

THE INNER EAR ANATOMY OF THE SQUIRREL MONKEY

The Study of Horizontal Serial Sections*

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Monograph No. 8

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PREFACE

The squirrel monkey (*saimiri sciurina*) is probably one of the most useful experimental primates in recent days. They are small, not very difficult to handle, inexpensive primates, and good for all kinds of vestibular and cochlear functional experiments, behavioral conditioning, and so on.

Since all inner ear sensory end organs are only purely mechanically stimulated in the vital bodies under natural circumstances, it is worthwhile to know the anatomical construction before performing any functional experimentation. For this purpose, the horizontal serial sections are excellent for acquiring good three-dimensional figures of the inner ear structures. All illustrations in this monograph will be limited within the usual anatomical (light-microscopical) structures, not extending to ultrastructures.

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ABST

Part I of this monograph includes a series of microphotographs of the horizontal serial sections under low magnification (about 20 x). This series is the right ear viewing from the superior. A branched arrow, which appears at the corner of each picture, indicates the plane parallel to the sagittal (occipito-frontal) line. The arrow is pointing toward the front, and the extension is toward the lateral. The interval between each picture is 200 microns. Some very important structure may not be labeled in every picture to avoid congestion.

Part II includes higher magnification views of some important structures from this series and from the other animals, and some humans.

Part III includes several bilateral temporal bone microphotographs (horizontal sections) of squirrel monkeys and cats. The modiolar angle and the posterior semicircular canal plane are clearly demonstrated in this series.

Author

PREPARATION OF MONKEY TEMPORAL BONE

A normal, healthy, young squirrel monkey was deeply anesthetized, and perfused intravitaly (cardiac) with 300 ml. of normal saline solution, followed by 300 ml. of 10% formalin solution. After the perfusion, the temporal bone was dissected out and immersed into 10% formalin solution (4°C) for further fixation. After the fixation was completed, the bone was decalcified with 5% trichloroacetic acid solution (21 days), chemically tested, neutralized with 5% sodium sulfate solution, dehydrated with graduated percentages of ethyl alcohol (7 days), embedded in celloidin (7 weeks), and hardened (4 weeks). The shaking apparatus was employed during decalcification and celloidin-embedding. The tissue was serially sectioned at 20 microns in the horizontal plane. One out of each ten sections was stained in hematoxylin-eosin, and mounted on glass slides with xylene-balsam.

Part I

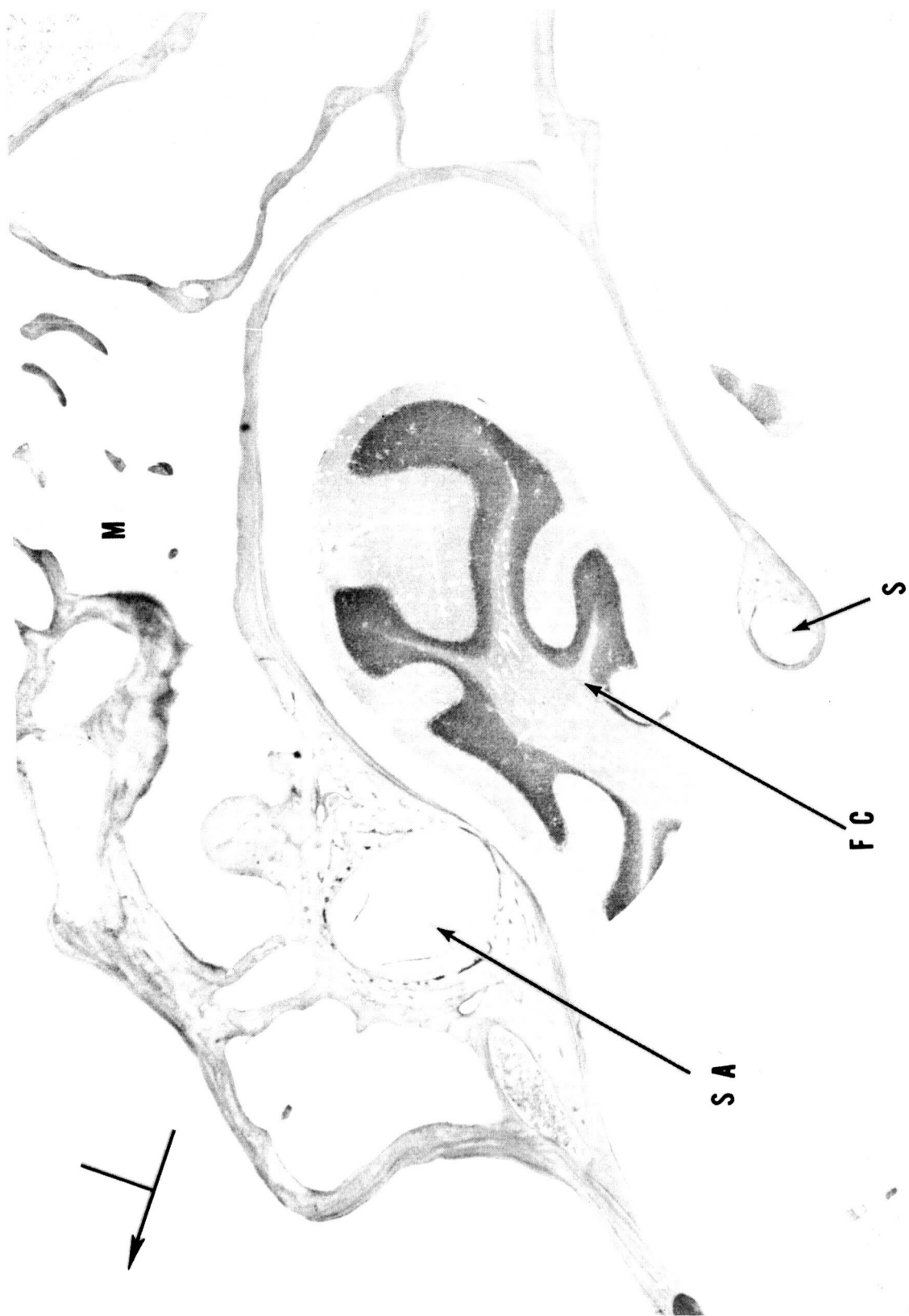


Figure 1-1

Legend I-1

- M : Mastoid
- SA : Superior semicircular canal ampulla
- FC : Cerebellar flocculus
- S : Superior semicircular canal

The highest inner ear structure is the superior semicircular canal. This section shows the upper part of the superior canal ampulla, which is much wider than the canal side. A thin bony wall separates a large mastoid air space from the cerebellar side.

The plane of the superior semicircular canal is about $35 - 40^{\circ}$ (degrees) to the sagittal mid-line.



Figure 1-2

Legend I-2

- H : Horizontal semicircular canal
- SC : Superior semicircular canal crista
- S : Superior semicircular canal

The medial edge of the superior canal crista starts at this level. A large cerebellar flocculus sticks out posterior-laterally between two crura of the superior canal. The pneumatization of the temporal bone is quite extensive in the squirrel monkey, possibly to make their skulls lighter.

The highest part of the lateral (horizontal) semicircular canal appears.

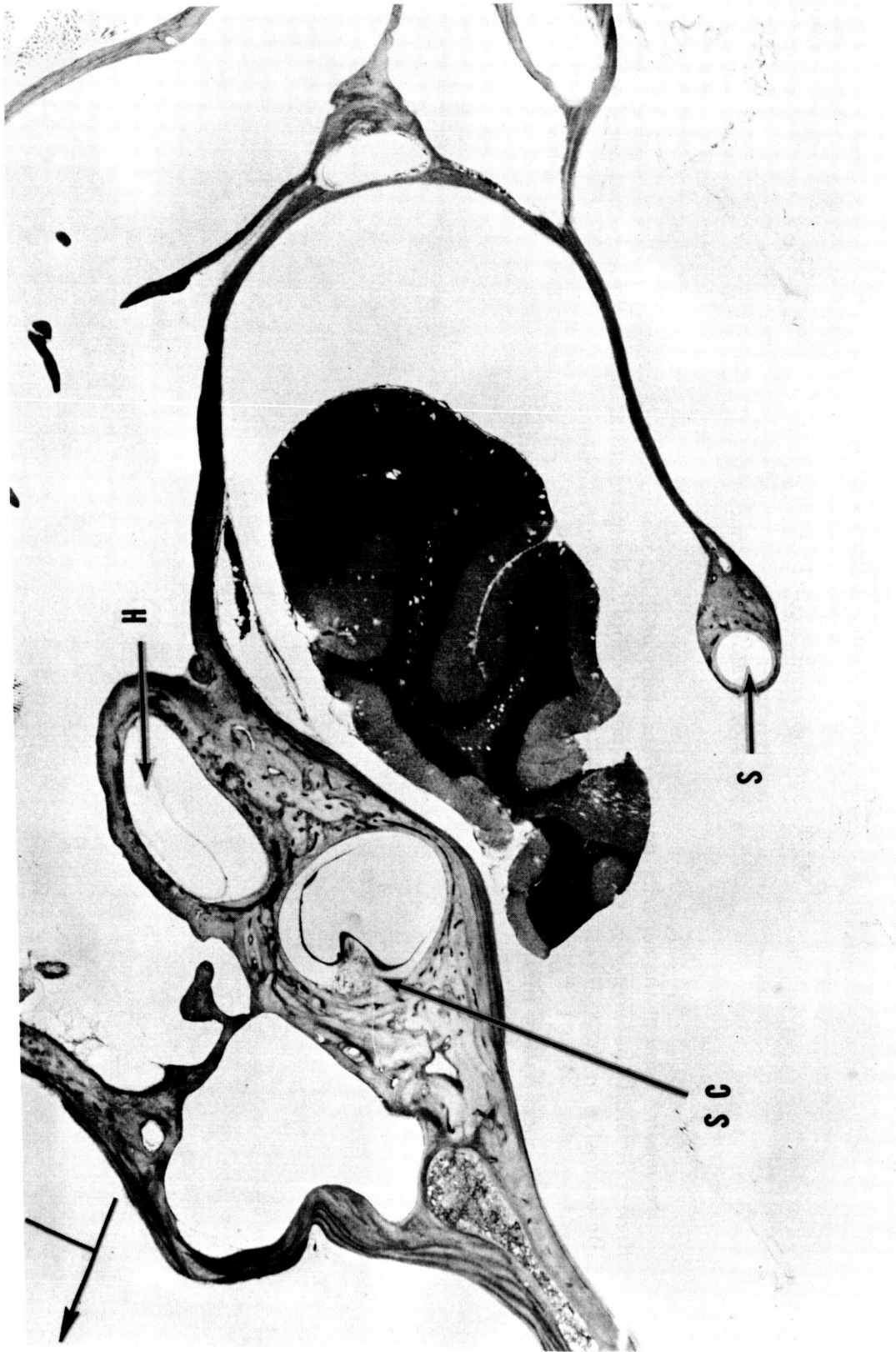


Figure 1-3

Legend I-3

- H : Horizontal semicircular canal
- SC : Superior semicircular canal crista
- S : Superior semicircular canal

Cupula is seen on the superior canal crista. Notice the long axis of the canal crista is slightly curved and is not crossing the exact diametrical center of the ampulla.

The horizontal (lateral) canal is approaching to the ampulla.

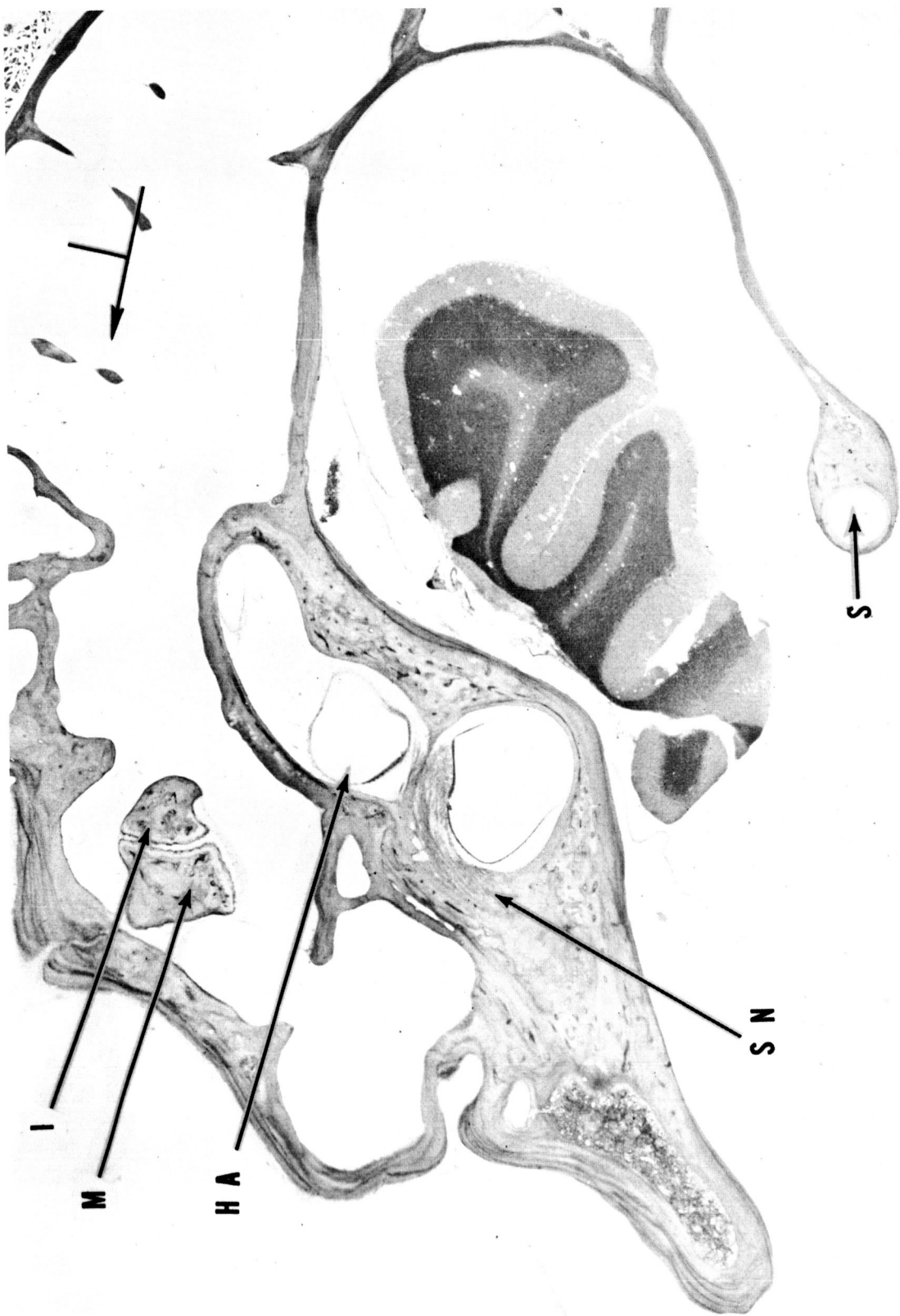


Figure 1-4

Legend 1-4

M : Malleus

I : Incus

HA : Horizontal semicircular canal ampulla

SN : Superior ampullar nerve

S : Superior semicircular canal

At this level, a thin bony ridge exists between two ampullae (superior and horizontal). They both open to the utricle below this level. The utricle has five openings to the canals and one to the endolymphatic duct.

The top parts of the ossicles appear in the tympanic cavity.

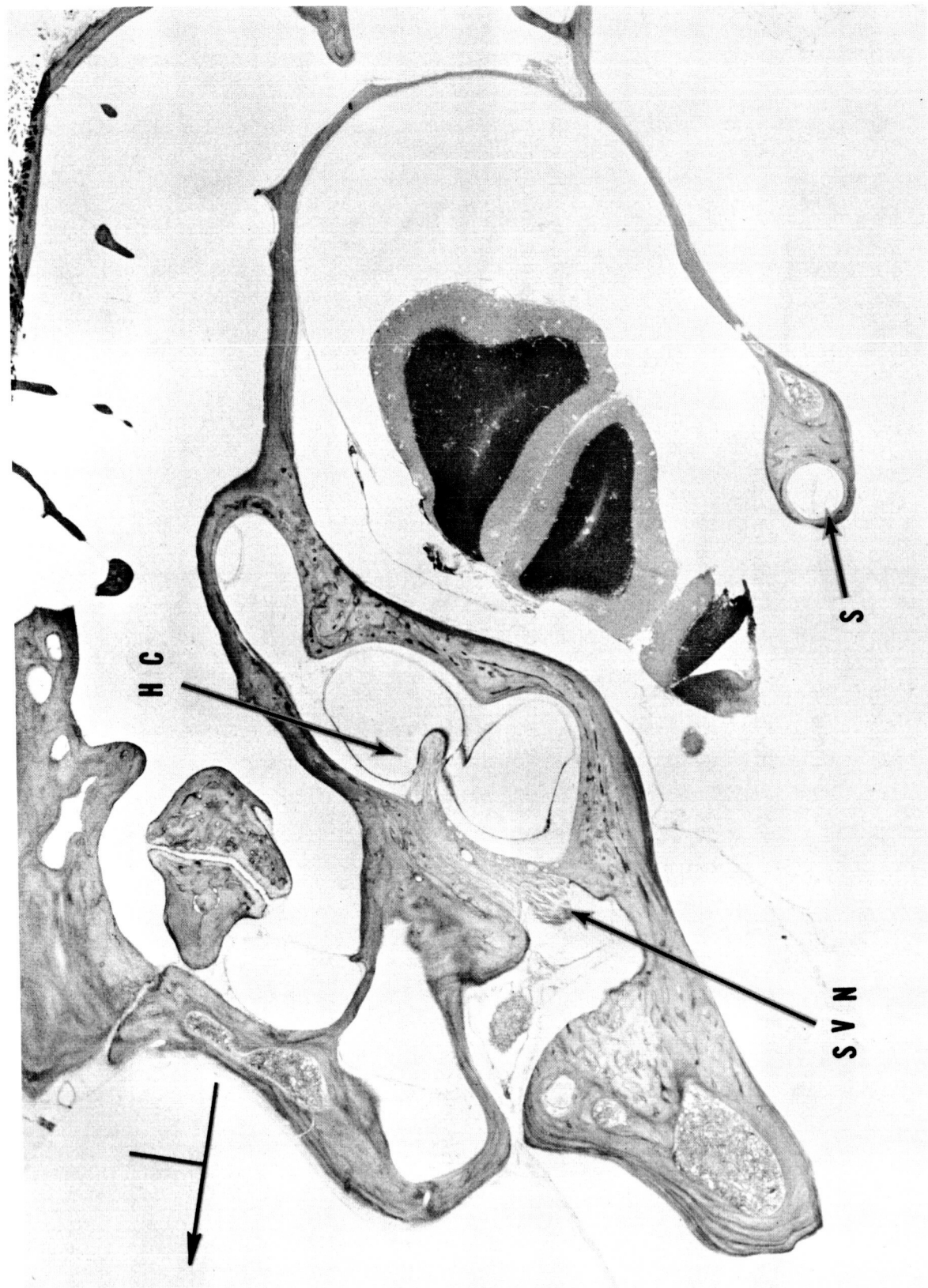


Figure 1-5

Legend I-5

HC : Horizontal semicircular canal crista

SVN: Superior vestibular nerve

S : Superior semicircular canal

A part of the superior vestibular nerve goes to the horizontal canal crista. The long axis of the crista ampullaris is slightly curved also. The openings of the superior canal ampulla and the horizontal canal ampulla into the utricle are very close to one another.

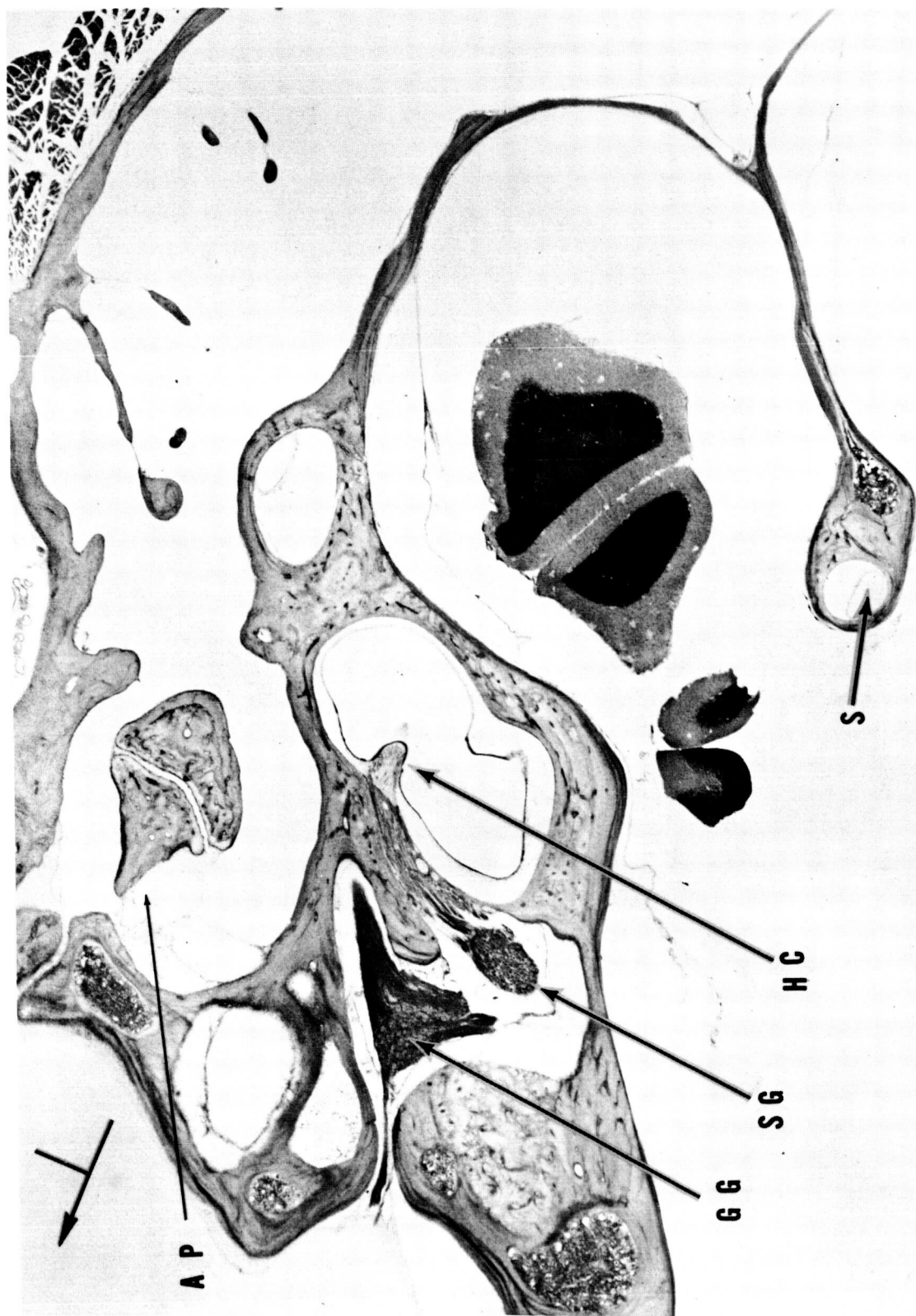


Figure 1-6

Legend I-6

AP : Anterior process of the malleus

GG : Geniculate ganglion (VII)

SG : Scarpa's ganglion of superior vestibular nerve

HC : Horizontal semicircular canal crista

S : Superior semicircular canal

Facial genu, the right angle corner of the internal portion and horizontal portion of the facial nerve, is observed here. Greater superficial petrosal nerve separates from genu facialis. Notice the difference between the Scarpa's ganglion and geniculate ganglion. Horizontal ampullar nerve is a part of the superior vestibular nerve. Cupula is seen on the horizontal canal crista. (See II-1.)^{*} Anterior process of the malleus carries a fairly wide anterior malleolar ligament. Malleo-incudal joint has a strong ligament also.

^{*}All references are to figure numbers not page numbers.



Figure 1-7

Legend 1-7

- AP : Anterior process of the malleus
- C : Cochlea (Basal turn)
- MU : Utricular macula
- H : Horizontal semicircular canal

The highest part of the cochlea, and the otolith organ appear in this picture. The cochlea shows the lateral-most structures: spiral ligament, stria vascularis, spiral prominence, outer sulcus cells, and Reissner's membrane. The utricular macula is facing posteriorly and slightly medially. Note the otoconia on the macula. Chorda tympani nerve appears right in the middle of the tympanic cavity.

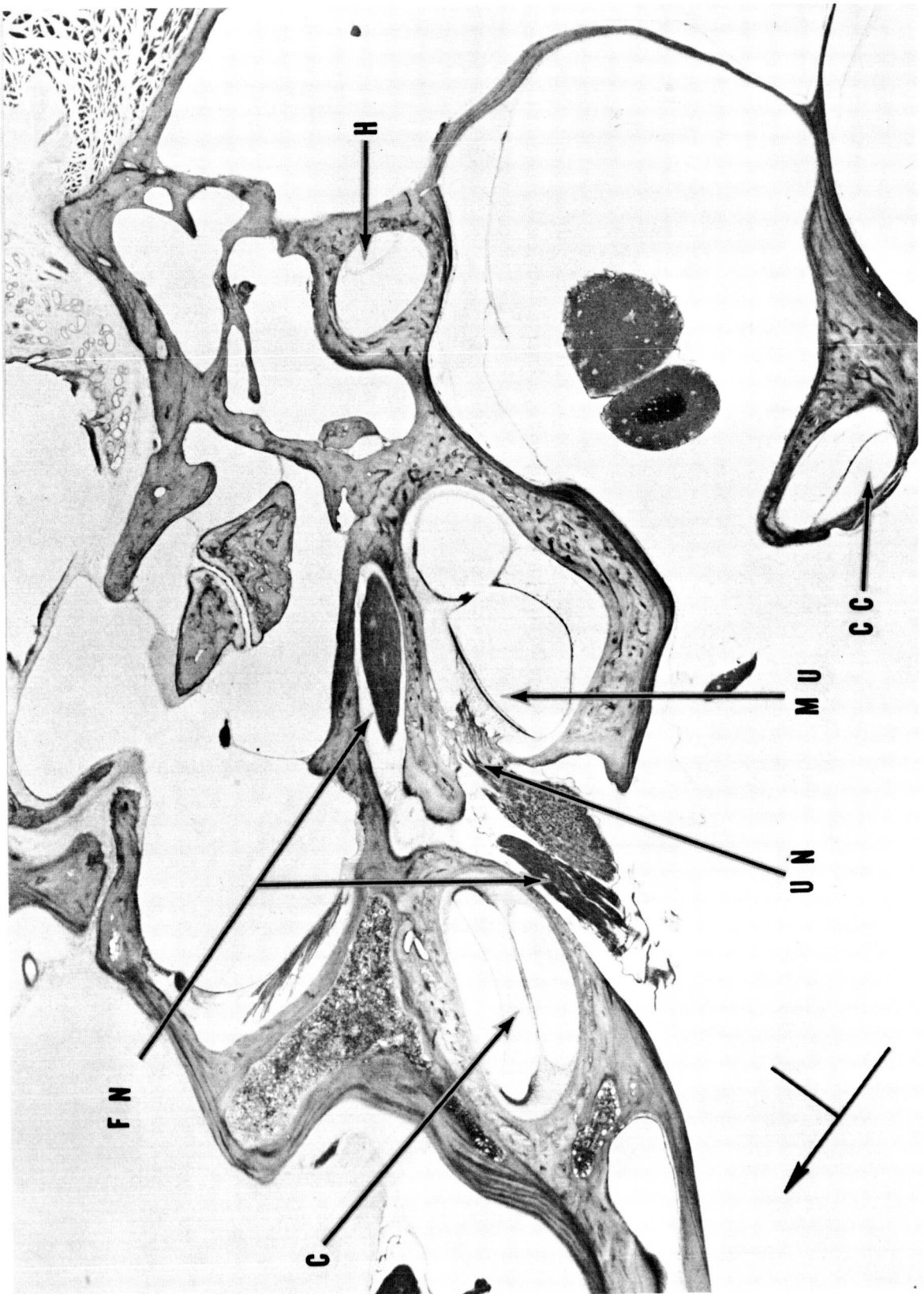


Figure 1-8

Legend 1-8

C : Basal turn of the cochlea

FN : Facial nerve

MU : Utricular macula

UN : Utricular nerve

CC : Common crus

H : Horizontal semicircular canal

The utricular nerve is a part of the superior vestibular nerve. The upper part of the macula utriculi is still located on the bony wall (see 11-2). Several epithelial folds are observed around the malleus and incus. Next to the macula utriculi is the horizontal canal ampulla.

Common crus is the junction of the nonampullated ends of the superior and posterior semicircular canals and is wider than other portions of the canals.

Tensor tympani muscle starts to appear in the middle ear cavity.



Figure 1-9

Legend 1-9

I : Short process of incus

TT : Tensor tympani muscle

MU : Utricular macula

CC : Common crus

The middle portion of the macula utriculi is coming away from the bony wall into the vestibular space. The facial nerve has almost finished its horizontal run. The posterior canal begins to extend from crus commune. (Note the angle.)

Chorda tympani is running across the middle ear cavity. Tensor tympani tendon will appear below this level.

Cochlea shows two views of the Organ of Corti on both sides; therefore, the tangential cut of the basal turn has already passed. (See 11-3 & 4.)

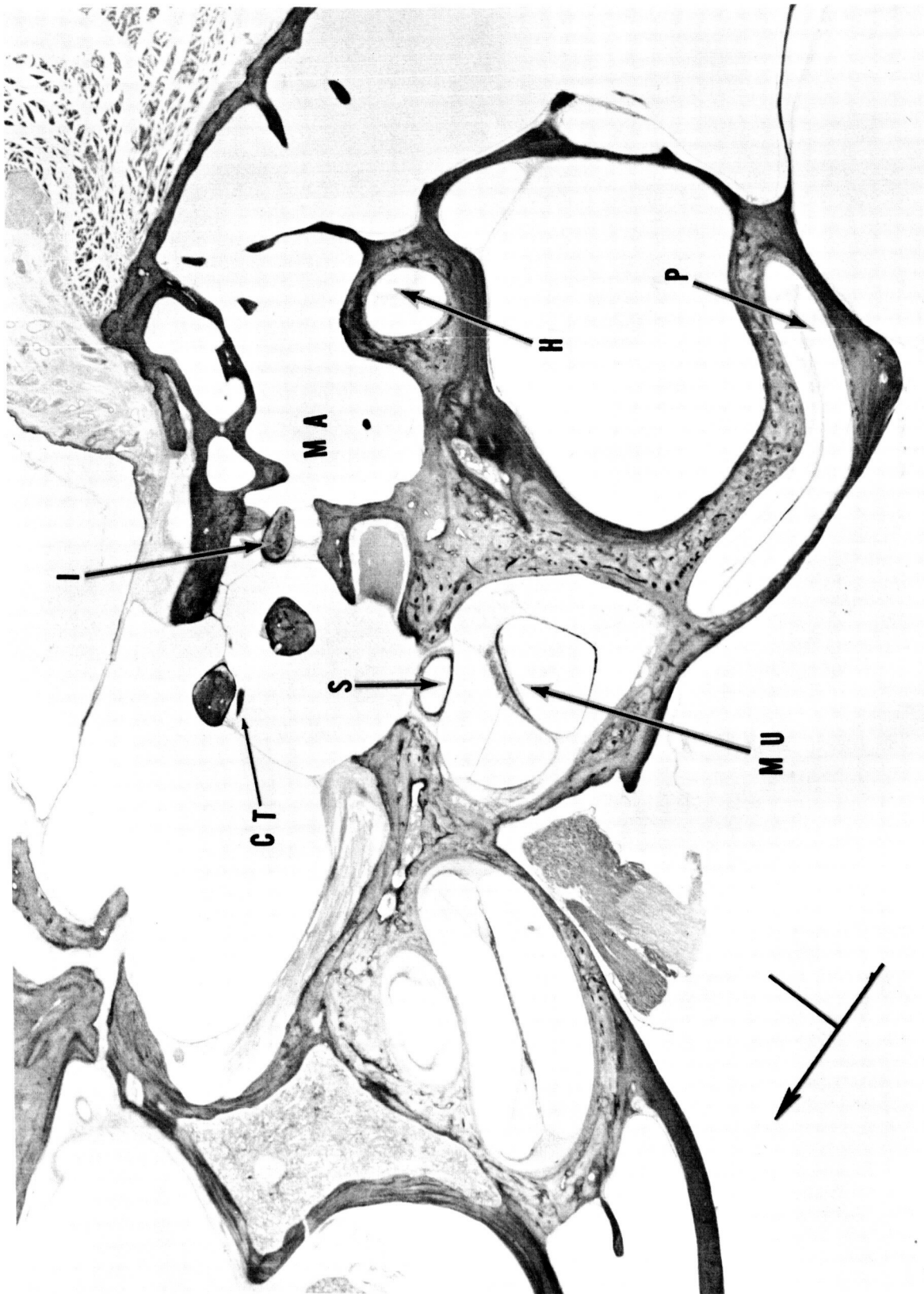


Figure I-10

Legend I-10

CT	: Chorda tympani nerve
I	: Short process of incus
MA	: Mastoid antrum
S	: Stapes footplate
MU	: Utricular macula
H	: Horizontal semicircular canal
P	: Posterior semicircular canal

The lower part of the macula utriculi is suspended in the vestibular space and faces posterior-medial (almost parallel to the basilar membrane of the cochlea). The upper part of the sacculle appears in this section (see I1-5). The angle between crus commune and the posterior canal is slightly over 90 degrees at this level. The facial canal has just crossed over the oval window. Chorda tympani is just going through between the malleus and incus. The short process of the incus is located at aditus ad antrum, the small opening between the tympanic cavity and mastoid antrum, and is surrounded by the posterior incudal ligament.

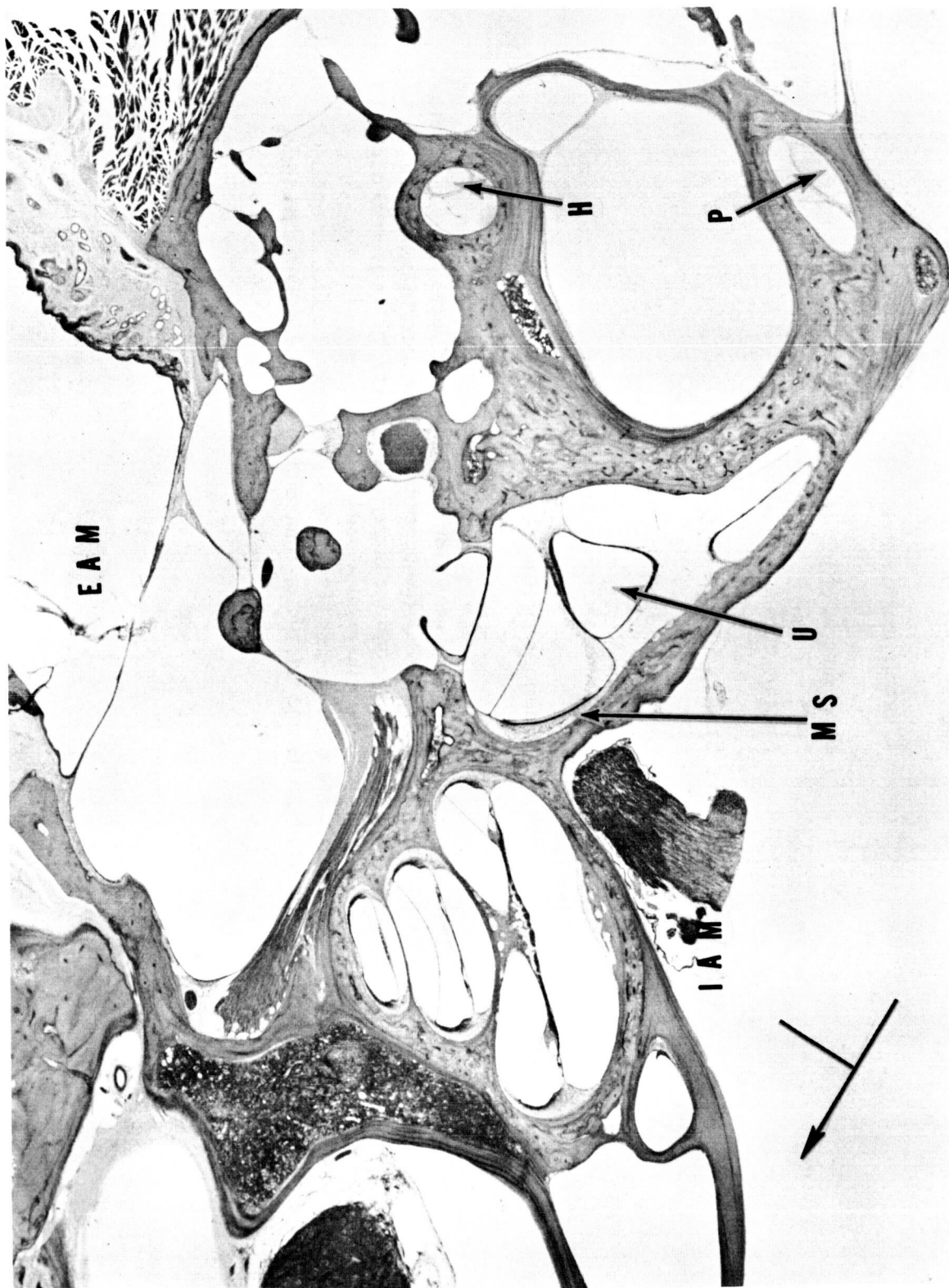


Figure I-11

Legend I-11

EAM:	External auditory meatus
IAM:	Internal auditory meatus
U	: Utricle
MS	: Sacculus macula
H	: Horizontal semicircular canal
P	: Posterior semicircular canal

Chorda tympani has just passed through between malleus and incus. Many epithelial folds around the ossicles are observed. Notice the relation between macula sacculi and the very low part of macula utriculi (almost at right angle). This picture shows a route of transmetal approach to the oval window area and the vestibular apparatus.

This section shows three turns of the cochlea with four views of the Organ of Corti.

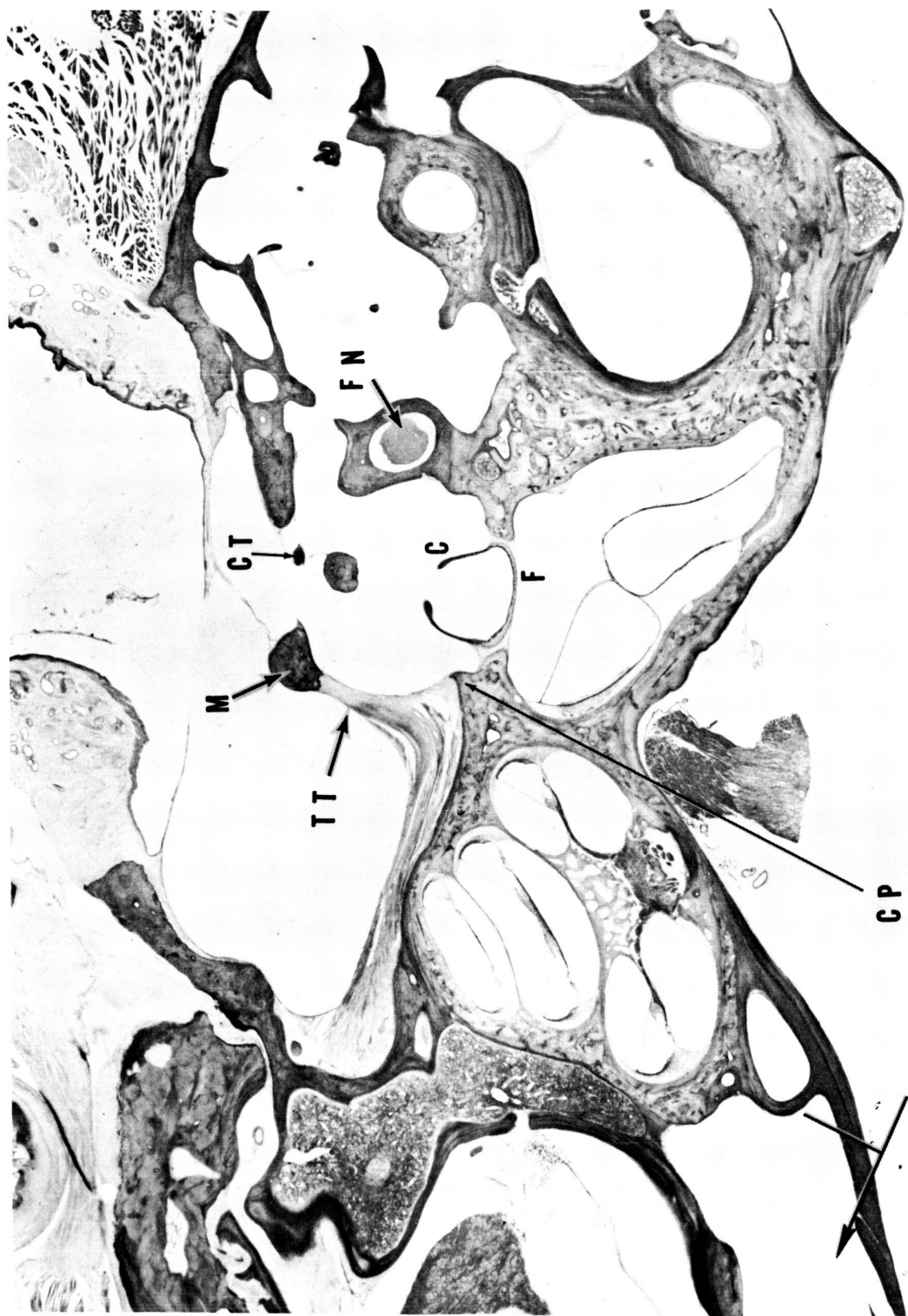


Figure I-12

Legend I-12

M	: Neck of malleus
TT	: Tensor tympani tendon (see II-9)
CT	: Chorda tympani nerve
FN	: Facial nerve
C	: Crura of stapes
F	: Footplate of stapes
CP	: Cochleaform process

The spiral ganglion of the basal turn is cut almost tangentially. Altogether, the cochlea shows six views of the Organ of Corti. The facial nerve is surrounded completely by bone at this level. The footplate is thin and not flat. The annular ligament is fairly wide, however. Crura look very fragile. A part of saccular membrane and utricular membrane is attached at this level. No definite reinforced area is observed on saccular membrane in this squirrel monkey. (See II-6,7,8.)

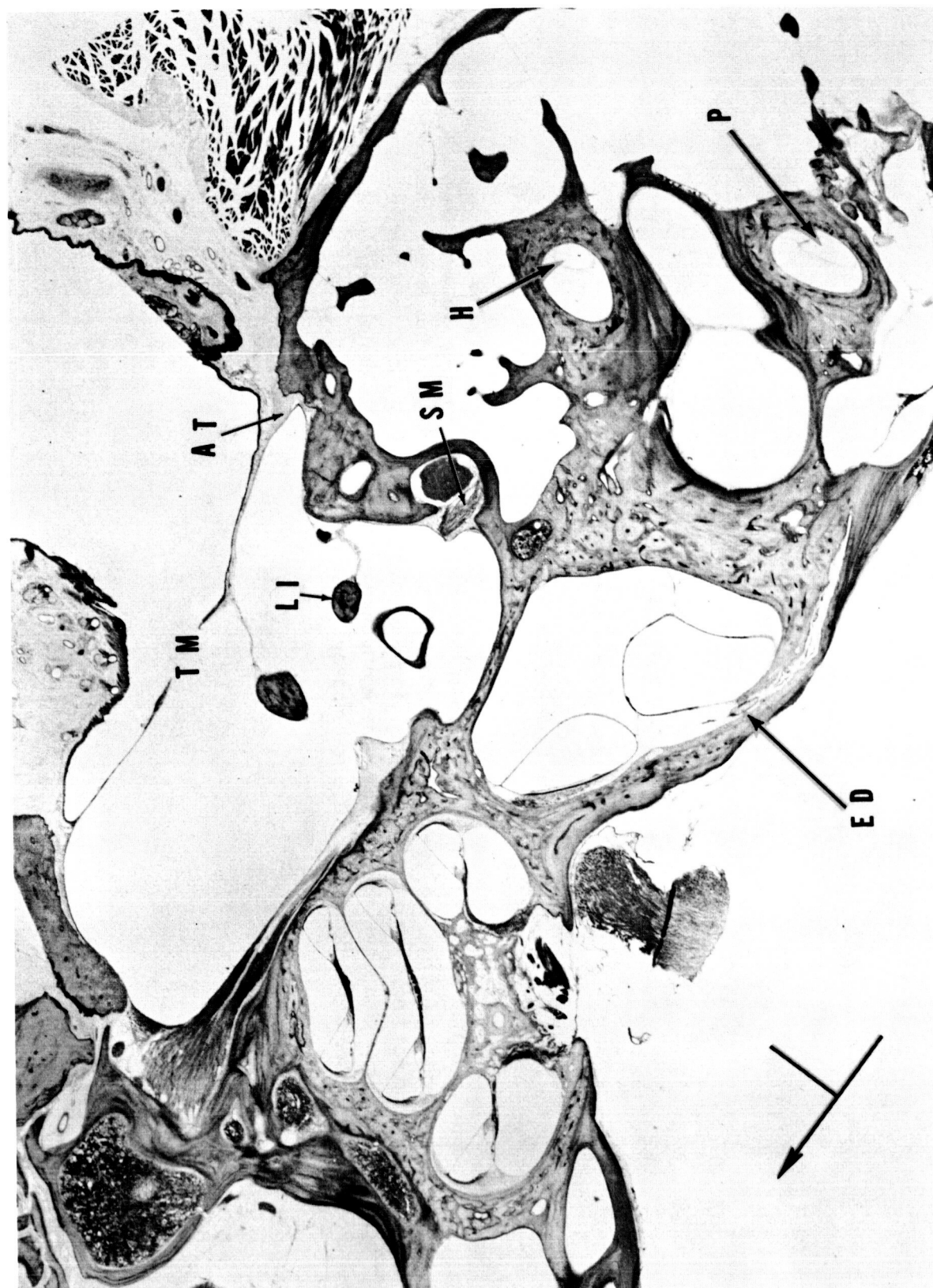


Figure I-13

Legend I-13

TM	: Tympanic membrane
AT	: Tympanic annulus
LI	: Long process of incus
SM	: Stapedial muscle
H	: Horizontal semicircular canal
P	: Posterior semicircular canal
ED	: Endolymphatic duct

The stapedial muscle is coming out from the facial canal. Both horizontal and posterior canals are protruding out into the mastoid air space. Macula sacculi is almost parallel to the modiolus. The endolymphatic duct has almost reached the sac. The saccular and utricular membranes will not be attached below this level.

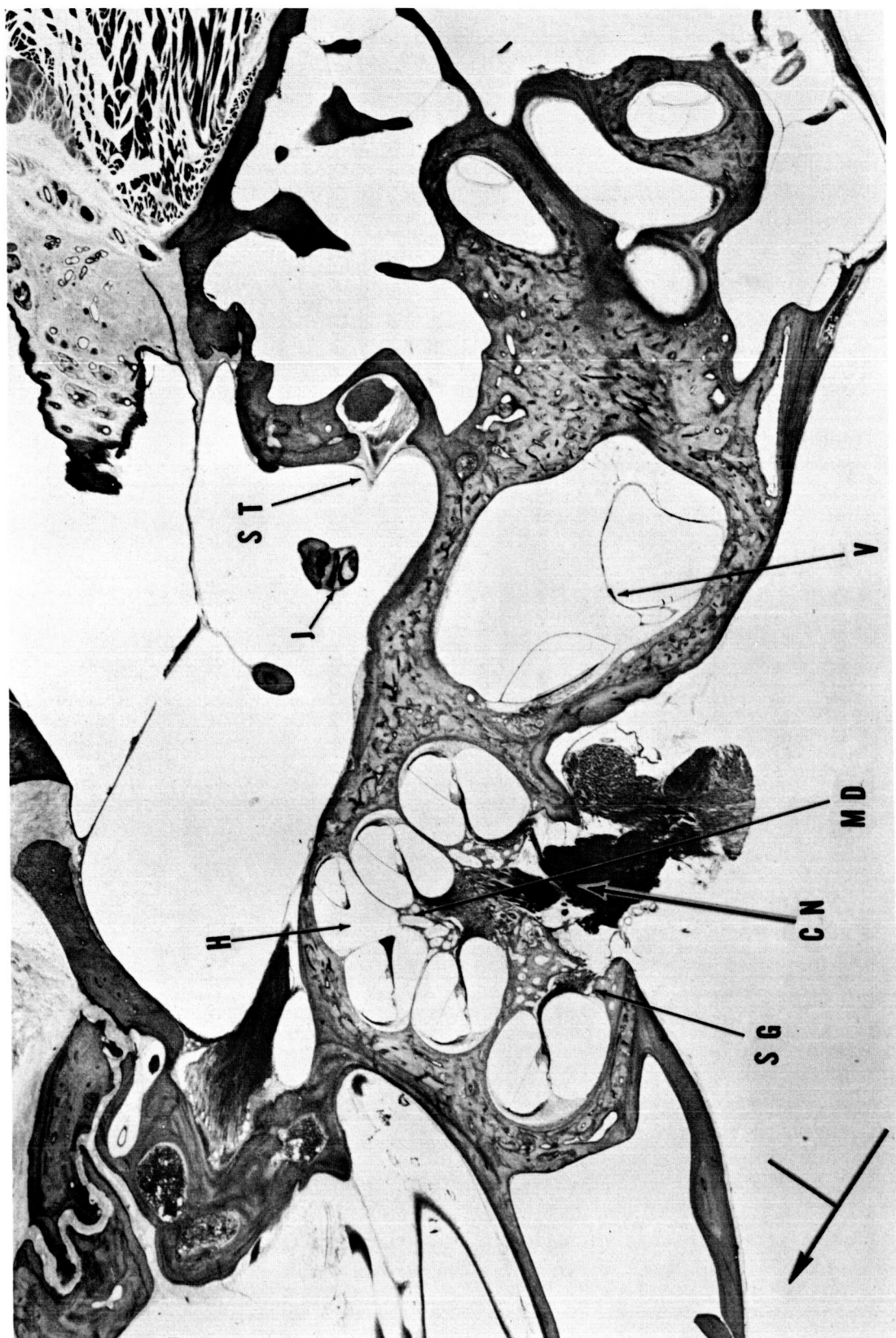


Figure I-14

Legend I-14

J	: Incudo-stapedial joint
ST	: Stapedial tendon
H	: Helicotrema
SG	: Spiral ganglion
CN	: Cochlear nerve
MD	: Modiolus
V	: Utriculo-endo-lymphatic valve (fold) (see II-10)

The mid-modiolus section shows the helicotrema which is the apical opening between scala tympani and scala vestibuli. Notice the twist of the cochlear nerve in the internal auditory meatus. Malleus is not attached to the drum at this level. The stapedial tendon will attach to the head of the stapes. Carotid artery comes into view from the anterior.

Three layers of the otic capsule are clearly definable around the cochlea. These layers are: periosteal (external perichondrial) zone, from the outside of the otic capsule, endochondral zone, and endosteal (internal perichondrial) zone.



Figure I-15

Legend I-15

HK	: Hook region of the cochlea
H	: Horizontal semicircular canal
P	: Posterior semicircular canal
IVN	: Inferior vestibular nerve
SN	: Sacculus nerve
SD	: Sacculus duct
PP	: Papilla at the junction of horizontal canal and utricle

The hook region of the cochlea begins to appear from the lateral wall of the vestibule, showing spiral ligament, stria vascularis, and Reissner's membrane. There is a papillary epithelial mound at the junction of the horizontal canal (posterior crus) and utricle, which has been referred to as the rudimentary macula neglecta by some investigators. The saccular nerve goes through the bony wall somewhat anterior to the macula. Notice a number of glands in the external canal skin.

Some Organ of Corti from the human and the cat will be seen at II-11, 12, 13, 14.

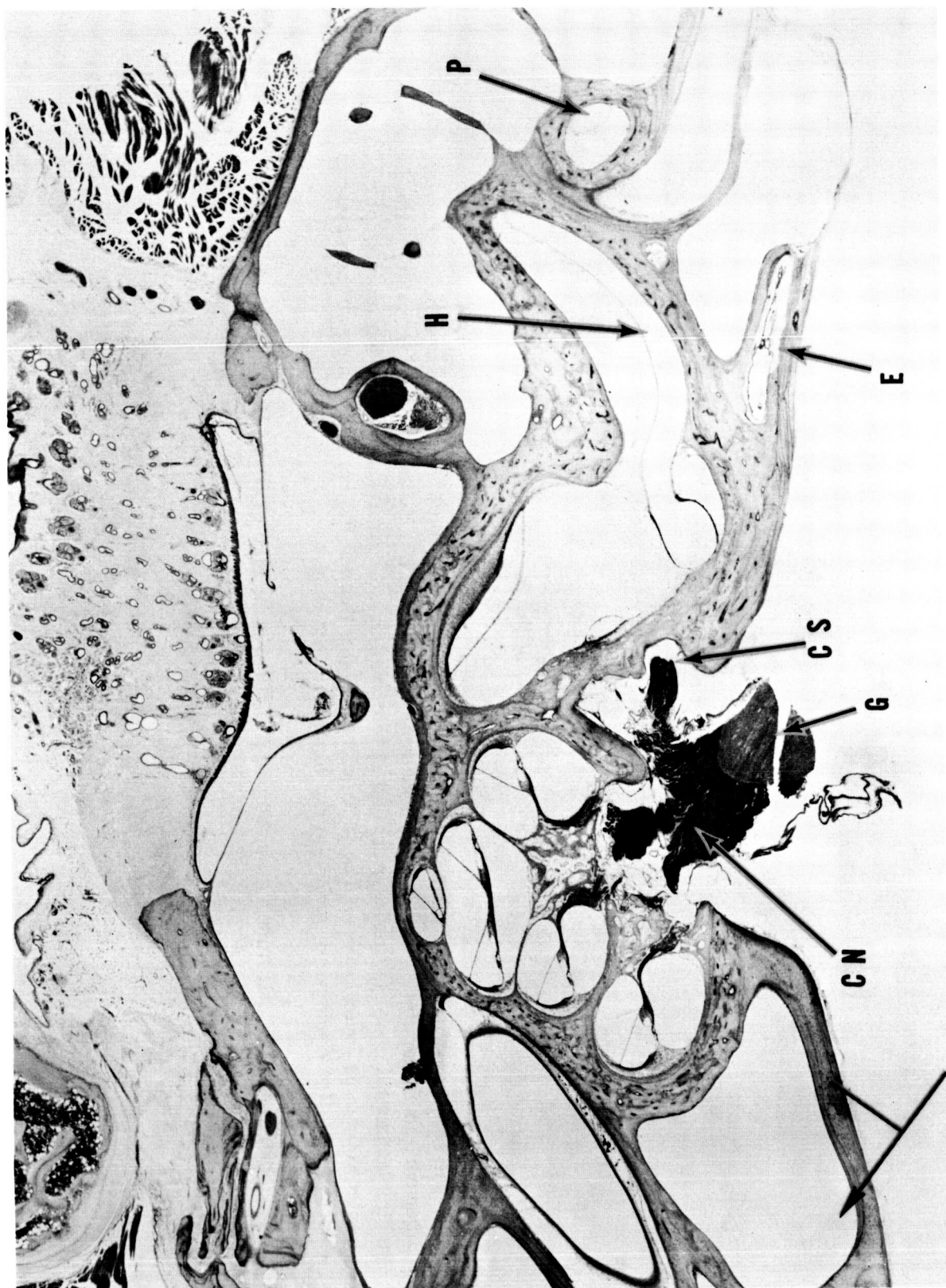


Figure I-16

Legend I-16

CN	: Cochlear nerve
G	: Glial zone
CS	: Canalis singularis (or Foramen singulare)
E	: Endolymphatic sac
H	: Horizontal semicircular canal
P	: Posterior semicircular canal

The twist of the cochlea nerve is observed. The cochlea nerve branch going to the basal hook end and the inferior vestibular nerve are so close that cross nerve fibers may exist. The posterior crus of horizontal canal is merging with the inferior utricular sinus. The rupture of the tympanic membrane is due to the middle ear irrigation with fixative solution after the temporal bone dissection. The purpose of this technique is to flush the air from the specimen.

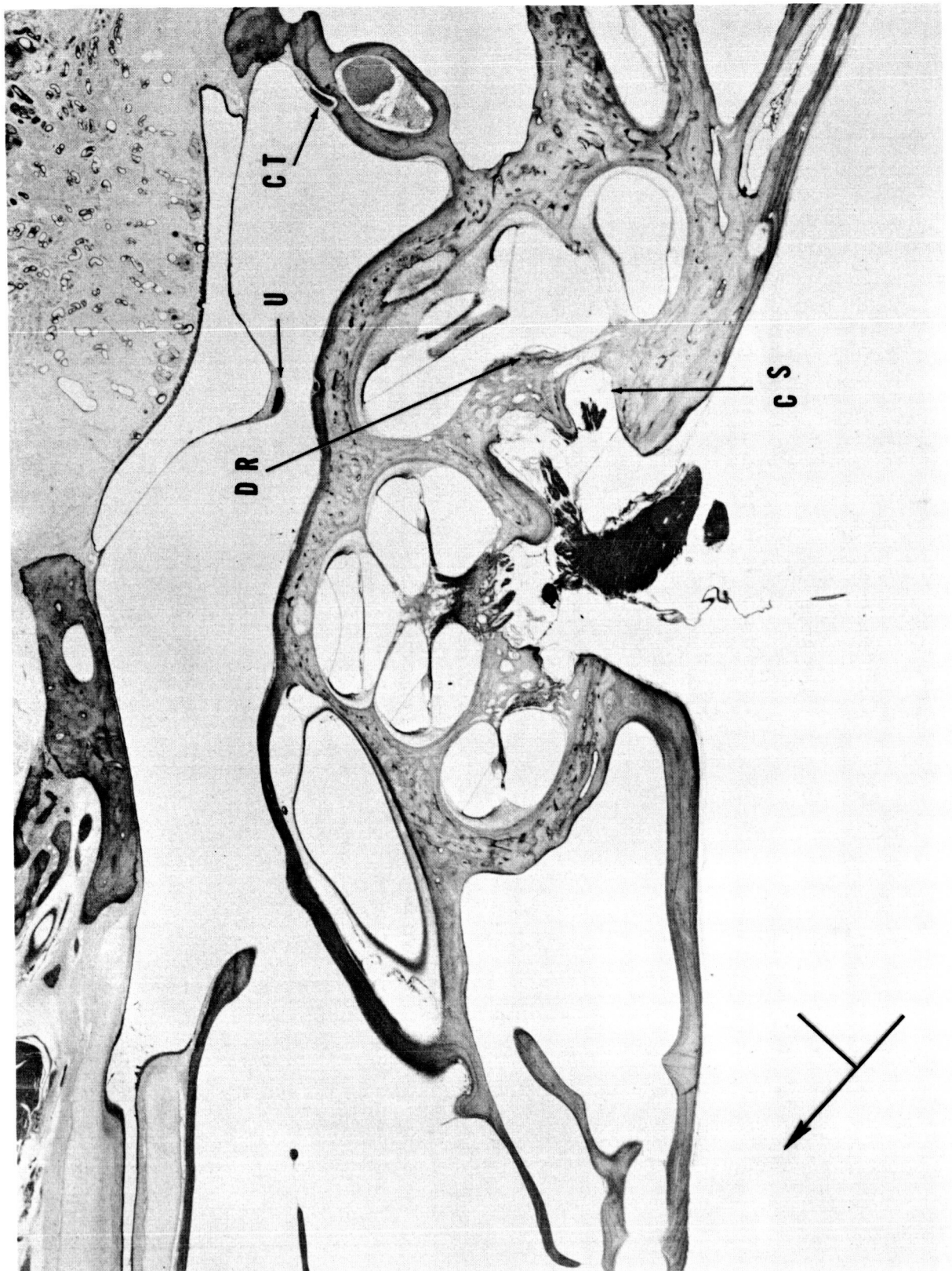


Figure I-17

Legend I-17

- U : Umbo (Malleus)
- CT : Chorda tympani nerve
- DR : Ductus reuniens
- CS : Canalis singularis (or Foramen singulare)

The open orifice of the Eustachian tube is surrounded by cartilage. Chorda tympani has just come out from the facial canal. The spiral ganglion of the middle turn is cut tangentially. The view of the hook area shows two views of the Organ of Corti (seven Organ of Corti altogether). Ductus reuniens usually runs almost horizontally, connecting sacculus to scala media, just below this level. No bony wall exists between scala vestibuli of the cochlear hook and posterior ampulla at this level. Notice the close location of canalis singularis nerve and the cochlear nerve innervating the hook region. These are also very close to the saccular nerve. The endolymphatic sac is completely surrounded by bone at this level.

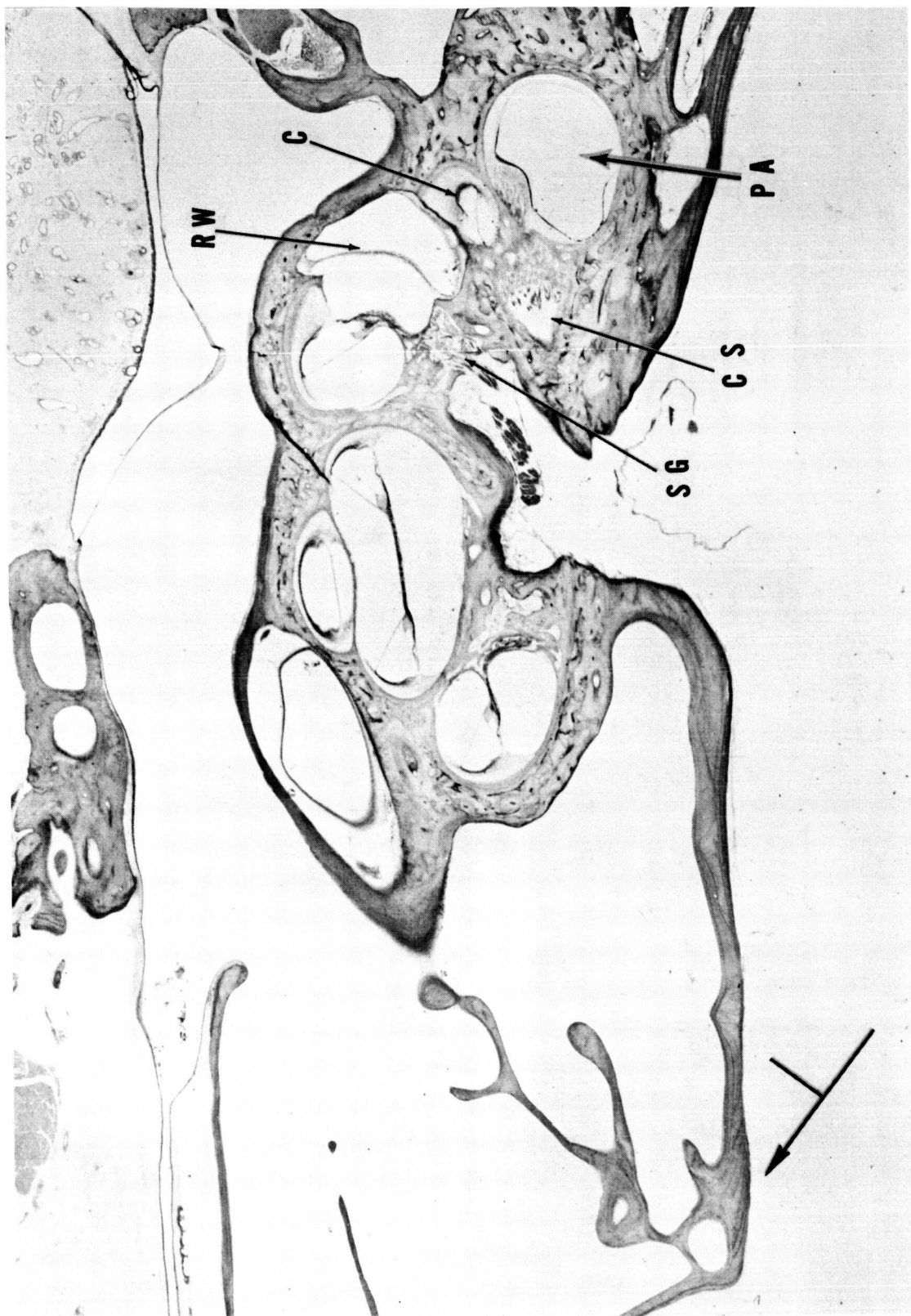


Figure I-18

Legend I-18

RW : Round window membrane

C : Caecum vestibulare

SG : Spiral ganglion

CS : Canalis singularis

PA : Posterior semicircular canal ampulla

The very basal end of the cochlear duct is located between the round window niche and posterior ampulla. Notice the reversed view of the cochlear duct at the end. A fairly large secondary osseous spiral lamina is seen next to the round window membrane. The lateral edge of the posterior crista starts in the posterior ampulla.

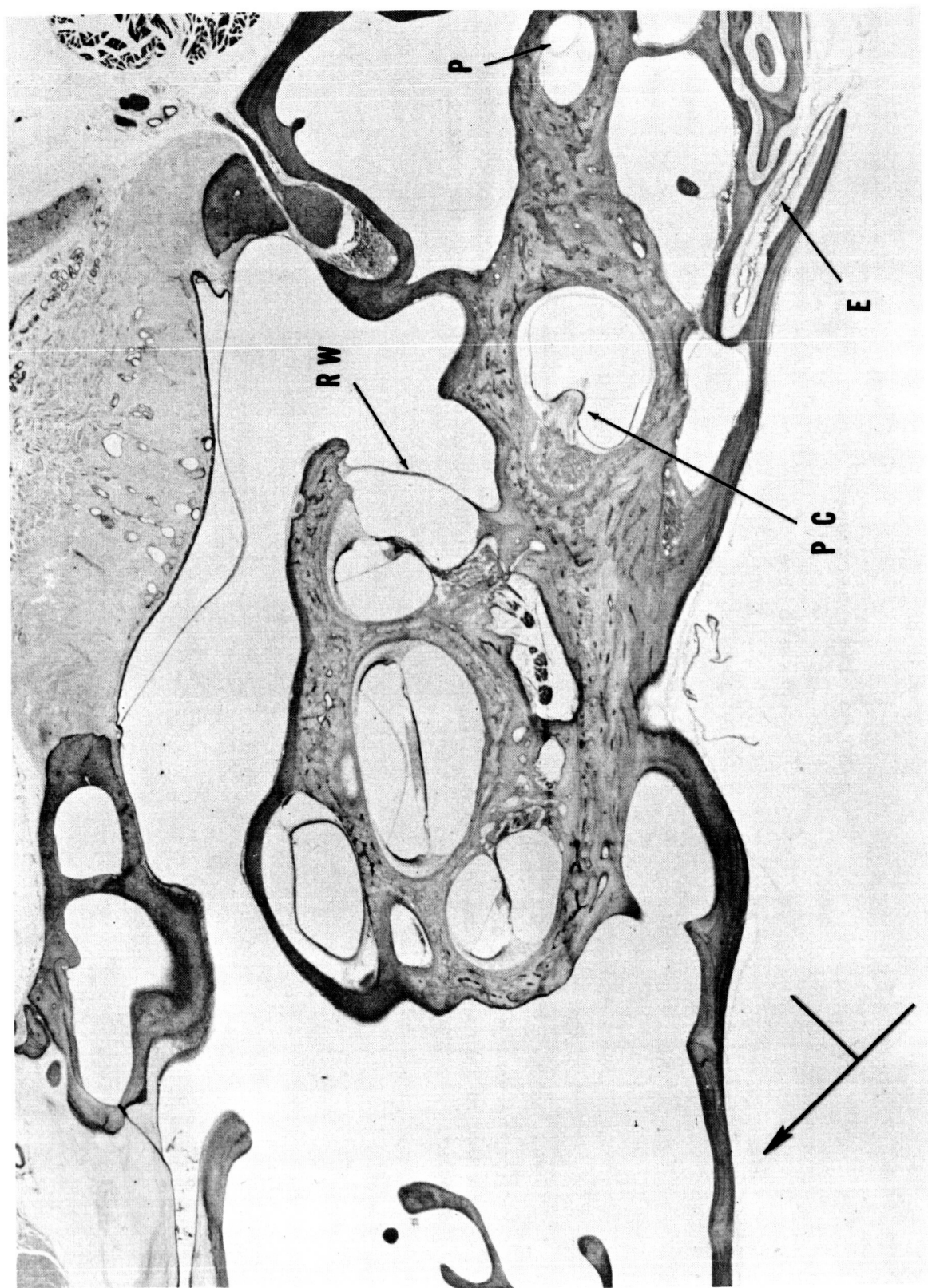


Figure I-19

Legend I-19

- RW : Round window membrane
P : Posterior semicircular canal
PC : Posterior semicircular canal crista
E : Endolymphatic sac

The entire round window membrane is observed facing latero-posteriorly. A small bony opening, possibly containing the inferior cochlear vein, is located posterior to the spiral ganglion of the lower basal turn of the cochlea. Cupula is observed on the posterior crista. The endolymphatic sac is still almost surrounded by bony tissue at this level. Notice a deep sinus tympani opposite to the round window niche. Jacobson's tympanic branch of the glossopharyngeus (IX) nerve is seen on promontory wall.

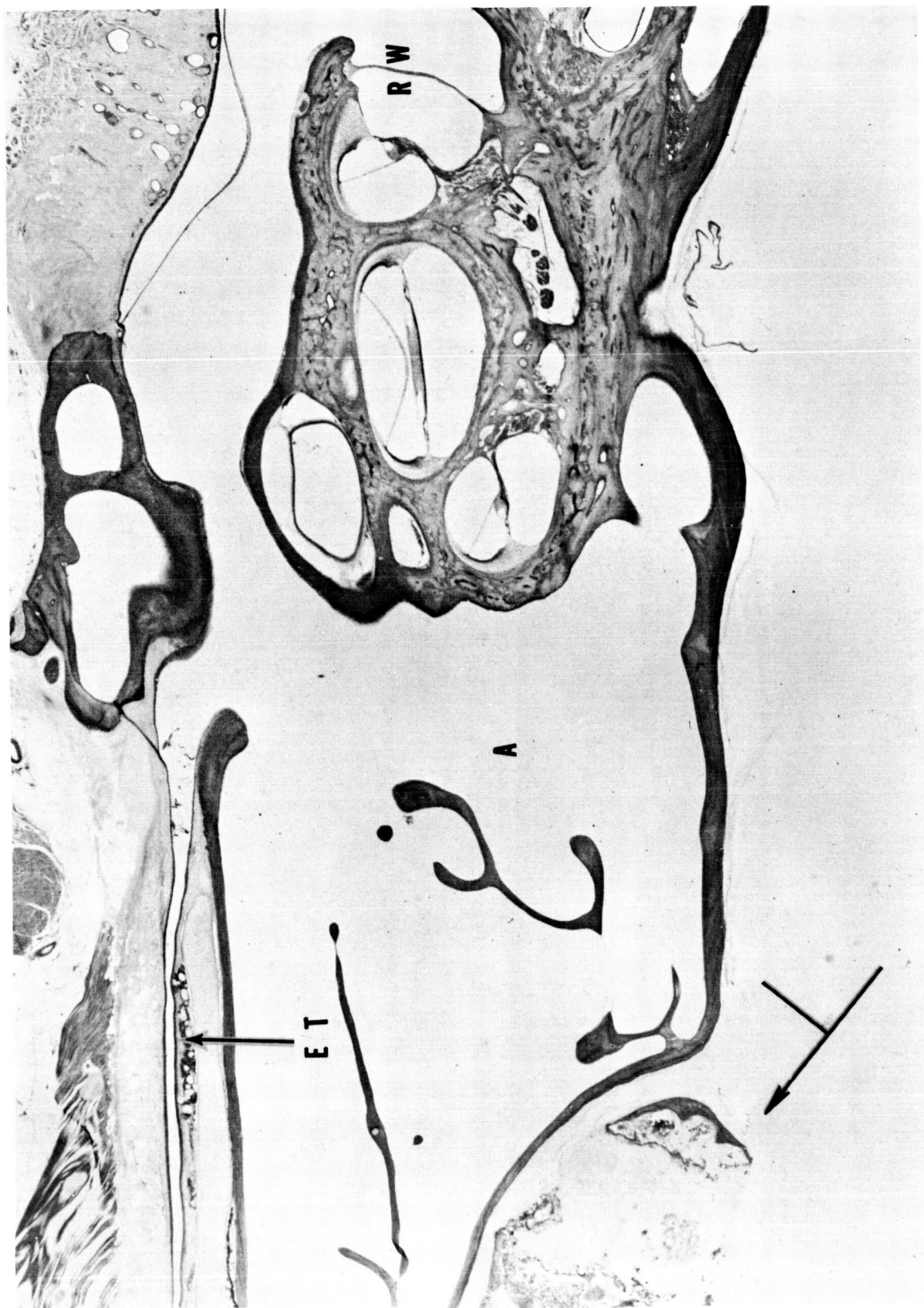


Figure I-20

Legend I-20

RW : Round window membrane

A : Apex

ET : Eustachian tube

The wide opened Eustachian tube, well surrounded by cartilage, is located lateral to the anterior pneumatization. The carotid artery is located immediately atop the cochlea. The extensive pneumatization is usually not seen in other experimental animals such as cats and dogs. These have bullae.

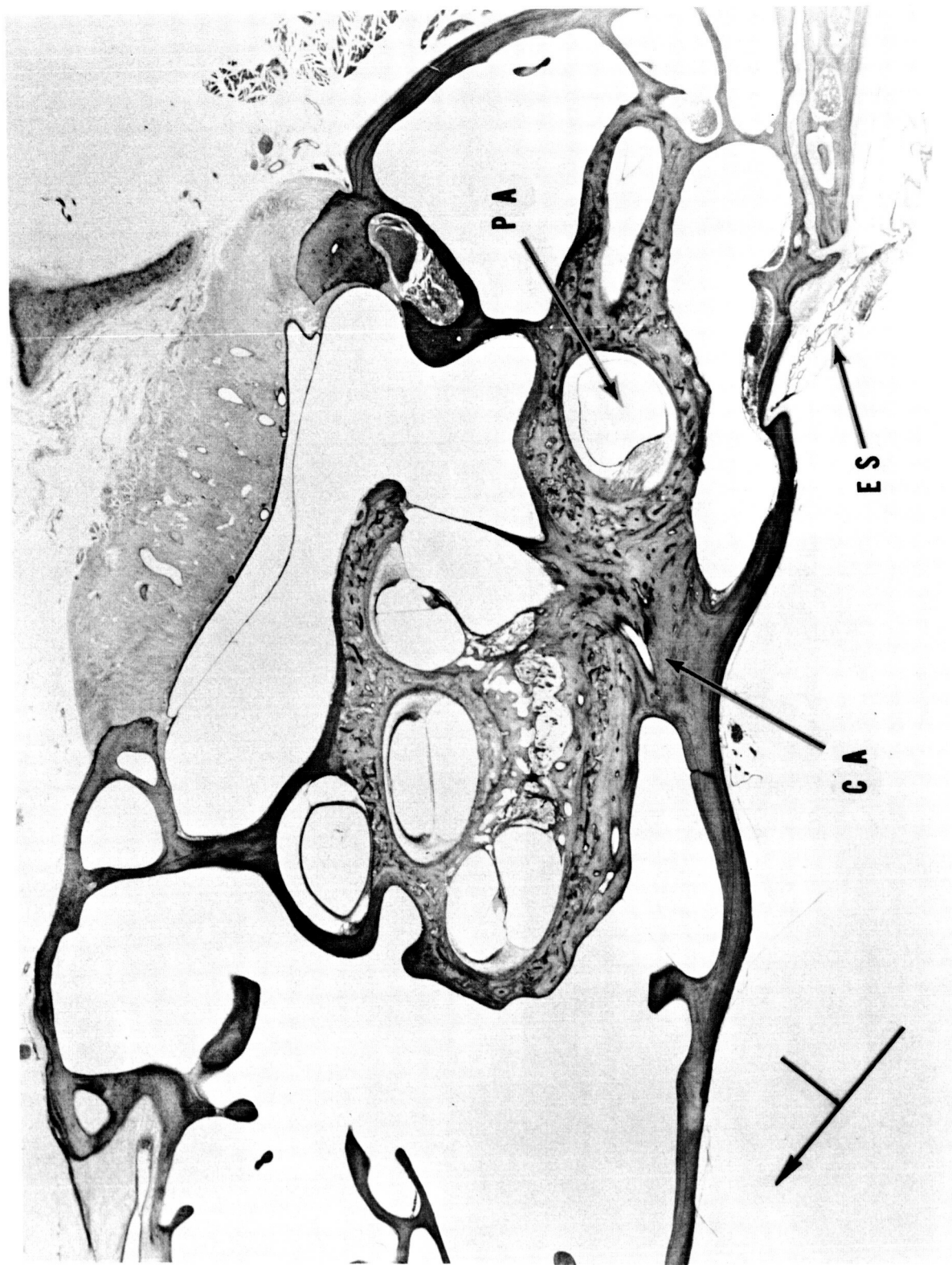


Figure I-21

Legend I-21

CA : Cochlear aqueduct

PA : Posterior semicircular canal ampulla

ES : Endolymphatic sac

The bony pattern of cochlear aqueduct is observed, which will open directly to the subarachnoidal space. The round window niche is extremely deep. A huge pneumatization exists anteriorly, and even medially, to the cochlea. The endolymphatic sac is now located intradurally, free from any surrounding bony tissue.

Notice the angle of the posterior semicircular canal to the sagittal plane.

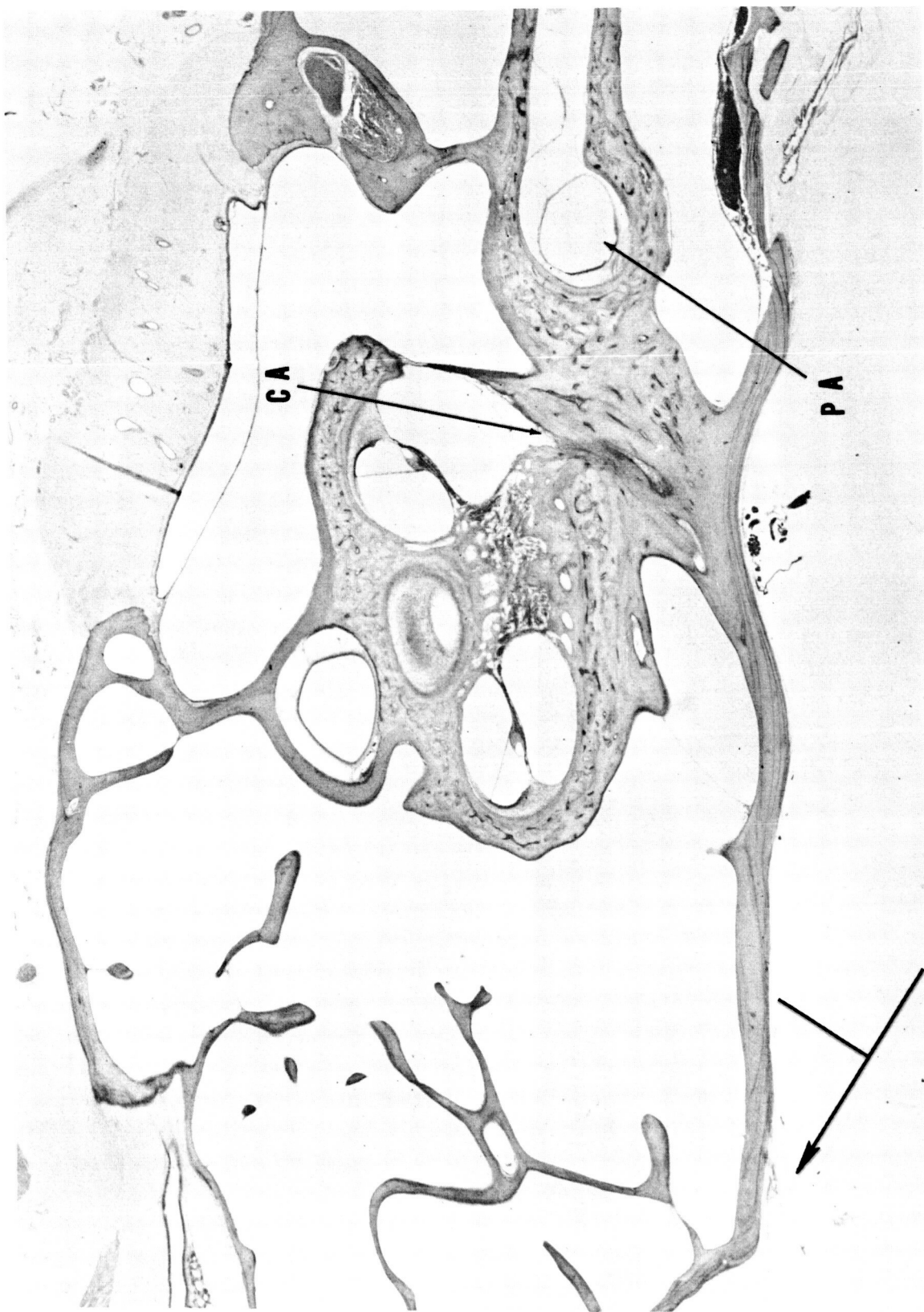


Figure I-22

Legend I-22

CA : Cochlear aqueduct

PA : Posterior semicircular canal ampulla

The high power view will be seen at II - 15.

Figure I-23



Legend I-23

RN : Round window niche
P : Posterior semicircular canal
A : Apex

The round window niche is still deep. The cochlea, together with the carotid artery and the posterior semicircular canal, is almost entirely surrounded by air space. The carotid artery is located between periosteal zone and endochondral zone of the otic capsule. The lowest part of the posterior canal is showing.



Figure I-24

Legend I-24

This section is 400 microns below the previous one. The posterior semicircular canal has disappeared. The cochlea is the only inner ear structure left. The tangential section of the basal turn Organ of Corti is slightly below this level.

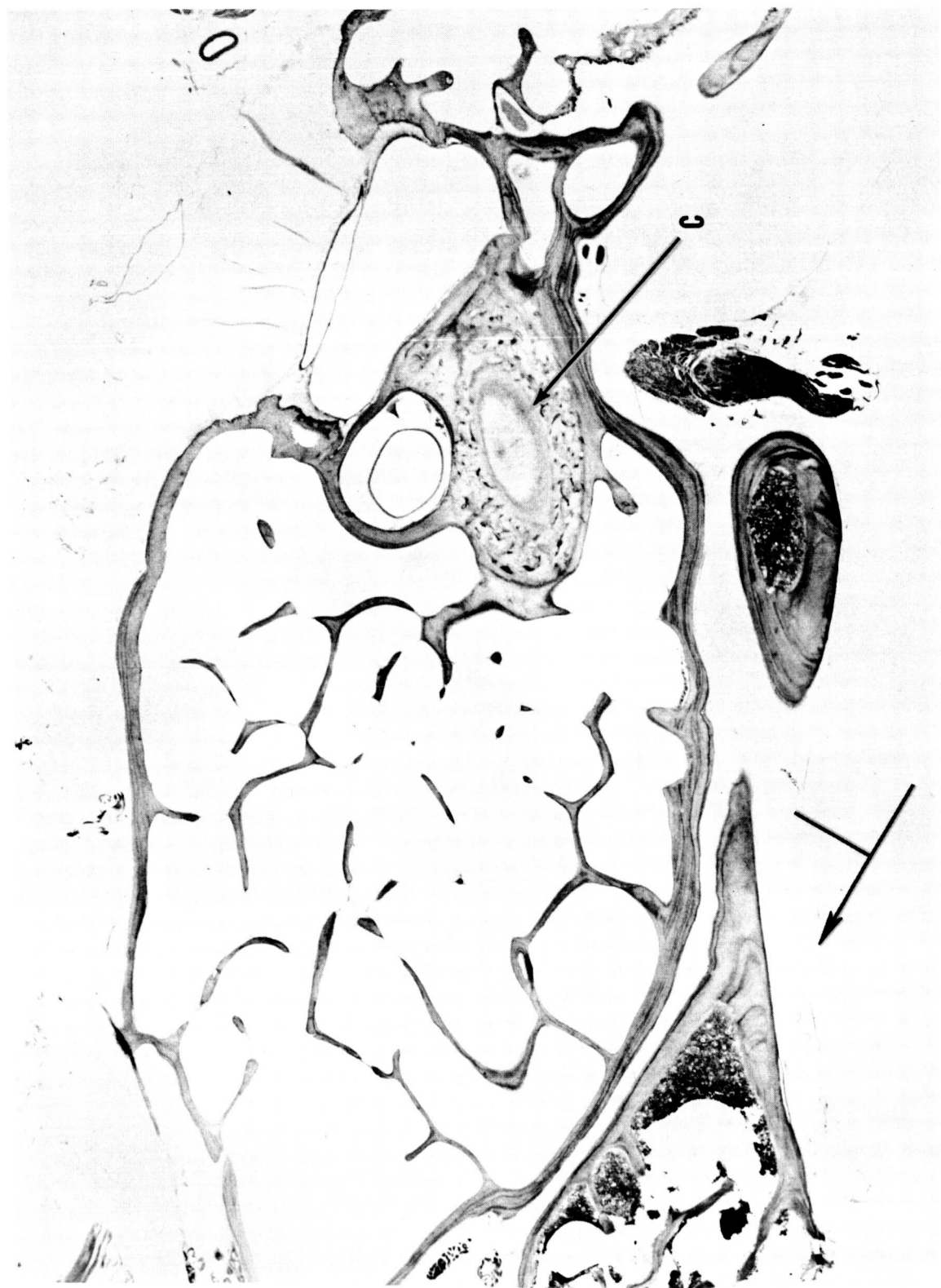


Figure I-25

Legend I-25

C : Cochlea

This section is again 400 microns below the previous one and shows the lowest part of the inner ear structures. The cochlea shows spiral ligament only. A part of the tympanic membrane still remains. Notice the extensive pneumatization anterior to the cochlea and the carotid artery.

Part II

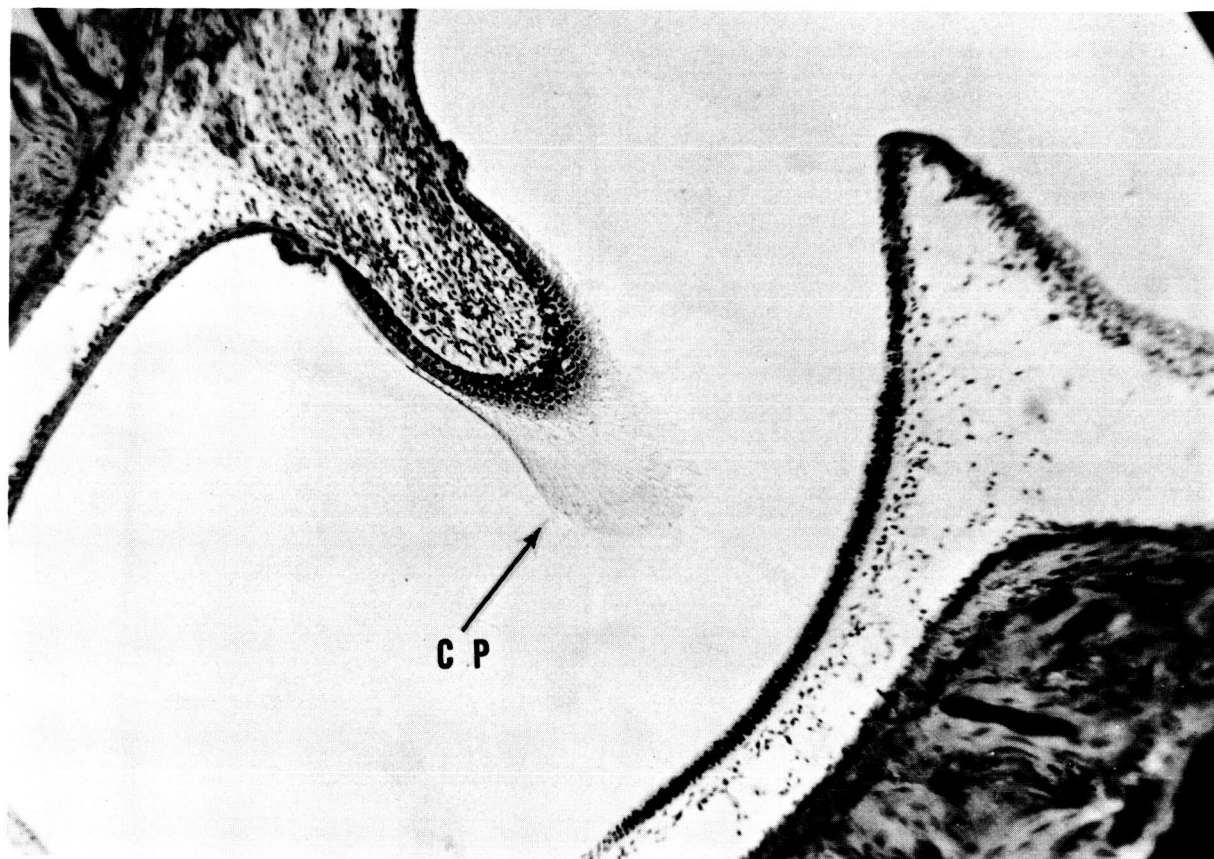


Figure II-1

This is a high power view of the horizontal semicircular canal crista from another squirrel monkey, perfused intravitaly (cardiac-normal saline and 10% formalin), showing a good pattern of cupula (CP).



Figure II-2

This shows a medium high power view of the macula utricle (from I-8). Neurons are innervating the macula rather evenly. Otoliths are well preserved.

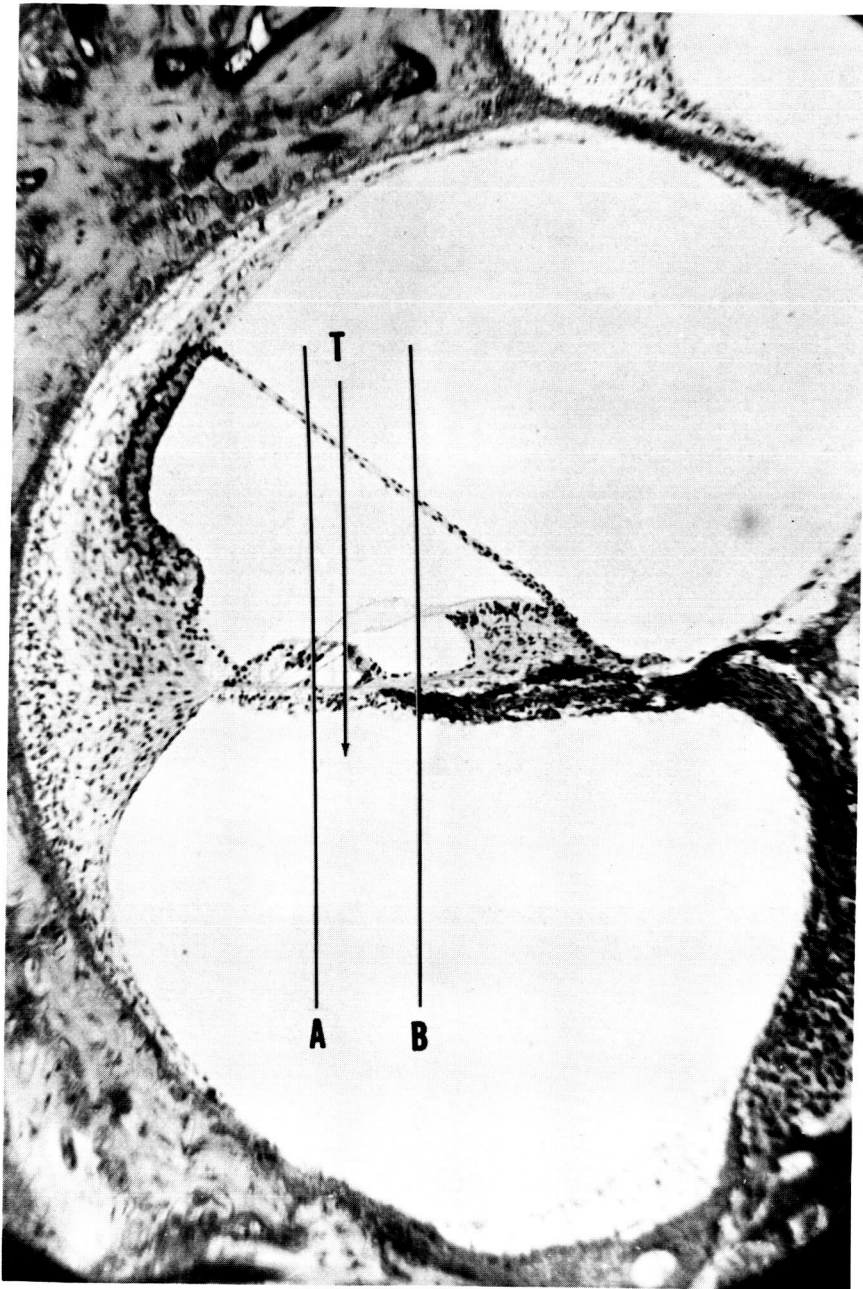


Figure II-3

This is a high power view of the Organ of Corti. The T-line indicates the tangential sectioning of the Organ of Corti, which should cut through the top of the Corti tunnel. The detailed terminology of the cochlear spiral is described elsewhere.

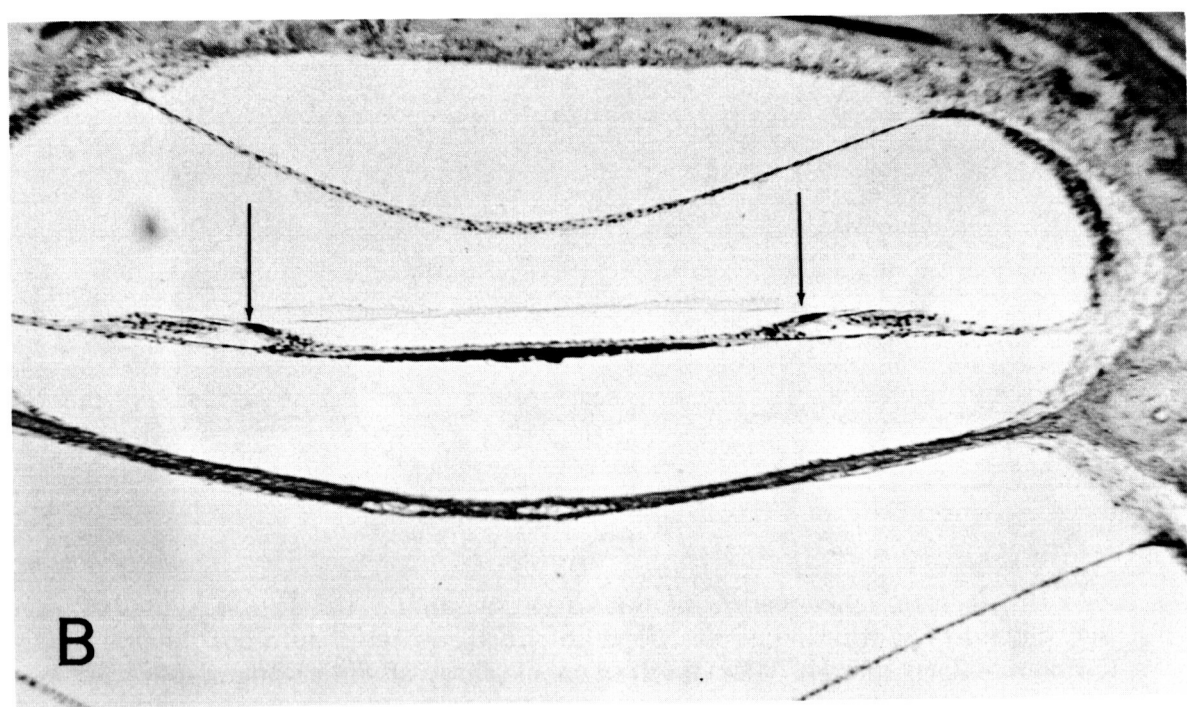
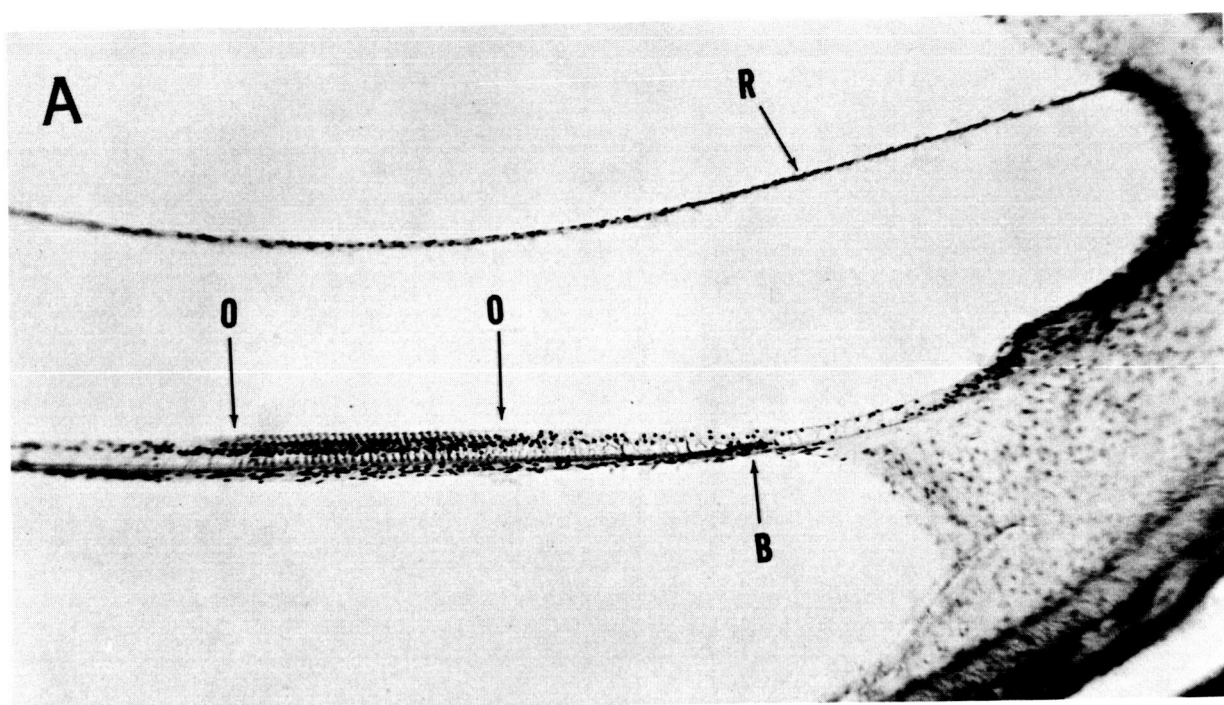


Figure II-4

Legend II-4

Picture A and picture B illustrate two different cutting planes indicated as line A and line B in the previous picture.

Picture A - R : Reissner's membrane
 B : Böttcher's cell
 O : Outer hair cells

Picture B - The two arrows indicate the top of Corti tunnel where the tangential section should cut through.

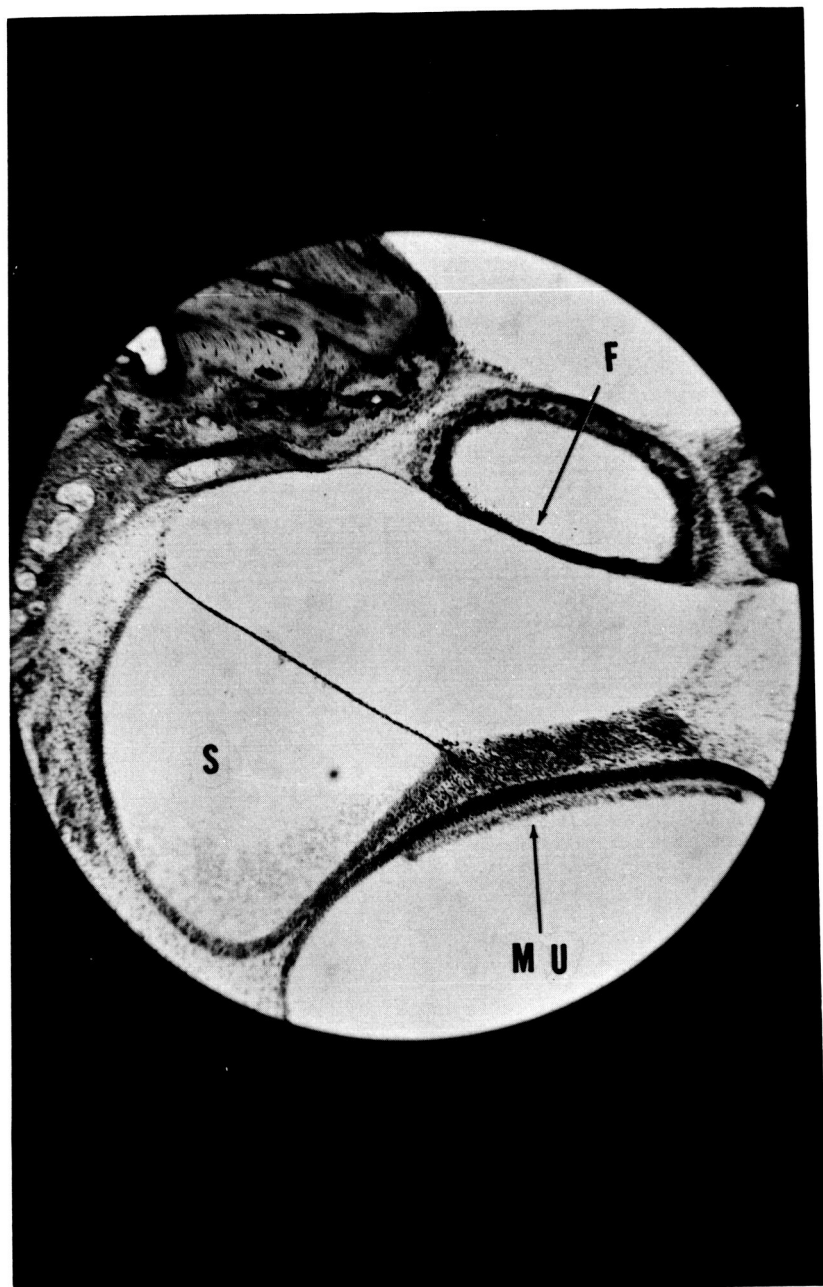


Figure II-5

Legend II-5

- F : Footplate of stapes
- S : Sacculle
- MU : Macula utriculi

This is a medium high power view of the oval window area (from I -10) showing the relationship between the stapes footplate and the vestibular labyrinth. Through the oval window, macula sacculi can be reached from the front, via saccular membrane. But macula utriculi can be reached from the reverse side only. Notice the otolithic membrane on the macula.



Figure 11-6

This shows a medium high power view of the macula sacculi (from I-12). Sensory hairs and otolithic membrane are well preserved with the intravital perfusion fixation. No definite reinforced area of saccular membrane is seen in this squirrel monkey.

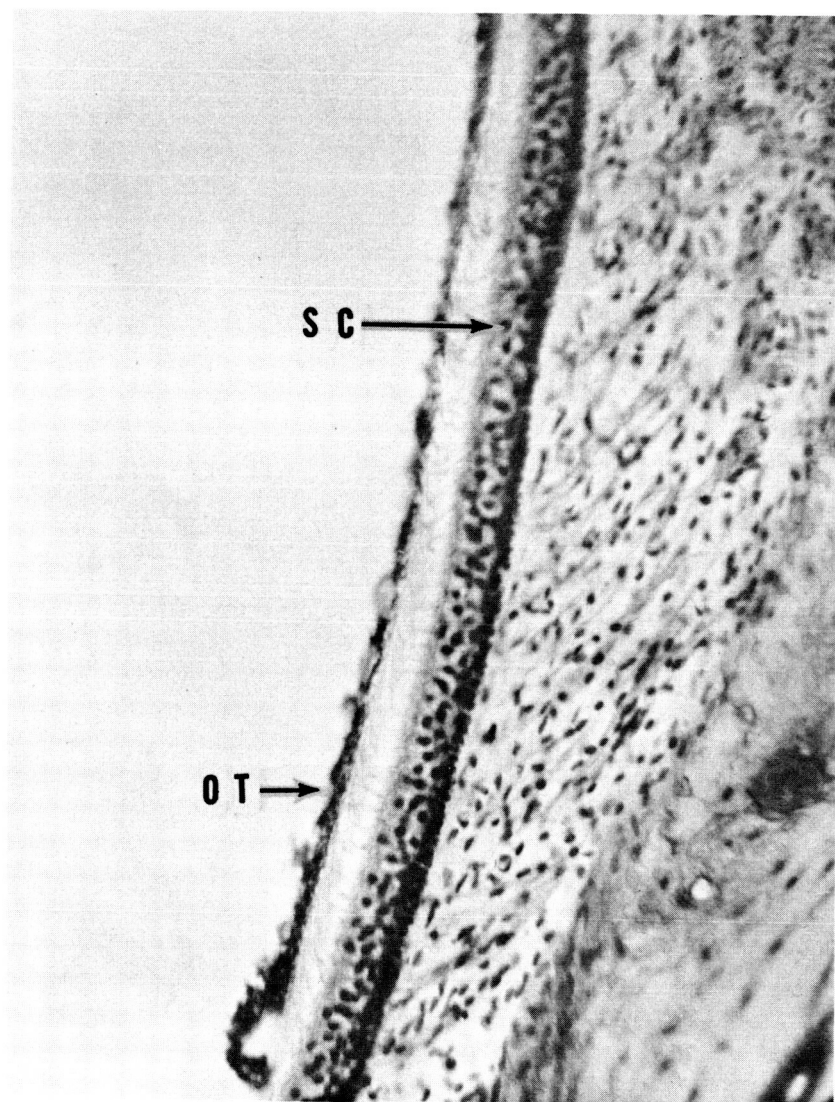


Figure 11-7

SC : Sensory hair cells

OT : Otoliths

This picture shows a high power view of macula sacculi from another squirrel monkey, fixed by intravital perfusion. Notice the beautiful preservation of sensory hairs and otoliths.

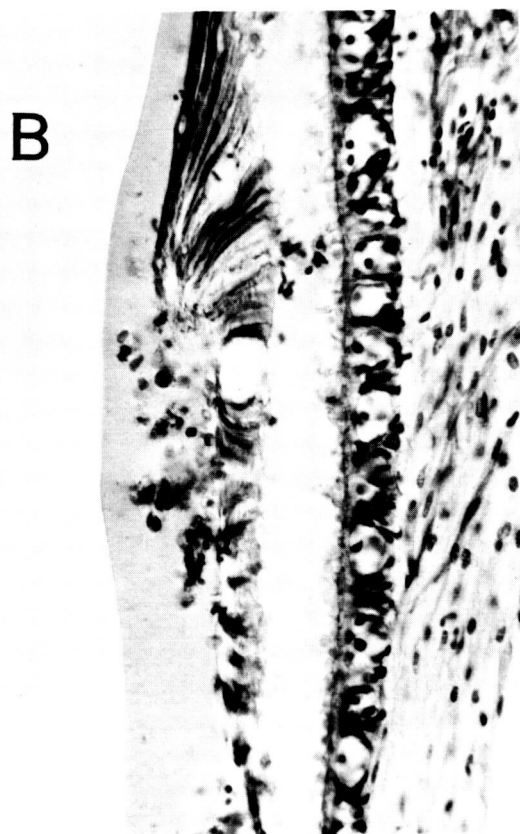
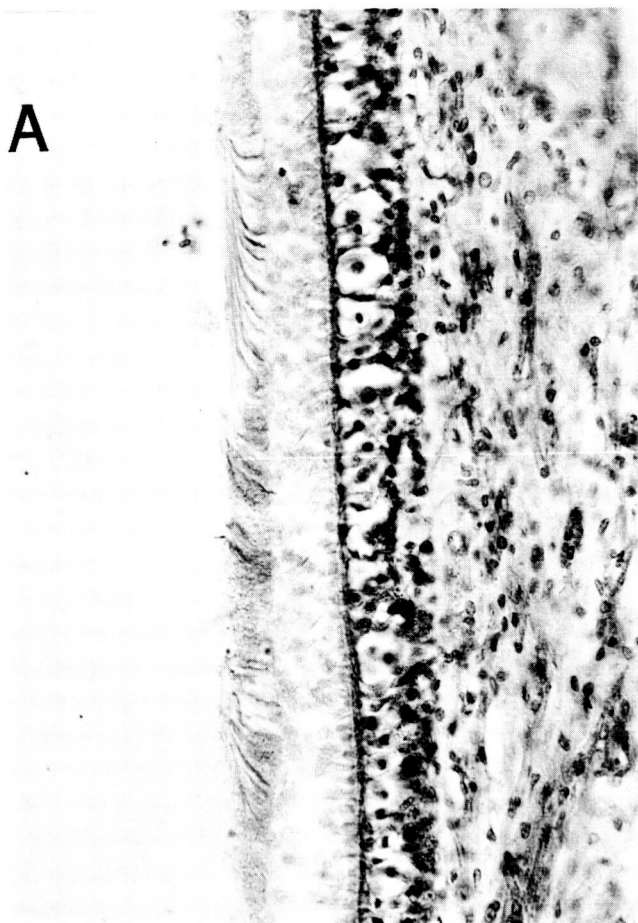


Figure II-8

Legend II-8

These are saccular maculae from two adult human temporal bones. "A" was removed from the cadaver four hours post mortem, and fixed (immersion) with Heidenhain-Susa fixative. The stapes was removed to aid the fixative penetration into the inner ear partition. Macular preservation is fairly good, with a minimal post-mortem autolysis, and the hair cell population is normal. However, no otoconia is observed. Five per cent trichloroacetic acid was used for decalcification.

Twenty per cent formalin was injected intratympanically to "B" three hours after the death of the patient. The temporal bone was secured one hour later (four hours post mortem), and fixed (immersion) with Heidenhain-Susa fixative. The stapes was not removed in this case. Post-mortem change is more advanced than in case "A".

These two cases had no otological disorder in their clinical histories. The end organ preservation in human cases is very difficult and never predictable.

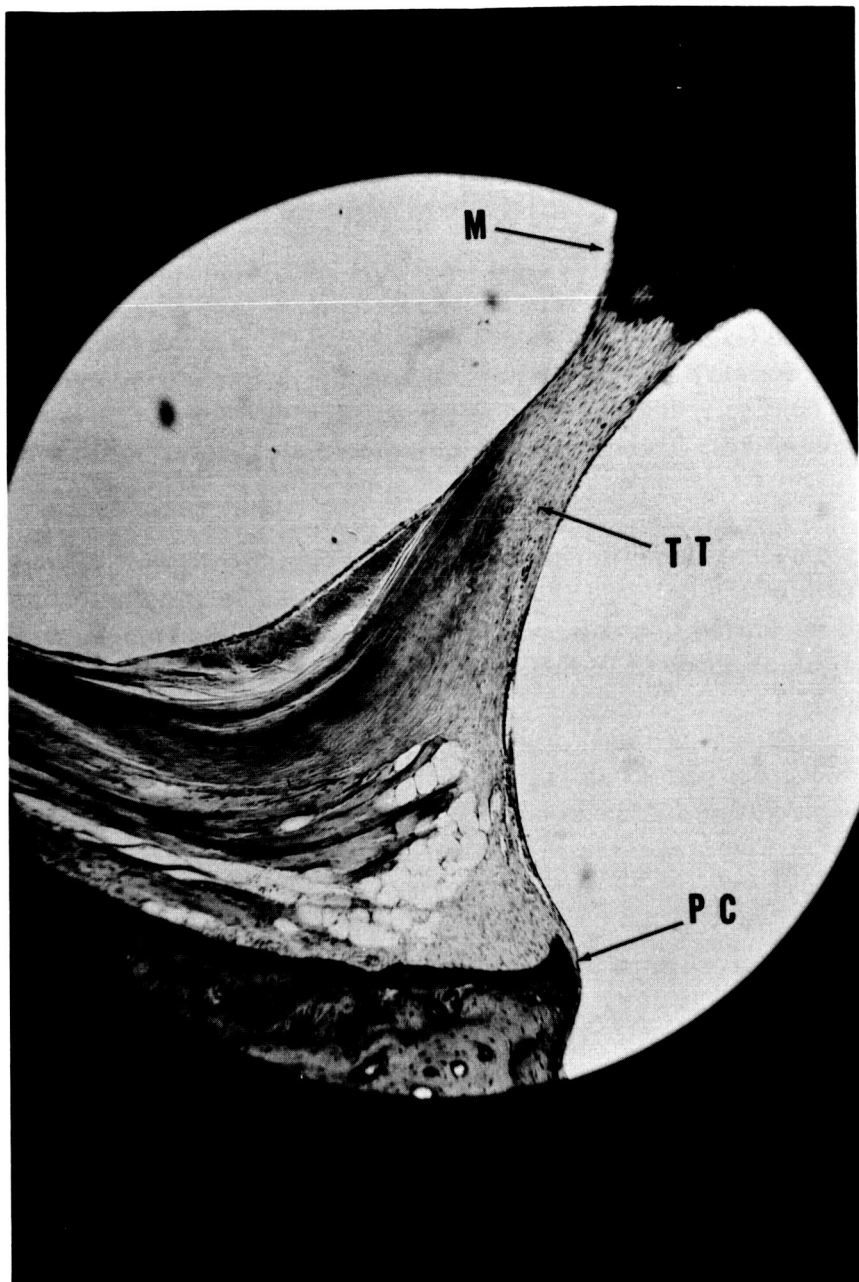


Figure 11-9

Legend II-9

- M : Neck of Malleus
- TT : Tensor tympani tendon
- PC : Processus cochleaformis

This is a medium high power view of tensor tympani tendon (from I-12). Notice adipose tissues beside the tensor tympani muscle, possibly aiding muscular activity. The angle between the tendon and the muscle is almost ninety degrees (right angle).

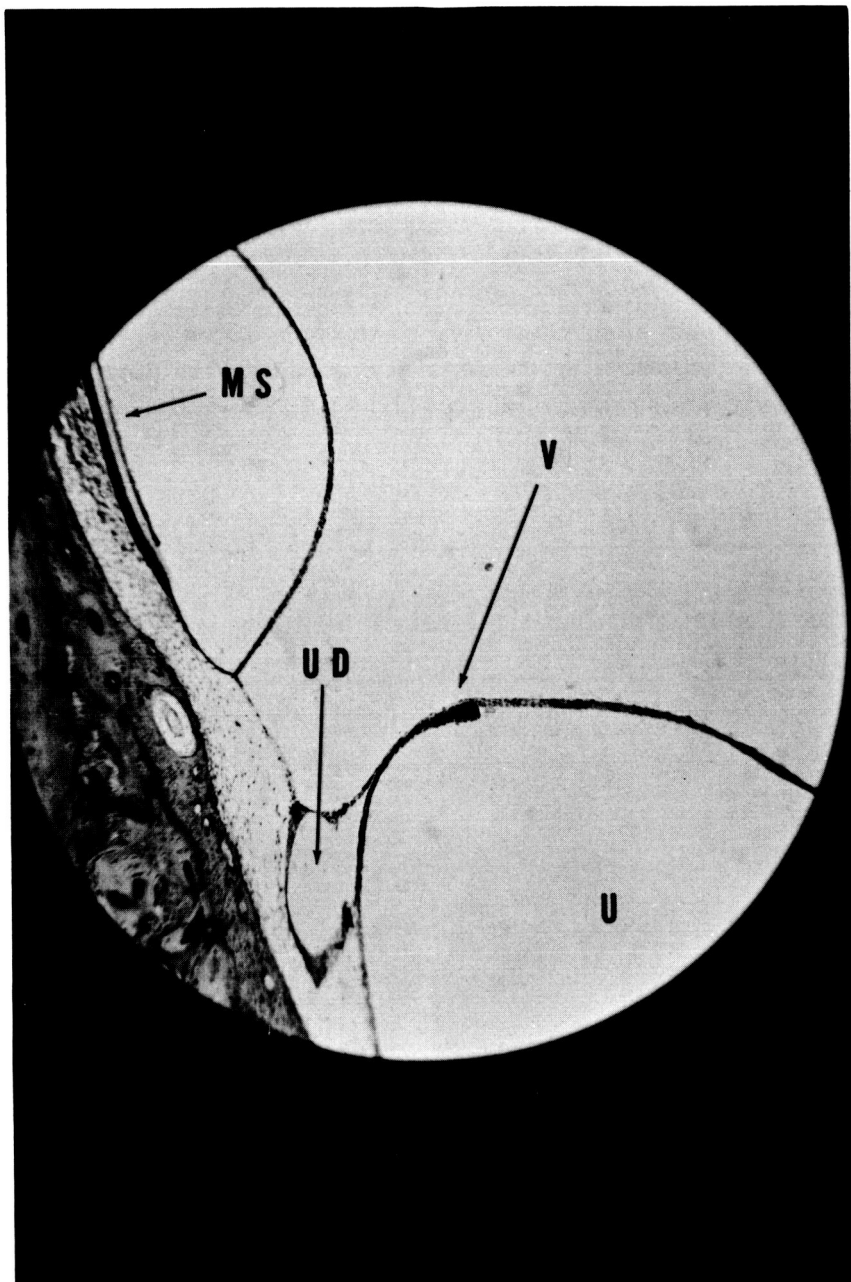


Figure II-10

Legend II-10

MS : Macula sacculi

U : Utricle

UD : Utricular duct (almost endolymphatic duct)

V : Utriculo-endolymphatic valve (or fold)

This medium high power view shows the endolymphatic duct area (from I - 14). From the morphological feature, it is quite possible that the utriculo-endolymphatic valve is regulating the endolymphatic flow from the utricle side to the utricular duct side.

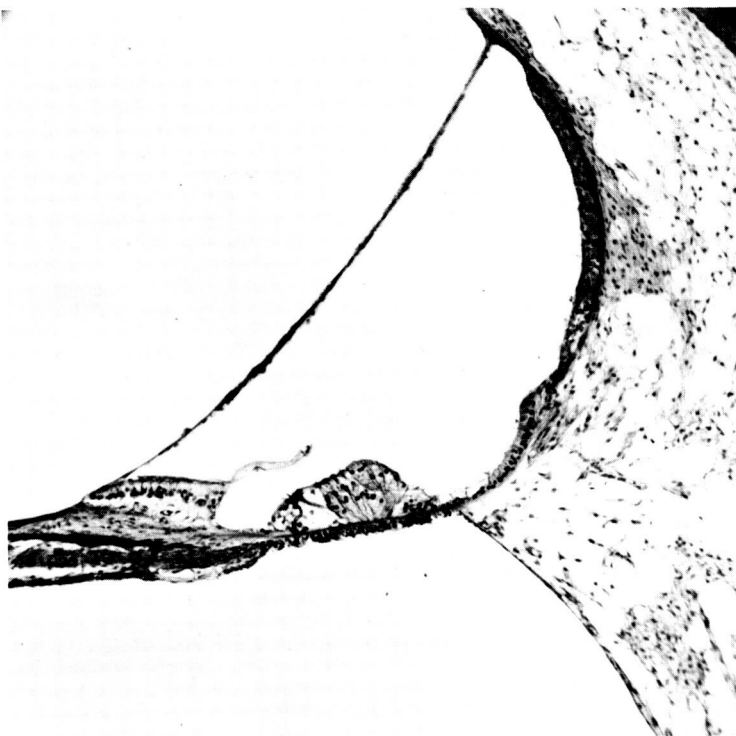


Figure II-11
II-16

Legend II-11

The best preserved normal human Organ of Corti (adult) in the author's series, under low and high magnification.

The temporal bone was secured three hours post mortem and fixed (immersion) with Heidenhain-Susa fixative. The top of the superior semicircular canal was opened to aid the fixative penetration into the inner ear. The initiation of post-mortem change is seen in the area of the inner hair cells and inner supporting cells, though it is minimal.

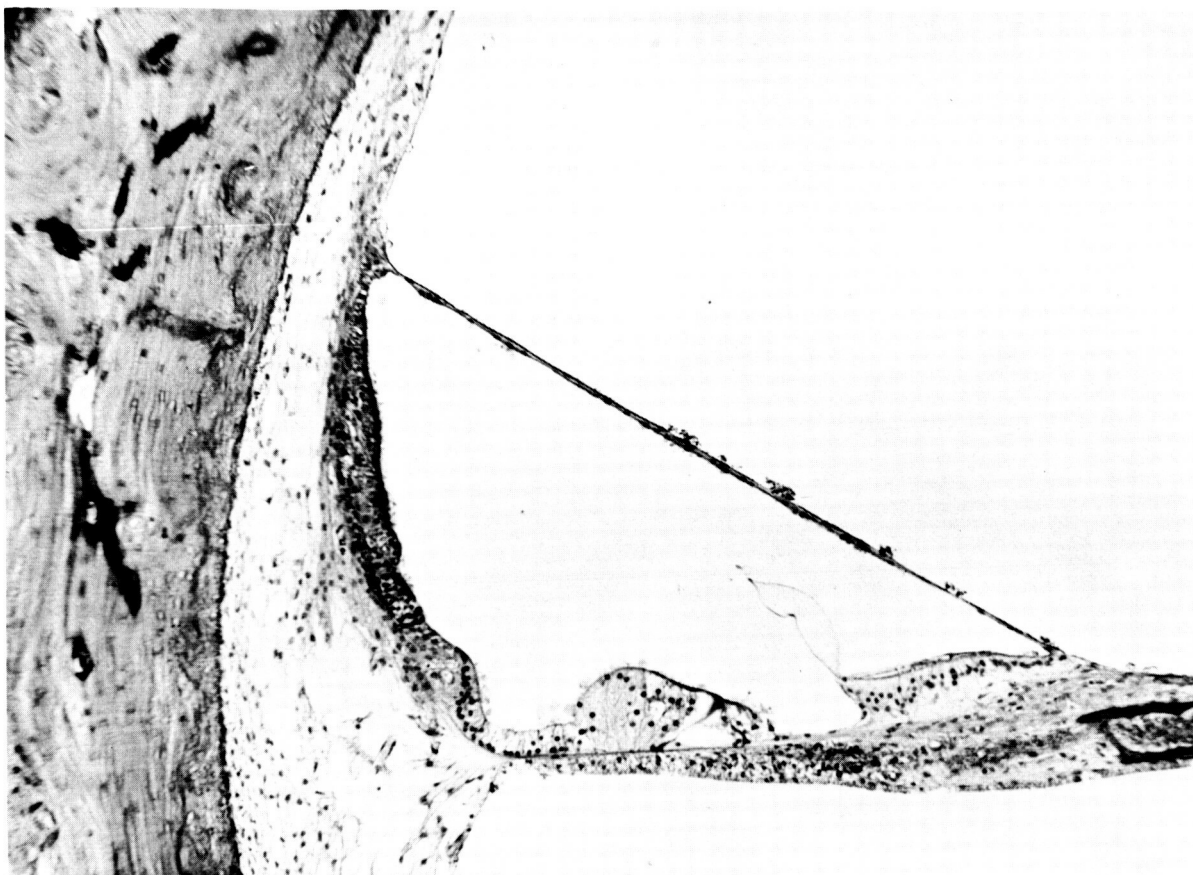


Figure II-12

A normal human Organ of Corti with a slight post-mortem autolysis.

The temporal bone was removed from the cadaver four hours post mortem, and was fixed (immersion) with Heidenhain-Susa fixative. The stapes was removed in this case. Post-mortem change is more advanced than in the preceding picture.

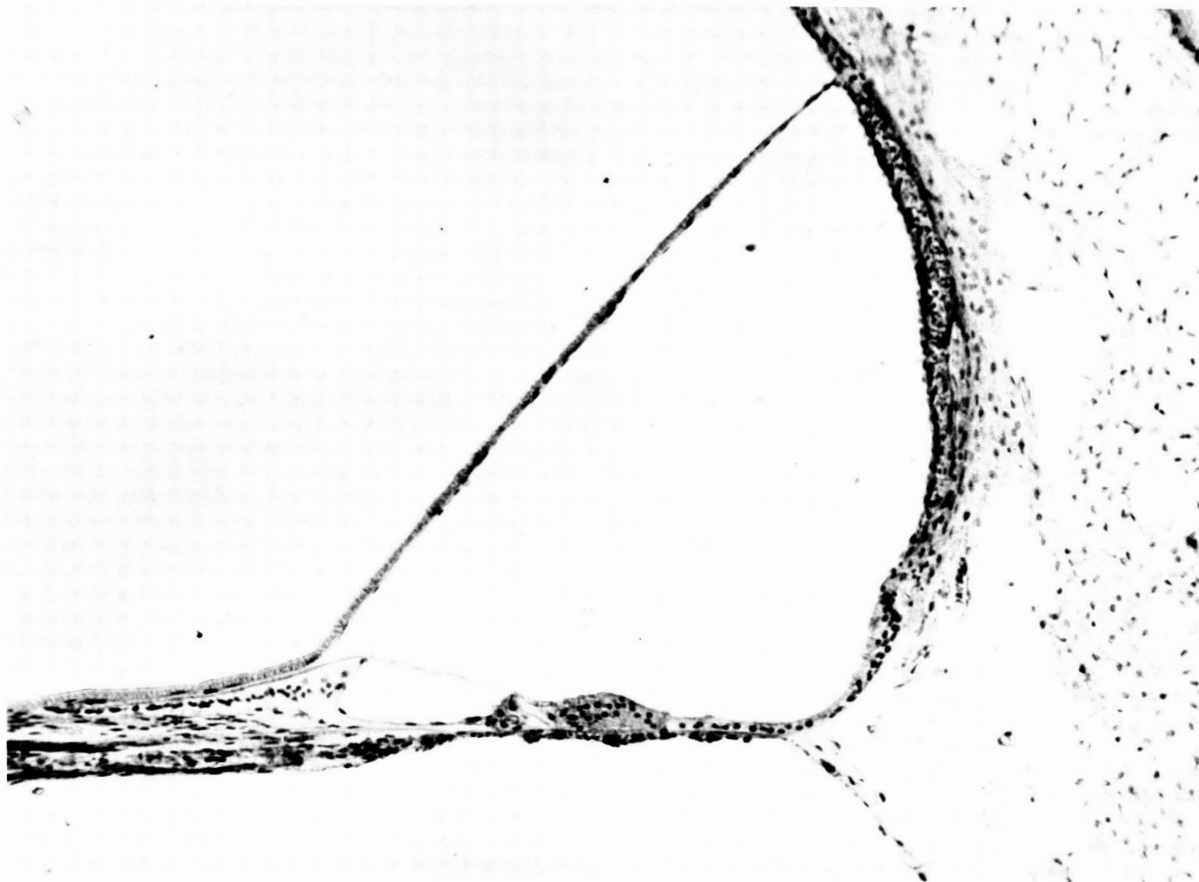


Figure II-13

This picture shows the hypotonic post-mortem change of the human Organ of Corti (normal adult). The temporal bone was secured four hours post mortem and fixed (immersion) with Heidenhain-Susa fixative. But neither stapes removal nor superior canal opening was performed in this case.

The change is extensive, and it is impossible to define hair cell nuclei. This sort of preservation is not adequate for pathological study.

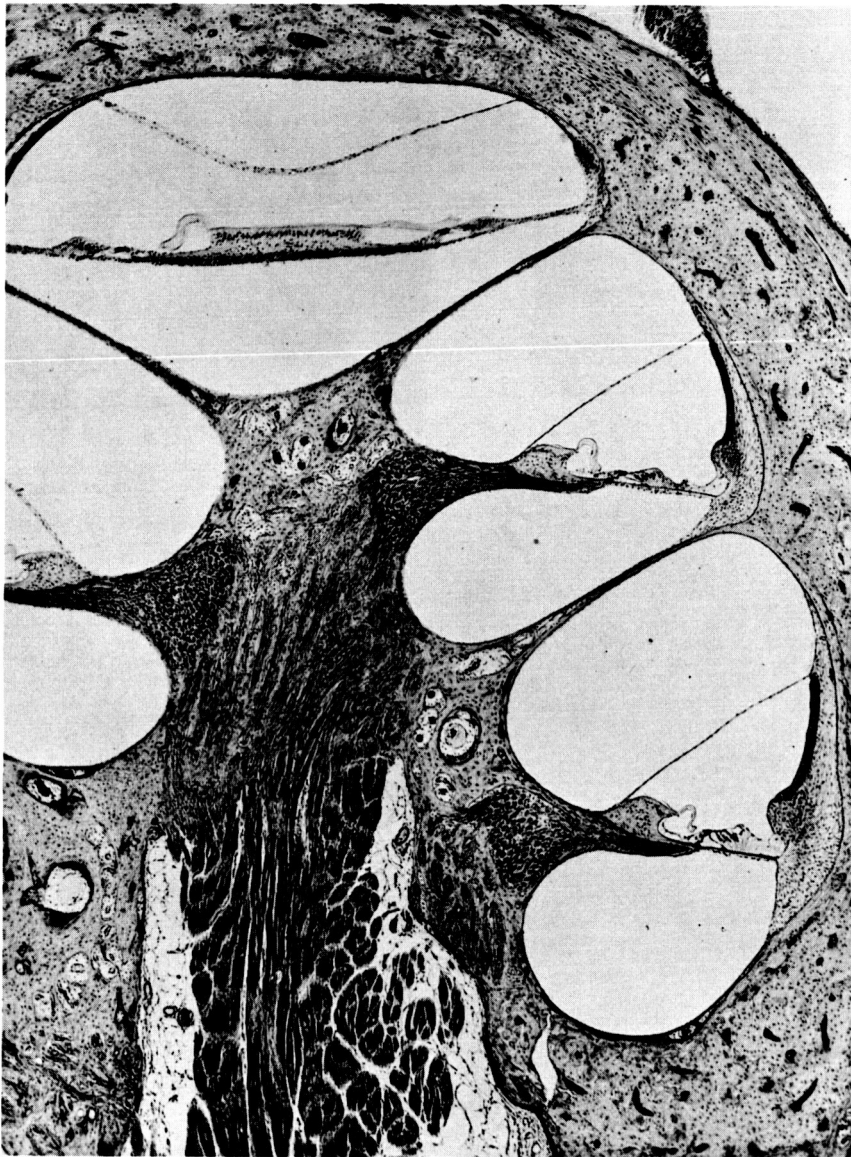


Figure II-14

This is a view of the cochlea from a cat which was not perfused. Heidenhain-Susa fixative was injected intratympanically several times within the first two hours after death. Thereafter, the temporal bone was secured, the stapes was removed, and the bone was fixed (immersion) with Heidenhain-Susa solution. No post-mortem change is observed.

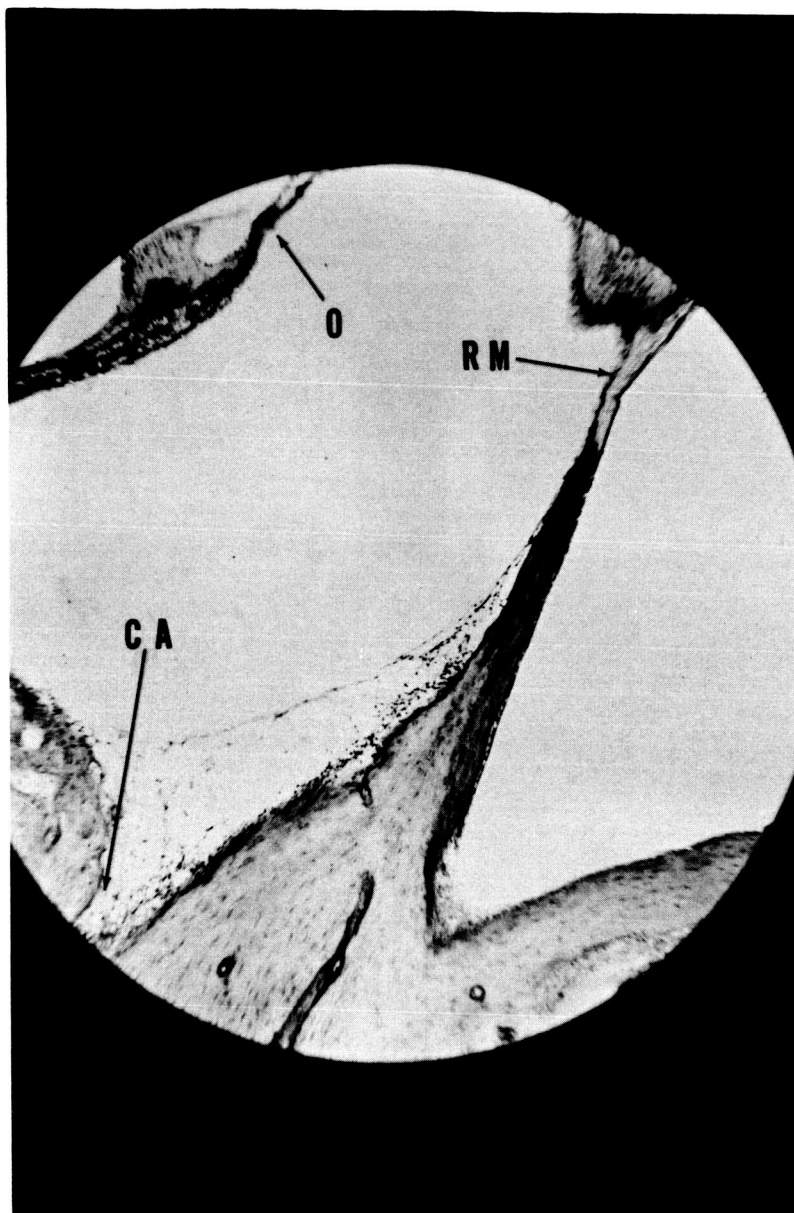


Figure 11-15

- O : Organ of Corti in lower basal turn
- RM : Round window membrane
- CA : Cochlear aqueduct

This is a medium high power view of the round window area (from 1-21). Notice the connective tissues filling up the orifice of the cochlear aqueduct.

Part III

Pictures III-1,2,3 are the squirrel-monkey specimens; III-4,5 are the cat. The modiolar lines indicated by large arrows and small arrows are showing the plane of the posterior semicircular canals. All temporal bones are cut in a horizontal plane, and the tops of the pictures are pointing anteriorly. The average for the open angle between modiolar lines and sagittal (occipito-frontal) midlines was 40 degrees (range 37° - 44°) in the squirrel monkey, and 10 degrees in the cat. The average for the angle between the posterior semicircular canals and the sagittal mid-lines was 37 degrees in the squirrel monkey and 38.5 degrees in the cat.

Notice the tremendous pneumatization in squirrel monkey temporal bones. This is not seen in the cat as they have bullae.

III-6 is a low power view of a horizontal section of a human temporal bone, fairly close to the midmodiolar section. The posterior semicircular canal is going to join the utricular space (about 35° - 40° to the sagittal line).

The angle between the modiolar line and the sagittal line is about 40 degrees.

A close resemblance can be observed in the structural arrangement of human and monkey.

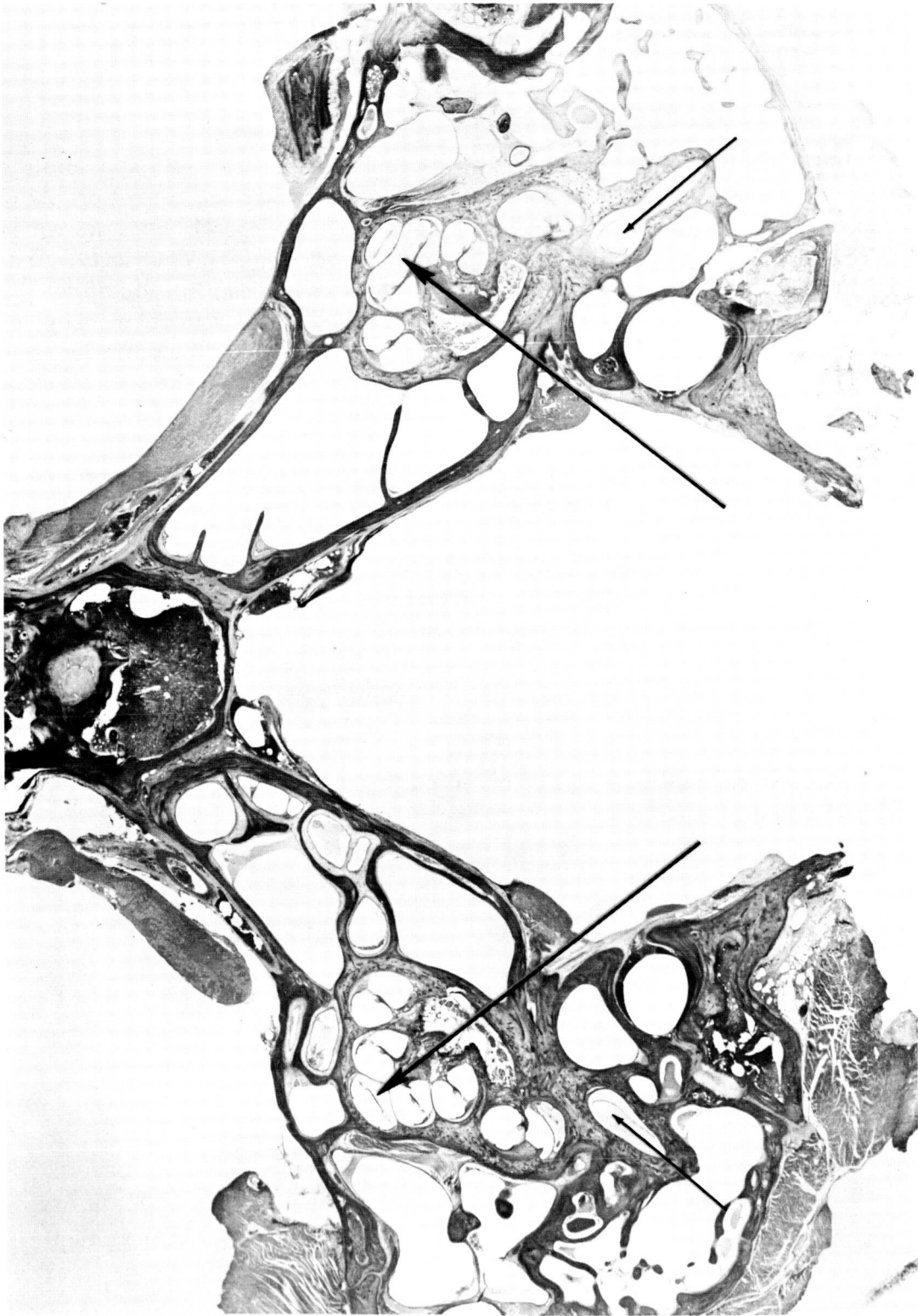


Figure III-1

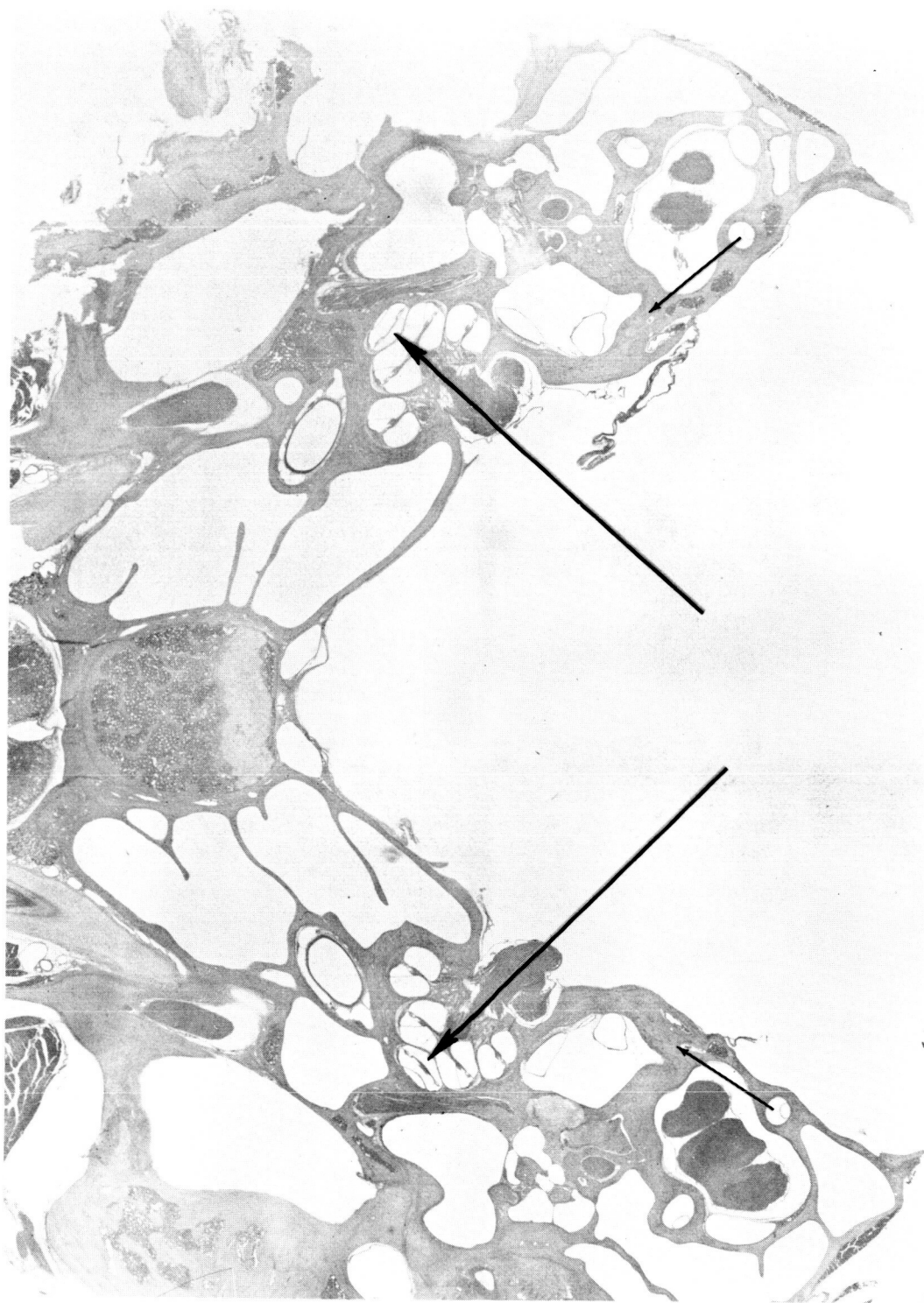


Figure III-2

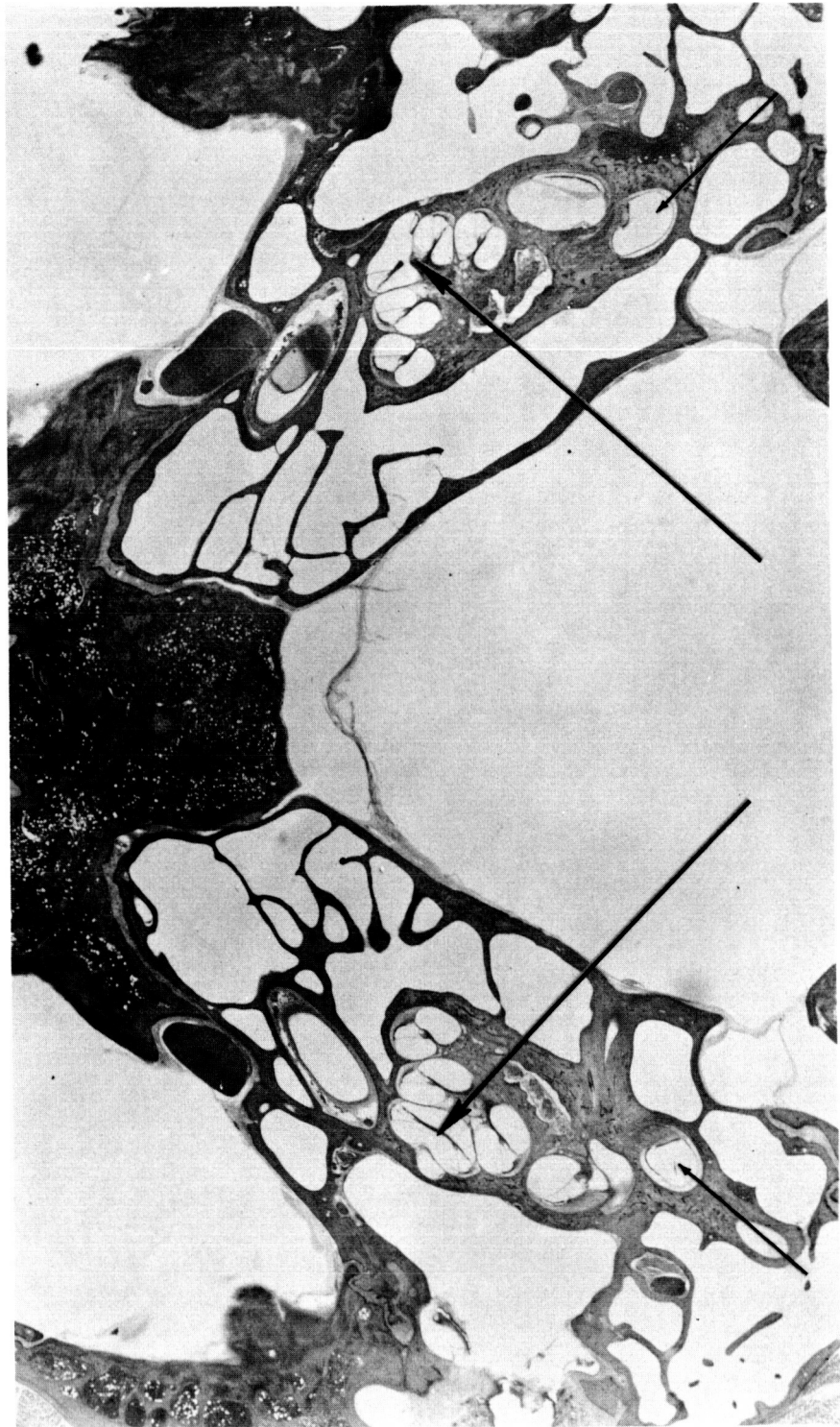


Figure III-3

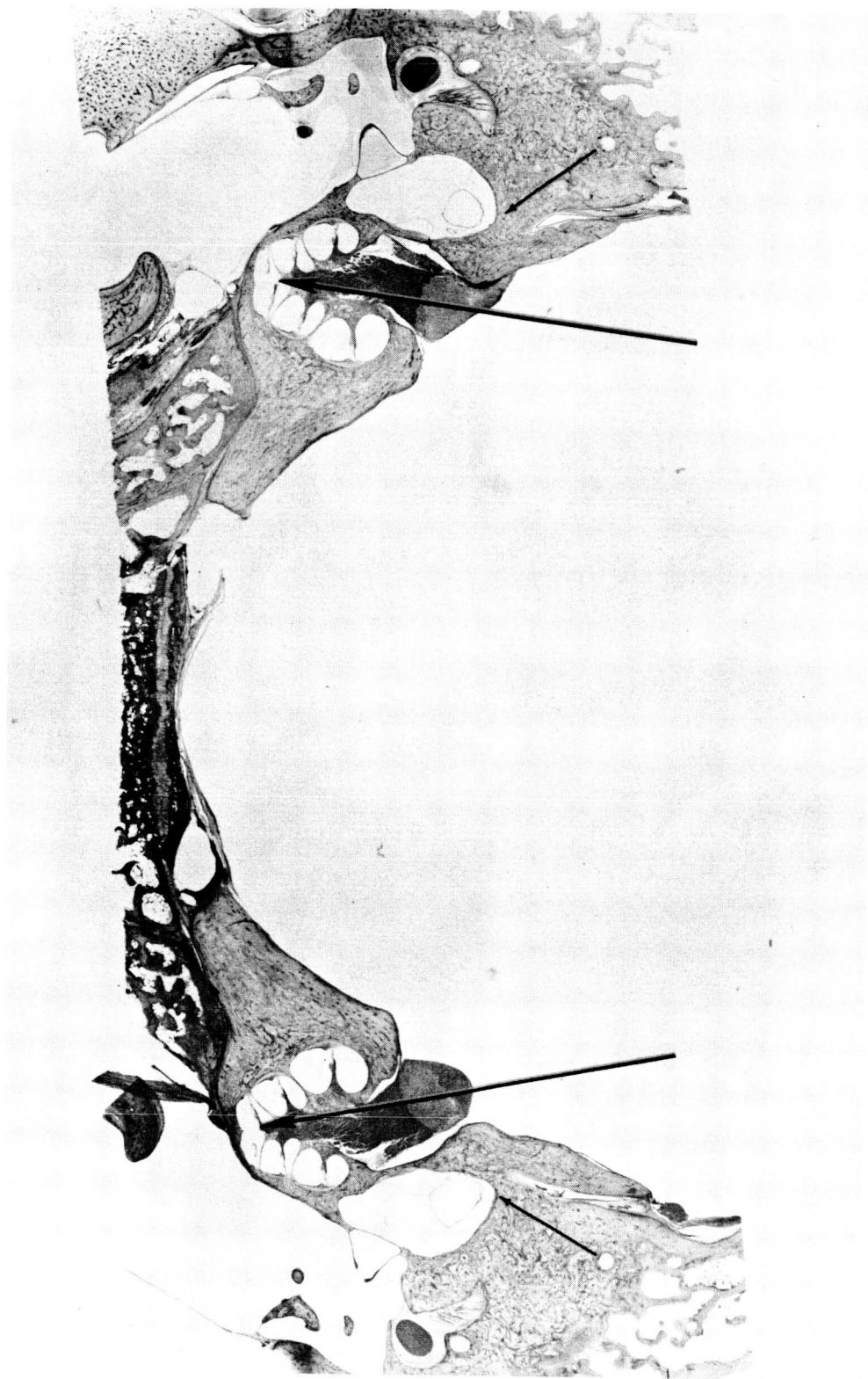


Figure III - 4

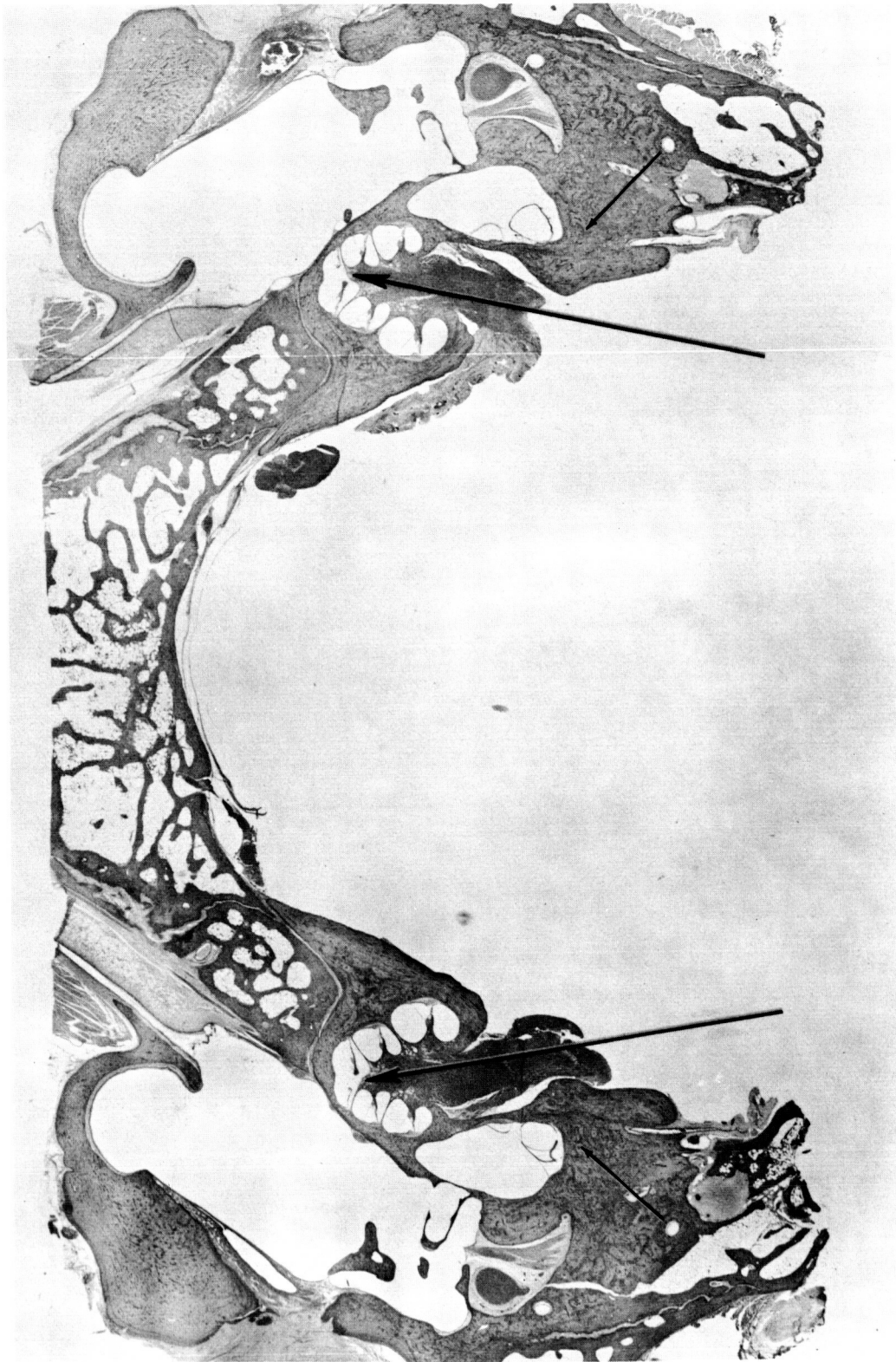


Figure III-5

Figure III-6



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APPENDIX A

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BIBLIOGRAPHY

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