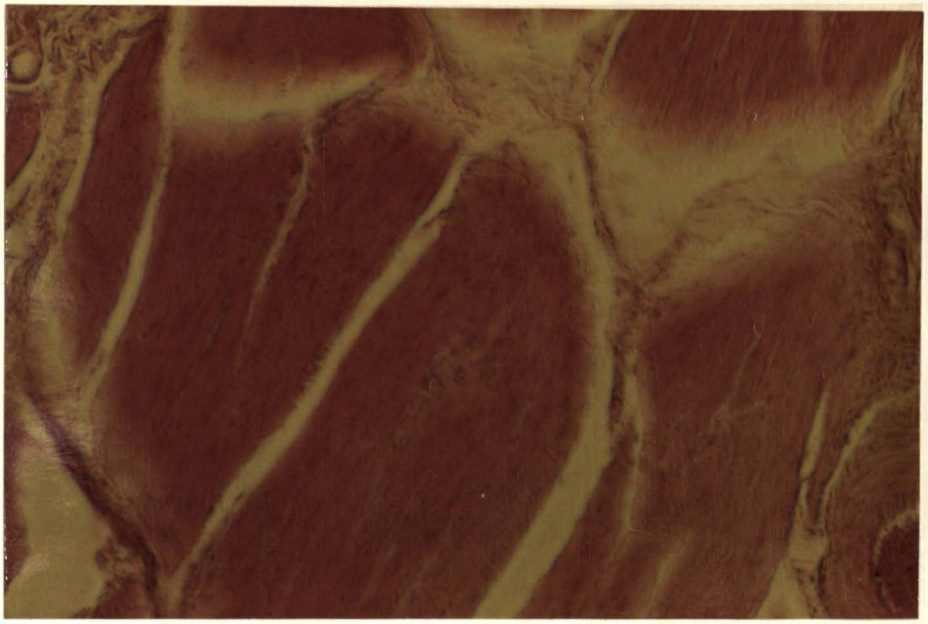

Figure 1

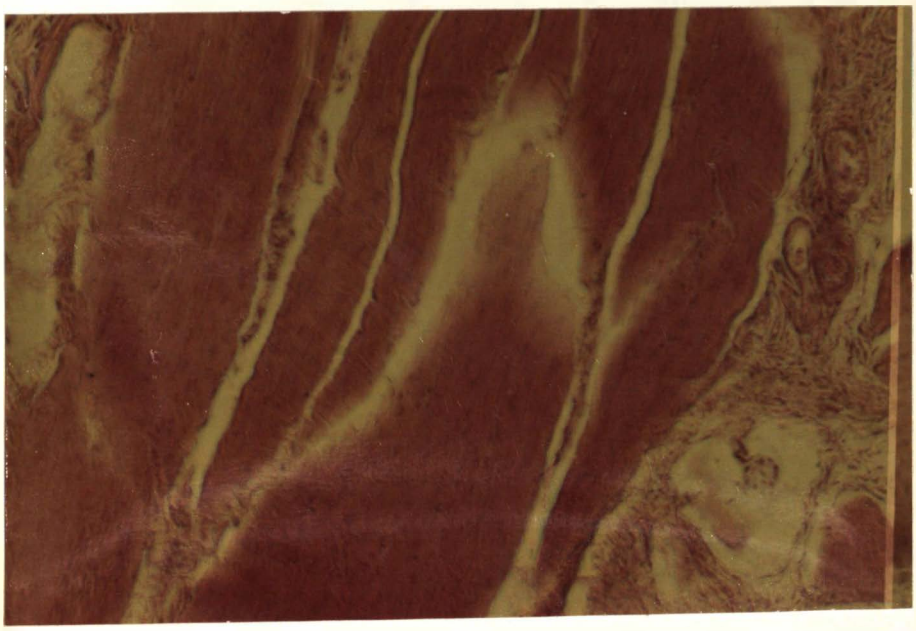

Figure 2

Figure 3. Photomicrographic cross section through the esophagus mucosa of the sheep: Stain H&Ery.B, X 100.

Note stratified squamous epithelium with cornified and partly desquamated cells; papillary bodies of mucosa projecting into the lamina propria.

Figure 4. Photomicrographic cross section through the rumen mucosal layer of the sheep: Stain H&Ery.B, X 400.

Note stratum corneum; stratum granulosum and stratified squamous epithelium; also lymphocytes.

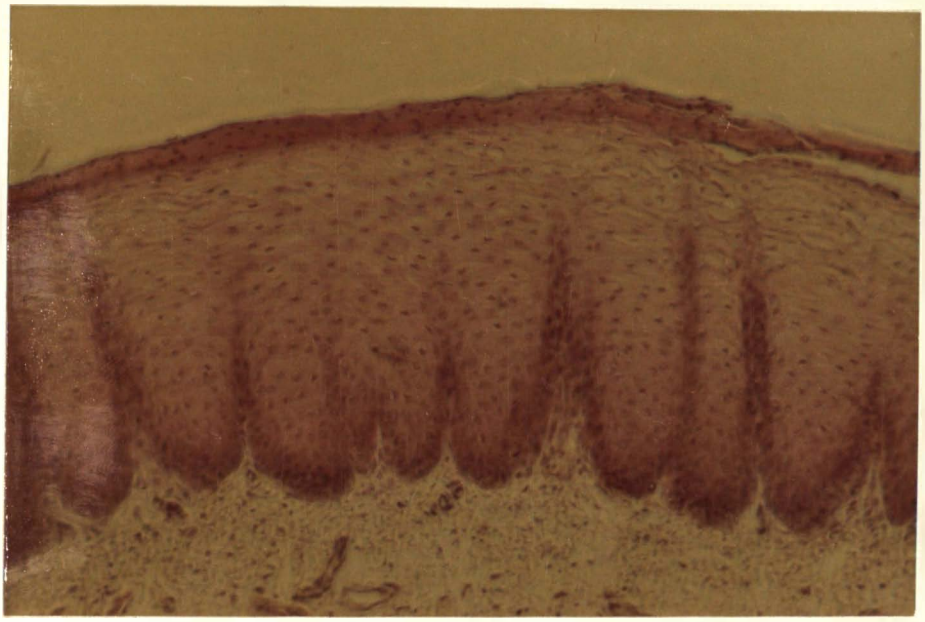

Figure 3

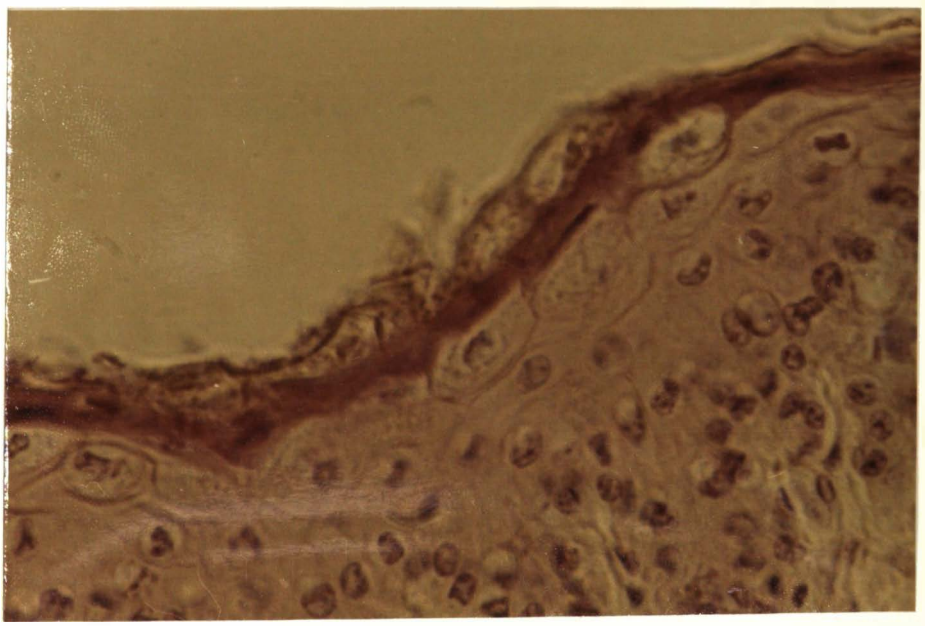

Figure 4

Figure 5. Photomicrographic cross section through the tunica muscularis of the sheep rumen: Stain H&Ery.B, X 100.

Note inner circular muscle layer, above; Auerbach's plexus, middle; an outer longitudinal muscle layer, below.

Figure 6. Photomicrographic longitudinal section through the reticulum of the sheep: Stain H&Ery.B, X 100.

Note stratum corneum, stratum granulosum, and stratified squamous epithelium; lamina propria; inner circular muscle.

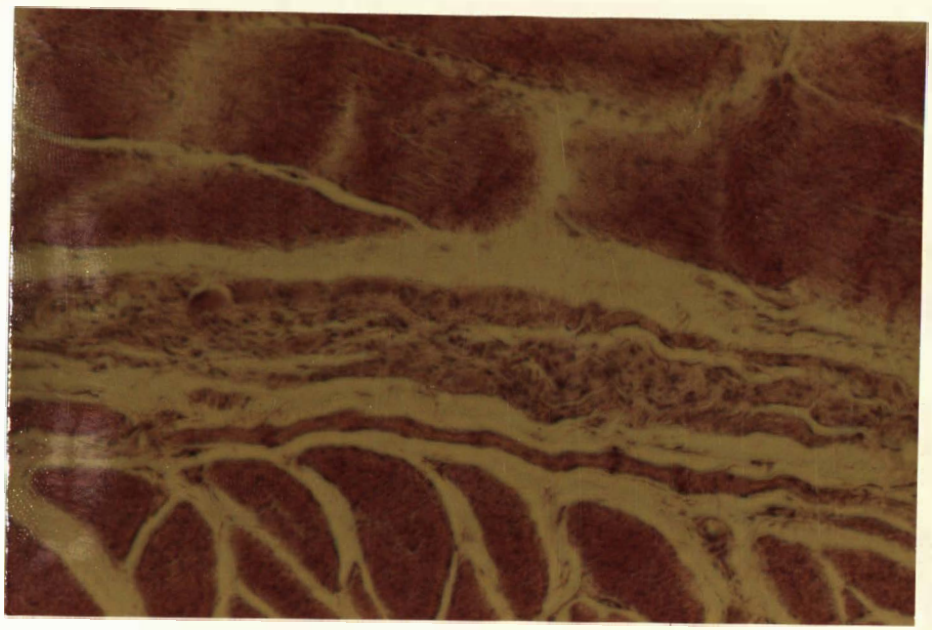

Figure 5

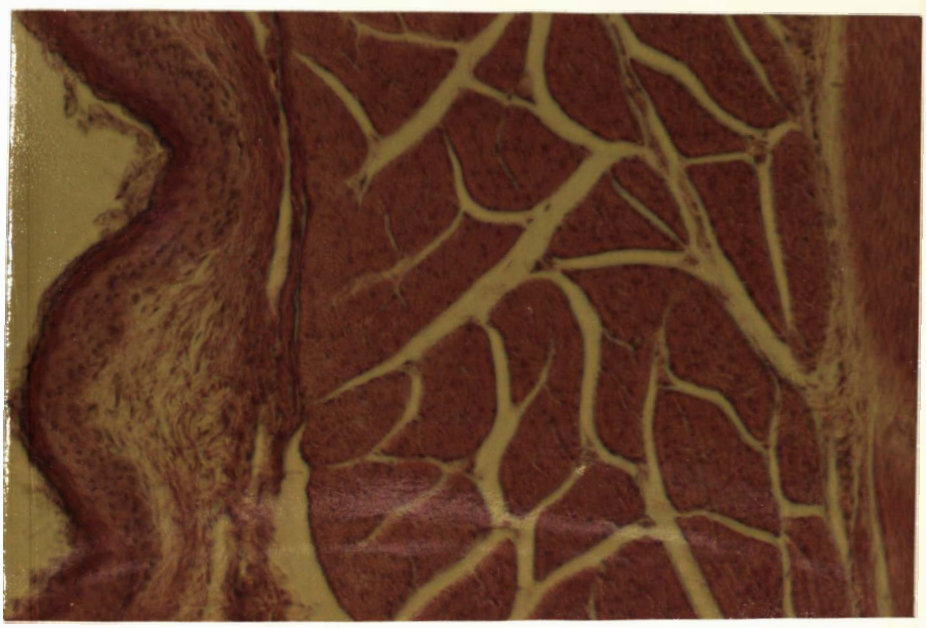

Figure 6

Figure 7. Photomicrographic cross section through the reticulum mucosal layer of the sheep: Stain H&Ery.B, X 400.

Note stratum corneum, stratum granulosum and stratified squamous epithelium; portion of the lamina propria and lymphocytes.

Figure 8. Photomicrographic cross section through the abomasum mucosal layer of the sheep: Stain H&Ery.B, X 400.

Note glands, lamina propria background, parietal cells of glands and lymphocytes.

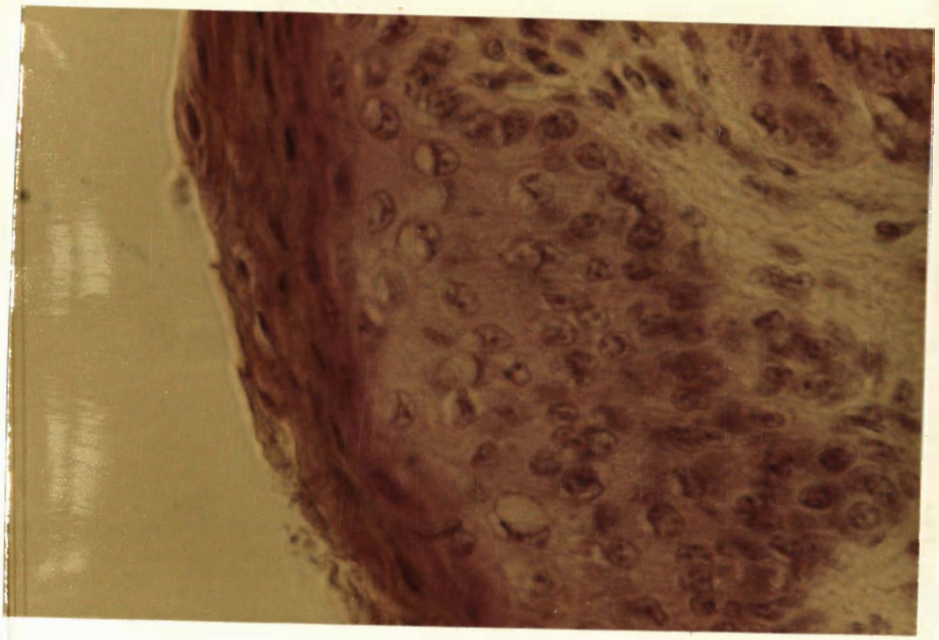

Figure 7

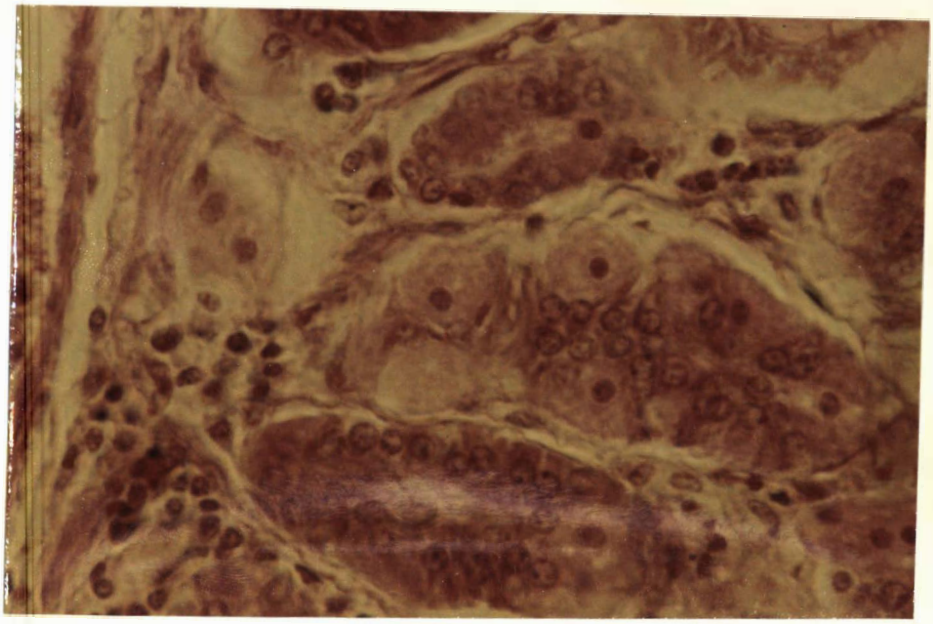

Figure 8

Figure 9. Photomicrographic cross section through the abomasum mucosal layer of the sheep: Stain H&Ery.B, X 100.

Note simple columnar epithelium; gastric pits and gastric furrows; lamina propria and numerous lymphocytes.

Figure 10. Photomicrographic cross section through the ileum of the sheep: Stain H&Ery.B, X 100.

Note long villi covered with simple columnar epithelium; lamina propria; glands of Lieberkuhn; lymphocytes; muscularis mucosa; blood vessels in submucosa; portion of inner circular muscle.

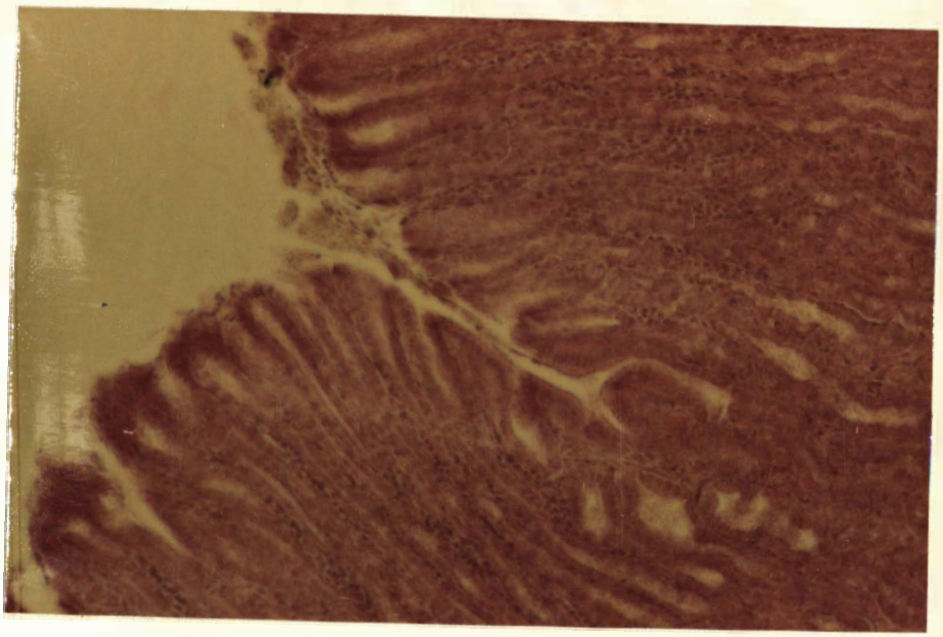

Figure 9

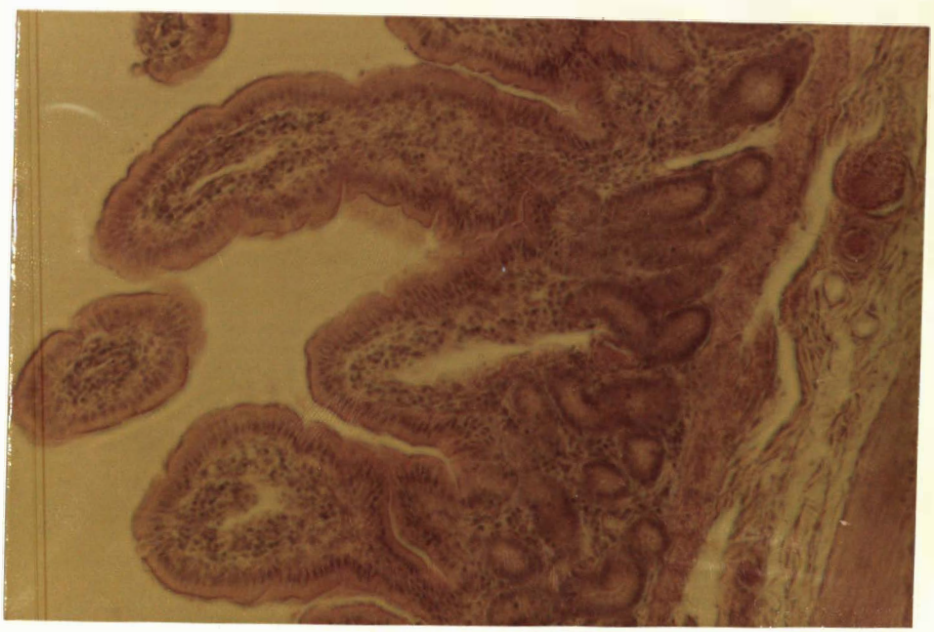

Figure 10

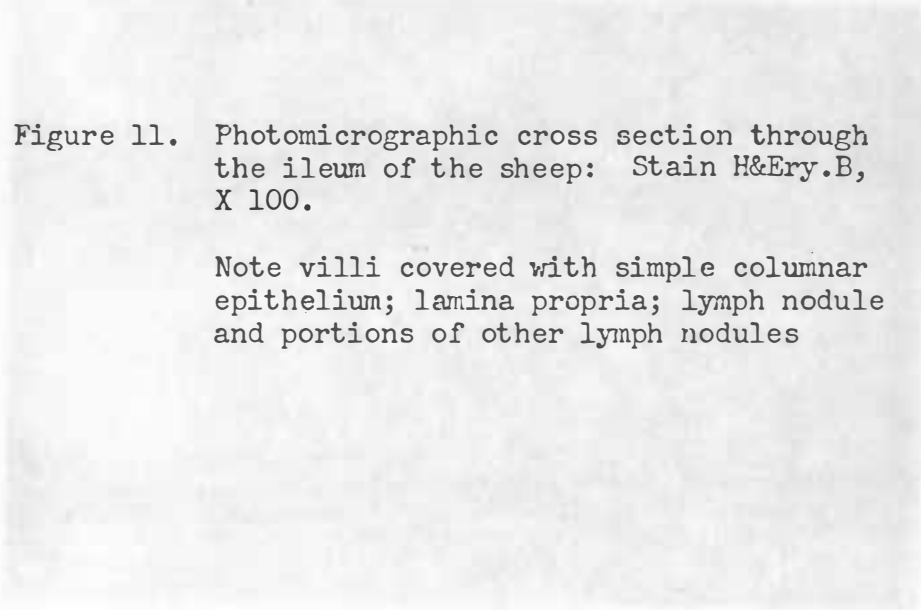

Figure 11. Photomicrographic cross section through the ileum of the sheep: Stain H&Ery.B, X 100.

Note villi covered with simple columnar epithelium; lamina propria; lymph nodule and portions of other lymph nodules

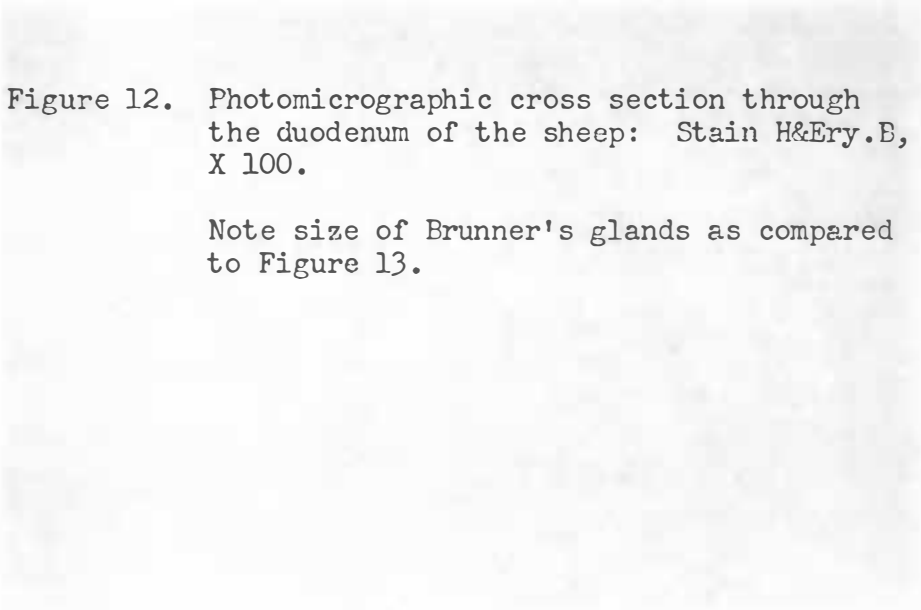

Figure 12. Photomicrographic cross section through the duodenum of the sheep: Stain H&Ery.B, X 100.

Note size of Brunner's glands as compared to Figure 13.

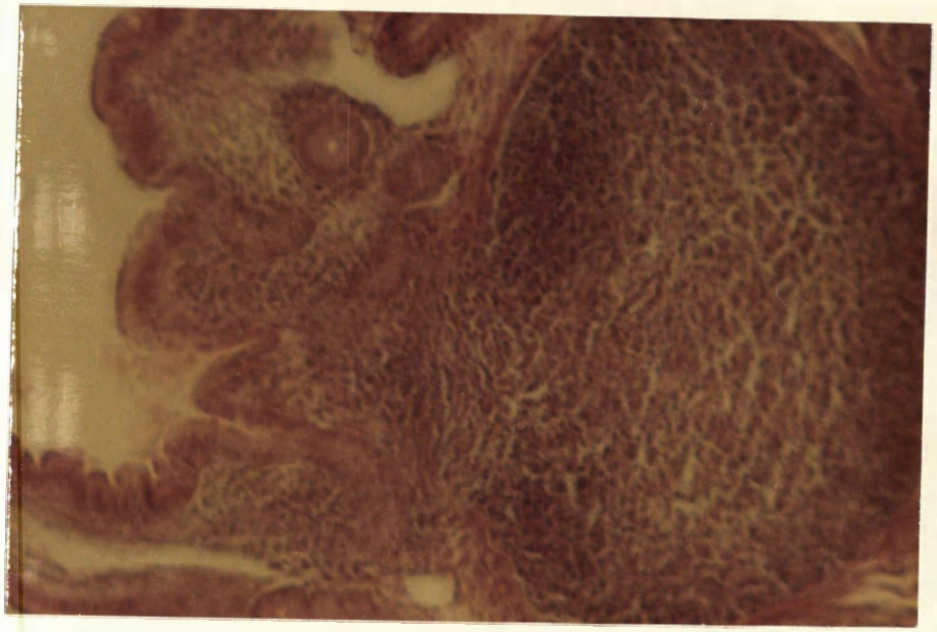

Figure 11

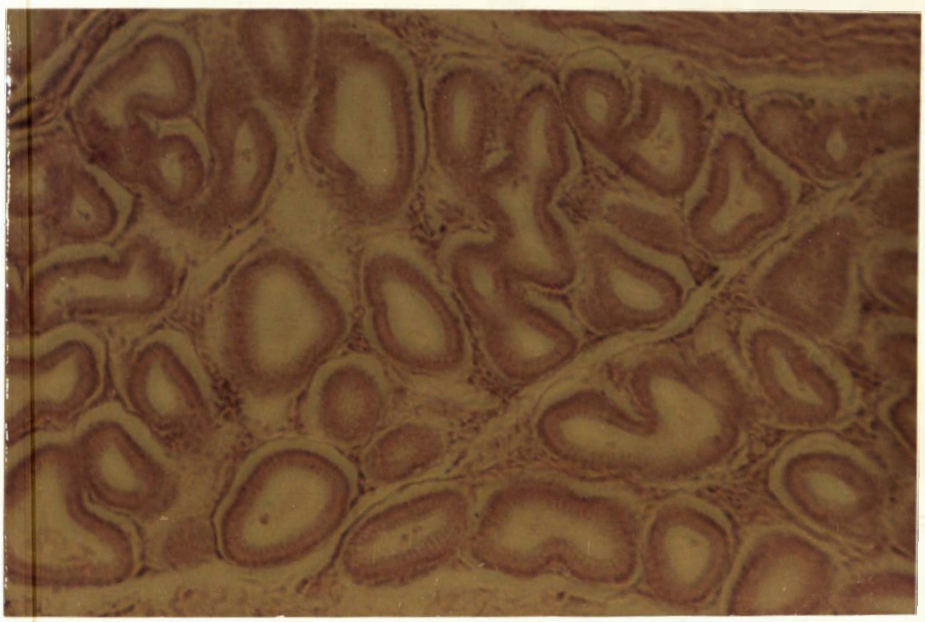

Figure 12

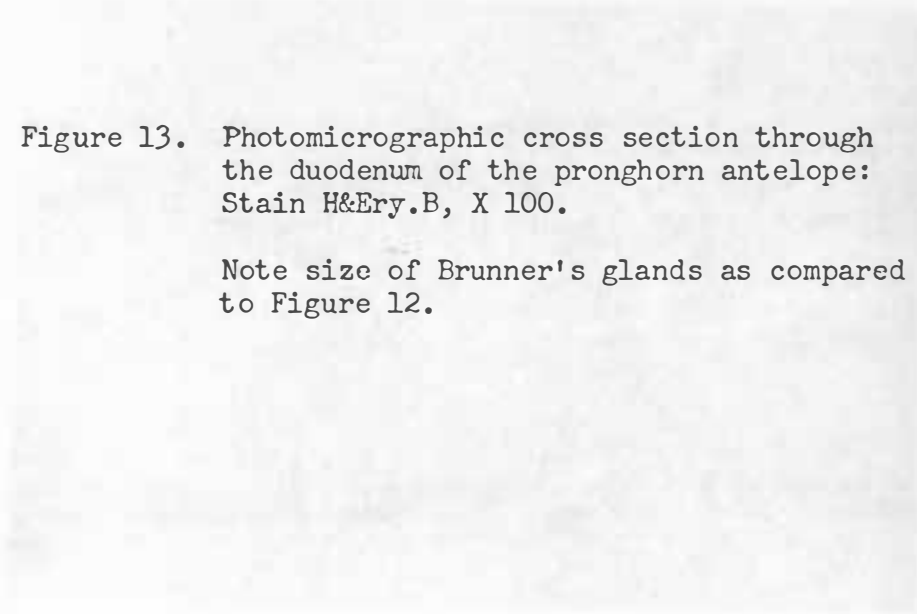

Figure 13. Photomicrographic cross section through the duodenum of the pronghorn antelope: Stain H&Ery.B, X 100.

Note size of Brunner's glands as compared to Figure 12.

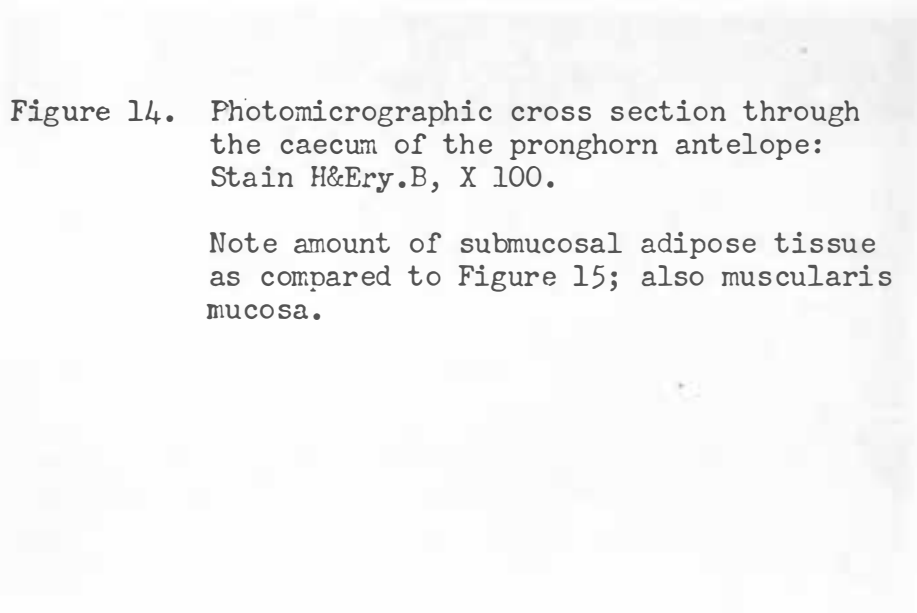

Figure 14. Photomicrographic cross section through the caecum of the pronghorn antelope: Stain H&Ery.B, X 100.

Note amount of submucosal adipose tissue as compared to Figure 15; also muscularis mucosa.

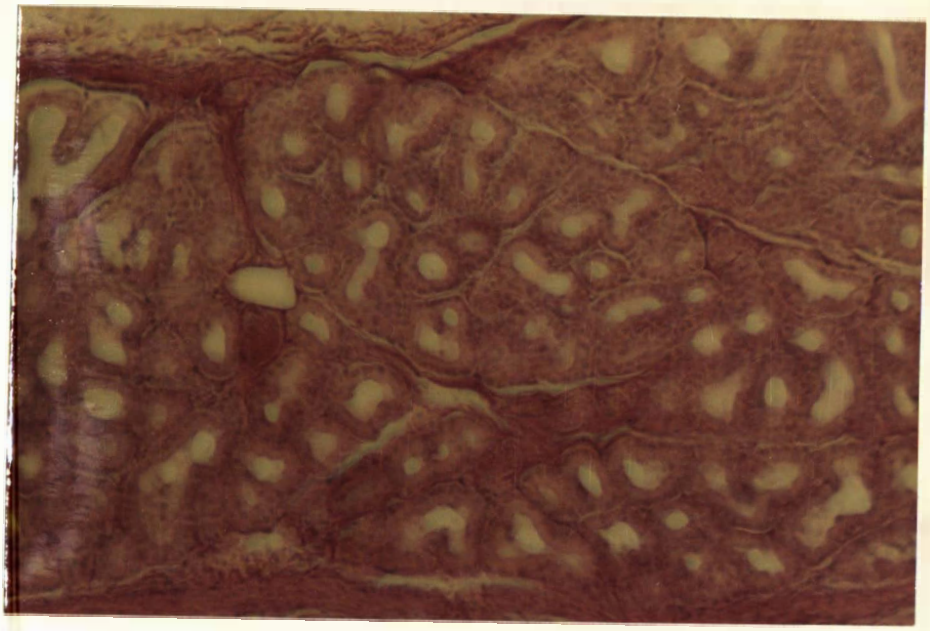

Figure 13

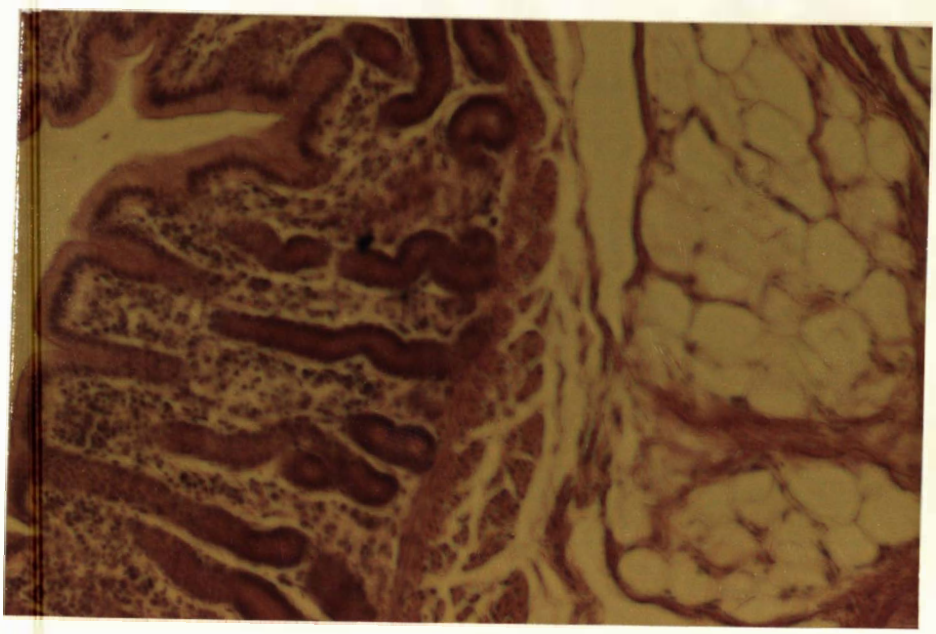

Figure 14

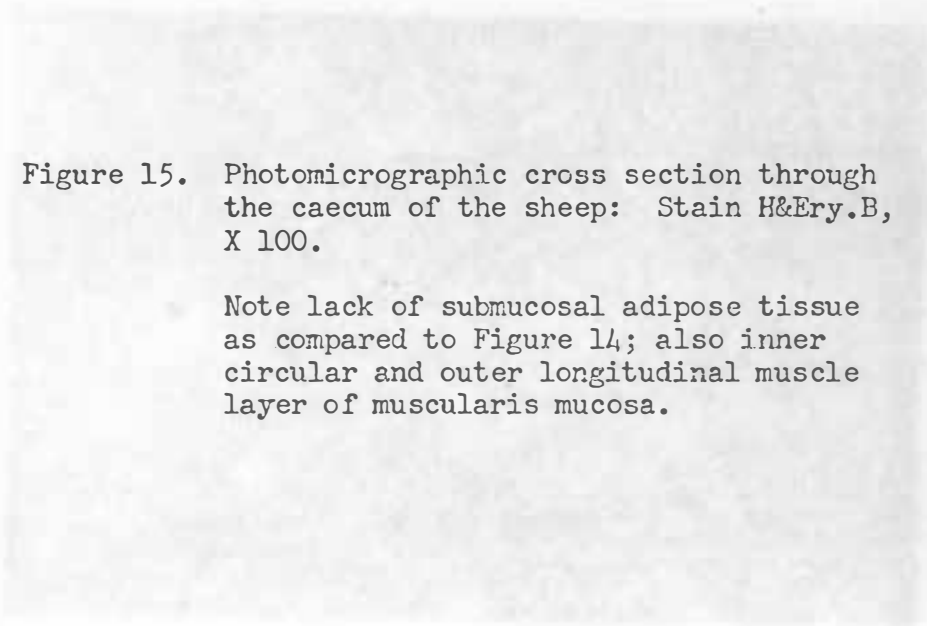

Figure 15. Photomicrographic cross section through the caecum of the sheep: Stain H&Ery.B, X 100.

Note lack of submucosal adipose tissue as compared to Figure 14; also inner circular and outer longitudinal muscle layer of muscularis mucosa.

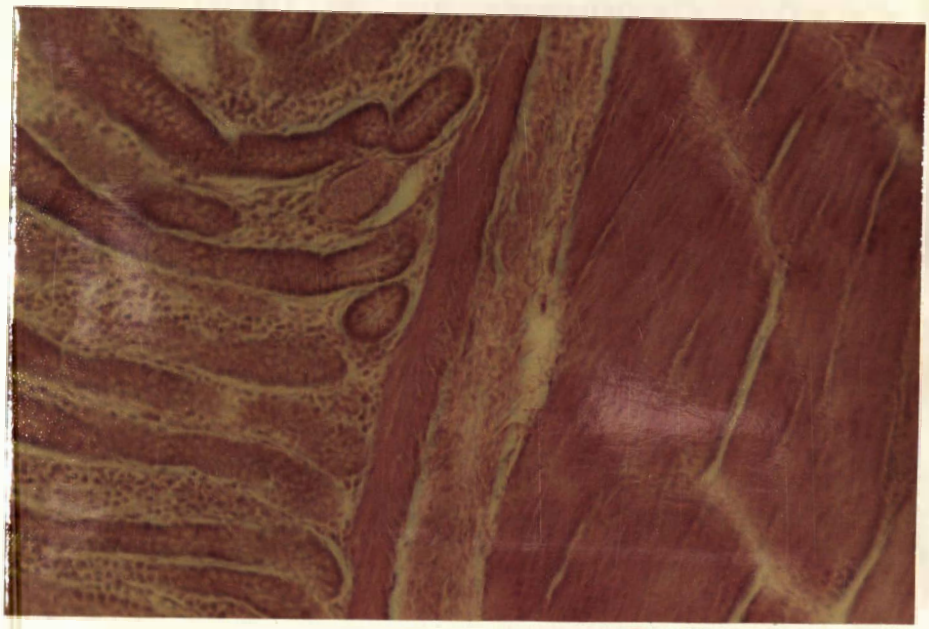

Figure 15

Table 6. Minimum, maximum and mean total thickness measurements of sheep and pronghorn antelope.

Area	Sheep (mm)			Antelope (mm)		
	Min.	Max.	Mean	Min.	Max.	Mean
Esophagus	2.390	4.064	3.148	2.057	4.064	2.810
Rumen	1.905	3.556	2.936	1.049	2.134	1.662
Reticulum	2.088	4.699	3.465	1.228	3.117	2.120
Omasum	0.110	0.632	0.470	0.251	0.683	0.461
Abomasum	2.083	3.454	2.624	1.219	3.023	2.171
Duodenum	1.387	2.845	2.169	0.809	2.223	1.668
Jejunum	1.051	2.616	2.039	0.698	1.549	1.047
Ileum	1.956	3.175	2.394	0.955	2.286	1.591
Caecum	0.858	1.590	1.324	0.744	1.193	0.983
Colon	1.143	2.159	1.666	0.604	0.930	0.723
Rectum	1.778	3.937	2.852	3.734	5.652	4.571

Table 6. Minimum, maximum and mean total thickness measurements of sheep and pronghorn antelope.

Area	Sheep (mm)			Antelope (mm)		
	Min.	Max.	Mean	Min.	Max.	Mean
Esophagus	2.390	4.064	3.148	2.057	4.064	2.810
Rumen	1.905	3.556	2.936	1.049	2.134	1.662
Reticulum	2.088	4.699	3.465	1.228	3.117	2.120
Omasum	0.110	0.632	0.470	0.251	0.683	0.461
Abomasum	2.083	3.454	2.624	1.219	3.023	2.171
Duodenum	1.387	2.845	2.169	0.809	2.223	1.668
Jejunum	1.051	2.616	2.039	0.698	1.549	1.047
Ileum	1.956	3.175	2.394	0.955	2.286	1.591
Caecum	0.858	1.590	1.324	0.744	1.193	0.983
Colon	1.143	2.159	1.666	0.604	0.930	0.723
Rectum	1.778	3.937	2.852	3.734	5.652	4.571

Table 7. Minimum, maximum and mean mucosa and villi measurements of sheep and pronghorn antelope.

Area	Sheep (mm)			Antelope (mm)		
	Min.	Max.	Mean	Min.	Max.	Mean
Esophagus	0.288	0.558	0.438	0.326	0.628	0.485
Rumen villi	0.291	0.769	0.356	0.233	0.535	0.439
Rumen mucosa	0.078	0.126	0.108	0.082	0.115	0.096
Reticulum	0.073	0.134	0.106	0.061	0.140	0.097
Omasum	0.077	0.158	0.096	0.077	0.149	0.100
Abomasum	0.603	1.004	0.776	0.541	1.397	0.903
Duodenum	0.628	1.107	0.834	0.212	0.920	0.612
Jejunum	0.628	1.765	1.202	0.419	1.117	0.726
Ileum	0.628	1.676	0.937	0.391	0.884	0.672
Caecum	0.391	0.877	0.562	0.326	0.581	0.408
Colon	0.558	0.837	0.705	0.331	0.586	0.395
Rectum	0.372	0.697	0.510	0.338	0.791	0.526

SUMMARY

Biologic as well as statistically significant differences were noted between gastrointestinal tracts of sheep and pronghorn antelope. However, gross and histologic observations of the alimentary canal in both species produced essentially similar sets of overall criteria for identification of specific gastrointestinal areas. Shape and size of villi, as well as the appearance of mucosal surfaces throughout the tract, provided excellent identification criteria for localizing tissue samples from both species. Therefore, with but few exceptions, it would appear valid to base diagnosis of gastrointestinal pathology in pronghorn antelope and closely related wild ruminants on the same histopathologic criteria as used in domestic species. This assumption can only be proven, however, by additional morphologic studies in wild ruminants, with emphasis on comparative pathologic studies with domestic species.

Hans (1947) noted differing luminal diameters in duodenal glands between species. He emphasized the importance of establishing species "normals" before differential diagnosis of pathology is based on appearance of these glands in duodenal tissue sections. Data obtained in this investigation indicated the size of duodenal glands was one of the more striking biologic differences noted between species studied. It was noted that duodenal glands in sheep were invariably larger and apparently present in much larger numbers than in the antelope.

Data published by Doza (1965), showing remarkable uniformity in length of rumen villi in sheep, was supported by data observations in this study in both species as was the presence of occasional lymphoid nodules in jejunum as reported by Sisson and Grossman (1953) for sheep. It was also noted that parietal cells, characteristic in size and shape to those described in other mammalian species, were numerous in the abomasum of both species.

Presence of submucosal fat was found to be a valuable criteria for identification of two gastrointestinal areas in both sheep and antelope. It was found in approximately equal amounts in the colon of both species but in much larger amounts in the caecum of antelope, Figure 14.

As noted previously, the mucosal surface of the gastrointestinal tract was chosen for making specific measurements in comparing species studied. After maturity, this layer is affected less than other related areas by such variables as sex, age and weight.

Analysis of variance showed highly significant ($P < .01$) mucosal differences between species in the colon. Highly significant ($P < .01$) differences were observed in total thickness between species in reticulum, jejunum, ileum, colon and rectum.

Significant ($P < .05$) mucosal differences between species were observed in duodenum, jejunum and caecum. The rumen and caecum were significant ($P < .05$) in total thickness. Tables summarizing analyses of variance data measurements between species are listed in Tables 8 - 30.

An IBM model 1620 computer was employed in statistical analysis. Raw data obtained from mucosa, villi and total thickness measurements are listed in Tables 31 - 42. Raw data summarizing the maximum, minimum and mean measurements containing these values for sheep and pronghorn antelope are cited in Tables 6 - 7.

CONCLUSIONS

The gastrointestinal tract of domestic sheep and pronghorn antelope were compared by gross and microscopic observations and by statistical analysis of measurements taken from 11 specific areas along the alimentary canal of both species. Tissues were sectioned from the following gastrointestinal areas in both species: esophagus, rumen, reticulum, omasum, abomasum, duodenum, jejunum, ileum, caecum, colon and rectum. Data were obtained from four slides prepared from each of eleven areas listed in all six specimens.

An IBM model 1620 computer was employed for statistical analysis of measurement data. Raw data punched on IBM cards for computer use included duplicate measurements, in millimeters (mm.), from specific mucosal surfaces in two of the four prepared slides from each segment in both sheep and antelope. An additional measurement of villi width in the rumen was also included.

In addition to specific mucosal measurements, detailed histologic observations were recorded that described the overall microscopic anatomy of each gastrointestinal area studied. Numerous photomicrographs were taken to record visual observations.

Analyses of variance was the statistical method used to interpret all final data. Highly significant differences between species were noted in mucosal thickness in the colon of sheep, also, highly significant differences in total thickness were noted in the

reticulum, jejunum, ileum and colon of sheep. Highly significant differences between species appeared in the rectum of antelope.

Significant differences between species were noted in mucosal thickness in the duodenum, jejunum and caecun of sheep, also, significant differences between species were noted in total thickness in the rumen and caecum of the sheep.

Differences noted between animals within species and between slides within animals are statistically but not biologically significant. They result from variations within individual tissue segments measured.

Tables six through thirty summarize statistical data.

LITERATURE CITED

Andrew, A. 1959. Textbook of comparative histology. Oxford University Press, New York. 275-276.

Blasco, A. 1932. Structure of the digestive organs of ruminants. Rev. Hig. y san. Pecuar. 22(4/5):246-263.

Cockrum, E. L. 1962. Introduction to mammalogy. Ronald Press Co., New York. 413-418.

Coleman, G. I. 1967. Personal communication. Biological Science Section, Science Information Exchange, Washington, D.C.

Dozsa, L., Anderson, G. C., and Mebee, J. L. 1965. Histologic characteristics of the ovine rumen mucosa. Amer. J. Veterinary Res. 26(110):120-122.

Francis, W. 1967. Personal communication. Chief, Division of Reference, United States Department of Agriculture, National Agricultural Library, Washington, D.C.

Hall, R. C. 1946. Mammals of Nevada. University of California Press, Berkeley, Calif., 629pp.

Hans, E. 1947. Comparison of duodenal glands in domestic animals. Amer. J. Veterinary Res. 8(28):311-313.

May, D. S. 1964. The anatomy of the sheep. 2nd. ed. U. of Queensland Press, Brisbane, Australia. 70-106.

Nelsen, E. W. 1912. A new subspecies of pronghorn antelope from lower California. Proc. Biol. Soc., Wash., D.C. 25:107-108.

Pennak, R. W. 1964. Collegiate dictionary of zoology. Ronald Press Co., New York. 70.

Seton, E. T. 1929. Lives of game animals. Doubleday, Doran and Co. Inc., Garden City, New York. 3(2):413-467.

Shaver, J. R. 1967. Personal communication. Secretary, American Society of Zoologist, Chicago, Ill.

Sisson, S., and Grossman, J. D. 1953. Anatomy of the domestic animals. 4th. ed. Saunders Co., Phila. 454-483.

Thorne, T. 1967. Personal communication. Research Veterinarian, Game and Fish Commission, Cheyenne, Wyoming.

Trautmann, A., and Fiebiger, J. 1952. Fundamentals of the histology of domestic animals. Comstock Publishing Assoc., Ithaca, New York. 177-216.

Trotter, D. M. 1967. Personal communication. Associate Dean, College of Veterinary Medicine, Kansas State University, Manhattan, Kansas.

Weber, A. F. 1967. Personal communication. Professor and Head, Department of Veterinary Anatomy, University of Minnesota, St. Paul, Minnesota.

Wenzel, L. E. 1955. The anatomy of the pronghorn antelope Antilocapra americana americana (Ord) 1815, with special reference to the digestive system. M.S. Thesis. U. of Wyoming, Laramie, Wyoming. 102pp.

APPENDIX

Table 8. Analysis of variance showing gastrointestinal differences between esophagus mucosal layers of sheep and pronghorn antelope.

Esophagus	d.f.	Sum Squares	Mean Squares	"F"
Total	47	0.37200	0.00792	
Species	1	0.02623	0.02623	0.92
Animals/Species	10	0.28510	0.02851	34.86**
Slides/Animals/Species	12	0.00981	0.00082	0.38
Error	24	0.05086	0.00219	

** $P < .01$.

Table 9. Analysis of variance showing gastrointestinal differences between rumen mucosal layers of sheep and pronghorn antelope.

Rumen mucosa	d.f.	Sum Squares	Mean Squares	"F"
Total	47	0.00817	0.00017	
Species	1	0.00183	0.00184	4.67
Animals/Species	10	0.00393	0.00039	4.58**
Slides/Animals/Species	12	0.00103	0.00009	1.49
Error	24	0.00137	0.00005	

** $P < .01$.

Table 10. Analysis of variance showing villi width differences in the rumen of sheep and pronghorn antelope.

Rumen villi	d.f.	Sum Squares	Mean Squares	"F"
Total	47	0.68395	0.01455	
Species	1	0.08308	0.08308	1.56
Animals/Species	10	0.53017	0.05302	41.18**
Slides/Animals/Species	12	0.01545	0.00129	0.55
Error	24	0.05529	0.00230	

** $P < .01$.

Table 11. Analysis of variance showing gastrointestinal differences between reticulum mucosal layers of sheep and pronghorn antelope.

Reticulum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	0.01709	0.00039	
Species	1	0.00079	0.00079	1.11
Animals/Species	10	0.00710	0.00071	3.25*
Slides/Animals/Species	12	0.00262	0.00022	0.79
Error	24	0.00659	0.00027	

* $P < .05$.

Table 12. Analysis of variance showing gastrointestinal differences between omasum mucosal layers of sheep and pronghorn antelope.

Omasum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	0.01668	0.00035	
Species	1	0.00021	0.00021	0.25
Animals/Species	10	0.00847	0.00085	5.75**
Slides/Animals/Species	12	0.00177	0.00015	0.57
Error	24	0.00624	0.00026	

** $P < .01$.

Table 13. Analysis of variance showing gastrointestinal differences between abomasum mucosal layers of sheep and pronghorn antelope.

Abomasum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	2.22799	0.04740	
Species	1	0.19291	0.19291	0.98
Animals/Species	10	1.96781	0.19678	290.06**
Slides/Animals/Species	12	0.00814	0.00068	0.28
Error	24	0.05913	0.00246	

** $P < .01$.

Table 14. Analysis of variance showing gastrointestinal differences between duodenum mucosal layers of sheep and pronghorn antelope.

Duodenum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	1.84928	0.03934	
Species	1	0.59563	0.59563	5.29*
Animals/Species	10	1.12663	0.11266	57.49**
Slides/Animals/Species	12	0.02352	0.00195	0.45
Error	24	0.10348	0.00432	

* $P < .05$.
** $P < .01$.

Table 15. Analysis of variance showing gastrointestinal differences between jejunum mucosal layers of sheep and pronghorn antelope.

Jejunum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	6.78211	1.44300	
Species	1	2.71748	2.71748	7.12*
Animals/Species	10	3.81736	0.38174	259.71**
Slides/Animals/Species	12	0.01764	0.00147	0.15
Error	24	0.22964	0.00957	

* $P < .05$.
** $P < .01$.

Table 16. Analysis of variance showing gastrointestinal differences between ileum mucosal layers sheep and pronghorn antelope.

Ileum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	3.49591	0.07438	
Species	1	0.84748	0.84748	3.39
Animals/Species	10	2.50229	0.25023	42.05**
Slides/Animals/Species	12	0.07143	0.00595	1.91
Error	24	0.07474	0.00311	

** $P < .01$.

Table 17. Analysis of variance showing gastrointestinal differences between caecum mucosal layers of sheep and pronghorn antelope.

Caecum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	0.71760	0.015268	
Species	1	0.28459	0.284592	7.25*
Animals/Species	10	0.39257	0.039257	38.43**
Slides/Animals/Species	12	0.01226	0.001022	0.87
Error	24	0.02818	0.001174	

* $P < .05$.
** $P < .01$.

Table 18. Analysis of variance showing gastrointestinal differences between colon mucosal layers of sheep and pronghorn antelope.

Colon	d.f.	Sum Squares	Mean Squares	"F"
Total	47	1.38222	0.02940	
Species	1	1.14886	1.14886	86.25**
Animals/Species	10	0.13318	0.01332	4.72**
Slides/Animals/Species	12	0.03389	0.00282	1.02
Error	24	0.06629	0.00276	

** $P < .01$.

Table 19. Analysis of variance showing gastrointestinal differences between rectum mucosal layers of sheep and pronghorn antelope.

Rectum	d.f.	Sum Squares	Mean Squares	"F"
Total	47	0.49976	0.01063	
Species	1	0.00317	0.00032	0.07
Animals/Species	10	0.40306	0.04031	21.46**
Slides/Animals/Species	12	0.02258	0.00188	0.64
Error	24	0.07096	0.00296	

** $P < .01$.

Table 20. Analysis of variance showing gastrointestinal differences between total esophagus thickness of sheep and pronghorn antelope.

Esophagus	d.f.	Sum Squares	Mean Squares	"F"
Total	23	9.20366	0.40015	
Species	1	0.68580	0.68580	0.82
Animals/Species	10	8.35643	0.83564	62.12**
Error	12	0.16143	0.01345	

** $P < .01$.

Table 21. Analysis of variance showing gastrointestinal differences between total rumen thickness of sheep and pronghorn antelope.

Rumen	d.f.	Sum Squares	Mean Squares	"F"
Total	23	16.86488	0.73326	
Species	1	6.29248	6.29248	7.04*
Animals/Species	10	8.93771	0.89377	6.56**
Error	12	1.63469	0.13622	

* $P < .05$.
** $P < .01$.

Table 22. Analysis of variance showing gastrointestinal differences between total reticulum thickness of sheep and pronghorn antelope.

Reticulum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	23.08563	1.00372	
Species	1	10.84877	10.84877	9.48**
Animals/Species	10	11.44949	1.14494	17.45**
Error	12	0.78736	0.06561	

** $P < .01$.

Table 23. Analysis of variance showing gastrointestinal differences between total omasum thickness of sheep and pronghorn antelope.

Omasum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	0.45729	0.01988	
Species	1	0.00459	0.00459	0.21
Animals/Species	10	0.21776	0.02178	1.09
Error	12	0.23908	0.01992	

Table 24. Analysis of variance showing gastrointestinal differences between total abomasum thickness of sheep and pronghorn antelope.

Abomasum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	10.11201	0.43965	
Species	1	1.22763	1.22763	1.44
Animals/Species	10	8.53618	0.85362	29.42**
Error	12	0.34819	0.02902	

** $P < .01$.

Table 25. Analysis of variance showing gastrointestinal differences between total duodenum thickness of sheep and pronghorn antelope.

Duodenum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	7.49523	0.32588	
Species	1	1.50500	1.50500	2.53
Animals/Species	10	5.93813	0.59381	136.77**
Error	12	0.05210	0.00434	

** $P < .01$.

Table 26. Analysis of variance showing gastrointestinal differences between total jejunum thickness of sheep and pronghorn antelope.

Jejunum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	9.84035	0.42784	
Species	1	5.90042	5.90042	15.44**
Animals/Species	10	3.82135	0.38214	38.67**
Error	12	1.18577	0.00988	

** $P < .01$.

Table 27. Analysis of variance showing gastrointestinal differences between total ileum thickness of sheep and pronghorn antelope.

Ileum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	7.67975	0.3390	
Species	1	3.87126	3.87126	10.48**
Animals/Species	10	3.69299	0.36929	38.37**
Error	12	0.11549	0.00962	

** $P < .01$.

Table 28. Analysis of variance showing gastrointestinal differences between total caecum thickness of sheep and pronghorn antelope.

Caecum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	1.74049	0.07567	
Species	1	0.69700	0.69700	6.78*
Animals/Species	10	1.02827	0.10283	81.10**
Error	12	0.01522	0.00127	

* $P < .05$.
** $P < .01$.

Table 29. Analysis of variance showing gastrointestinal differences between total colon thickness of sheep and pronghorn antelope.

Colon	d.f.	Sum Squares	Mean Squares	"F"
Total	23	6.52774	0.28381	
Species	1	5.33738	5.33738	48.70**
Animals/Species	10	1.09592	0.10959	13.92**
Error	12	0.09444	0.00787	

** $P < .01$.

Table 30. Analysis of variance showing gastrointestinal differences between total rectum thickness of sheep and pronghorn antelope.

Rectum	d.f.	Sum Squares	Mean Squares	"F"
Total	23	26.98939	1.17345	
Species	1	17.72461	17.72461	19.59**
Animals/Species	10	9.04839	0.90484	50.18**
Error	12	0.21639	0.01803	

** $P < .01$.

Table 31. Raw data measurements of mucosa, villi and complete thickness between sheep no. I.

Sheep I	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.339	0.344	2.565	0.327	0.381	2.591
Rumen villi	0.414	0.413	2.944	0.400	0.396	2.845
Rumen mucosa	0.104	0.110		0.113	0.126	
Reticulum	0.124	0.134	2.997	0.116	0.098	3.106
Omasum	0.128	0.090	0.632	0.158	0.084	0.558
Abomasum	0.603	0.604	2.083	0.604	0.598	2.093
Duodenum	0.791	0.930	2.464	0.732	0.921	2.477
Jejunum	0.723	0.670	2.093	0.744	0.628	1.974
Ileum	0.674	0.628	3.175	0.744	0.856	3.048
Caecum	0.428	0.391	1.254	0.450	0.459	1.204
Colon	0.629	0.623	1.143	0.688	0.721	1.219
Rectum	0.437	0.400	3.289	0.419	0.405	3.378

Table 32. Raw data measurements of mucosa, villi and complete thickness between sheep no. II.

Sheep II	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.539	0.461	3.112	0.539	0.446	2.997
Rumen villi	0.577	0.360	3.518	0.530	0.419	3.556
Rumen mucosa	0.083	0.078		0.099	0.098	
Reticulum	0.132	0.083	4.191	0.088	0.099	4.445
Omasum	0.084	0.079	0.586	0.081	0.088	0.456
Abomasum	0.716	0.679	2.134	0.725	0.698	2.108
Duodenum	0.905	0.869	2.413	0.716	0.919	2.474
Jejunum	1.575	1.397	2.453	1.651	1.321	2.391
Ileum	0.878	0.907	2.388	0.781	0.849	2.096
Caecum	0.613	0.577	1.574	0.530	0.595	1.549
Colon	0.651	0.813	2.159	0.790	0.605	2.032
Rectum	0.372	0.586	2.286	0.446	0.567	2.413

Table 33. Raw data measurements of mucosa, villi and complete thickness between sheep no. III.

Sheep III	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.344	0.305	2.477	0.333	0.288	2.390
Rumen villi	0.344	0.362	2.896	0.419	0.344	2.946
Rumen mucosa	0.121	0.102		0.116	0.121	
Reticulum	0.110	0.099	3.429	0.105	0.112	3.480
Omasum	0.077	0.084	0.461	0.084	0.088	0.110
Abomasum	0.700	0.733	2.403	0.744	0.672	2.413
Duodenum	0.723	0.837	1.422	0.744	0.770	1.506
Jejunum	0.849	0.838	1.051	0.803	0.827	1.173
Ileum	0.645	0.730	2.126	0.691	0.625	2.159
Caecum	0.440	0.495	0.865	0.508	0.512	0.858
Colon	0.608	0.558	1.701	0.651	0.570	1.715
Rectum	0.599	0.549	2.878	0.517	0.533	2.626

Table 34. Raw data measurements of mucosa, villi and complete thickness between sheep no. IV.

Sheep IV	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.558	0.446	3.358	0.512	0.474	3.112
Rumen villi	0.291	0.335	2.139	0.293	0.349	1.905
Rumen mucosa	0.098	0.117		0.121	0.109	
Reticulum	0.099	0.109	4.699	0.101	0.095	3.607
Omasum	0.108	0.088	0.605	0.116	0.105	0.445
Abomasum	0.814	0.791	2.540	0.848	0.791	2.477
Duodenum	0.812	0.837	1.397	0.756	0.786	1.387
Jejunum	1.256	1.234	1.658	1.346	1.331	1.751
Ileum	0.934	0.773	1.956	1.023	0.949	2.032
Caecum	0.597	0.558	1.397	0.578	0.599	1.354
Colon	0.660	0.709	1.430	0.700	0.680	1.524
Rectum	0.486	0.524	2.903	0.422	0.534	2.789

Table 35. Raw data measurements of mucosa, villi and complete thickness between sheep no. V.

Sheep V	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.480	0.505	3.383	0.502	0.393	3.734
Rumen villi	0.409	0.335	2.159	0.419	0.381	0.428
Rumen mucosa	0.091	0.099		0.105	0.110	
Reticulum	0.110	0.073	2.220	0.117	0.095	2.088
Omasum	0.099	0.088	0.558	0.110	0.101	0.418
Abomasum	0.884	0.791	3.454	0.837	0.860	3.302
Duodenum	0.628	0.698	2.456	0.695	0.744	2.388
Jejunum	1.430	1.067	2.616	1.270	1.161	2.286
Ileum	0.837	0.941	2.322	0.930	0.833	2.413
Caecum	0.877	0.721	1.587	0.791	0.712	1.590
Colon	0.837	0.756	1.905	0.707	0.744	1.955
Rectum	0.607	0.595	2.159	0.669	0.697	1.778

Table 36. Raw data measurements of mucosa, villi and complete thickness between sheep no. VI.

Sheep VI	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.544	0.419	3.988	0.539	0.488	4.064
Rumen villi	0.698	0.632	3.467	0.769	0.651	3.429
Rumen mucosa	0.117	0.125		0.110	0.127	
Reticulum	0.121	0.116	3.810	0.104	0.093	3.505
Omasum	0.102	0.091	0.512	0.084	0.081	0.298
Abomasum	1.004	0.990	3.251	0.953	0.986	3.226
Duodenum	1.107	0.949	2.794	1.032	1.125	2.845
Jejunum	1.588	1.765	2.540	1.689	1.676	2.477
Ileum	1.560	1.483	2.413	1.676	1.549	2.604
Caecum	0.493	0.498	1.321	0.512	0.558	1.334
Colon	0.799	0.833	1.575	0.744	0.832	1.638
Rectum	0.456	0.437	3.937	0.462	0.507	3.785

Table 37. Raw data measurements of mucosa, villi and complete thickness between pronghorn antelope no. I.

Antelope I	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.476	0.493	2.883	0.488	0.535	2.870
Rumen villi	0.381	0.400	1.905	0.391	0.419	2.004
Rumen mucosa	0.113	0.091		0.099	0.094	
Reticulum	0.090	0.087	3.117	0.087	0.112	2.997
Omasum	0.110	0.081	0.549	0.088	0.077	0.353
Abomasum	1.116	0.930	2.870	1.046	1.023	2.871
Duodenum	0.605	0.595	1.778	0.604	0.614	1.694
Jejunum	0.474	0.419	0.698	0.465	0.512	0.763
Ileum	0.884	0.849	1.397	0.885	0.698	1.245
Caecum	0.372	0.358	1.144	0.395	0.349	1.143
Colon	0.348	0.356	0.781	0.418	0.344	0.604
Rectum	0.400	0.418	5.652	0.432	0.434	5.461

Table 38. Raw data measurements of mucosa, villi and complete thickness between pronghorn antelope no. II.

Antelope II	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.442	0.572	4.064	0.567	0.549	4.034
Rumen villi	0.326	0.309	1.727	0.306	0.297	1.371
Rumen mucosa	0.101	0.095		0.102	0.103	
Reticulum	0.099	0.094	2.362	0.088	0.110	2.540
Omasum	0.121	0.112	0.673	0.112	0.077	0.523
Abomasum	1.023	1.004	2.906	1.042	0.902	2.880
Duodenum	0.623	0.670	1.938	0.618	0.619	2.083
Jejunum	1.079	1.069	1.549	1.016	1.117	1.372
Ileum	0.651	0.607	2.118	0.611	0.651	1.956
Caecum	0.409	0.465	0.809	0.411	0.421	0.753
Colon	0.418	0.383	0.721	0.365	0.358	0.704
Rectum	0.465	0.338	4.953	0.400	0.402	4.757

Table 39. Raw data measurements of mucosa, villi and complete thickness between pronghorn antelope no. III.

Antelope III	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.366	0.384	2.743	0.326	0.350	2.731
Rumen villi	0.279	0.288	1.049	0.275	0.372	1.143
Rumen mucosa	0.102	0.095		0.083	0.085	
Reticulum	0.098	0.134	2.667	0.128	0.120	2.794
Omasum	0.088	0.093	0.651	0.087	0.092	0.356
Abomasum	0.595	0.541	1.600	0.569	0.586	1.601
Duodenum	0.716	0.671	1.461	0.675	0.605	1.324
Jejunum	0.790	0.660	1.171	0.791	0.744	1.049
Ileum	0.698	0.688	2.286	0.689	0.707	2.214
Caecum	0.581	0.539	1.080	0.523	0.558	1.193
Colon	0.413	0.431	0.723	0.465	0.431	0.698
Rectum	0.558	0.460	5.041	0.563	0.535	4.953

Table 40. Raw data measurements of mucosa, villi and complete thickness between pronghorn antelope no. IV.

Antelope IV	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.381	0.419	2.921	0.395	0.409	2.794
Rumen villi	0.233	0.242	1.397	0.276	0.251	1.448
Rumen mucosa	0.082	0.094		0.090	0.085	
Reticulum	0.061	0.088	1.600	0.129	0.077	1.524
Omasum	0.099	0.092	0.620	0.088	0.091	0.391
Abomasum	0.605	0.586	1.219	0.623	0.604	1.300
Duodenum	0.837	0.791	2.223	0.920	0.835	2.032
Jejunum	0.698	0.670	0.884	0.744	0.722	1.011
Ileum	0.756	0.837	1.079	0.698	0.724	0.955
Caecum	0.344	0.372	0.893	0.354	0.371	0.976
Colon	0.418	0.586	0.930	0.349	0.400	0.722
Rectum	0.512	0.577	3.734	0.437	0.493	3.988

Table 41. Raw data measurements of mucosa, villi and complete thickness between pronghorn antelope no. V.

Antelope V	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.539	0.535	2.108	0.523	0.628	2.413
Rumen villi	0.535	0.512	1.981	0.511	0.535	1.803
Rumen mucosa	0.095	0.083		0.090	0.080	
Reticulum	0.093	0.116	1.448	0.140	0.102	1.801
Omasum	0.118	0.149	0.479	0.130	0.125	0.316
Abomasum	0.911	0.930	1.956	0.911	0.804	1.397
Duodenum	0.212	0.251	0.809	0.256	0.214	0.810
Jejunum	0.930	0.763	1.219	0.908	0.735	1.295
Ileum	0.391	0.399	1.461	0.395	0.442	1.397
Caecum	0.367	0.381	1.143	0.418	0.381	1.128
Colon	0.419	0.414	0.670	0.367	0.418	0.632
Rectum	0.512	0.628	4.013	0.530	0.605	4.039

Table 42. Raw data measurements of mucosa, villi and complete thickness between pronghorn antelope no. VI.

Antelope VI	Slide I		Complete Thickness	Slide II		Complete Thickness
Esophagus	0.558	0.577	2.096	0.535	0.581	2.057
Rumen villi	0.321	0.288	2.134	0.382	0.414	1.981
Rumen mucosa	0.115	0.102		0.113	0.108	
Reticulum	0.072	0.068	1.303	0.072	0.073	1.288
Omasum	0.118	0.085	0.372	0.077	0.088	0.251
Abomasum	1.397	1.240	2.433	1.346	1.334	3.023
Duodenum	0.763	0.586	1.956	0.701	0.698	1.905
Jejunum	0.465	0.577	0.725	0.605	0.465	0.827
Ileum	0.679	0.744	1.461	0.744	0.721	1.524
Caecum	0.372	0.385	0.744	0.326	0.344	0.791
Colon	0.352	0.331	0.610	0.354	0.344	0.883
Rectum	0.716	0.698	4.064	0.791	0.712	4.191