# X-RAY COMPUTED TOMOGRAPHY in RESEARCH COLLECTIONS

Timothy Rowe
Vertebrate Paleontology Laboratory
University of Texas High Resolution X-ray Computed Tomography Facility
Jackson School of Geosciences
University of Texas at Austin

# 3D Volumetric Scanning

Volumetric scanning generates voxels:

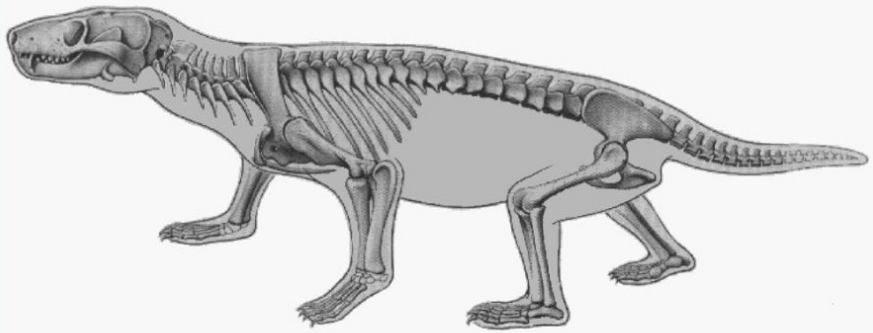
- Voxels are 3D equivalent of pixels
- Volumetric Scanners: Computed Tomography (CT), Synchrotron Tomography, Magnetic Resonance Imaging (MRI), Confocal Microscopy

What volumetric scanning is not:

- Photogrammetry
- Reflectance Transformation Imaging
- Laser surface scanning
  - Produces surface meshes (not voxels) enabling 3D printing
  - From voxel data, one can generate surfaces meshes; the reverse is not true

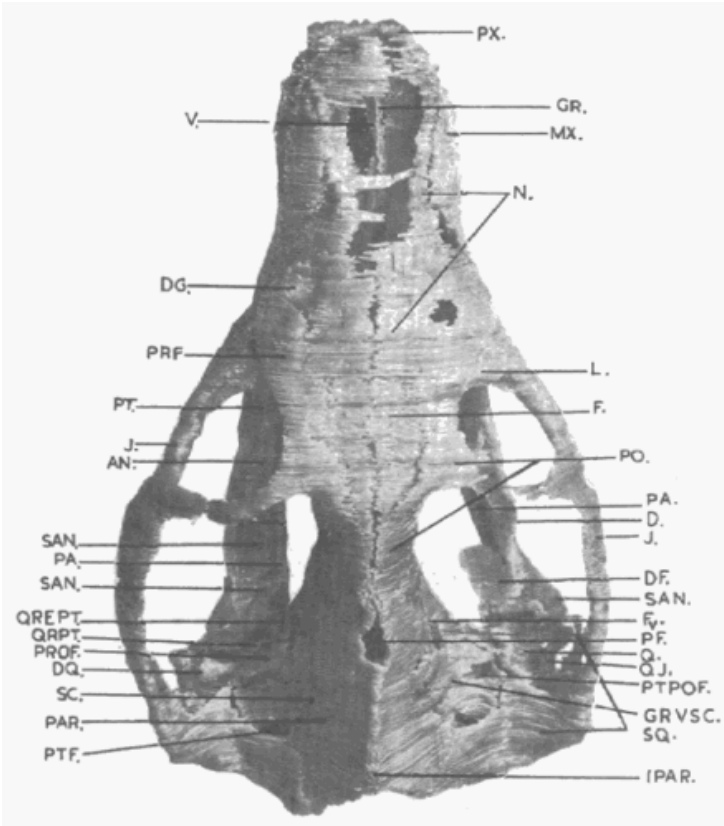
Today's talk:

- CT Scanners
- CT Scanning in Research
- CT Scanning for Collections
- Managing CT Data as part of a Collection – voxels as a new data species



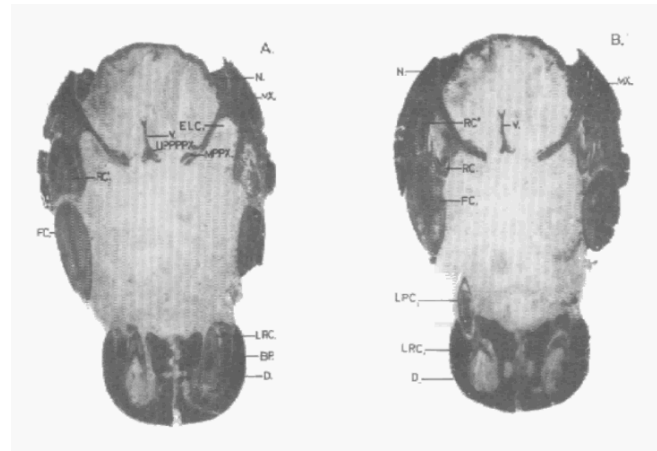
*Thrinaxodon liorhinus*

image courtesy of F A Jenkins, Jr.




wax plate reconstruction (now lost?)

**THE CRANIAL MORPHOLOGY OF *THRINAXODON LIORHINUS* SEELEY** (1974) by Steve Fourie
Annals of the South African Museum




0.2 mm mechanical (destructive) serial sections

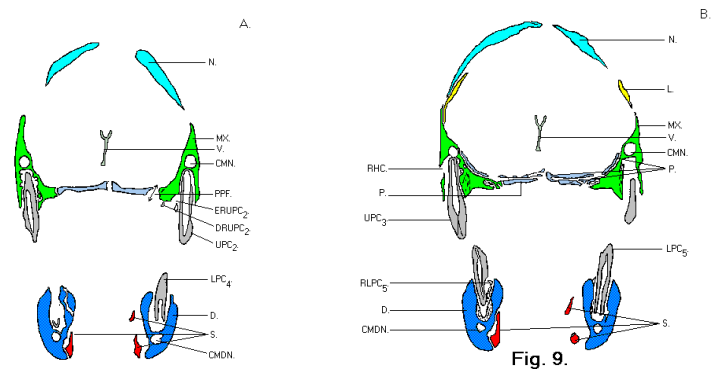
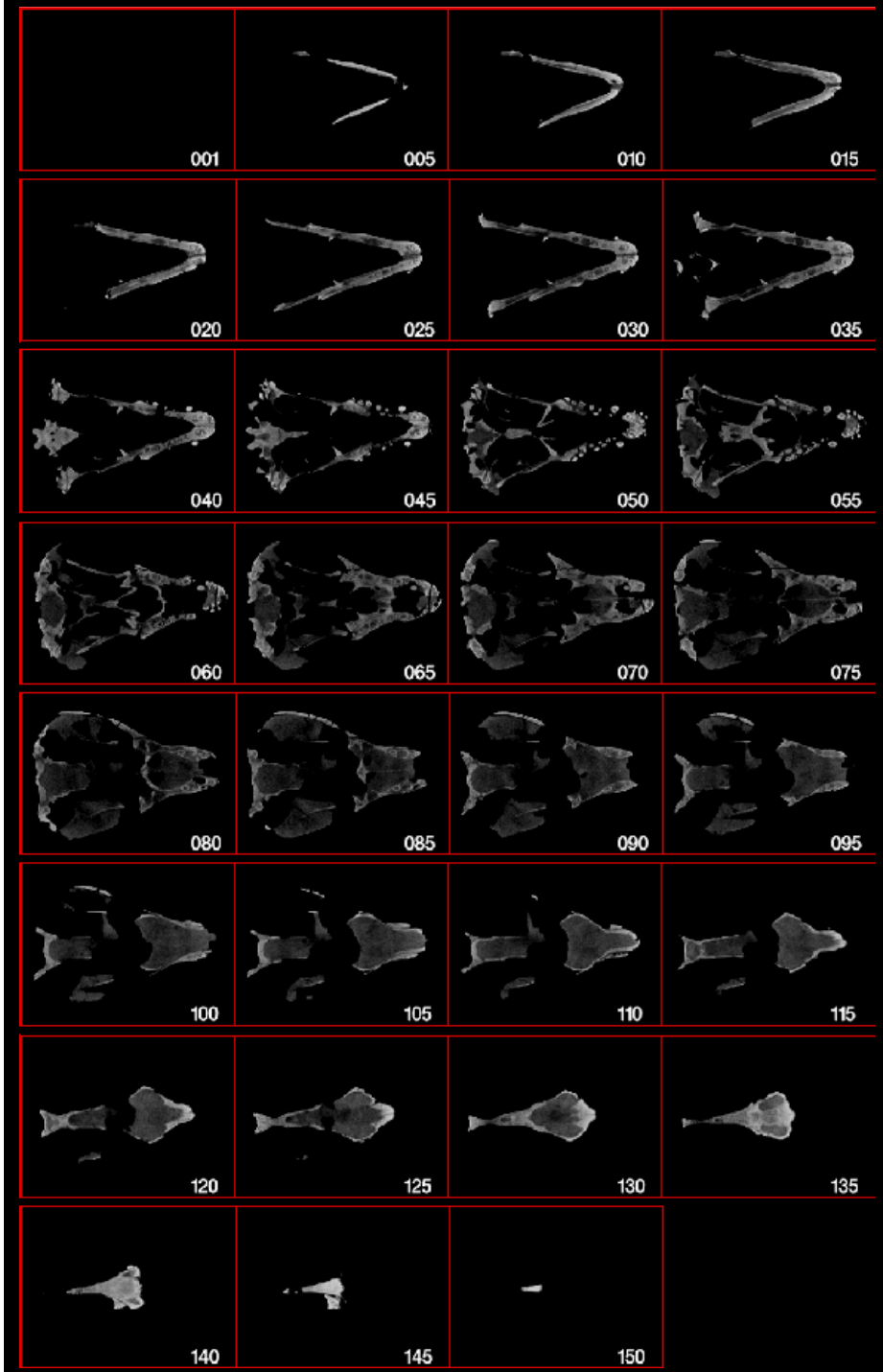
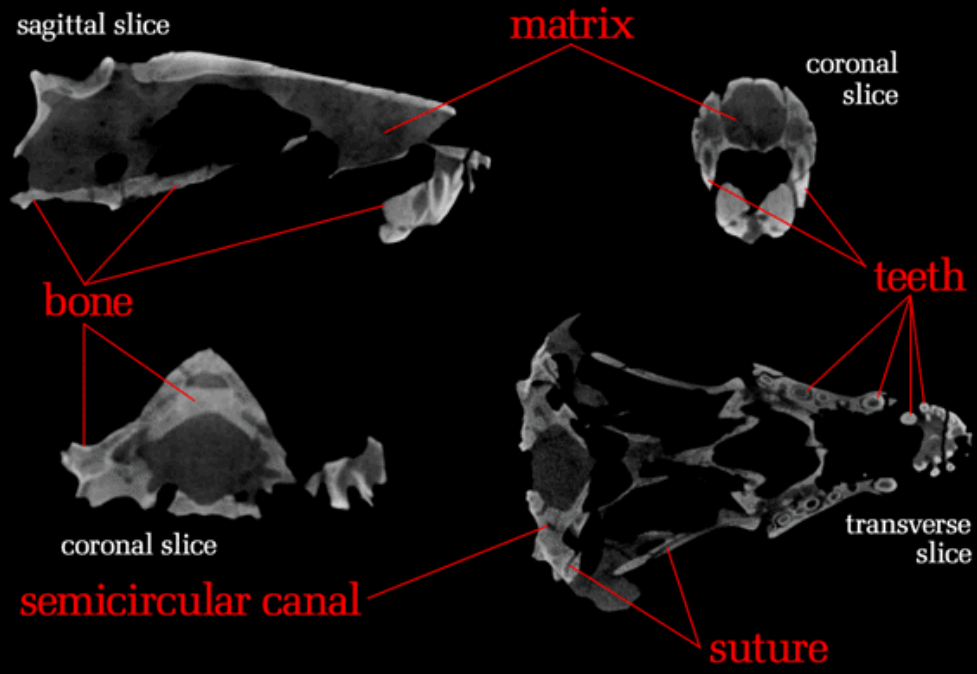



Fig. 9.

analog illustrations, selected slices




*Thrinaxodon* – Original 1992 CT dataset

We *had* to have our own instrument to innovate.

*UTCT*
*The University of Texas High Resolution Computed Tomography Facility*

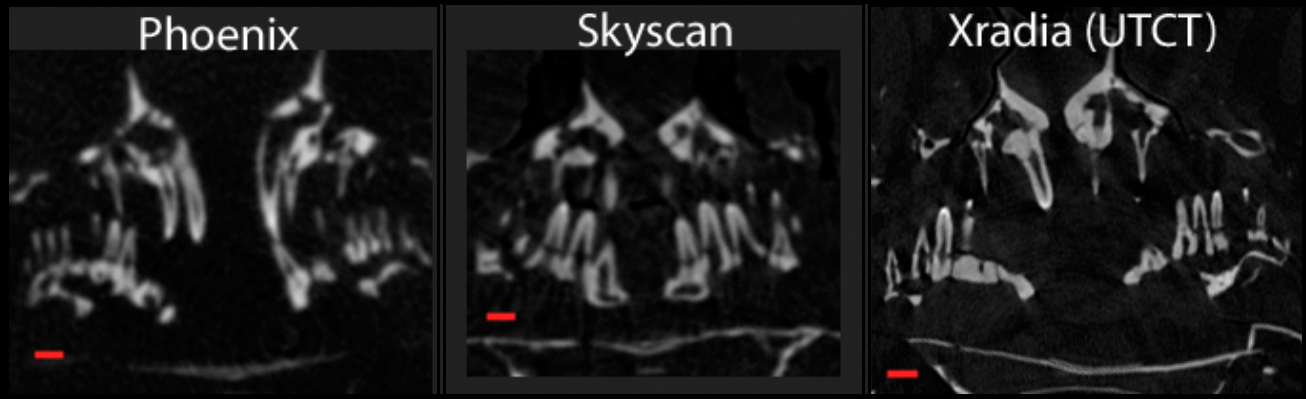
*founded 1997*

# High-Resolution X-ray Computed Tomography Facility

Principal Research Instrument: Dual High-Energy, High-Resolution scanners


Xradia Micro CT Scanner

Old and new Image Processing Lab, Data Management System




***Xradia Micro CT scanner***

X-ray source: 40 kV - 150 kV

Scintillator-coated lenses (0.5X 35-mm lens, and 4X, 10X, 20X and 40X microscope objectives)

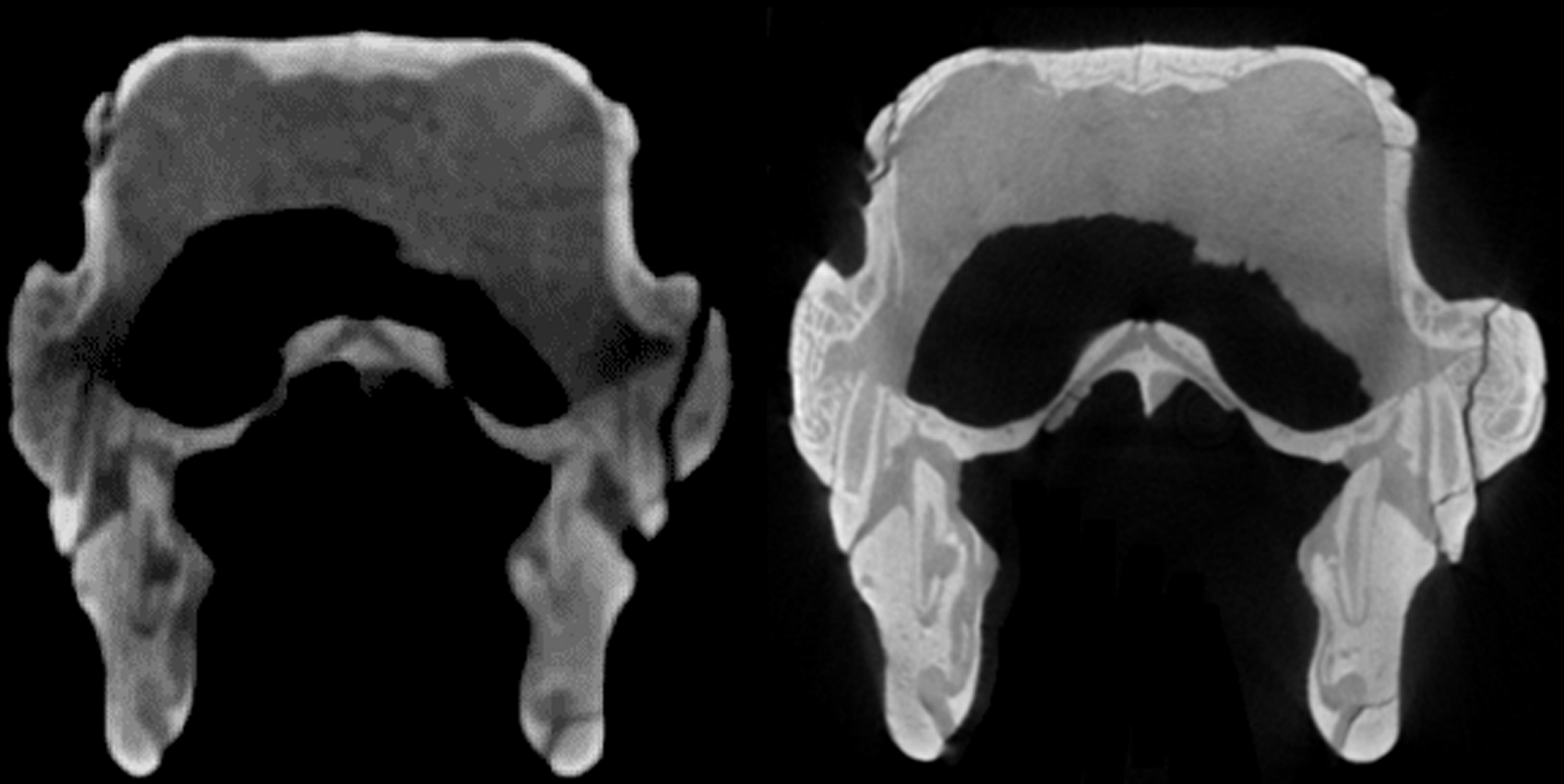
2048x2048 CCD camera

Captures up to 2000 slices in a single turntable rotation

Voxel sizes are 1/1024 or 1/2048 of the imaged volume diameter, ranging down to 0.2 µm.

SMS Scanner 1992

UTCT ACTIS Scanner 1997

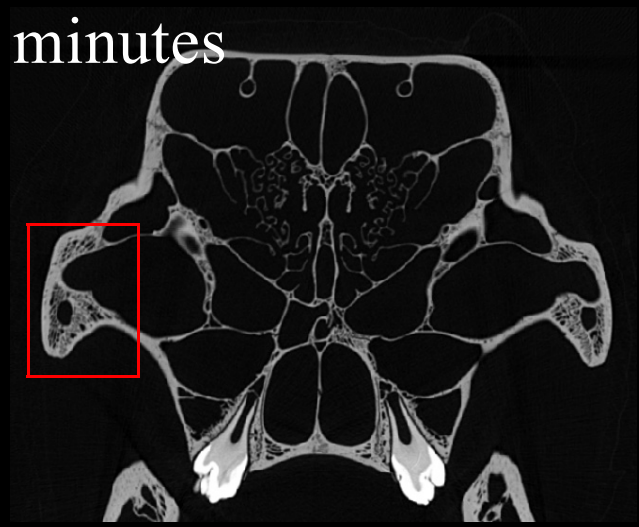


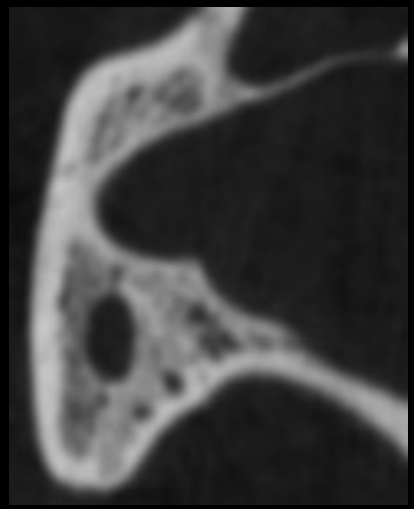
# Time Comparison: Pig skull

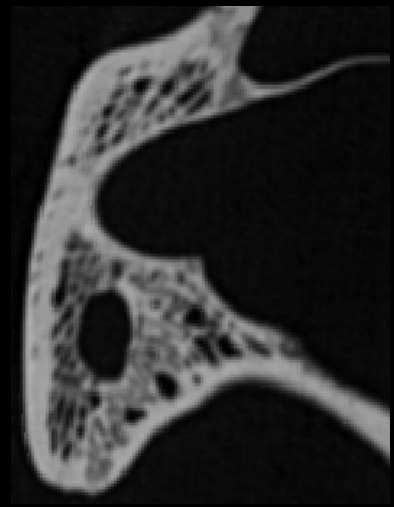
ACTIS: 353 minutes

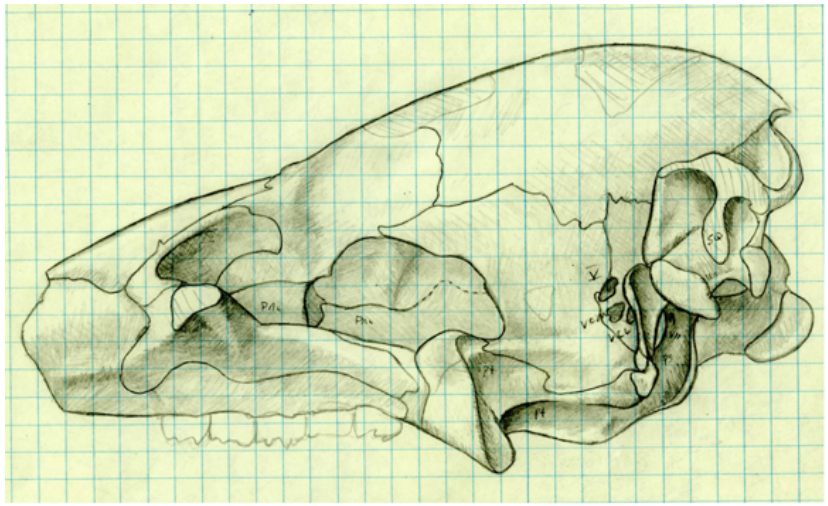
5 cm

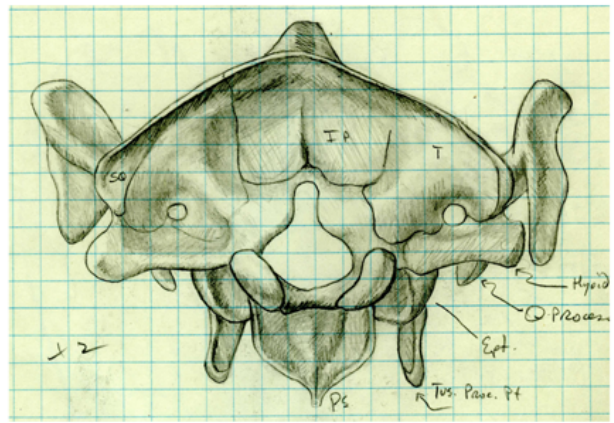
North Star: 36 minutes

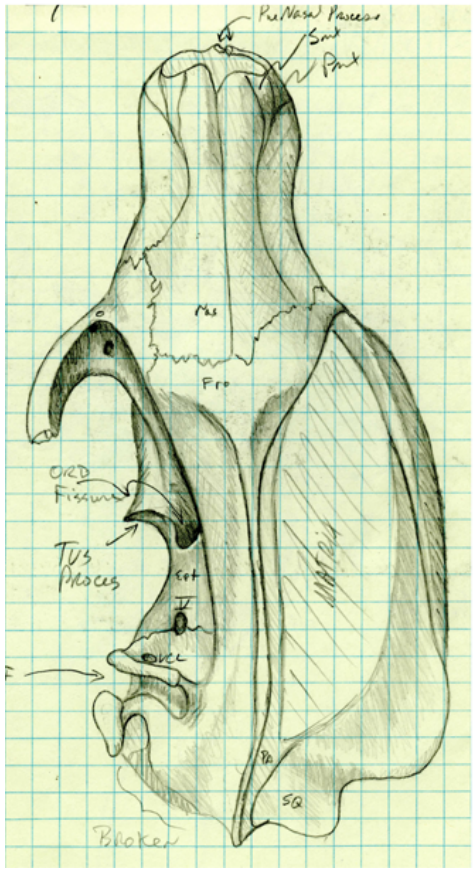


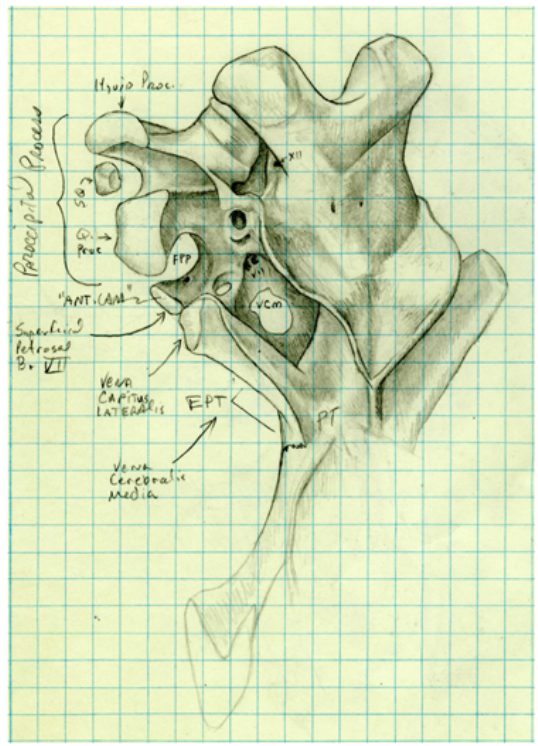


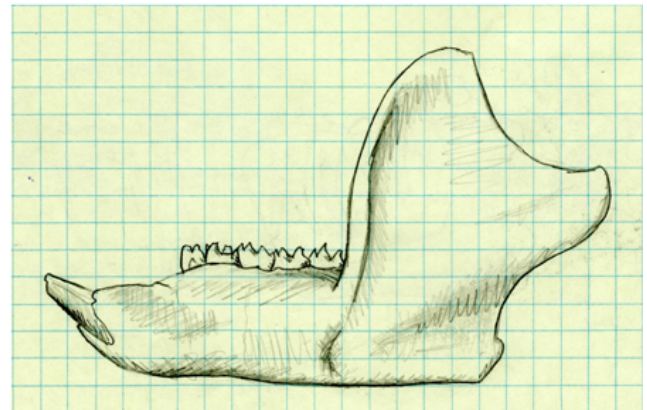


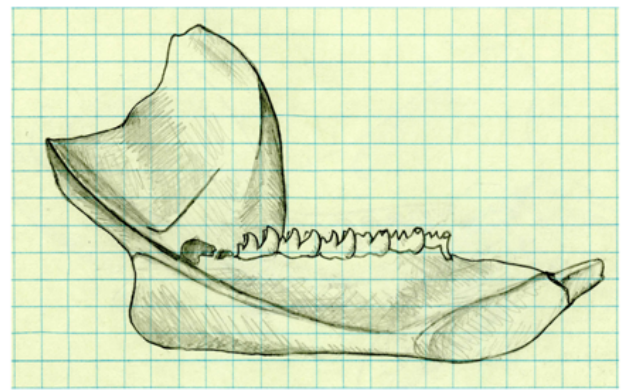

Pmx
Pmx
SQ
PT
PT


IP
T
SQ
Hyoid
Q Process
Ept.
PS
Tus. Proc. PT


Pre Nasal Process
Smx
Pmx
Mes
Fro
ORB Fissure
TUS Process
Ept
Orbit
PA
SQ
Broken


Hyoid Proc.
Paroccipital Process
SQ
Q Proc.
FPP
"ANT. CANAL"
Superficial Petrosal Br. VII
Vena Capitis Lateralis
EPT
PT
Vena Cerebralis Media

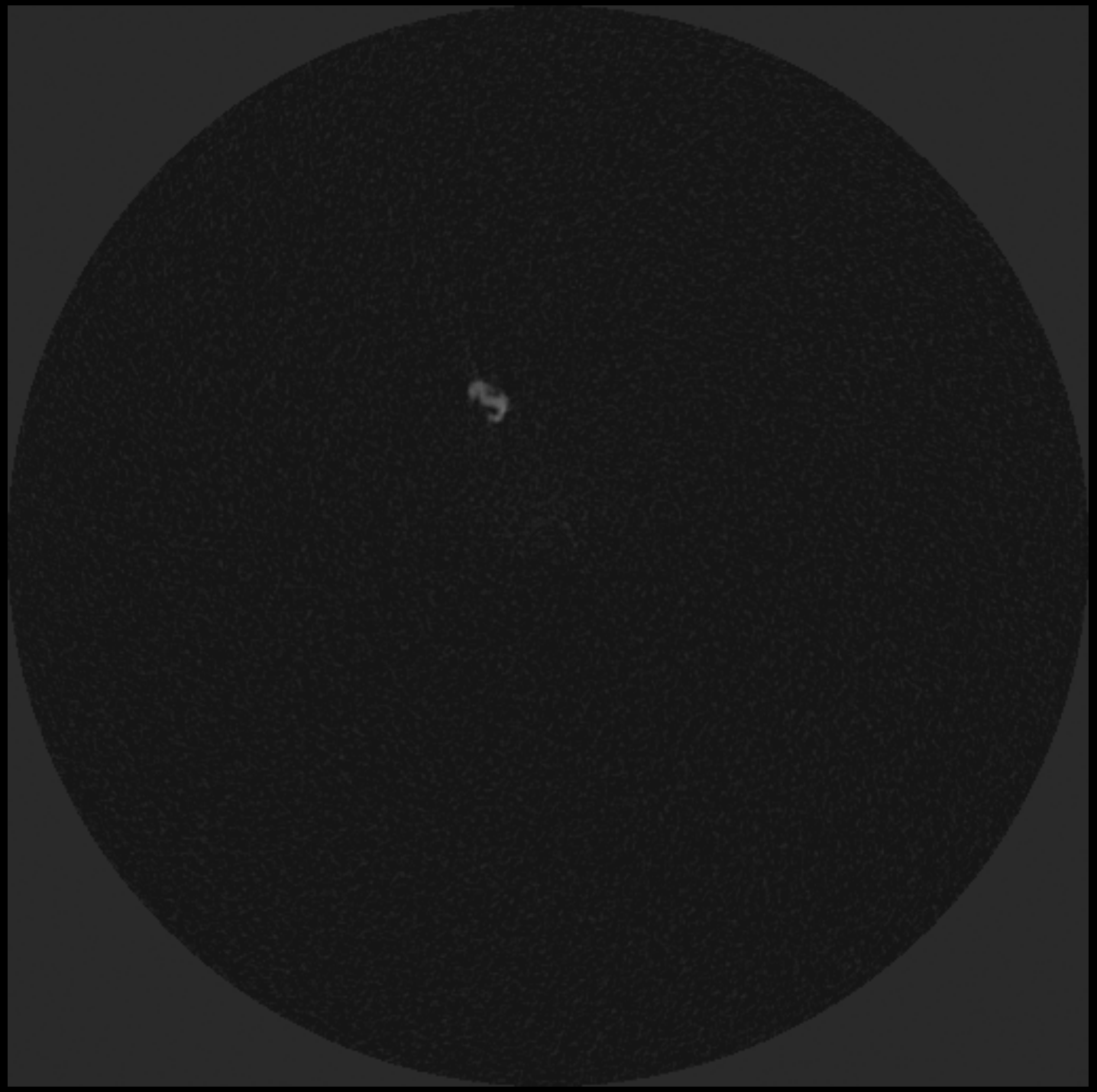


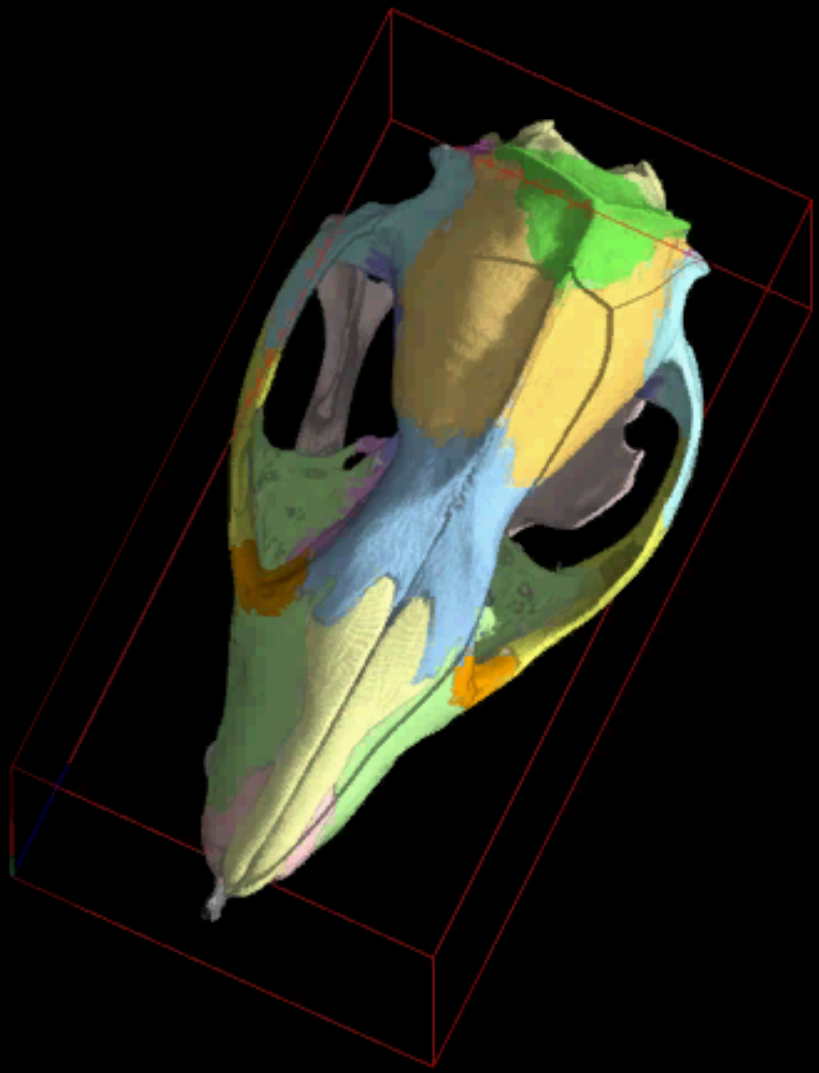


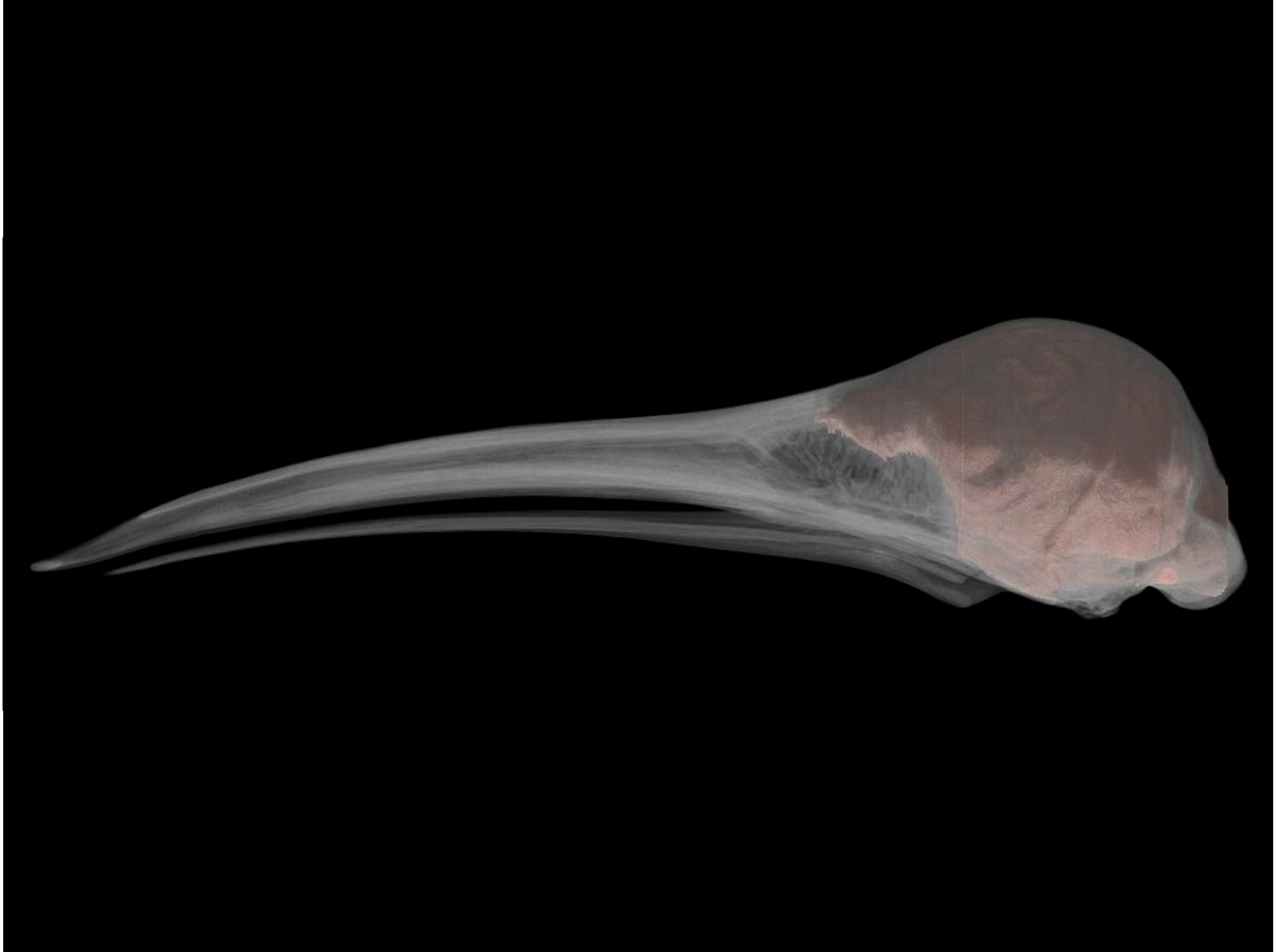

Elvis

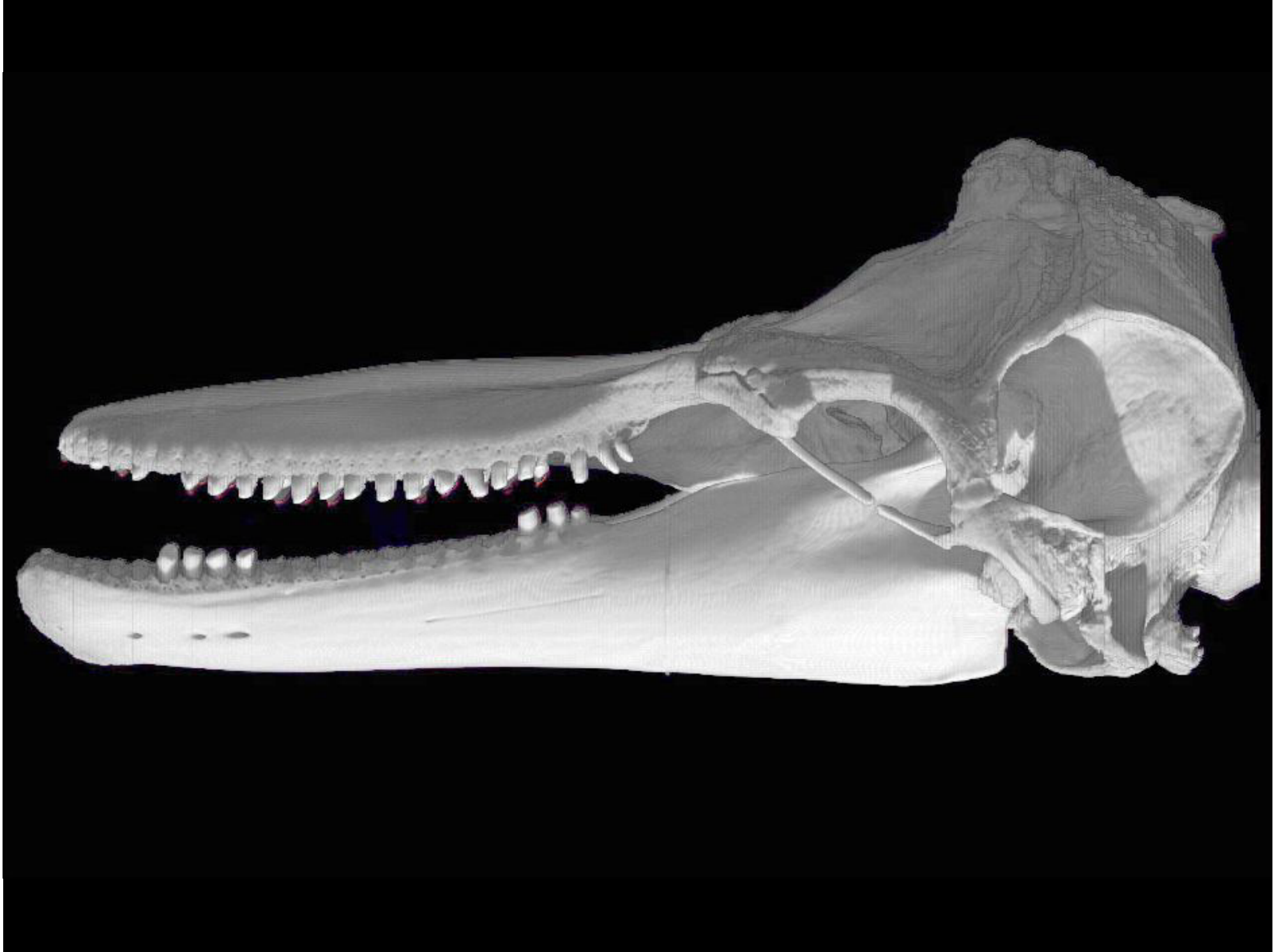
Movies: Research Applications

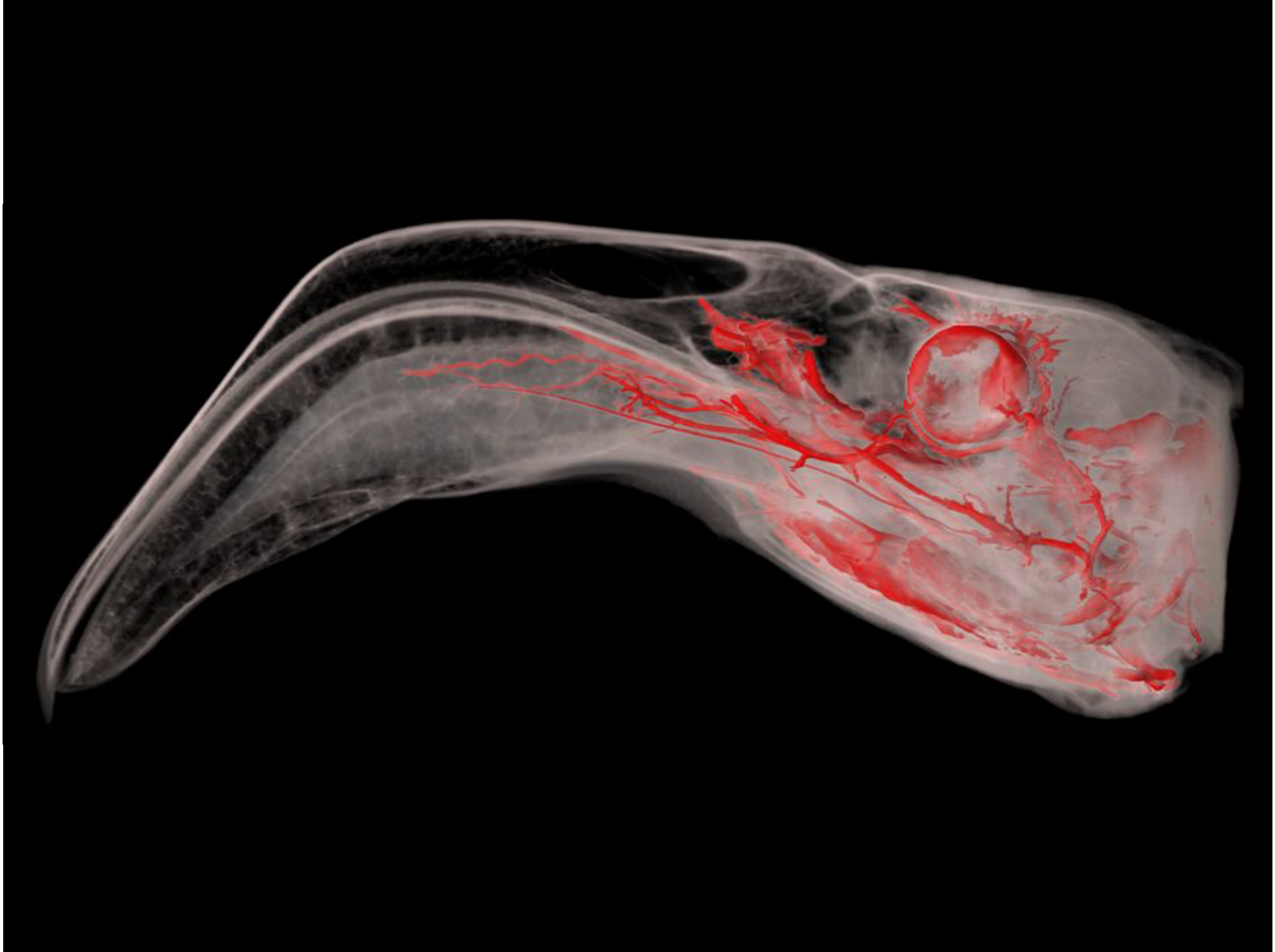
01 Mus slices
02 Mus Spins
03 Chamaleo color
04 JuvieHelo
05 MoNose
06 Segmented Skull
07 Zaglossus endo
08 Lanthanotus
09 Flamingo
10 Nycti
11 MoThrx
12 Smonodelph

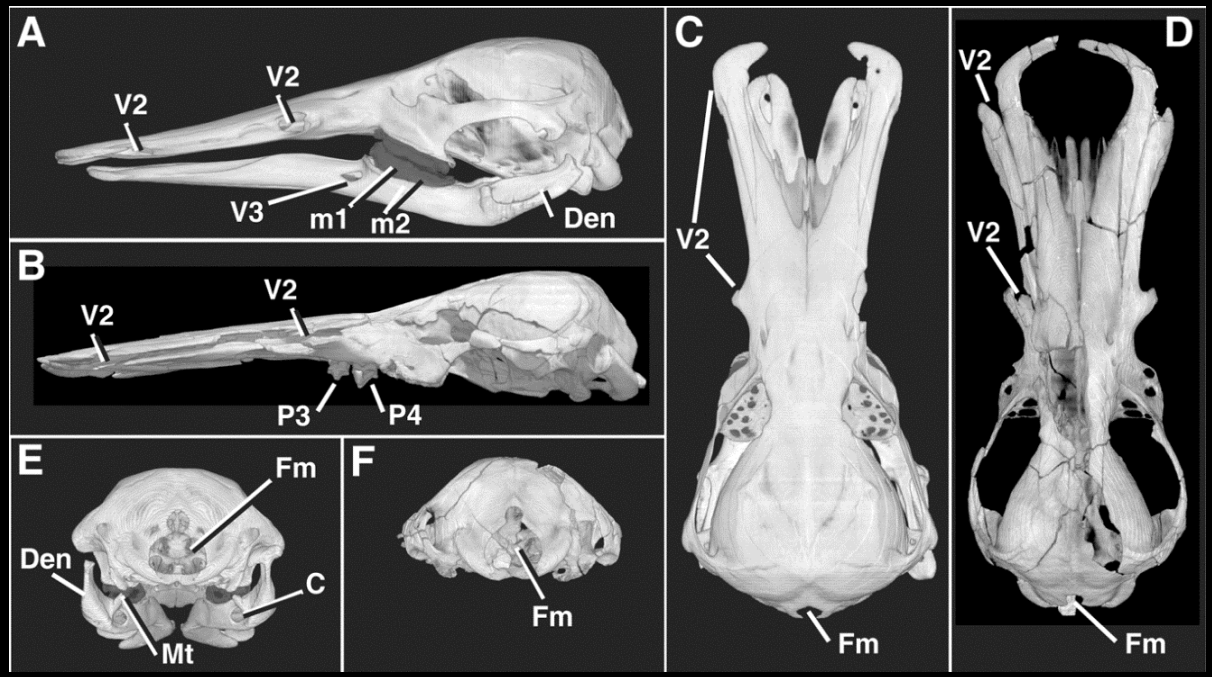




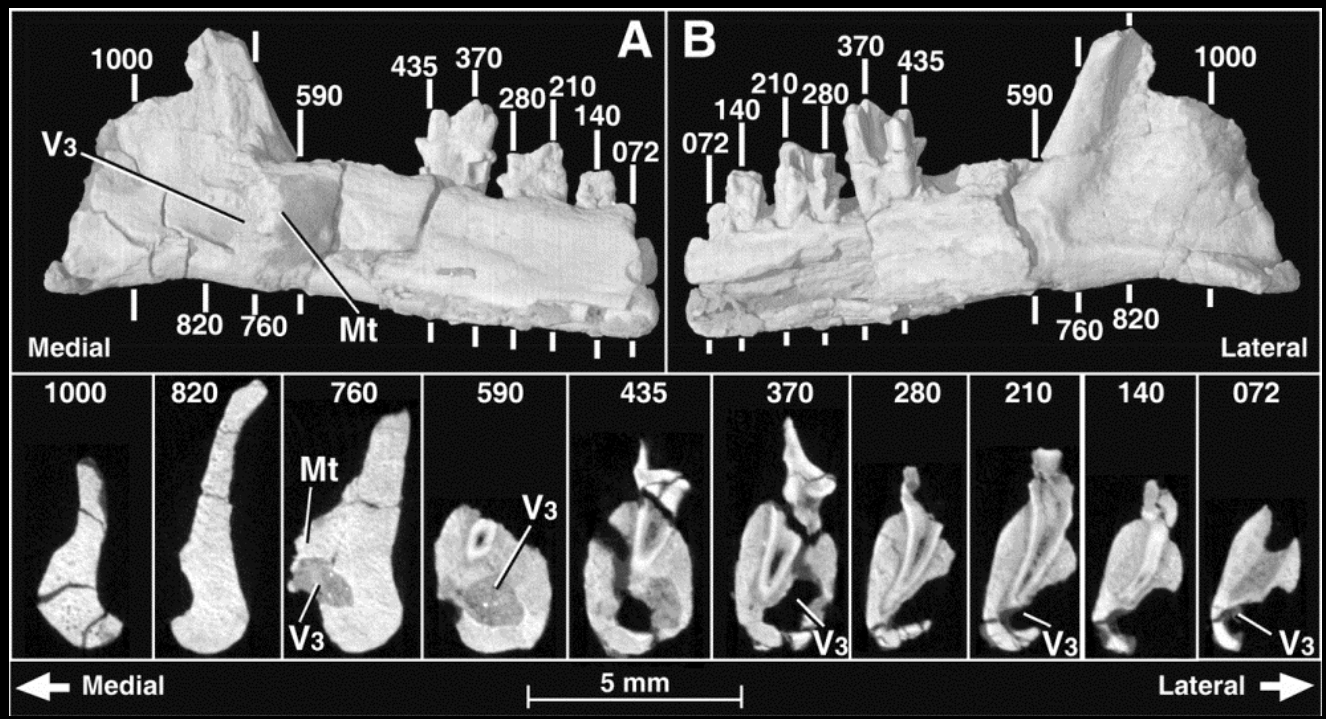


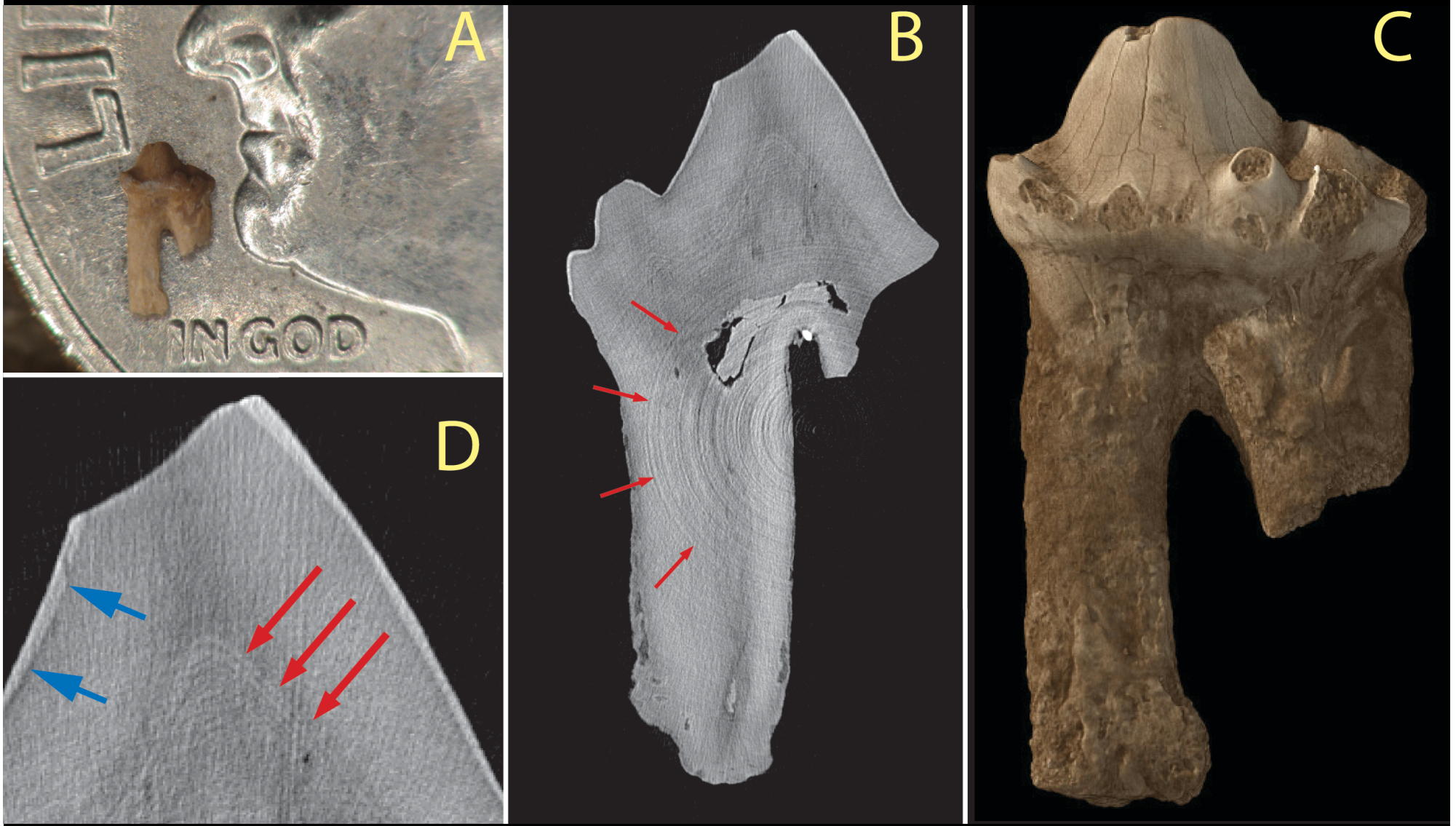


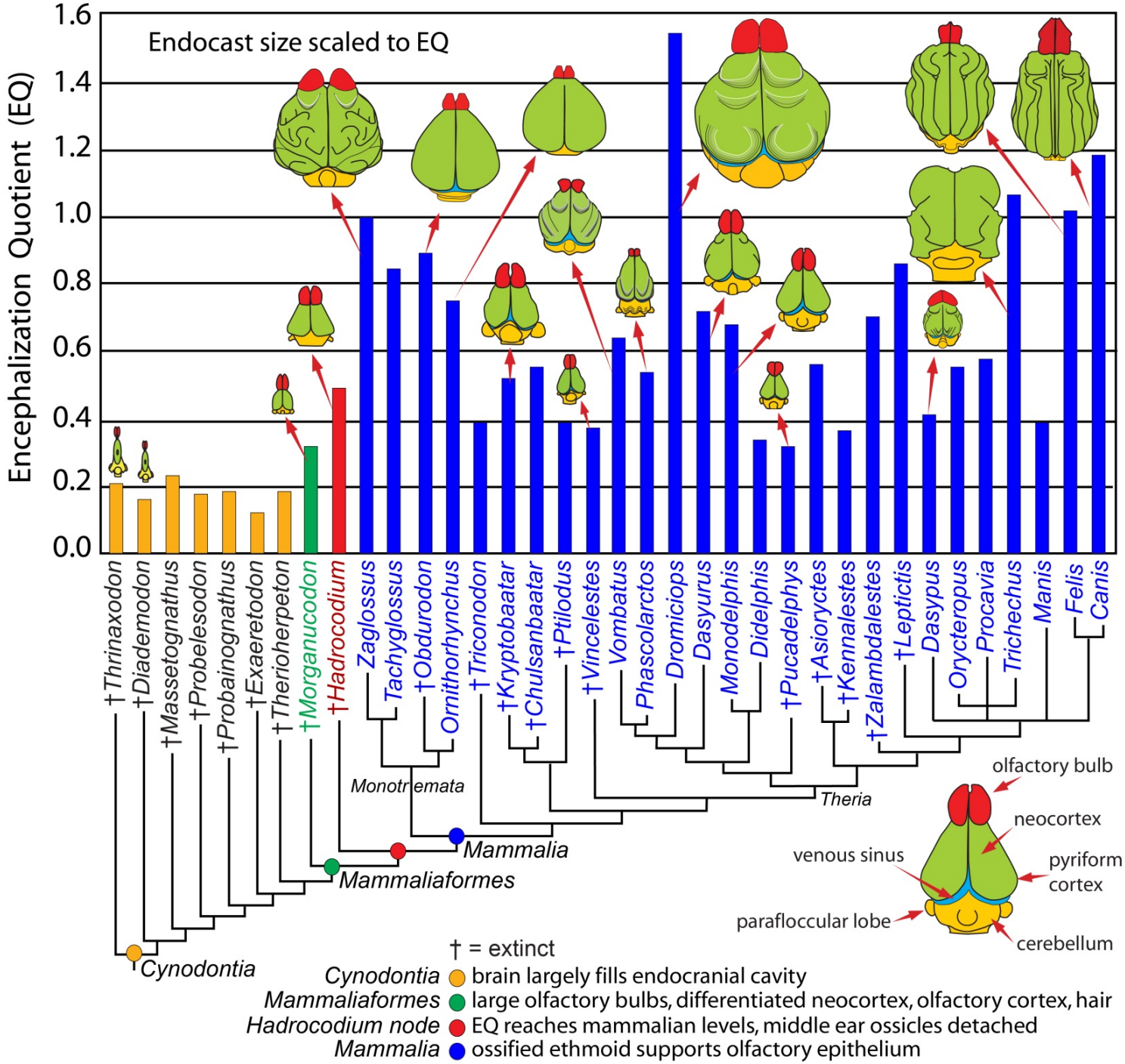





# CT imagery in conventional illustration

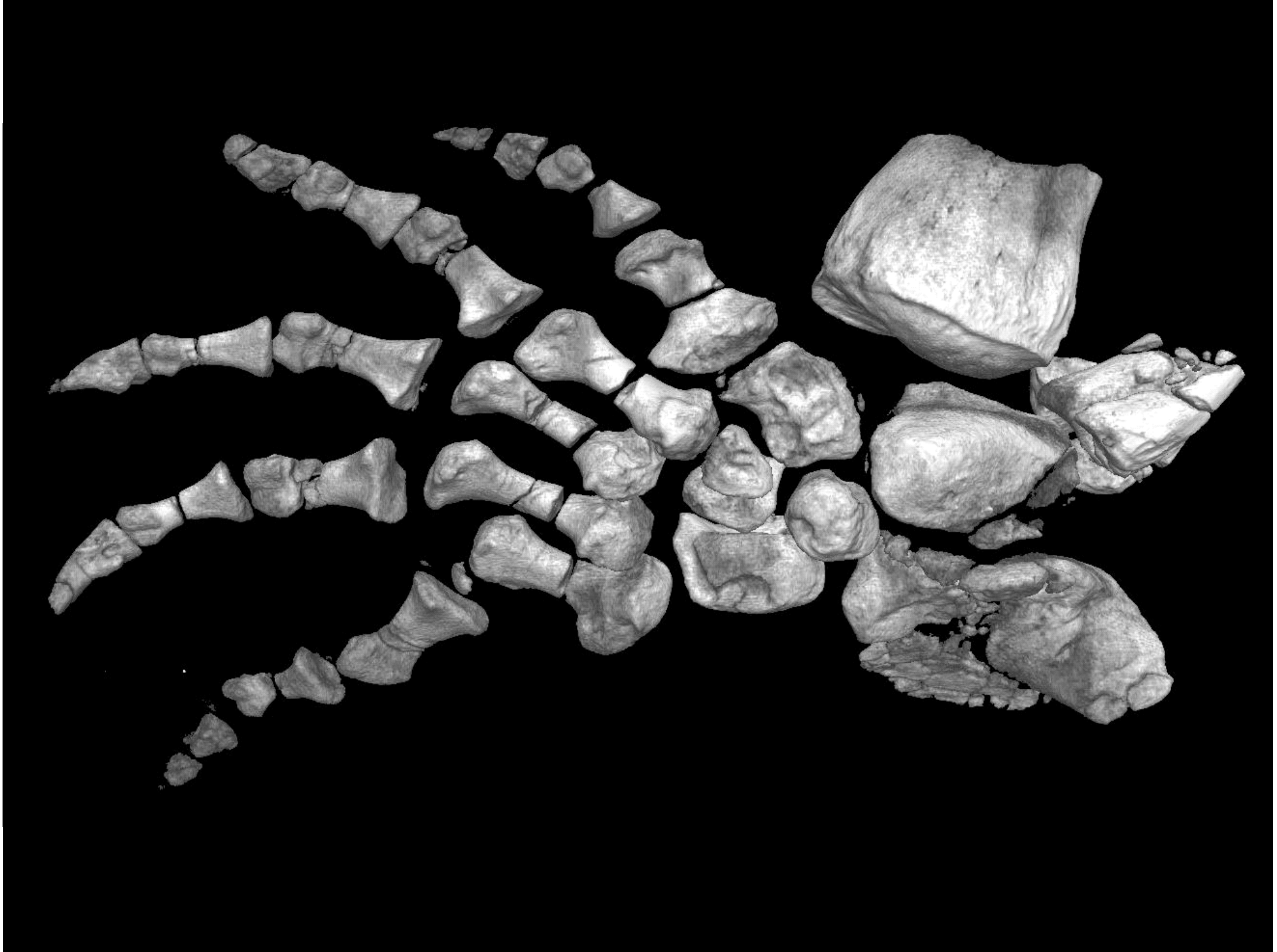


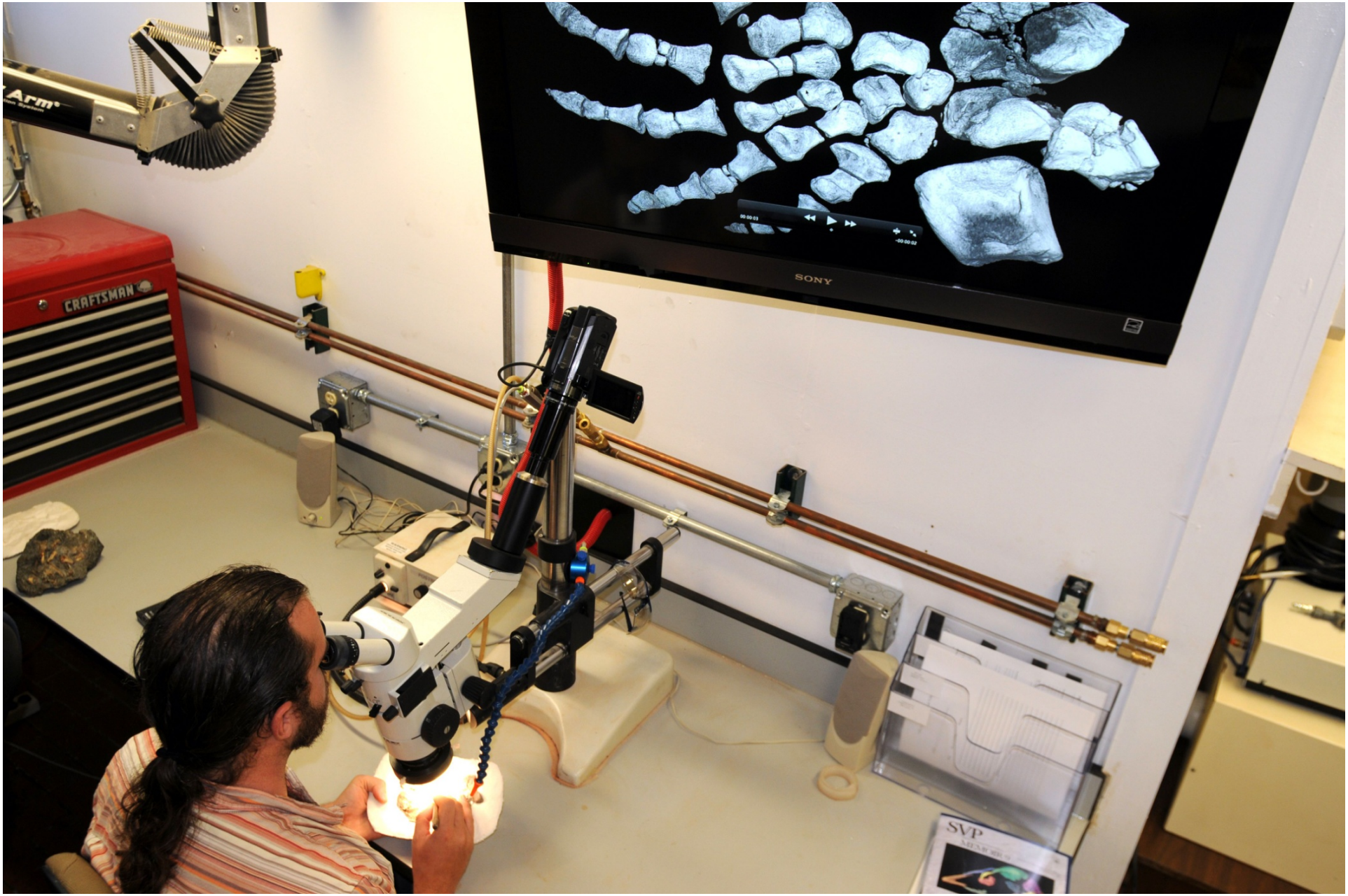

A
IN GOD
B
C
D

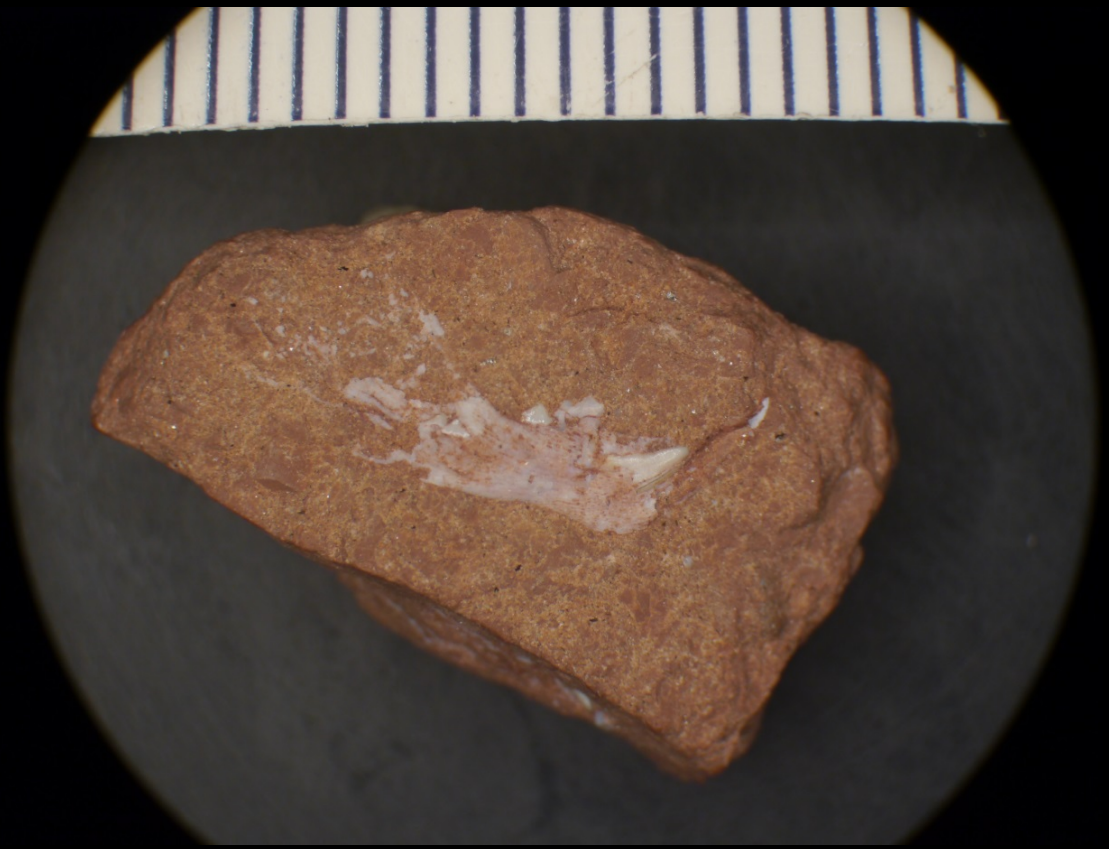

Endocast size scaled to EQ
Encephalization Quotient (EQ)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
†Thrinaxodon
†Diademodon
†Massetognathus
†Probelesodon
†Probainognathus
†Exaeretodon
†Therioherpeton
†Morganucodon
†Hadrocodium
Zaglossus
Tachyglossus
†Obdurodon
Ornithorhynchus
†Triconodon
†Kryptobaatar
†Chulsanbaatar
†Ptilodus
†Vincelestes
Vombatus
Phascolarctos
Dromiciops
Dasyurus
Monodelphis
Didelphis
†Pucadelphys
†Asioryctes
†Kennalestes
†Zalambdalestes
†Lepticitis
Dasypus
Orycteropus
Procavia
Trichechus
Manis
Felis
Canis
Monotremata
Theria
Mammalia
Mammaliaformes
Cynodontia
olfactory bulb
neocortex
pyriform cortex
venous sinus
paraflocculer lobe
cerebellum
† = extinct
Cynodontia brain largely fills endocranial cavity
Mammaliaformes large olfactory bulbs, differentiated neocortex, olfactory cortex, hair
Hadrocodium node EQ reaches mammalian levels, middle ear ossicles detached
Mammalia ossified ethmoid supports olfactory epithelium

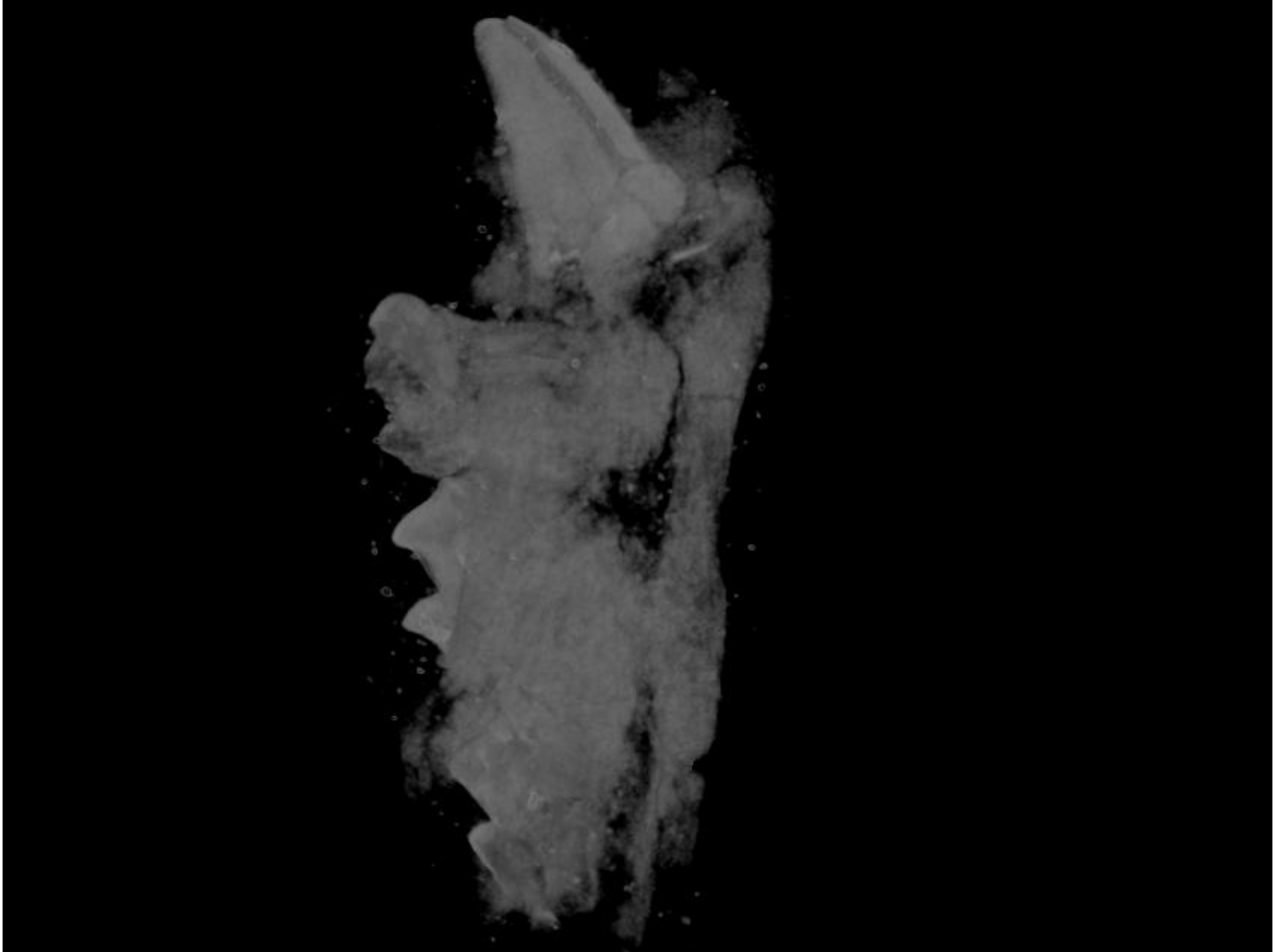

TR 00/20

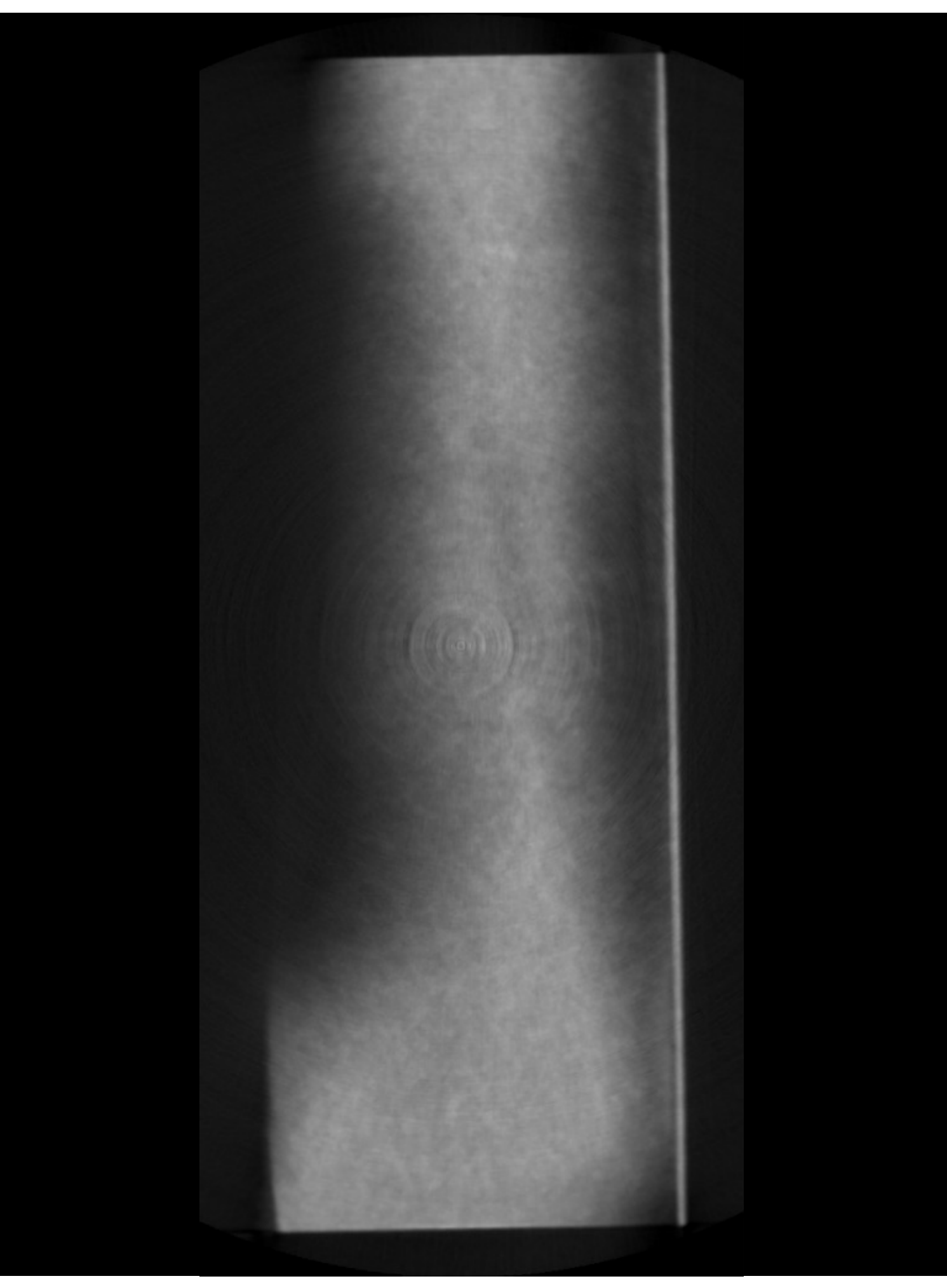

3
4
5
6
7
8
9
10
11
4

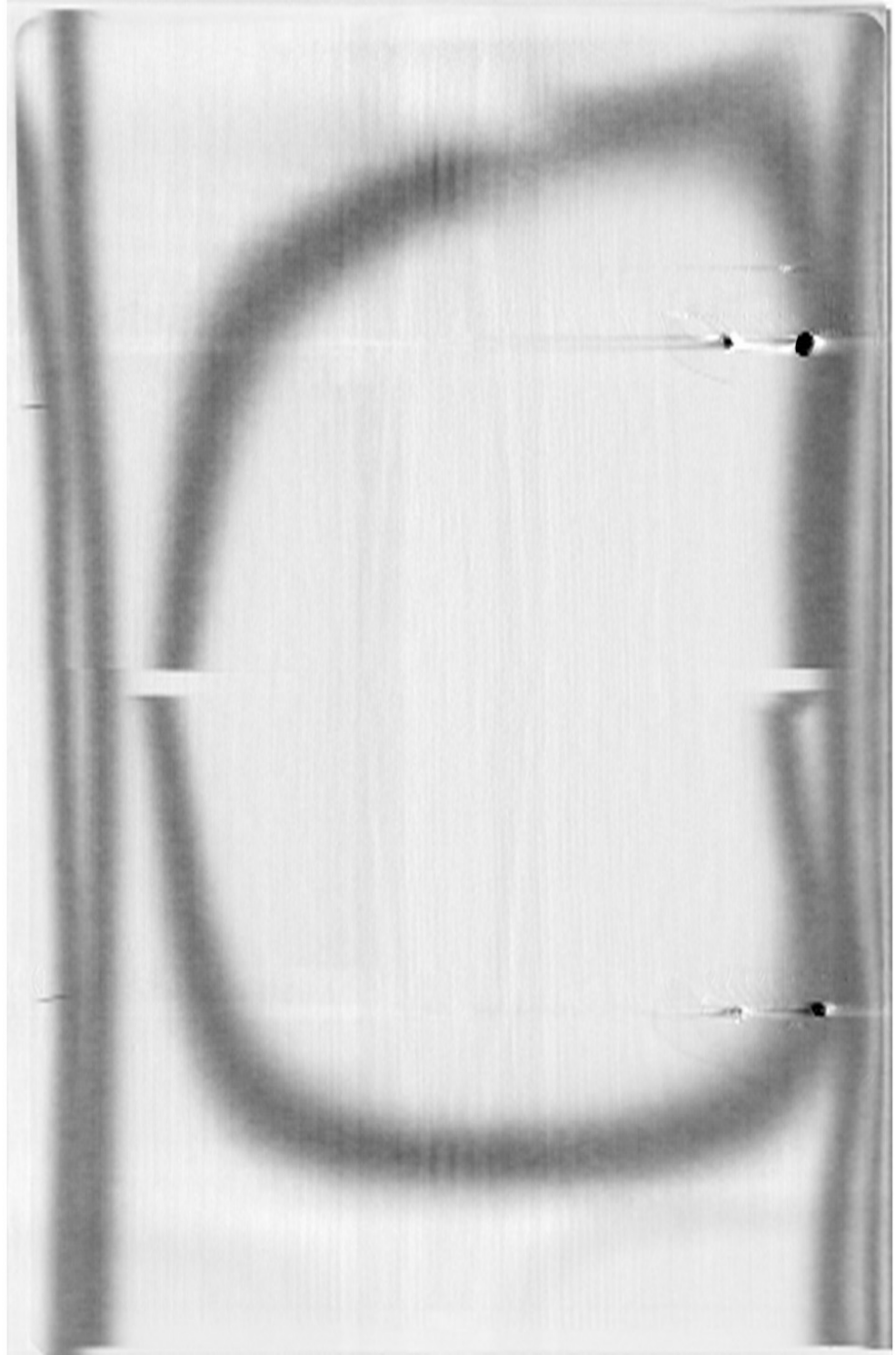


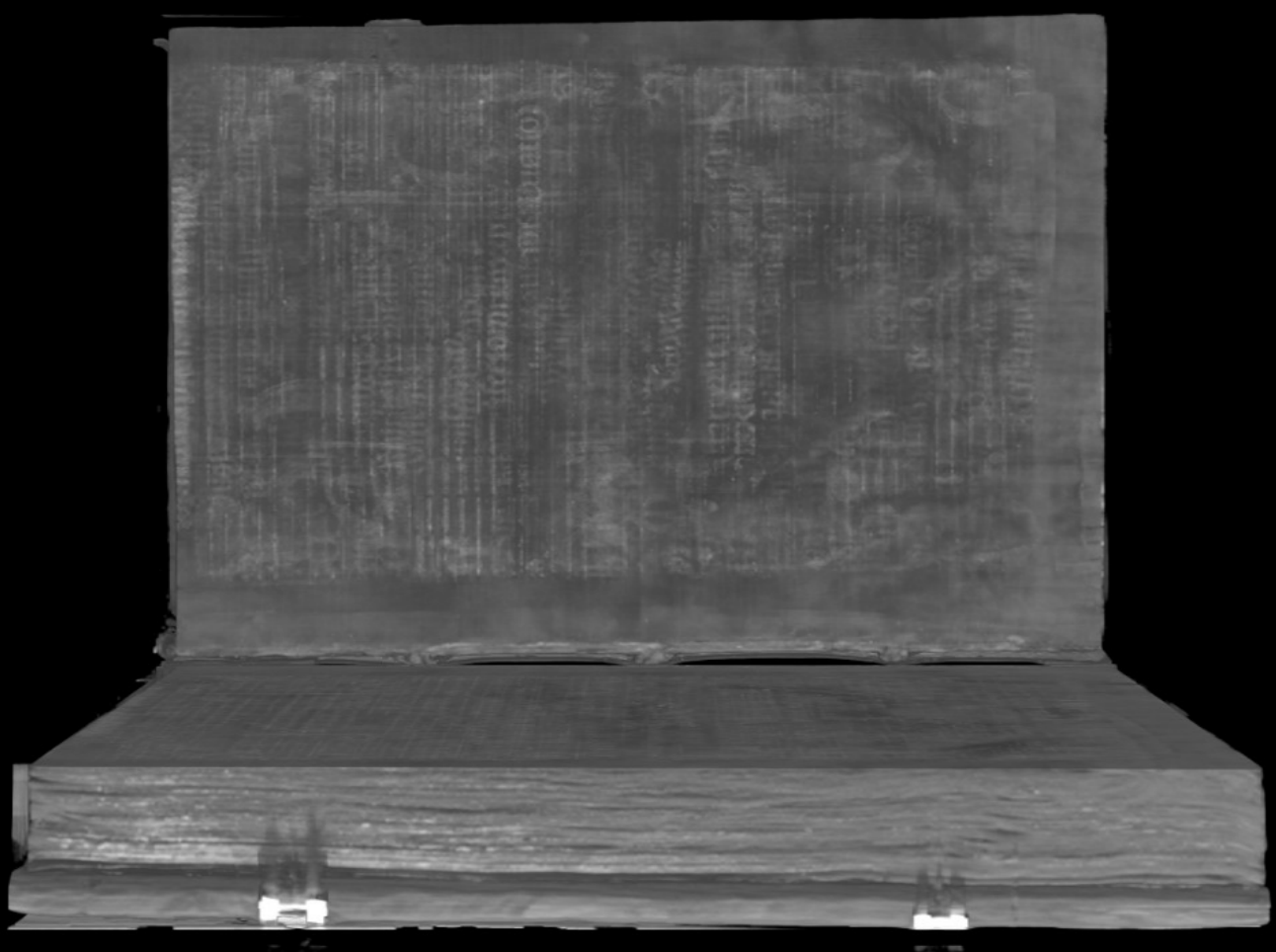

CRAFTSMAN
SONY
SVP

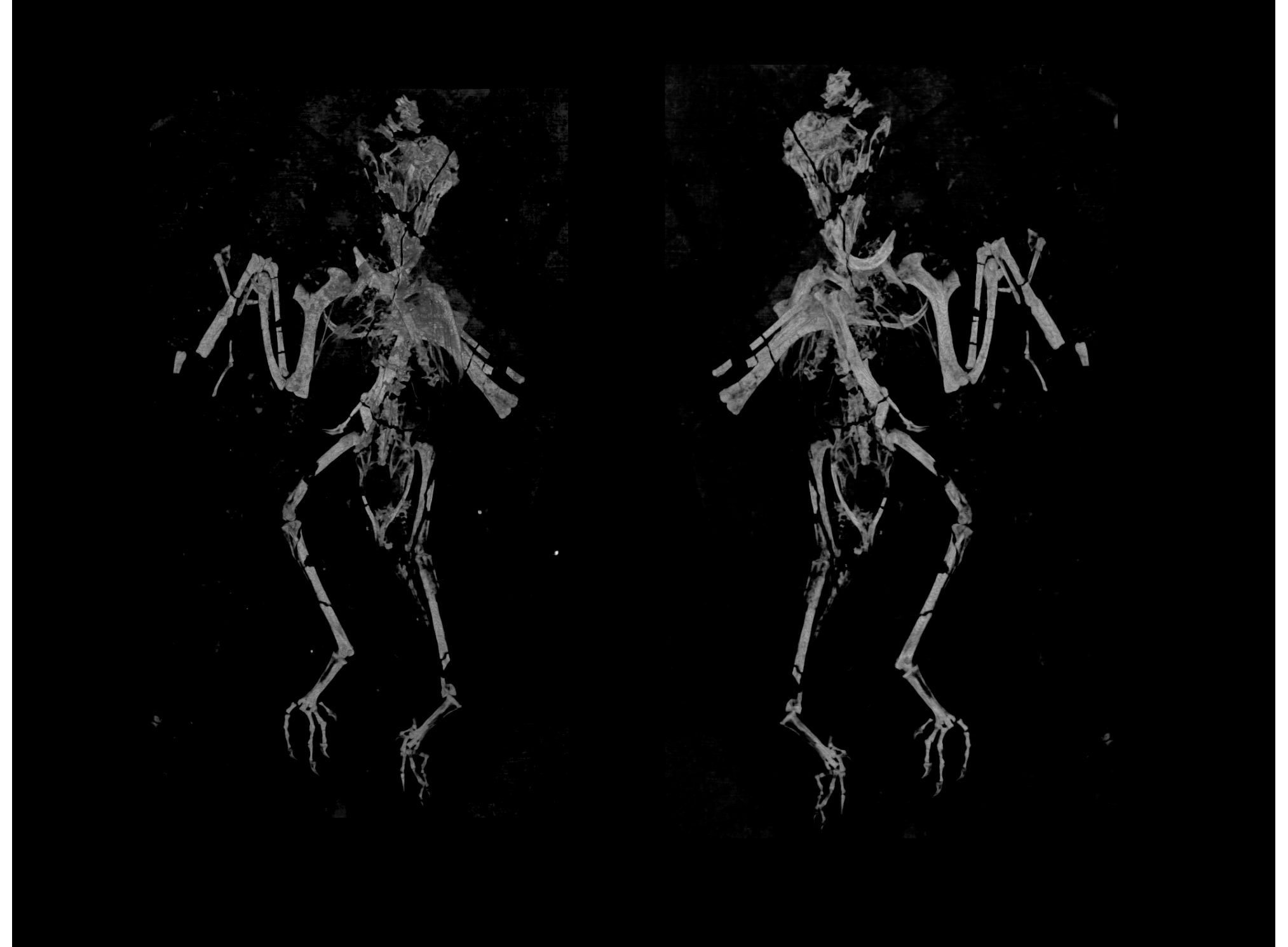


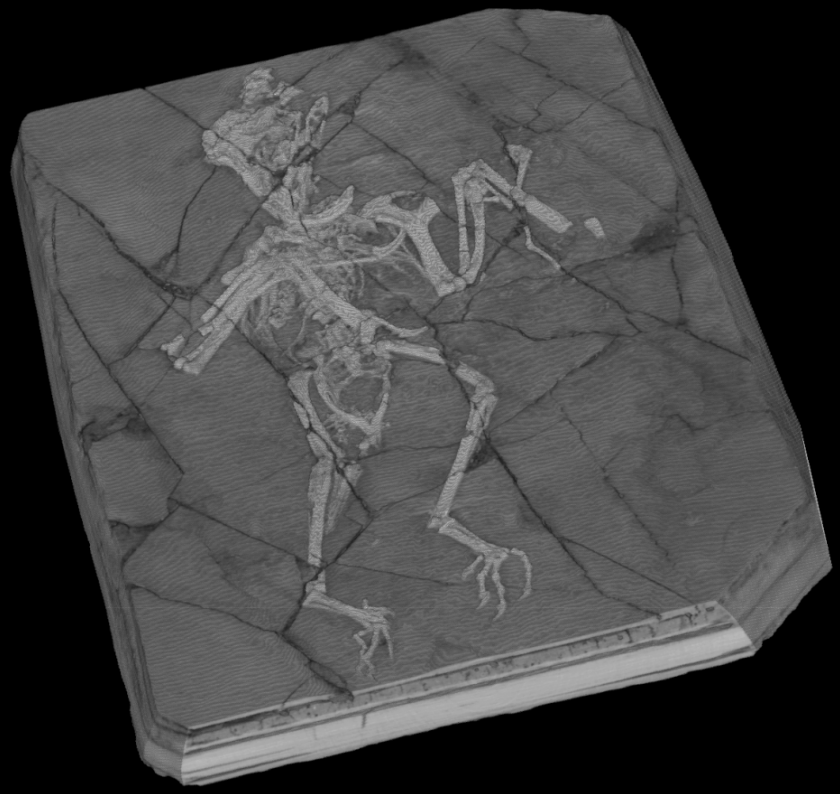


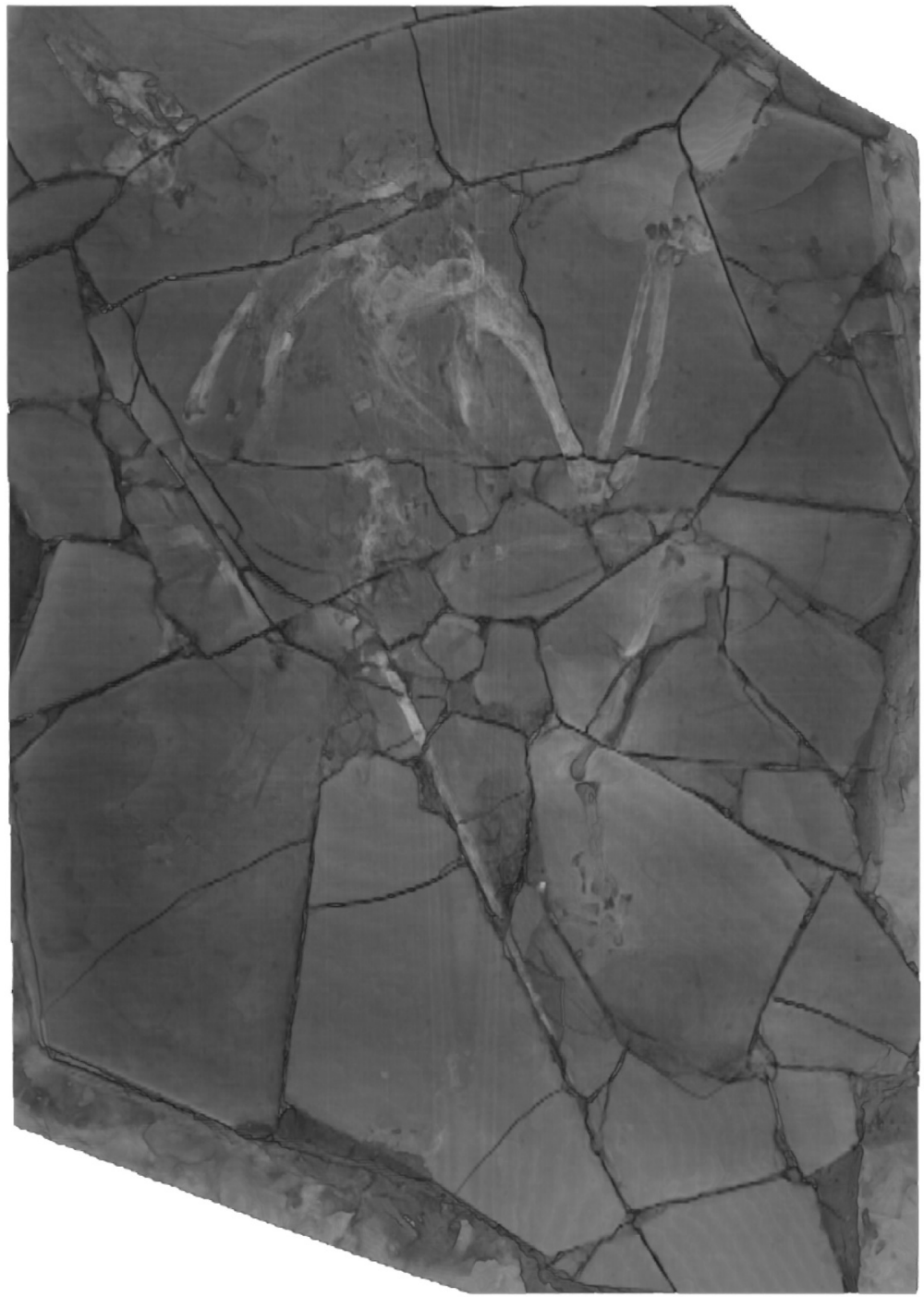


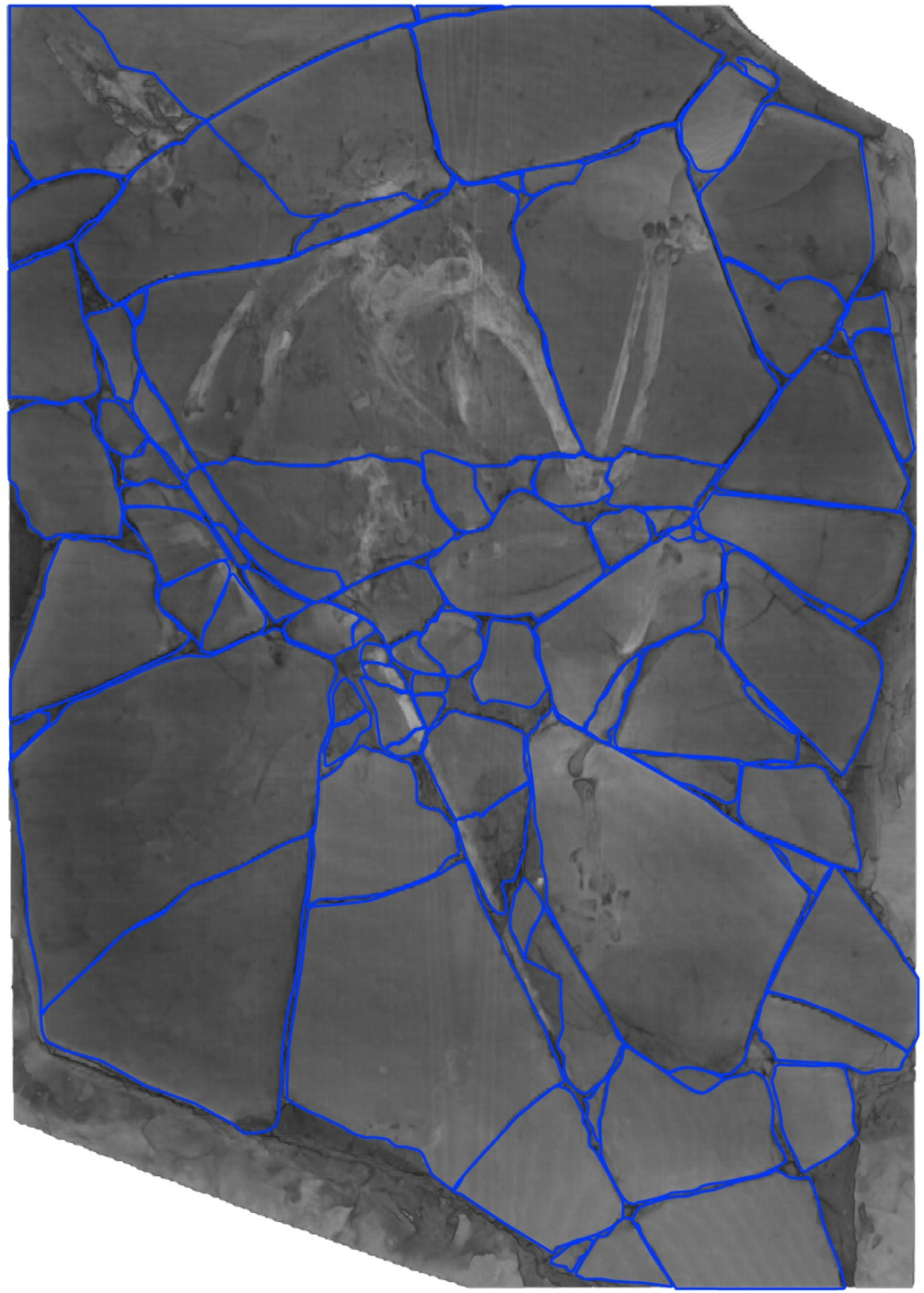


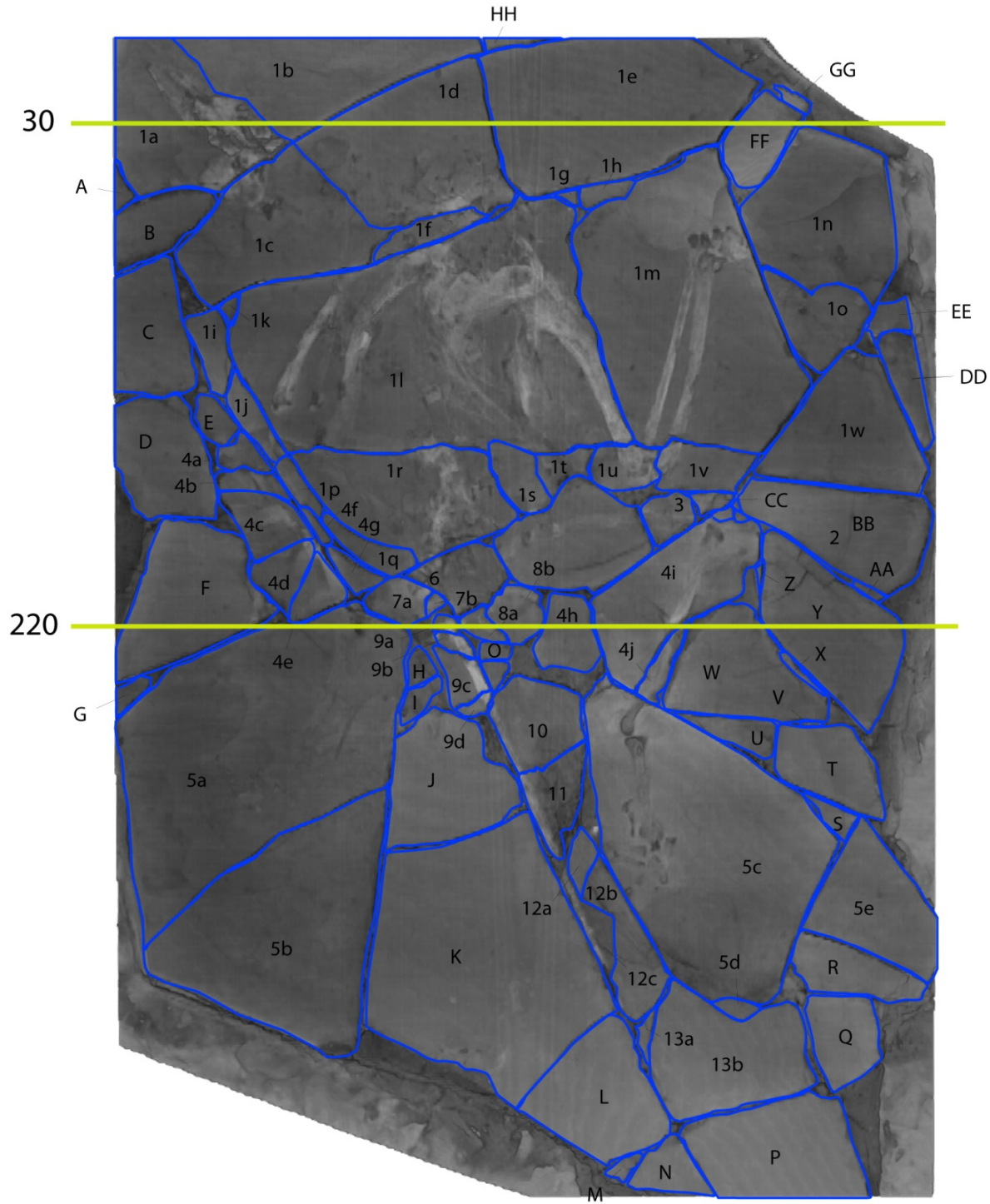




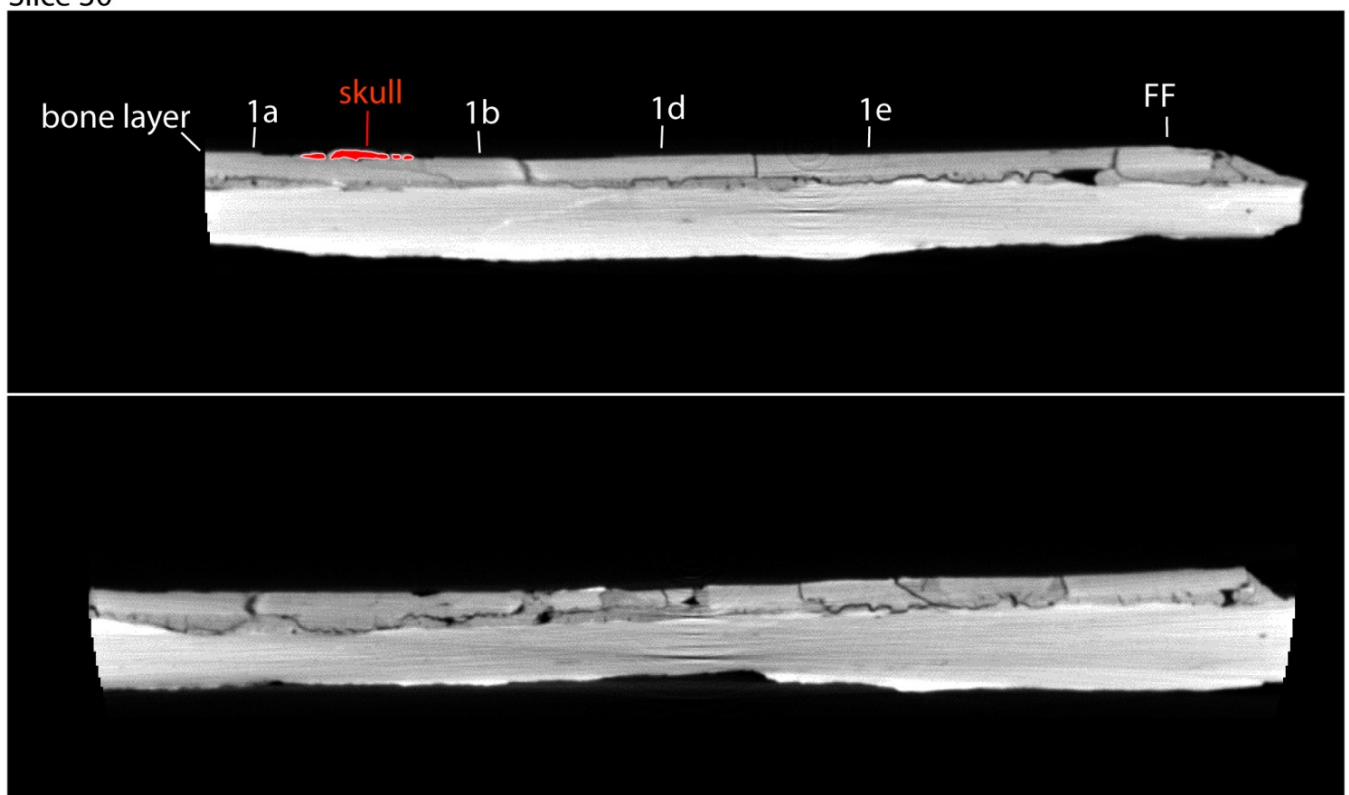






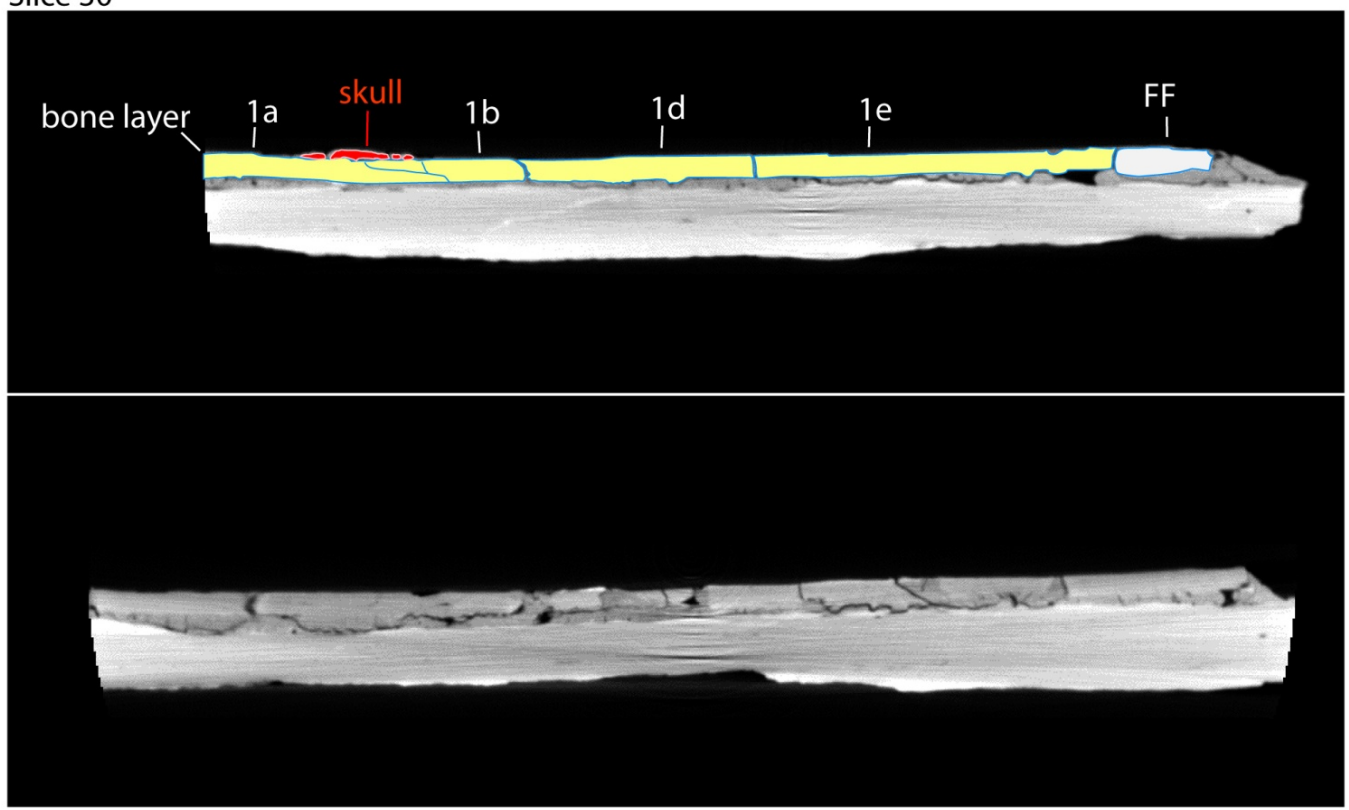

HH
1b
1d
1e
GG
30
1a
FF
A
1g
1h
B
1f
1n
1c
1m
1o
EE
C
1i
1k
1l
DD
1j
E
1w
D
4a
1r
1t
1u
1v
4b
1p
1s
3
CC
4f
4g
2
BB
4c
1q
8b
4i
AA
6
Z
F
4d
7a
7b
8a
4h
Y
220
9a
O
4j
X
4e
9b
H
9c
W
G
I
V
10
U
9d
T
5a
J
11
S
5c
12b
12a
5e
5b
K
5d
R
12c
13a
Q
13b
L
P
N
M

Slice 30



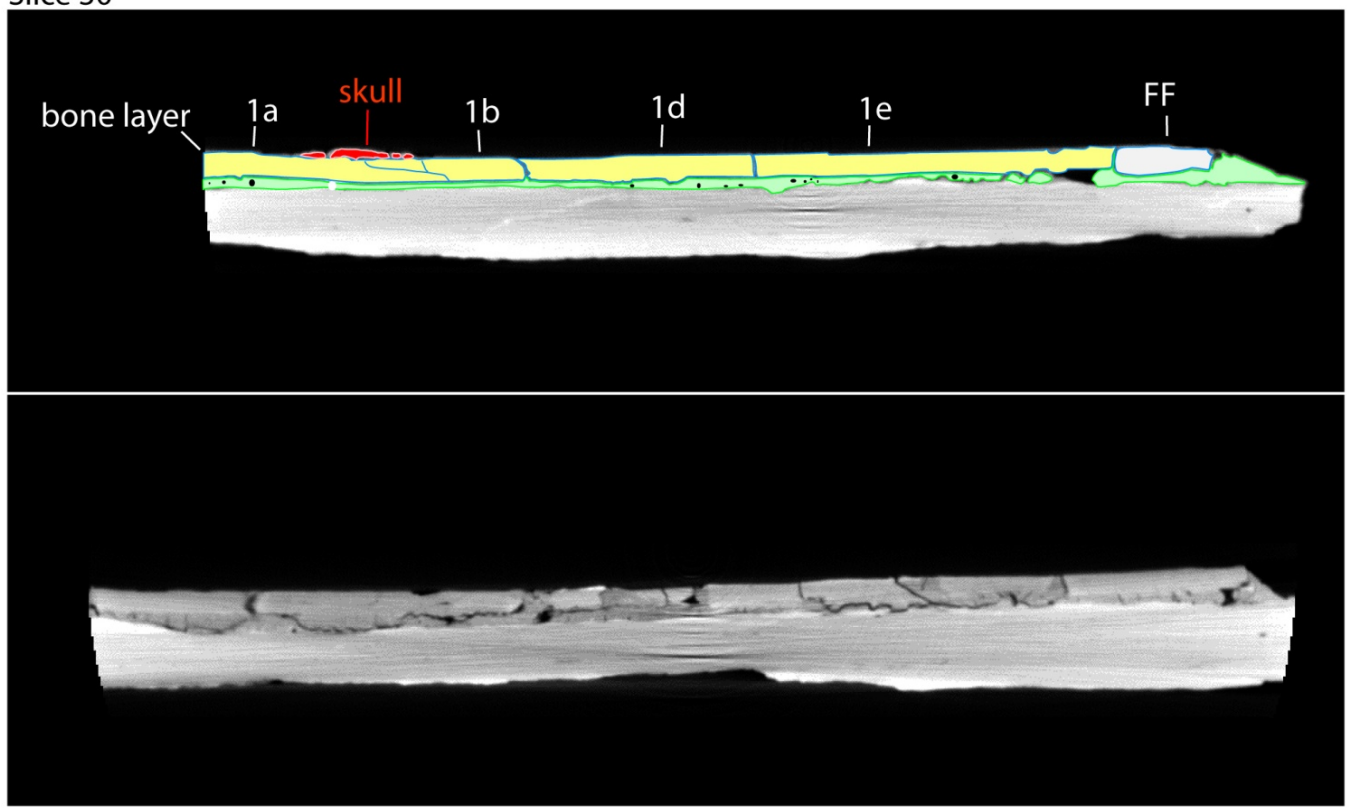

Slice 220

Slice 30



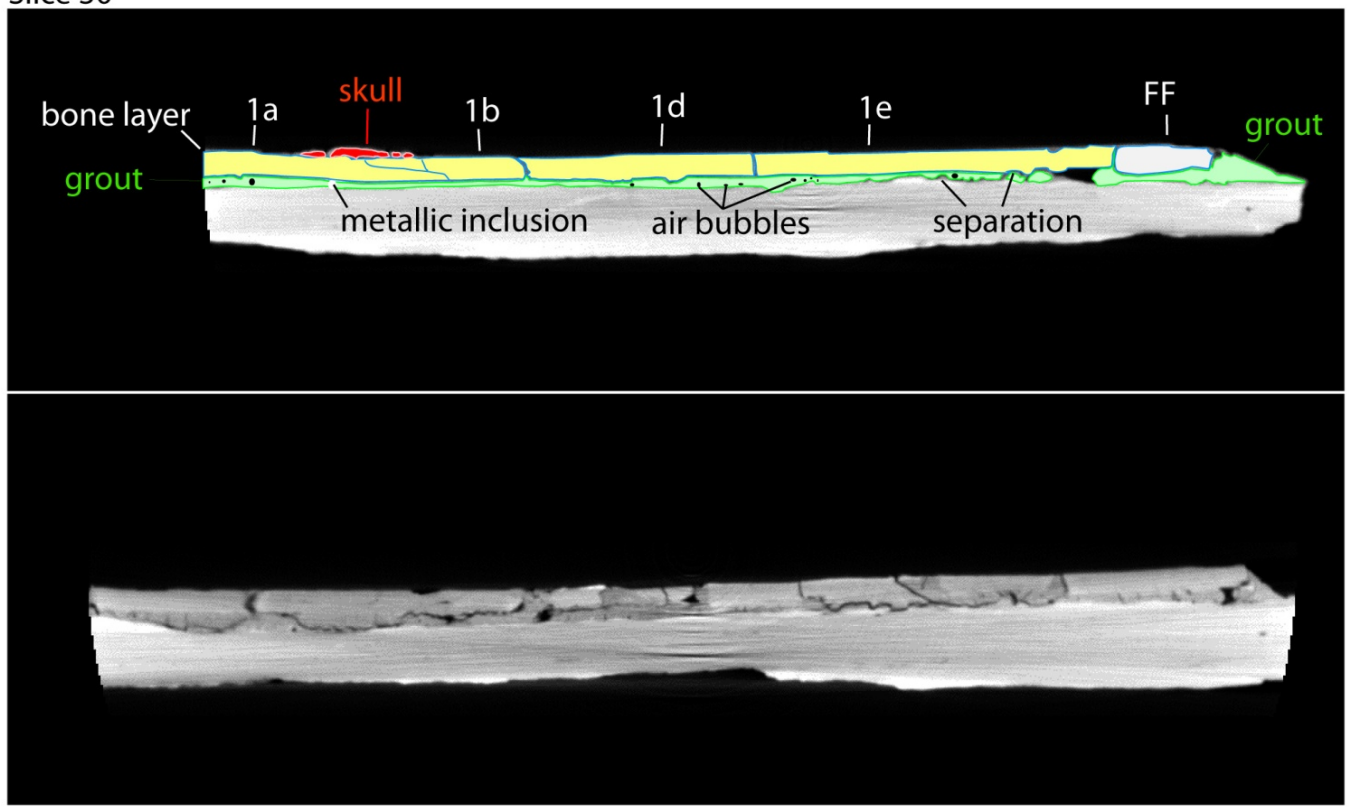

Slice 220

Slice 30



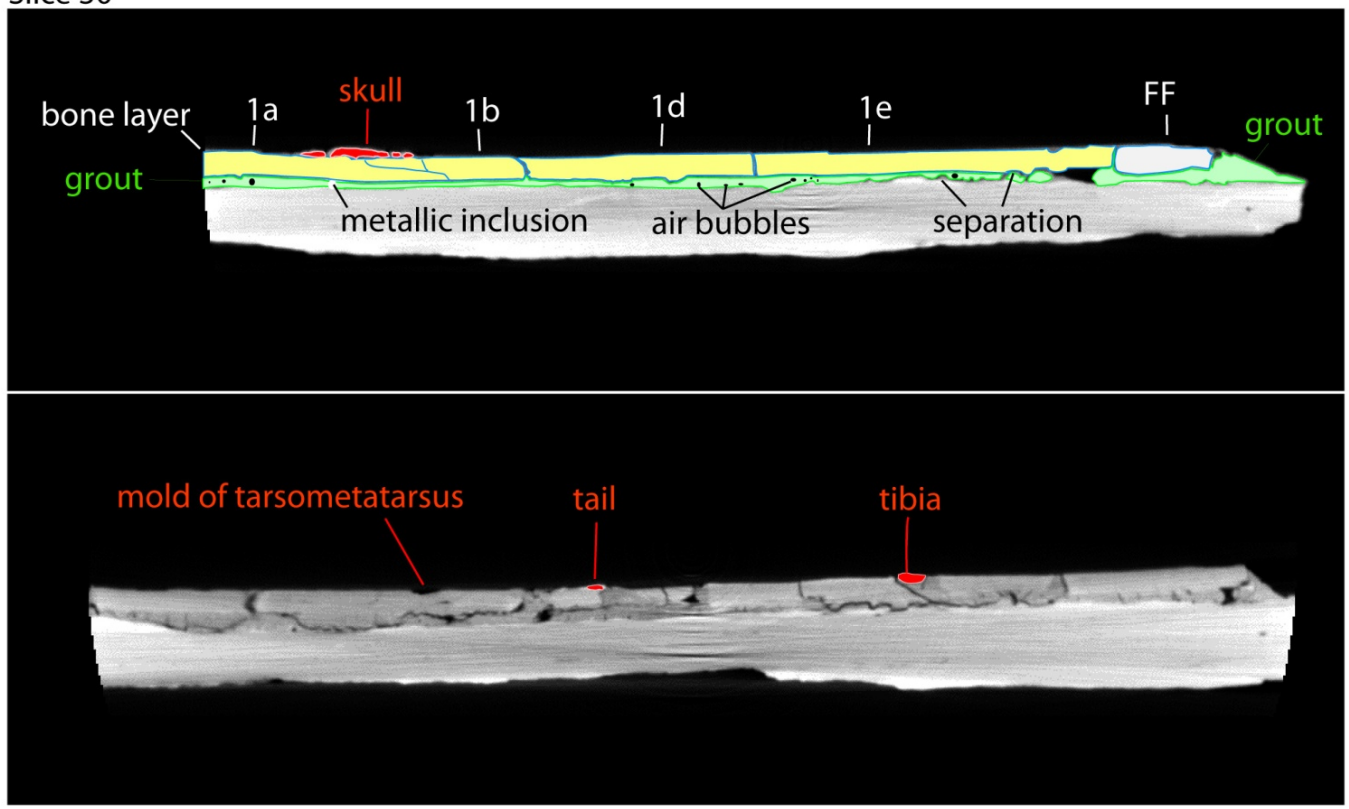

Slice 220

Slice 30



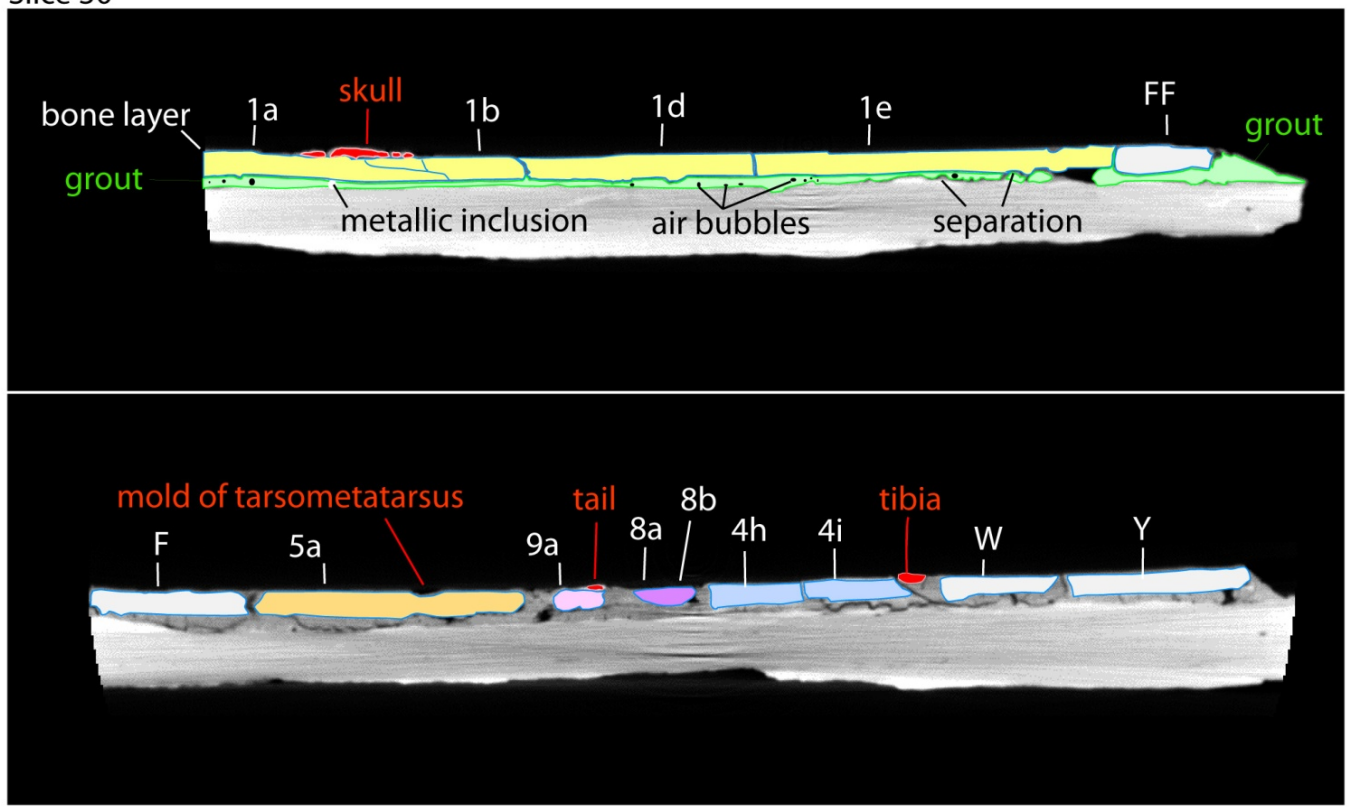

Slice 220

Slice 30



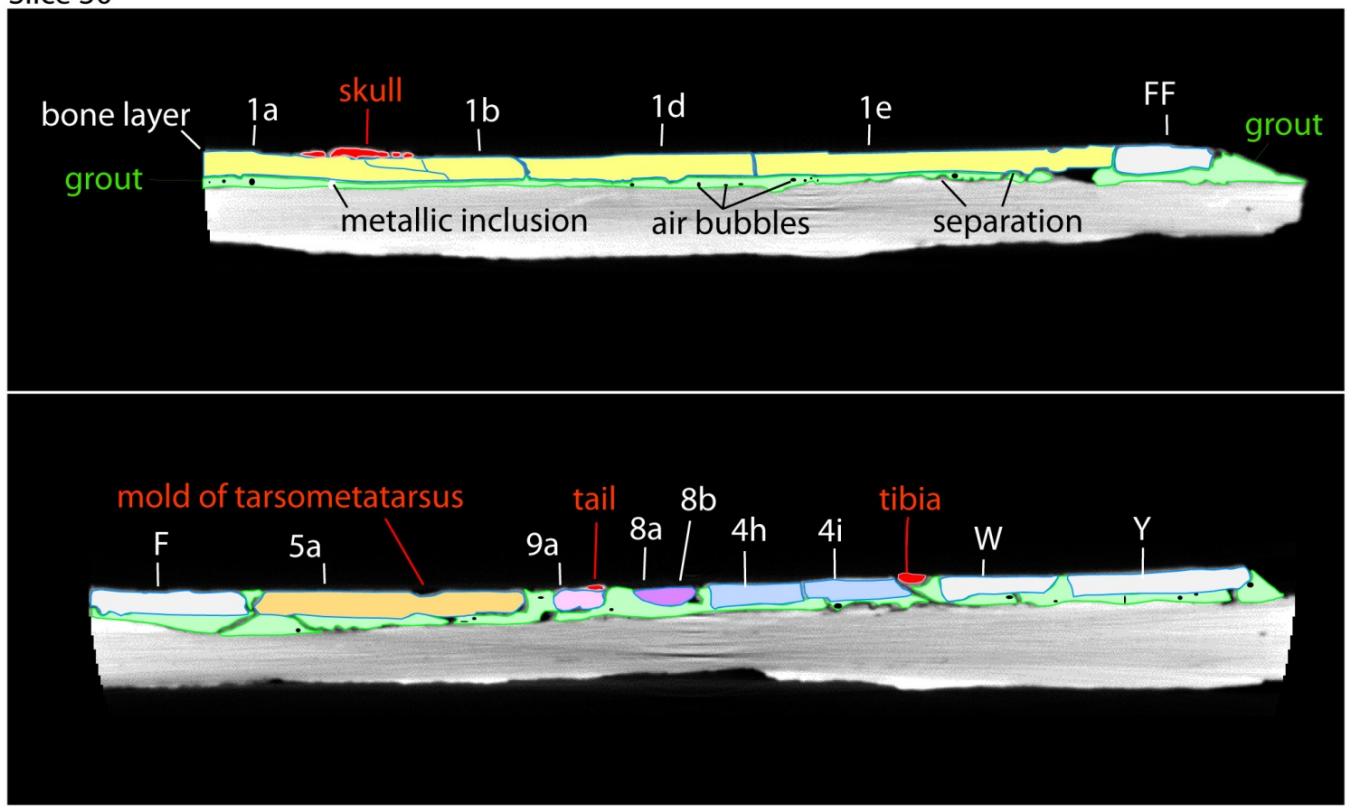

Slice 220

Slice 30

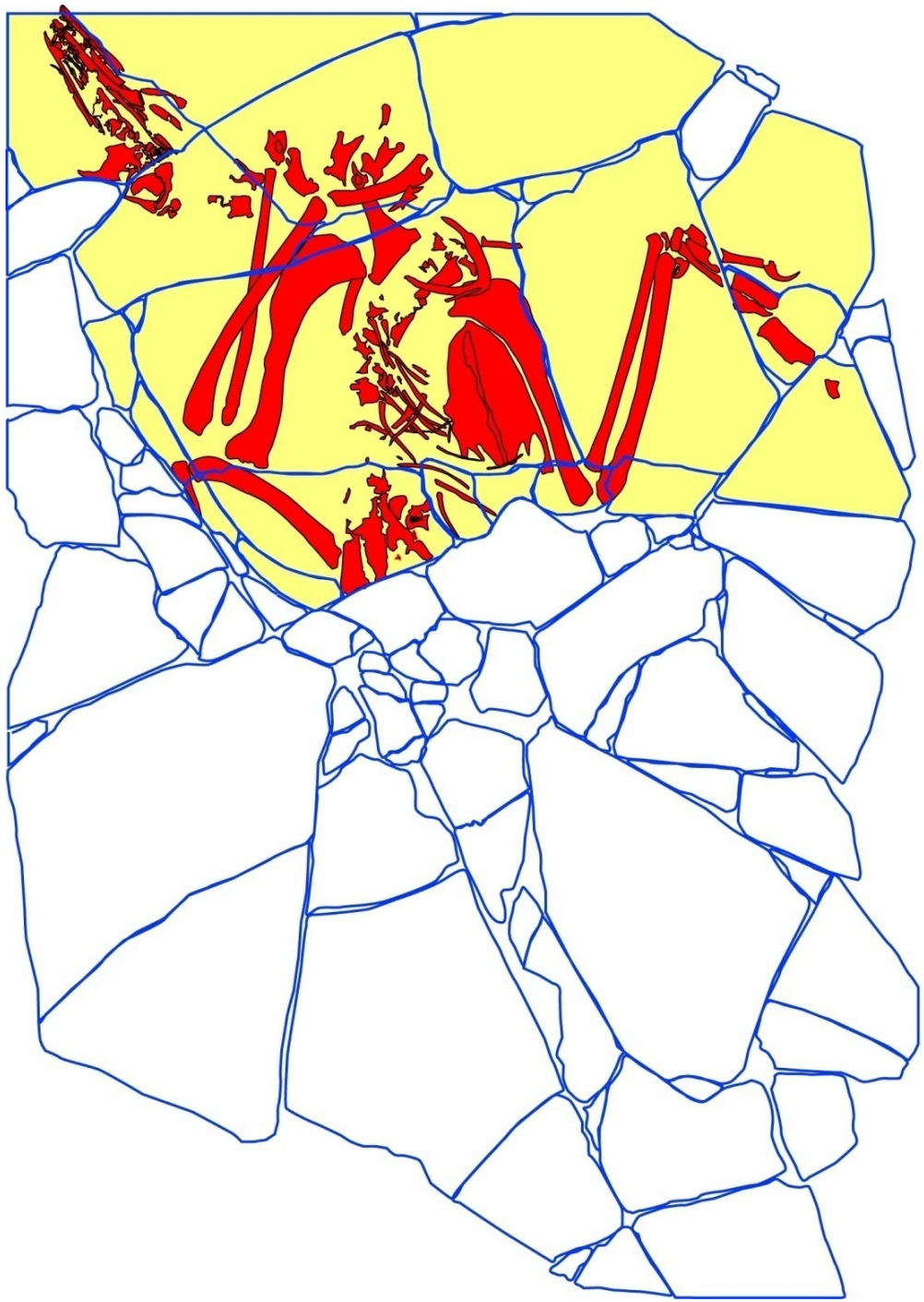


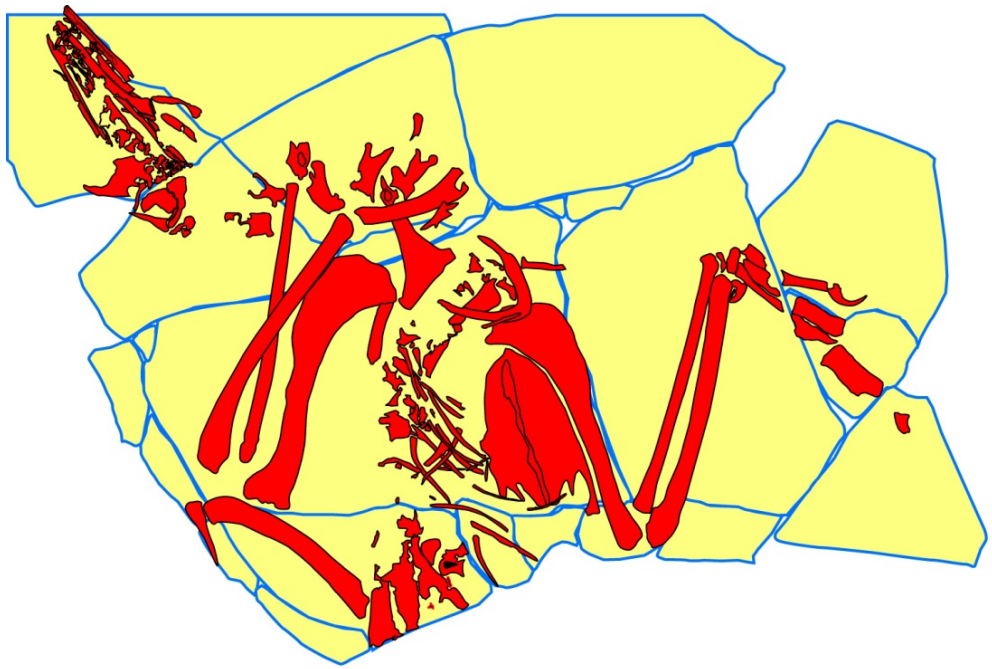

Slice 220

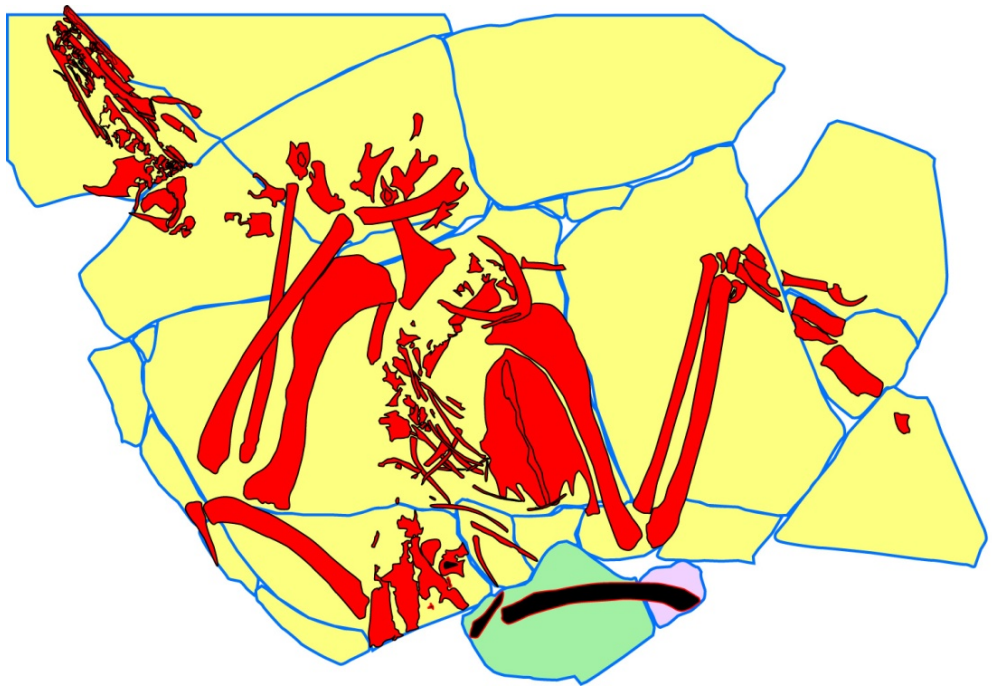
Slice 30

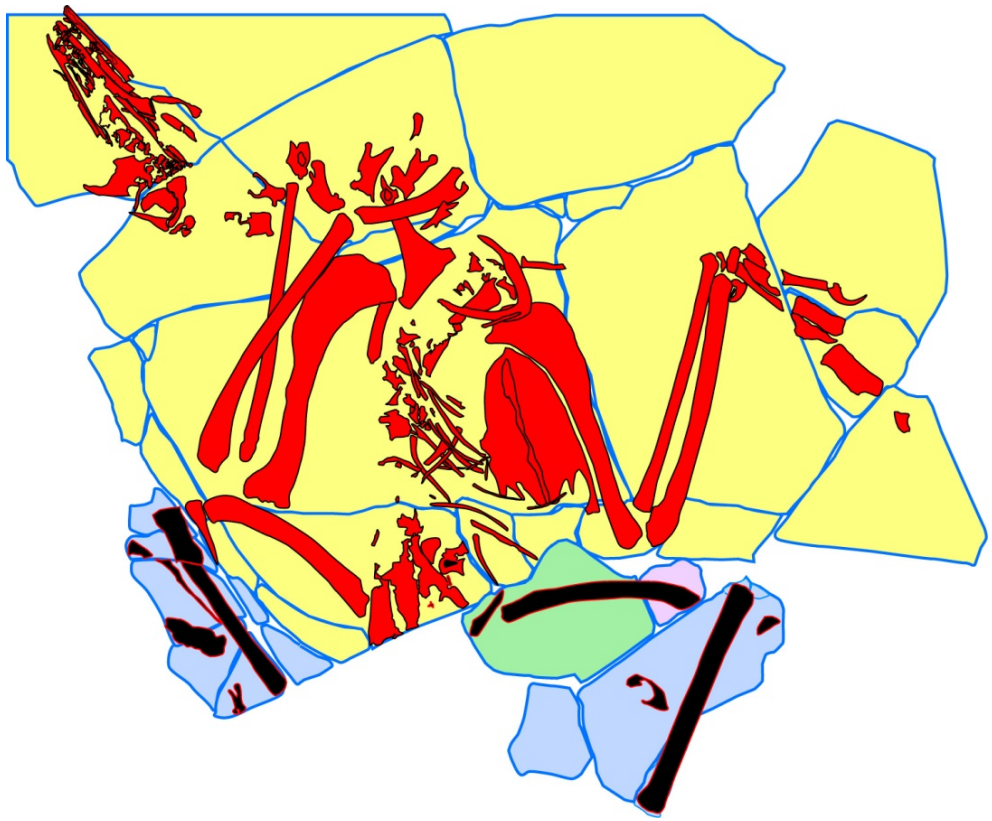


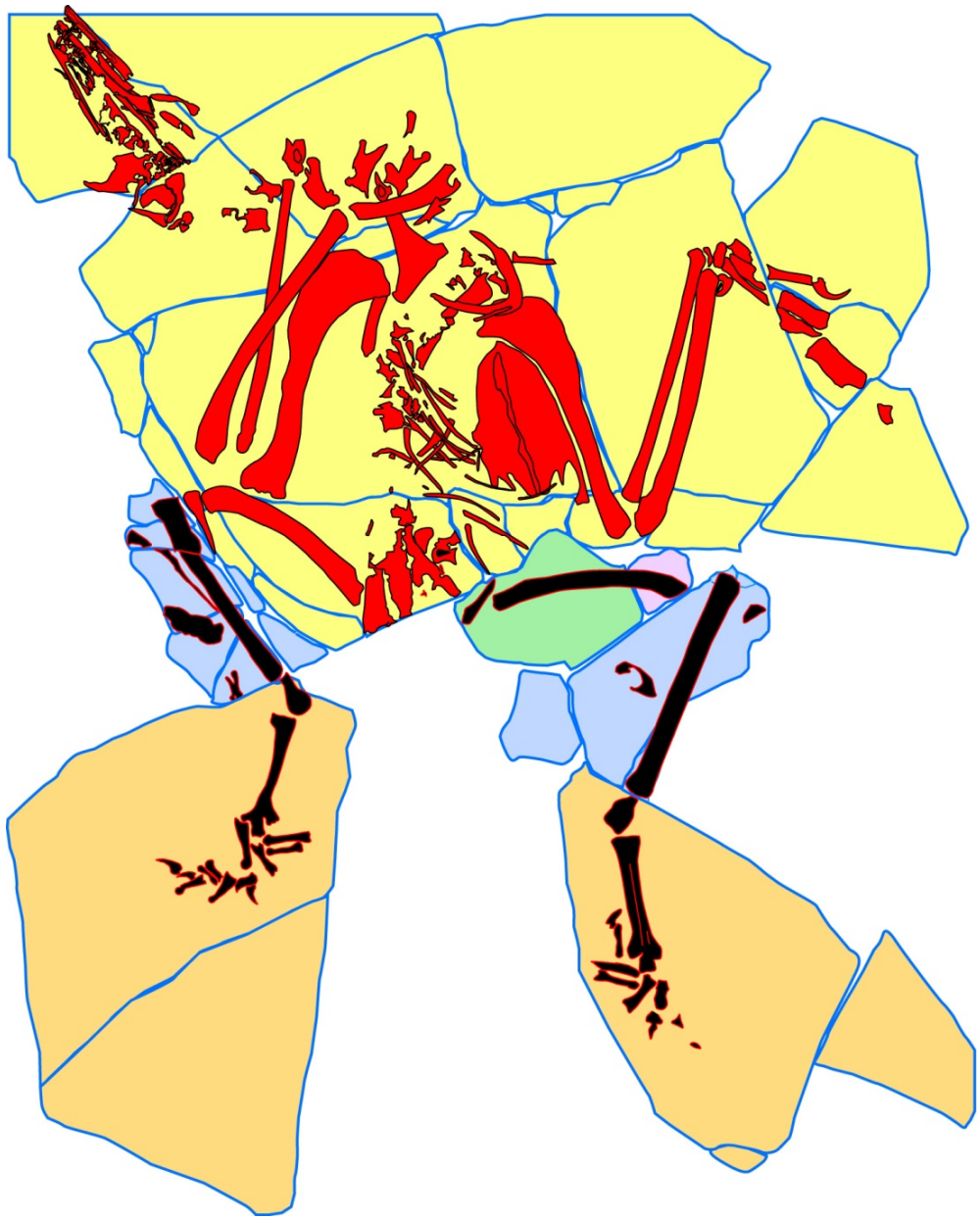

Slice 220

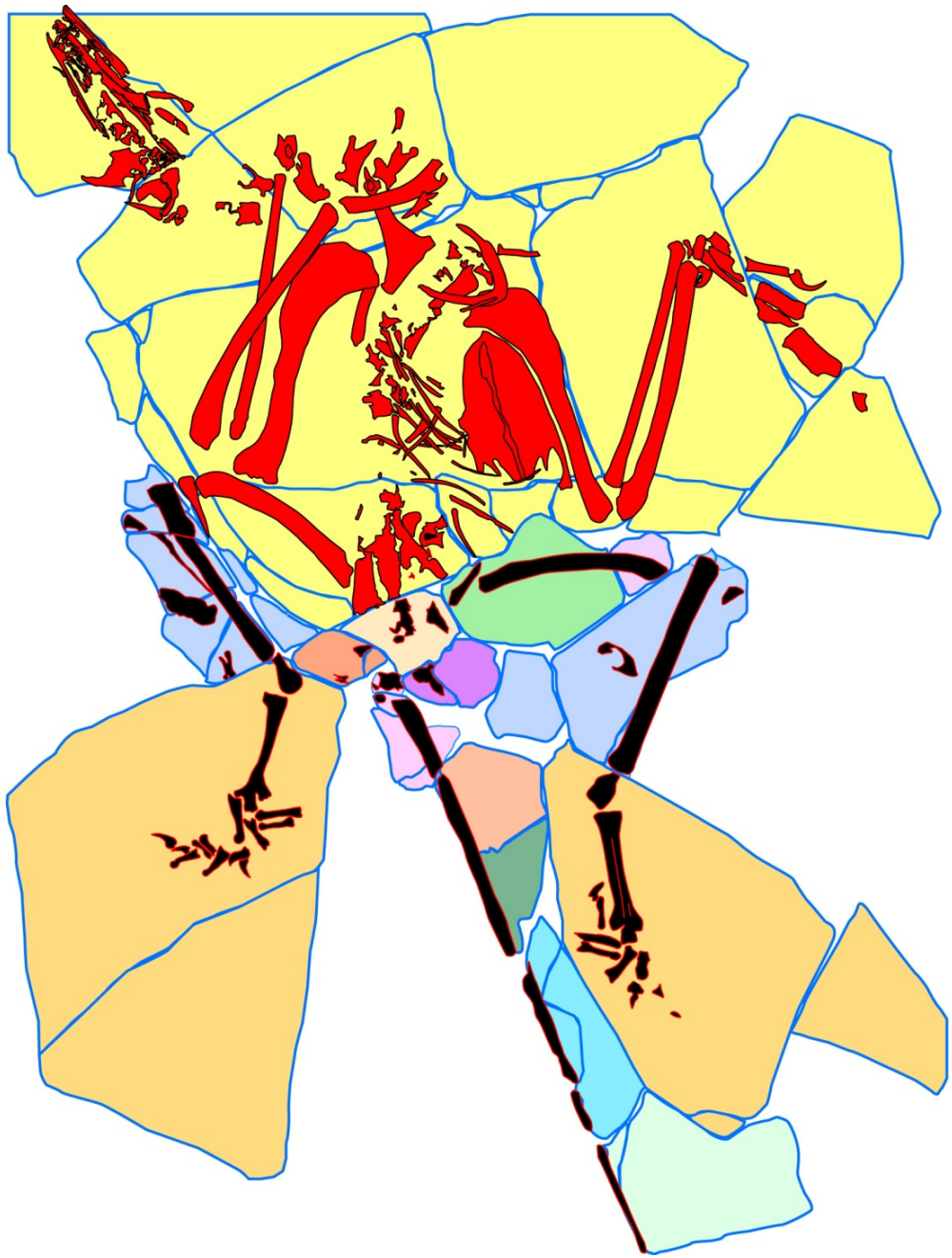


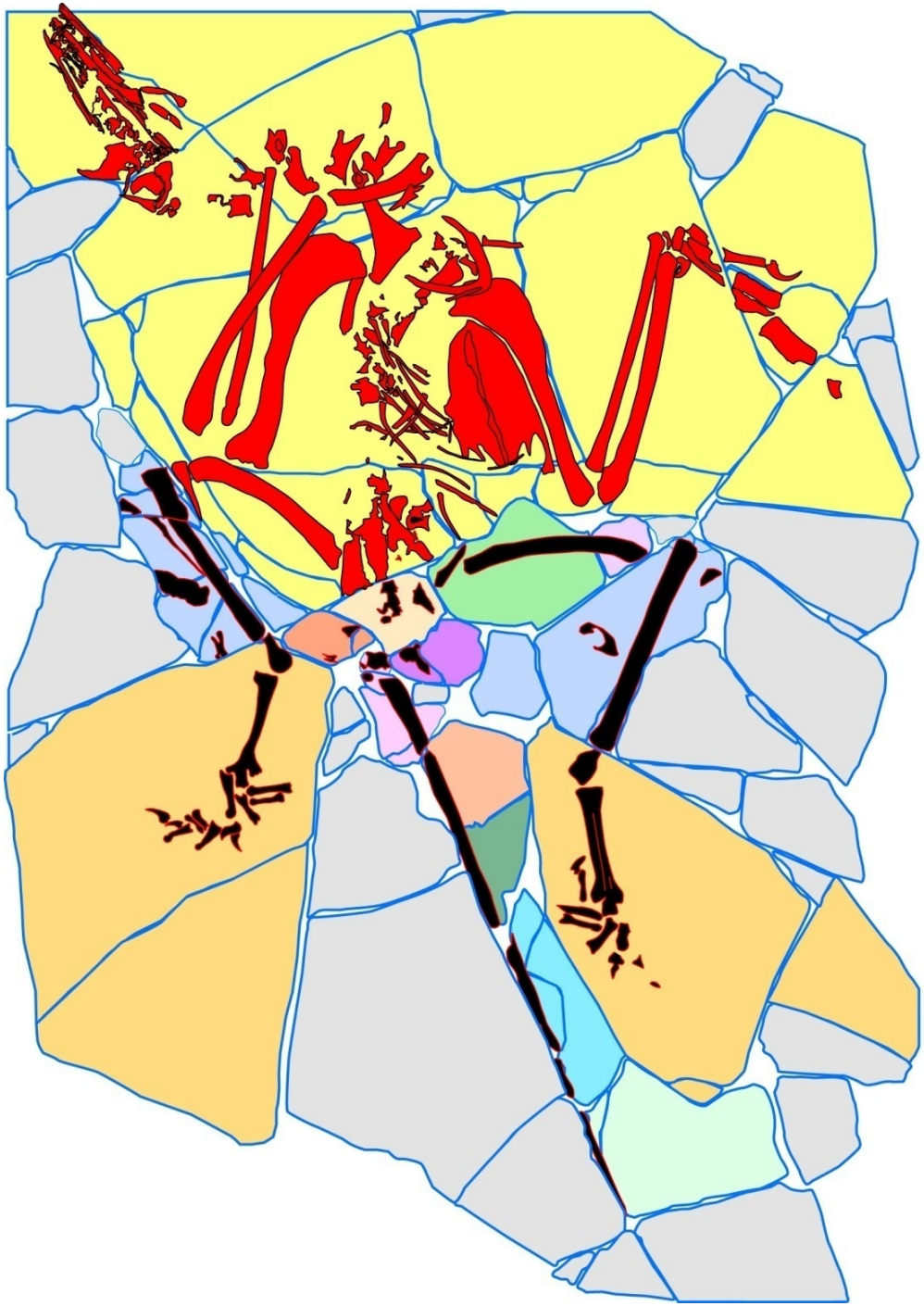


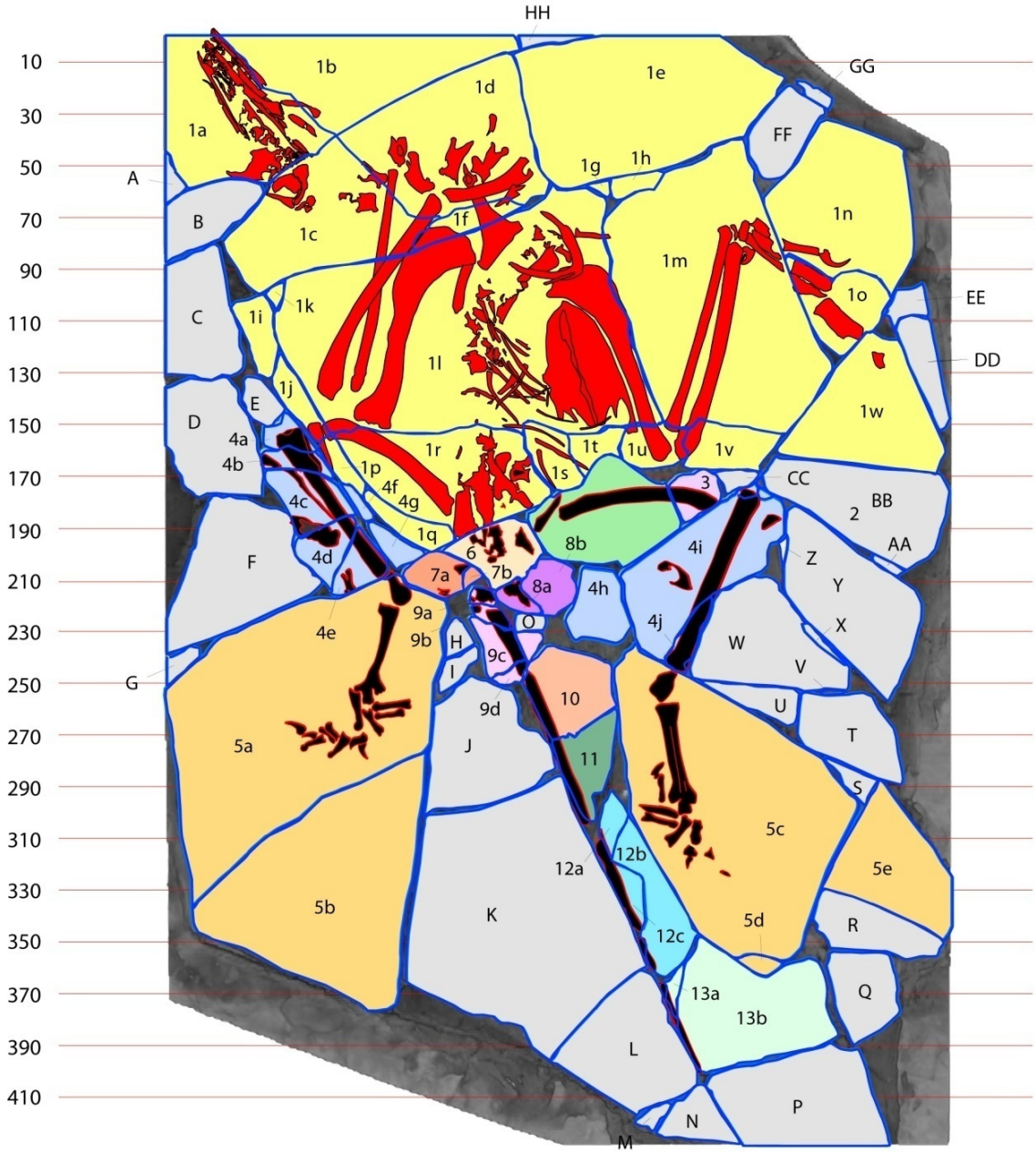













Map of the "Archaeoraptor" slab
as it was presented for CT scanning at
the University of Texas High-Resolution X-ray CT facility
on July 29, 1999.

KEY

Bones

- Verifiably associated bird skeleton, lying in natural burial position
- Unverified "associated bones"

Slab Facing Pieces

- 1a-w — Naturally associated facing pieces

"Associated pieces" with no verifiable relationship to 1a-w

- 2, 3 — unverified associated "left" femur pieces
- 4a-j — Piece and counter-piece of left tibia/fibula
- 5a-e — Piece and counter-piece of right foot/ankle
- 6, 7a-b, 8a-c — bone fragment pieces
- 9a-b, 10, 11, 12a-c, 13a-b — dromaeosaur tail pieces
- A-HH — Shims

## A FLYING DINOSAUR?

MODEL BY STEPHEN CZERKAS

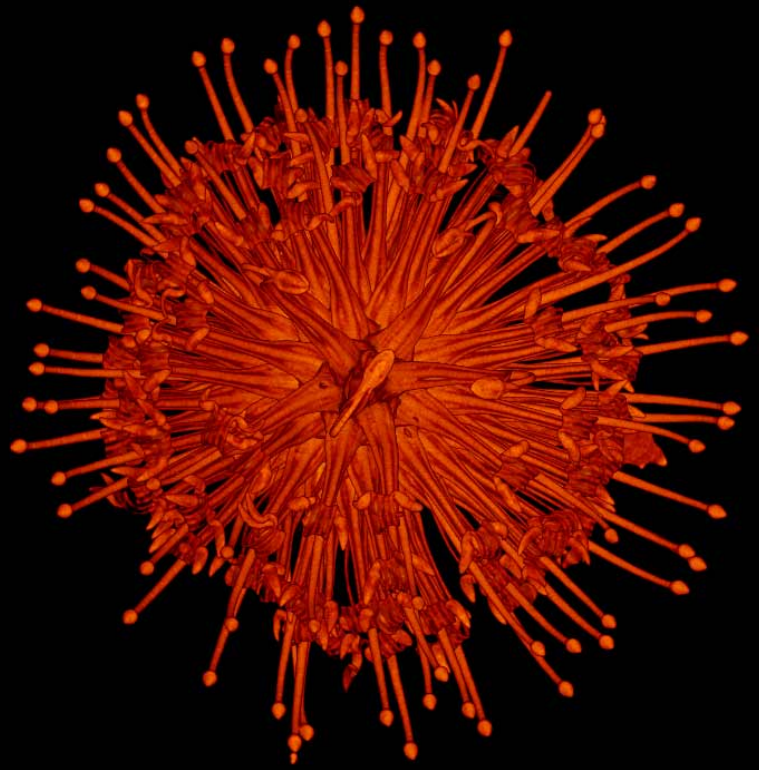
# "IT'S A MISSING LINK

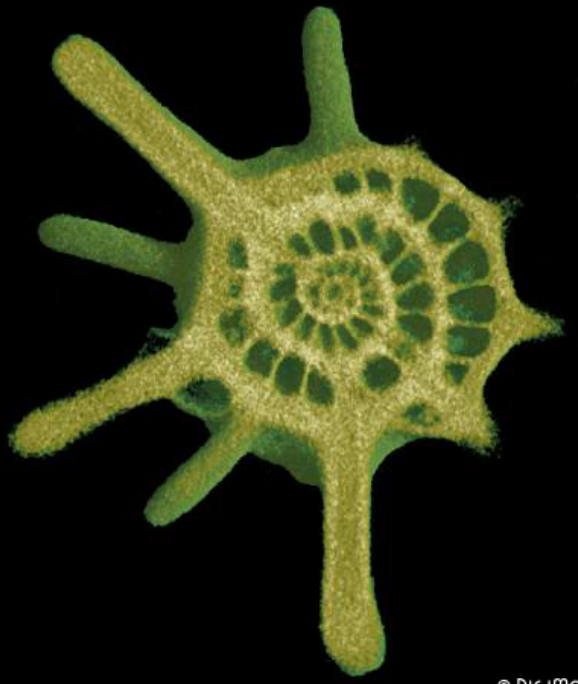
**between terrestrial dinosaurs and birds that could actually fly."**

—STEPHEN CZERKAS



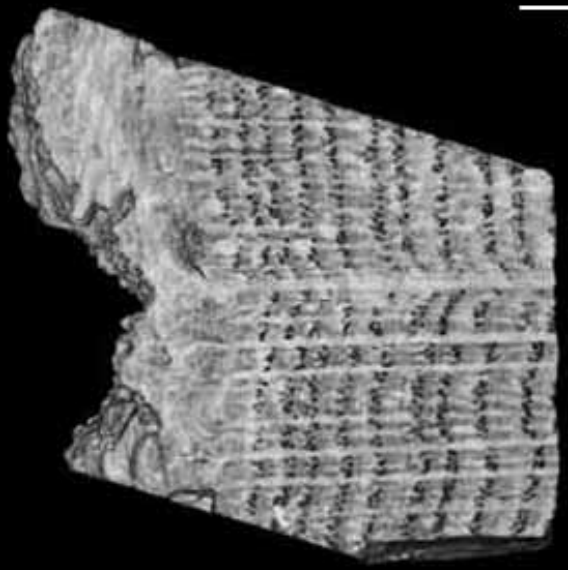

With arms of a primitive bird and the tail of a dinosaur, this creature found in Liaoning Province, China, is a true missing link in the complex chain that connects dinosaurs to birds. Scientists funded by National Geographic studied the animal, named *Archaeoraptor liaoningensis*, under ultraviolet light (above) and used CT scans to view parts of the animal obscured by rock. Preliminary study of the arms suggests that it was a better flier than *Archaeopteryx*, the earliest known bird. Its tail, however, is strikingly similar to the stiff tails of a family of predatory dinosaurs called dromaeosaurs. This mix of advanced and primitive features is exactly what scientists would expect to find in dinosaurs experimenting with flight. Stephen Czerkas, who led the study of the specimen, reconstructed the new animal (inset), which resembles *Archaeopteryx*. "This fossil is perhaps the best evidence since *Archaeopteryx* that birds did, in fact, evolve from certain types of carnivorous dinosaurs," says Czerkas.







1 cm



# Voxel Axiom

Insofar as Voxel Datasets are the sources of new discovery….

# Voxel Axiom

Insofar as Voxel Datasets are the sources of new discovery….

….then Voxel Datasets are of evidentiary status comparable to biological specimens, or molecular sequences.

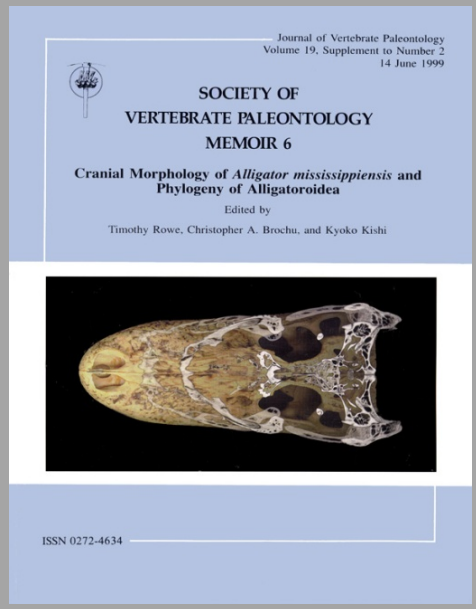
# Voxel Axiom

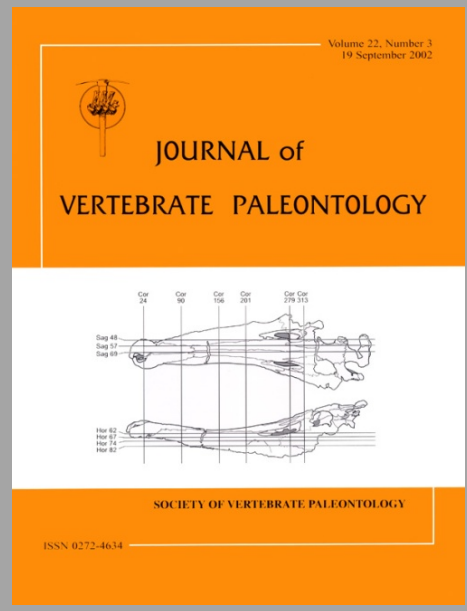
Insofar as Voxel Datasets are the sources of new discovery….

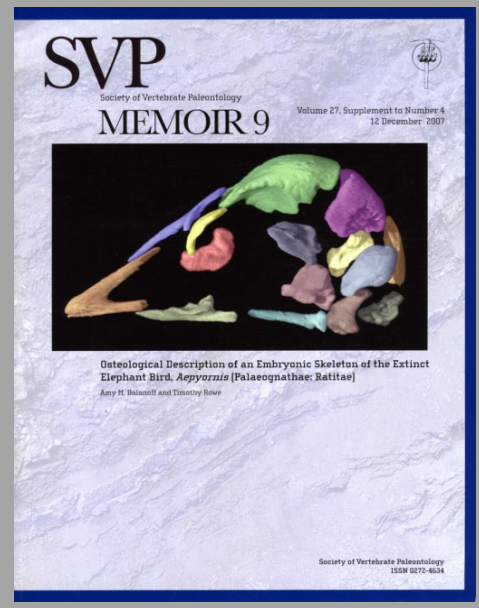
….then Voxel Datasets are of evidentiary status comparable to biological specimens, or molecular sequences

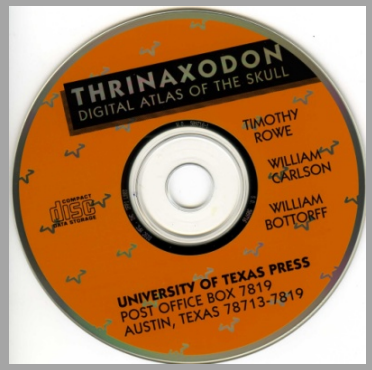
….and they must be released for validation and repurposing.


NEWLY DESIGNED FOR WINDOWS USERS
THRINAXODON
DIGITAL ATLAS OF THE SKULL
Timothy Rowe•William Carlson•William Bottorff
Foreword by Everett C. Olson
CD-ROM


Journal of Vertebrate Paleontology
Volume 19, Supplement to Number 2
14 June 1999
SOCIETY OF
VERTEBRATE PALEONTOLOGY
MEMOIR 6
Cranial Morphology of *Alligator mississippiensis* and Phylogeny of Alligatoroidea
Edited by
Timothy Rowe, Christopher A. Brochu, and Kyoko Kishi
ISSN 0272-4634

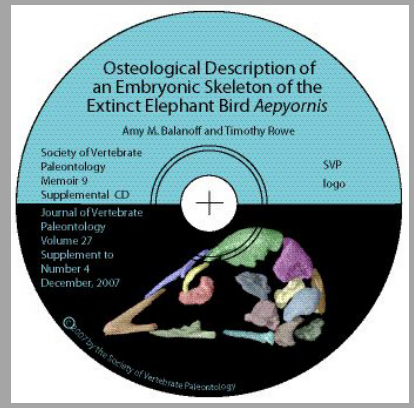

Volume 22, Number 3
19 September 2002
JOURNAL of
VERTEBRATE PALEONTOLOGY
SOCIETY OF VERTEBRATE PALEONTOLOGY
ISSN 0272-4634


SVP
Society of Vertebrate Paleontology
MEMOIR 9
Volume 27, Supplement to Number 4
12 December 2007
Osteological Description of an Embryonic Skeleton of the Extinct Elephant Bird, *Aepyornis* (Palaeognathae: Ratitae)
Amy M. Balanoff and Timothy Rowe
Society of Vertebrate Paleontology
ISSN 0272-4634

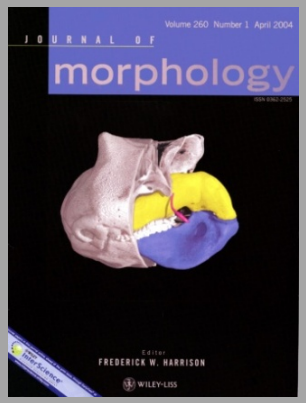

THRINAXODON
DIGITAL ATLAS OF THE SKULL
TIMOTHY ROWE
WILLIAM CARLSON
WILLIAM BOTTORFF
UNIVERSITY OF TEXAS PRESS
POST OFFICE BOX 7819
AUSTIN, TEXAS 78713-7819


Alligator:
Digital Atlas
of the Skull
Society of
Vertebrate
Paleontology
Memoir 6

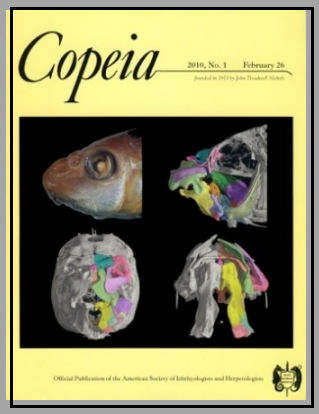

SOCIETY OF VERTEBRATE PALEONTOLOGY
*Calsoyasuchus valliceps*

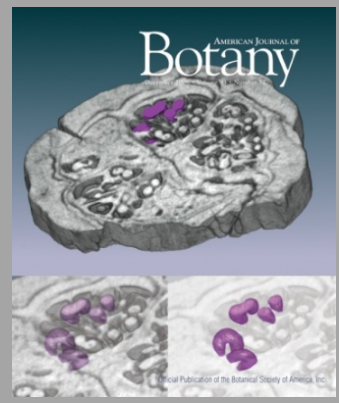

Osteological Description of an Embryonic Skeleton of the Extinct Elephant Bird *Aepyornis*
Amy M. Balanoff and Timothy Rowe
Society of Vertebrate Paleontology
Memoir 9
Supplemental CD
SVP
logo
Journal of Vertebrate Paleontology
Volume 27
Supplement to
Number 4
December, 2007

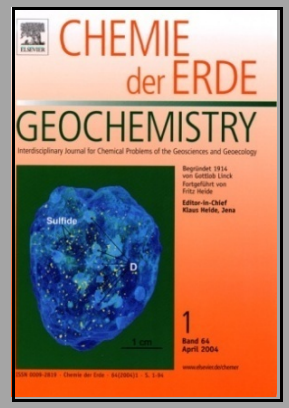
# Finishing the Job…….



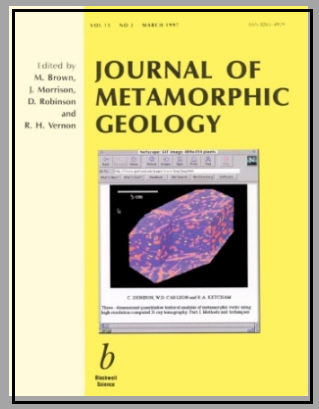


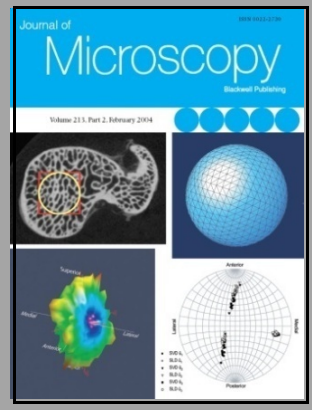


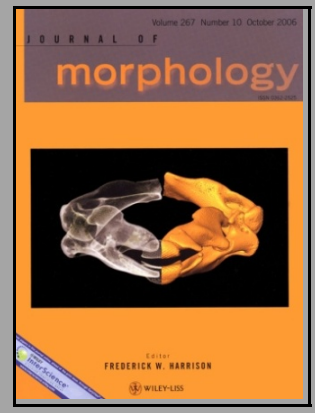



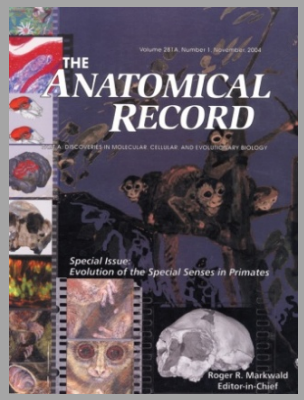


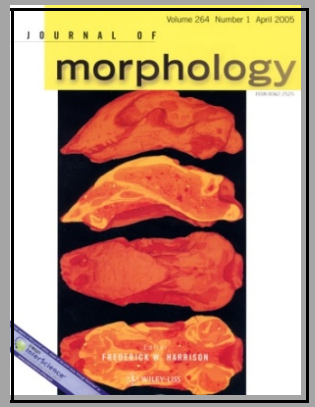


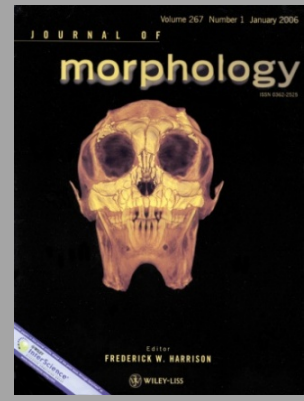







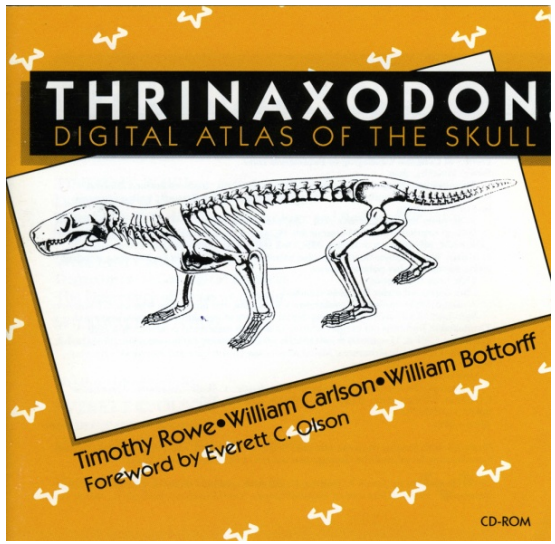


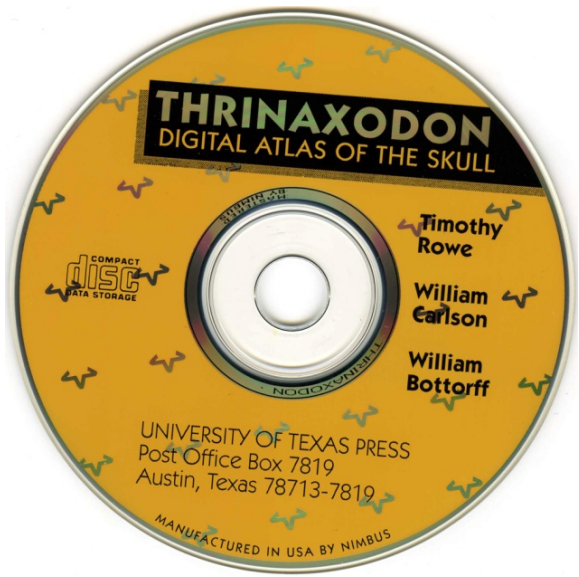


# Digital Morphology

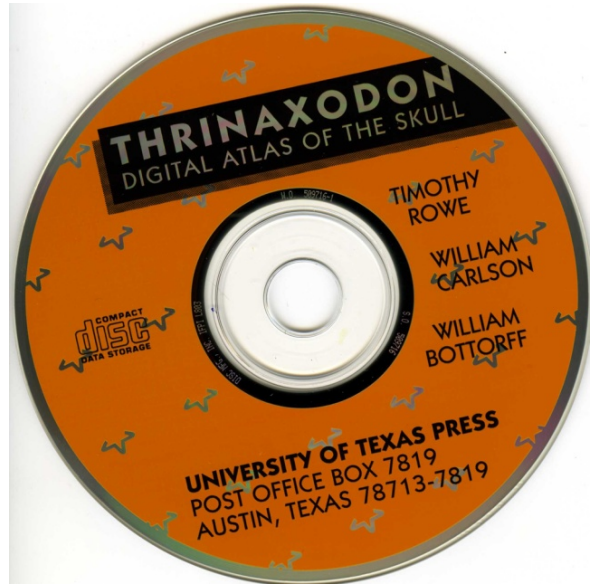
an NSF Sponsored Digital Library at the University of Texas

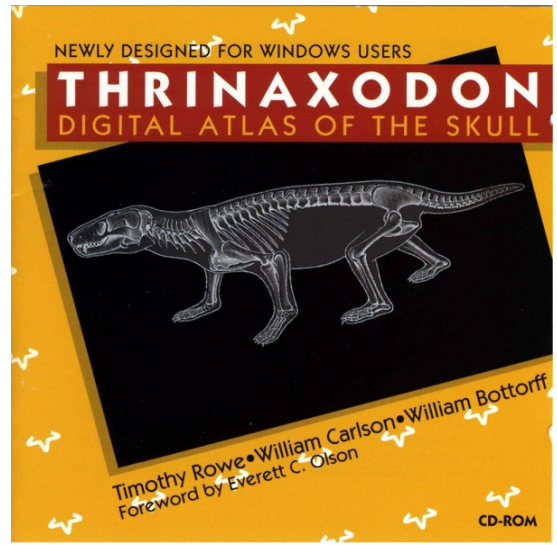
1993 MS-Dos platform



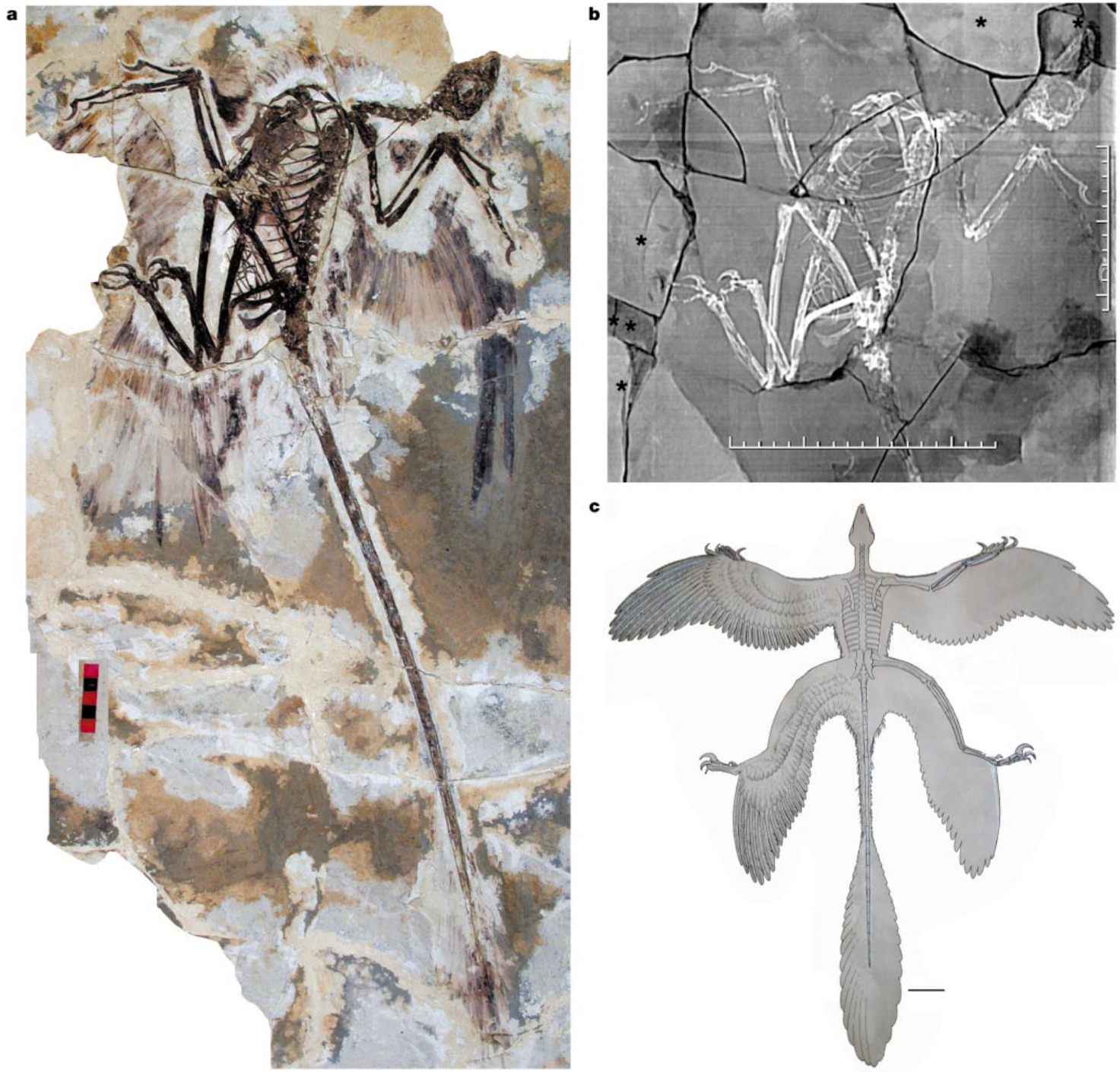

1995 MS Windows 3.0



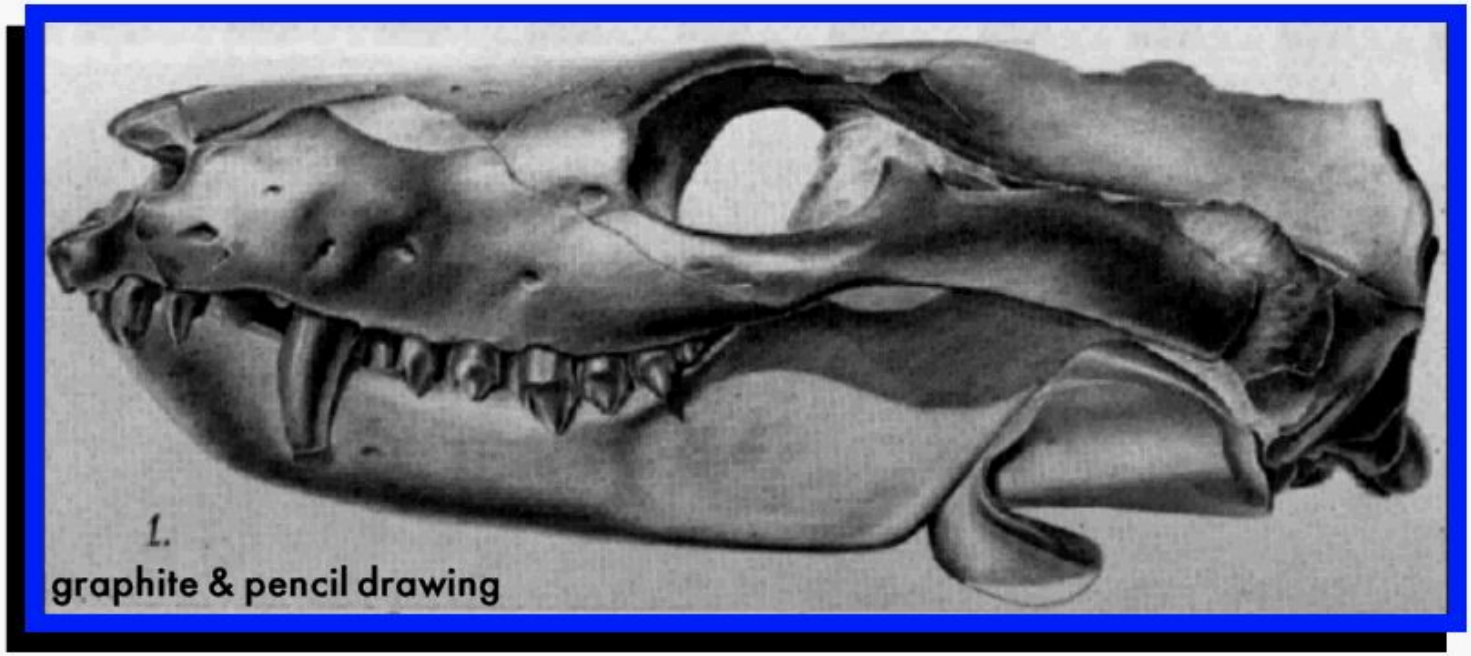



Holotype

Microraptor gui




Xu, X., et al., 2003,
*Nature*: 421: 335-340




# THRINAXODON

## DIGITAL ATLAS OF THE SKULL

Timothy Rowe • William Carlson • William Bottorff

Foreword by Everett C. Olson

University of Texas Press

Austin

1993

# The Nascent Revolution….

1) The Molecular Revolution, as a model for voxel science

# The Nascent Revolution….

1) The Molecular Revolution, as a model for voxel science

1983: Kerry Mullis conceives of the Polymerase Chain Reaction

# The Nascent Revolution….

1) The Molecular Revolution, as a model for voxel science

- 1983: Kerry Mullis conceives of the Polymerase Chain Reaction
- 1993: Mullis wins Nobel Prize for PCR

# The Nascent Revolution….

1) The Molecular Revolution, as a model for voxel science

1983: Kerry Mullis conceives of the Polymerase Chain Reaction

1993: Mullis wins Nobel Prize for PCR

Revolutionary Components:

# The Nascent Revolution….

## 1) The Molecular Revolution, as a model for voxel science

1983: Kerry Mullis conceives of the Polymerase Chain Reaction

1993: Mullis wins Nobel Prize for PCR

Revolutionary Components:

Inexpensively digitize molecular sequences

# The Nascent Revolution….

## 1) The Molecular Revolution, as a model for voxel science

1983: Kerry Mullis conceives of the Polymerase Chain Reaction

1993: Mullis wins Nobel Prize for PCR

Revolutionary Components:

- Inexpensively digitize molecular sequences
- Analyse sequences on inexpensive computers

# The Nascent Revolution….

## 1) The Molecular Revolution, as a model for voxel science

1983: Kerry Mullis conceives of the Polymerase Chain Reaction

1993: Mullis wins Nobel Prize for PCR

Revolutionary Components:

- Inexpensively digitize molecular sequences
- Analyse sequences on inexpensive computers
- Inexpensively distribute sequences via the Internet

# The Nascent Revolution….

## 1) The Molecular Revolution, as a model for voxel science

1983: Kerry Mullis conceives of the Polymerase Chain Reaction

1993: Mullis wins Nobel Prize for PCR

Revolutionary Components:

- Inexpensively digitize molecular sequences
- Analyse sequences on inexpensive computers
- Inexpensively distribute sequences via the Internet
- Several National agencies funded sequence repositories

# The Nascent Revolution….

## 1) The Molecular Revolution, as a model for voxel science

1983: Kerry Mullis conceives of the Polymerase Chain Reaction

1993: Mullis wins Nobel Prize for PCR

Revolutionary Components:

- Inexpensively digitize molecular sequences
- Analyse sequences on inexpensive computers
- Inexpensively distribute sequences via the Internet
- Several National agencies funded sequence repositories

……and the revolution was on!