

**A RE-EVALUATION OF THE CRANIAL
MORPHOLOGY AND TAXONOMY OF THE
TRIASSIC DICYNODONT GENUS
*KANNEMEYERIA***

VOLUME TWO

Alain Joseph Renaut

A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2000

DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



Alain Joseph Renaut

This 22nd day of December 2000

ABSTRACT

The genus *Kannemeyeria* is one of the most important and distinctive taxa of the Triassic dicynodonts. It became the first Triassic dicynodont known to science, and thus forms the benchmark for the comparison of the evolution and morphology of other Triassic dicynodonts. An understanding of this genus forms an integral part of the biozonation of the Beaufort Group, and is pivotal in influencing the interpretation of the evolution, physiology and phylogenetic relationships of the Triassic dicynodonts. This study focuses on the detailed cranial morphology and relationships of the *Kannemeyeria*, and uses a rigorous morphological investigation as the basis for a meaningful elucidation of the functional and thus physiological aspects of this dicynodont.

The descriptions demonstrate that variations related to the skull size, distortion or naturally occurring variation within the genus allow for the synonymy of the formerly recognised species *K. latifrons* Broom (1898; 1913), *K. erithrea* Haughton (1915) and *K. wilsoni* Broom (1937). This conclusion is further supported by the allometric analysis which cannot distinguish the variation observed in the holotypes with that occurring naturally within a growth series. Apart from the large specimen, the other smaller individuals are accommodated in the genus as different ontogenetic stages of the growth series represented by *K. simocephalus* Weithofer (1888). Several allometric variables show unusual patterns of development, indicating that *Kannemeyeria* can be subdivided into ontological classes, as juvenile and adult forms, separated from each other by a particular level of development. An age-related threshold level is suggested, and considered to represent an animal reaching sexual maturity. It is consequently proposed that the *Kannemeyeria* population was, at an age-related level, subdivided into sexually mature and immature groups but remained ecologically homogeneous.

Both the descriptions and the allometric analysis of the species *K. cristarhynchus* Keyser & Cruickshank (1979) clearly indicate that it does not conform to the growth series of *K. simocephalus* and thus the differences observed between these two taxa are not constrained to size increases. Consequently, the recognition of the species *K. cristarhynchus* is considered valid. From the observations of the cranial morphology, tested using an

allometric analysis, generic and specific diagnoses are constructed for *Kannemeyeria* and its two African species.

Several features of *Kannemeyeria* are discussed in a functional context. A corrugated horn-covered snout and large caniniform processes are considered to be associated with defence and posturing behaviour. Several features of the braincase also suggest herding behaviour. *Kannemeyeria* also has a slightly different occipital musculature arrangement than that proposed for many other dicynodonts. Most *Kannemeyeria* cranial features are related to its masticatory function. From the analysis of masticatory cycle it is clear that the jaw action is described via a single pivot-point, which in *Kannemeyeria* approached the original, primitive position of the jaw hinge. The vertical orientation of the articulation and this pivot-point ensured that the muscle action during second phase of mastication produced an upward crushing and grinding action instead of the typical fore-and-aft motion of many other dicynodonts. It also meant that the muscle force was at their maximum, and little or no energy was lost to translation of the moment arm at the jaw articulation. Consequently, the *Kannemeyeria* masticatory cycle was both highly effective and extremely efficient. The morphology, and resultant physiology, of *Kannemeyeria* skull is considered to represent the innovative foundation for much of the success of many of the later Triassic dicynodonts.

ACKNOWLEDGEMENTS

I am extremely grateful to my supervisors, Prof. B. S. Rubidge and Dr. P. J. Hancox, for their advice, understanding and patience. I trust they will find this thesis worth the time and effort invested to produce a body of work I know to be the best possible. The following people assisted in the preparation of the numerous specimens: Mr. R. Lewis, Mr. Dr. J. W. Kitching, C. Dube and Mr. G. Modise, as well as sundry work by several other technical staff of the Bernard Price Institute, for which I am deeply grateful. I am indebted to the invaluable discussions and criticisms from Drs. J. W. Kitching, M. Raath, W. De Klerk, S. P. Modesto, R. Damiani, and especially J. van den Heever. Their critique helped to crystallise many of the specific hypotheses critical to this thesis. Dr. R. Adendorff and Mr. P. Emmanuel helped with the drawing and preparation of some of the figures, and their assistance is appreciated. This project was completed with the financial assistance of the Foundation for Research Development (National Research Foundation), with the provision of a postgraduate research grant. Finally, this thesis would not have been completed without the honest support and help from my wife, Ray.

LIST OF FIGURES

Figure 1	Cranial reconstructions of the genotype of <i>Kannemeyeria</i> modified from Pearson (1924a)	1
Figure 2	Drawing of the floor of the nasal cavity and ventral skull roof of BP/1/4648.	2
Figure 3	Dorsal view of specimen BP/1/5624.	2
Figure 4	Photographs of the nasal cavity floor and maxillary fovea of the right side of the nasal cavity of BP/1/4648 and the dorsal view of BP/1/5624	3
Figure 5	Dorsal and lateral views BP/1/1168	4
Figure 6	Photographs of the dorsal and lateral views of BP/1/1168	5
Figure 7	Dorsal and lateral views of SAM/PK/10555	6
Figure 8	Photographs of the dorsal and lateral views of SAM/PK/10555	7
Figure 9	Dorsal and lateral views of NMQR/1127	8
Figure 10	Photographs of the dorsal and lateral views of NMQR/1127	9
Figure 11	Dorsal and lateral views of PE/1199P. Holotype of <i>K. latifrons</i> Broom 1913.	10
Figure 12	Photographs of the dorsal and lateral views of PE/1199P. Holotype of <i>K. latifrons</i> Broom 1913.	11
Figure 13	Dorsal and lateral views of BP/1/4648.	12
Figure 14	Photographs of the dorsal and lateral views of BP/1/4648	13
Figure 15	Photographs of the dorsal and lateral view of BP/1/989	14
Figure 16	Dorsal and ventral views of BP/1/2092	15
Figure 17	Photographs of the dorsal and the lateral views of BP/1/2092	16
Figure 18	Dorsal and lateral views of SAM/PK/3017	17
Figure 19	Dorsal and lateral views of BP/1/4523	18
Figure 20	Photographs of the dorsal and lateral views of BP/1/4523	19
Figure 21	Dorsal and lateral views of EL/1. Holotype of <i>K. wilsoni</i> Broom 1937	20

Figure 22 Photographs of the dorsal and lateral views of EL/1 Holotype of <i>K. wilsoni</i> Broom 1937.	21
Figure 23 Dorsal and lateral views of BP/1/4524	22
Figure 24 Photographs of the dorsal and lateral views of BP/1/4524	23
Figure 25 Ventral view of BP/1/5624	24
Figure 26 Ventral view of BP/1/1168	24
Figure 27 Photographs of the ventral views of BP/1/5624 and BP/1/1168	25
Figure 28 Ventral view of SAM/PK/10555	26
Figure 29 Ventral view of NMQR/1127	26
Figure 30 Photographs of the ventral views of SAM/PK/10555 and NMQR/1127	27
Figure 31 Ventral view of PE/1199P. Holotype of <i>K. latifrons</i> Broom 1913.	28
Figure 32 Ventral view of BP/1/4648	28
Figure 33 Photographs of the ventral view of PE/1199P and BP/1/4648	29
Figure 34 Ventral view of BP/1/989	30
Figure 35 Ventral view of SAM/PK/3017. Holotype of <i>K. erithrea</i> Haughton 1915.	30
Figure 36 Ventral view of BP/1/2092	31
Figure 37 Ventral view of BP/1/4523	31
Figure 38 Photographs of the ventral views of BP/1/2092 and BP/1/4523	32
Figure 39 Ventral view of EL/1. Holotype of <i>K. wilsoni</i> Broom 1937.	33
Figure 40 Ventral view of BP/1/4524	33
Figure 41 Photographs of the ventral views of EL/1 and BP/1/4524	34
Figure 42 Sphenethmoid region of SAM/PK/3017	35
Figure 43 Occipital view of BP/1/5624	35
Figure 44 Photographs of the dorsal surface of the basisphenoid of BP/1/5624 and the distal end of the quadrate complex of BP/1/5624 and the occiput of BP/1/5624	36

	Figures	vii
Figure 45 Occipital view of BP/1/1168		37
Figure 46 Occipital view of NMQR/1127		37
Figure 47 Photographs of the occipital views of BP/1/1168 and NMQR/1127		38
Figure 48 Occipital view of SAM/PK/3017. Holotype of <i>K. erithrea</i> Haughton 1915		39
Figure 49 Occipital view of BP/1/4523		39
Figure 50 Occipital view of EL/1. Holotype of <i>K. wilsoni</i> Broom 1937.		40
Figure 51 Photographs of the occipital views of BP/1/4523 and EL/1		41
Figure 52 Dorsal, lateral and lingual views of the lower jaw of BP/1/5624		42
Figure 53 Photographs of the dorsal, lateral and lingual views of the lower jaw of BP/1/5624		43
Figure 54 Dorsal, lateral and medial views of the lower jaws of BP/1/4524		44
Figure 55 Photographs of the dorsal, lateral and medial views of the lower jaw of BP/1/4524		45
Figure 56 Dorsal and lateral view of the lower jaw SAM/PK/3017 Holotype of <i>K. erithrea</i> Haughton 1915		46
Figure 57 Dorsal, lateral and medial views of the lower jaw EL/1 Holotype of <i>K. wilsoni</i> Broom 1937		47
Figure 58 Photographs of the dorsal, lateral and medial views of the lower jaw of EL/1		48
Figure 59 Dorsal and right lateral view of BP/1/3638. Holotype <i>K. cristarhynchus</i> Keyser and Cruickshank 1979.		49
Figure 60 Photographs of the dorsal and right lateral views of BP/1/3638 Holotype of <i>K. cristarhynchus</i> Keyser and Cruickshank 1979.		50
Figure 61 Ventral and occipital views of BP/1/3638. Holotype of <i>K. cristarhynchus</i> Keyser and Cruickshank 1979		51
Figure 62 Photographs of the ventral and occipital views of BP/1/3638		52
Figure 63 Dorsal, lateral and medial views of the lower jaw of BP/1/3638 Holotype of <i>K. cristarhynchus</i> Keyser and Cruickshank 1979		53

Figure 64 Photographs of the dorsal, lateral and medial views of the lower jaw of BP/1/3638	54
Figure 65 <i>Kannemeyeria</i> skull measurements	55
Figure 66 Selected bivariate plots of taxonomic significance, or demonstrating the effects of specific ontological growth patterns	56
Figure 67 Further selected bivariate plots showing the allometric-growth trends of the genus <i>Kannemeyeria</i>	57
Figure 68 Cranial reconstruction of the skull of <i>Kannemeyeria simocephalus</i> :	58
Figure 69 Cranial reconstructions of the skull <i>Kannemeyeria simocephalus</i> : ventral and occipital views	59
Figure 70 Cranial reconstruction of the dorsal and lateral views of the skull of <i>Kannemeyeria cristarhynchus</i>	60
Figure 71 Cranial reconstructions of the skull of <i>Kannemeyeria cristarhynchus</i> : ventral and occipital view	61
Figure 72 Dorsal and lateral views of PVL/3465. Holotype of <i>K. argentinensis</i> Bonaparte 1966	62
Figure 73 Ventral and occipital views of PVL/3465. Holotype of <i>K. argentinensis</i> Bonaparte 1966	63
Figure 74 Lateral views of the lower jaw of PVL/3465. Holotype of <i>K. argentinensis</i> Bonaparte 1966	63
Figure 75 Occiput of <i>Kannemeyeria</i> demonstrating major muscle insertion sites, illustrated as functional units	64
Figure 76 Diagrammatic representation of the <i>Kannemeyeria</i> external adductor musculature	65
Figure 77 Diagrammatic representation of the posterior adductor and the internal adductor musculature	66
Figure 78 Phase One of the <i>Kannemeyeria</i> masticatory cycle	67
Figure 79 Force diagram depicting the movements of the lower jaw during Phase One of the <i>Kannemeyeria</i> masticatory cycle	68
Figure 80 Phase Two of the <i>Kannemeyeria</i> masticatory cycle	69
Figure 81 Force diagrams depicting the movements of the lower jaw during Phase Two of the <i>Kannemeyeria</i> masticatory cycle	70
Figure 82 Masticatory cycle of <i>Kannemeyeria</i>	71

LIST OF ABBREVIATIONS

Cranial

a.bpt	- anterior process of the basipterygoid	mc.q	- medial condyle of the quadrate
ao.s	- antorbital sulcus	m.np	- nasal plate of the maxilla
asr	- anterior sphenethmoid ridge	mes	- mesethmoid
bcr	- braincase roof	mg	- median groove
bo	- basioccipital	mj	- maxillary-jugal cavity
bot	- basioccipital tubera	mnr	- median nasal ridge
bpy	- basipterygoid of the parasphenoid	mor	- medial
bs	- basisphenoid	mtr	- medial tympanic ridge
cm	- caniniform process of the maxilla	mvf	- maxillary fovea
cp	- cultriform process	mvr	- median ventral ridge
cv	- cervical vertebrae	n	- nasal
d.ep	- dorsal pterygoid process of the epipterygoid	oc	- occipital condyle
dz	- dorsal zygomatic process of the maxilla	op	- opisthotic
e.ac	- exoccipital articulation condyle for the proatlas	or	- orbit roof
en	- external naris	os	- orbitosphenoid
enr	- external naris roof	p	- parietal
eo	- exoccipital	p.ant	- pila antotica
ep	- epipterygoid	p.pad	- palatal pad
ep.af	- anterior footplate of the epipterygoid	p.ptf	- posterior post temporal fenestra
ep.h	- epipterygoid head	p.sq	- parietal flange of the squamosal
ep.pf	- posterior footplate of the epipterygoid	pa	- palatine
f	- frontal	par	- paroccipital process of the opisthotic
f.p	- posterior process of the frontal	pb	- parasphenoid-basisphenoid complex
fm	- foramen magnum	pbs	- para-basisphenoid sulcus
fo	- fenestra ovalis	pf	- pineal foramen
gjo	- groove for the duct of Jacobson's organ	pgf	- pterygoid fossa
ic	- internal choana	plas	- plaster of paris
icc	- foramen leading to internal carotid canal	pm	- premaxilla
ip	- interparietal	pm.b	- broken surface of the premaxilla
ipv	- interpterygoid vacuity	po	- postorbital
j	- jugal	pp	- preparietal
jf	- jugular foramen	pre	- presphenoid
lac	- lacrimal	prf	- prefrontal
lac.f	- lacrimal foramen	pro	- prootic
lc.q	- lateral condyle of the quadrate	psph	- parasphenoid
lf	- labial fossa	psph.f	- parasphenoid foramen
lo	- opening to the labial fossa	pt	- pterygoid
lpf	- lateral palatal foramen	pt.m	- pterygoid process of the maxilla
m	- maxilla	pt.pf	- pterygo-parasphenoid fenestra
		ptf	- post temporal fenestra
		ptf.r	- recess of the post temporal fenestra
		q.sq	- quadrate flange of the squamosal
		qj	- quadratojugal
		qjf	- quadratojugal foramen

qjr	- quadratojugal recess
ql	- quadrate lamina
qr	- quadrate ramus of the pterygoid
qre	- quadrate recess
rp.psph	- rostral plate of the parasphenoid
sm	- septomaxilla
so	- supraoccipital
sor	- supraoccipital ridge
sp	- sphenethmoid
sq	- squamosal
st	- stapes
st.f	- stapedia foramen
tb	- tabular
tkr	- tusk root
tp	- temporal plate of the parietal
typ	- tympanic process of the opisthotic
v	- vomer
v.pa	- vertical plate of the palatine
v.tr	- ventral tympanic ridge
vf	- vidian foramen
vr.f	- ventral ridge of the frontal
vz	- ventral zygomatic process of the maxilla
z.sq	- zygomatic flange of the squamosal
za	- zygomatic arch
zp.sq	- zygomatic process of the squamosal

Mandible

ang	- angular
ap.art	- anterior process of the articular
art.r	- articular recess
d	- dentary
d.pad	- dentary pad
d.sh	- dentary shelf
dl.d	- dorsal ledge of the dentary
dp.d	- dorsal plate of the dentary
dr	- dentary recess of the angular
dr.d	- dorsal ridge of the dentary
ds	- dentary symphysis
dt	- dentary table
lc.art	- lateral condyle of the articular
ldg	- lateral dentary groove
ldr	- lateral ridge of the dentary symphysis
lg.ds	- lateral groove of the dentary symphysis
lhc	- limit of horny covering

mc.art	- medial condyle of the articular
mcn	- medial condylar notch
mdg	- median dentary groove
mf	- mandibular fenestra
mfe	- mandibular fosse
mr.d	- medial ridge of the dentary
mr.lc	- medial ridge of the lateral condyle of the articular
pra	- prearticular
r.art	- retroarticular process
rl.ang	- reflected lamina of the angular
spl	- splenial
sa	- surangular
tsk	- tusk
vp.d	- ventral plate of the dentary
vp.sa	- ventral plate of the surangular

Institutional

BP/BPI	- Bernard Price Institute for Palaeontological Research, Johannesburg
EL	- East London Museum
PE	- Port Elizabeth Museum
MACN	- Museo Argentino de Ciencias Naturales, Buenos Aires, Argentina
NMQR	- National Museum, Bloemfontein
PVL	- Paleontologia de Vertebrados, Instituto Lillo, Tucuman, Argentina
RC	- Rubidge Collection, Graaff-Reinet
SAM	- South African Museum, Cape Town

Other abbreviations are explained in the text.

CONTENTS

	Page
DECLARATION	i
ABSTRACT	ii
ACKNOWLEDGEMENTS	iv
LIST OF FIGURES	v
LIST OF ABBREVIATIONS	ix

VOLUME ONE

Chapter 1

INTRODUCTION

1.1 The Dicynodont Genus <i>Kannemeyeria</i>	1
1.2 Historical Review	3
1.3 Re-evaluation of the Genus <i>Kannemeyeria</i>	7
1.4 <i>Kannemeyeria</i> as Index Fossil of the Triassic.	10

Chapter 2

MATERIALS, METHODS AND PRESERVATION

2.1 <i>Kannemeyeria simocephalus</i> and Synonomised Species	12
2.1.1 Holotype Specimen	12
2.1.2 Study Sample and Referred Specimens.	12
2.2 <i>Kannemeyeria wilsoni</i>	18
2.3 <i>Kannemeyeria cristarhynchus</i>	19
2.4 <i>Kannemeyeria argentinensis</i>	20
2.4.1 Holotype Specimen	20
2.4.2 Referred Specimens	21

Chapter 3

CRANIAL MORPHOLOGY OF THE GENUS *KANNEMEYERIA*

3.1 Introduction: Definitive Aspects of <i>Kannemeyeria</i> Cranial Morphology	22
3.2 General Description	24
3.3 Dermocranium	26
3.3.1 Snout Region	27
3.3.2 Anterior Palate and Nasal Cavity	31

	Contents	xii
Anterior Palate		31
Nasal Cavity		32
3.3.3 Skull Roof		34
3.3.4 Palatal Region		43
3.4 Neurocranium		
3.4.1 Occiput and Braincase		48
Occiput		48
Braincase		54
3.4.2 Sphenethmoid Region		57
Sphenethmoid Complex		58
3.5 Visceral Arch Skeleton		60
3.5.1 Palatoquadrate		60
3.6 Lower Jaw		62
3.7 Discussion		69
3.7.1 Revised Generic Diagnosis		70
Systematic Palaeontology		70
3.7.2 <i>Kannemeyeria</i> and Permian Dicynodont Taxa		72

Chapter 4

CRANIAL MORPHOLOGY OF *KANNEMEYERIA SIMOCEPHALUS*

4.1 General Description		75
4.2 Dermocranium		77
4.2.1 Anterior Palate and Nasal Cavity		79
Anterior Palate		79
4.2.2 Skull Roof		79
4.2.3 Palatal Region		81
4.3 Neurocranium		82
4.3.1 Occiput		82
4.4 Visceral Arch Skeleton		82
4.4.1 Palatoquadrate		82
4.5 Lower Jaw		83
4.6 Discussion		85

Chapter 5

CRANIAL MORPHOLOGY OF *KANNEMEYERIA CRISTARHYNCHUS*

5.1	Introduction	87
5.2	General Description	88
5.3	Dermocranium	
5.3.1	Snout Region	89
5.3.2	Anterior Palate	91
5.3.3	Skull Roof	92
5.3.4	Palatal Region	93
5.4	Neurocranium	
5.4.1	Occiput	95
5.4.2	Sphenethmoid Region	95
5.5	Visceral Arch Skeleton	
5.5.1	Palatoquadrate	96
5.6	Lower Jaw	97
5.7	Discussion	98

Chapter 6

COMPARATIVE CRANIAL MORPHOLOGY OF *KANNEMEYERIA ARGENTINENSIS*

6.1	Introduction	103
6.2	General Description	104
6.3	Snout Region	107
6.4	Anterior Palate	108
6.5	Skull Roof	109
	Occiput	111
6.6	Palatal Region and Quadrate Complex	112
6.7	Lower Jaw	113
6.8	Discussion	114

Chapter 7

ALLOMETRIC ANALYSIS: ASPECTS OF RELATIVE GROWTH IN *KANNEMEYERIA*

7.1	Introduction	116
-----	--------------	-----

7.2 Materials and Methodology	
7.2.1 Methodology	117
7.2.2 Materials and Allometric Variables	119
7.3 Relative Growth and Variability	120
7.4 Discussion and Conclusions	124

Chapter 8

VARIATION AND TAXONOMY OF THE GENUS *KANNEMEYERIA*

8.1 Skull Variation Within the Genus <i>Kannemeyeria</i>.	126
8.2 Age-Related Variation	
8.2.1 Allometric Growth	127
8.2.2 Continuous Growth	128
8.2.3 Temporal Ossification	130
8.3 Distortion Effects	132
8.4 Intraspecific Variation	134
8.5 Revised Specific Diagnoses	
8.5.1 <i>Kannemeyeria simocephalus</i>	135
8.5.2 <i>Kannemeyeria cristarhynchus</i>	137
8.5.3 Taxonomic Status of <i>Kannemeyeria argentinensis</i>	139

Chapter 9

FUNCTIONAL AND EVOLUTIONARY ASPECTS OF THE *KANNEMEYERIA* CRANIAL MORPHOLOGY

9.1 General	141
9.2 Nasal Capsule	144
9.3 Pterygoid Complex and Sphenethmoid Region	145
9.4 Palatoquadrate	148
9.5 Occipital Musculature and Blood-vessels	150

Chapter 10

LOWER JAW FUNCTION AND THE *KANNEMEYERIA* MASTICATORY CYCLE

10.1 Introduction	154
The Dicynodont Masticatory Cycle	155
10.2 Masticatory Apparatus of <i>Kannemeyeria</i>	156

10.3	<i>Kannemeyeria</i> Jaw Musculature							
10.3.1	External Adductor Musculature	.	.	.	.	.	.	160
10.3.2	Internal Adductor Musculature	.	.	.	.	.	.	162
10.3.3	<i>Depressor Mandibulae</i>	.	.	.	.	.	.	163
10.4	Jaw Action and Muscle Forces							
10.4.1	Phase One: Depression and Elevation	.	.	.	.	.	.	165
10.4.2	Phase Two: Orthal Movements with the Jaw Closed	.	.	.	.	.	.	169
10.5	The Masticatory Cycle of <i>Kannemeyeria</i>	.	.	.	.	.	.	171
 Chapter 11								
CONCLUSIONS								
11.1	The <i>Kannemeyeria</i> Anatomical Pattern	.	.	.	.	.	.	174
11.1.1	The Genus and Species of <i>Kannemeyeria</i>	.	.	.	.	.	.	174
11.1.2	The Anatomical Pattern and Taxonomic Status of <i>K. argentinensis</i>	.	.	.	.	.	.	176
11.1.3	Palaeobiogeographic Considerations	.	.	.	.	.	.	177
11.2	Masticatory Cycle of <i>Kannemeyeria</i>	.	.	.	.	.	.	182
11.3	Anatomical Patterns and the Consequent Taxonomy of the Triassic Dicynodonts: An Interpretative Diagnosis of <i>Kannemeyeria</i> Cranial Morphology	.	.	.	.	.	.	184
11.3.1	Physiological Significance of the <i>Kannemeyeria</i> Anatomical Pattern	.	.	.	.	.	.	185
11.3.2	Origins of Triassic Dicynodonts.	.	.	.	.	.	.	185
REFERENCES		.	.	.	.	.	.	187
 VOLUME TWO								
FIGURES		.	.	.	.	.	.	1
 APPENDIX A								
A.1	Materials and Methods	.	.	.	.	.	.	72
A.2	List of Reference Specimens	.	.	.	.	.	.	73
 APPENDIX B								
B.1	Table of Allometric Measurements	.	.	.	.	.	.	74

	Contents	xvi
B.2 Table of Allometric Variables and Results	.	75
B.3 Cranial Measurements.	.	76

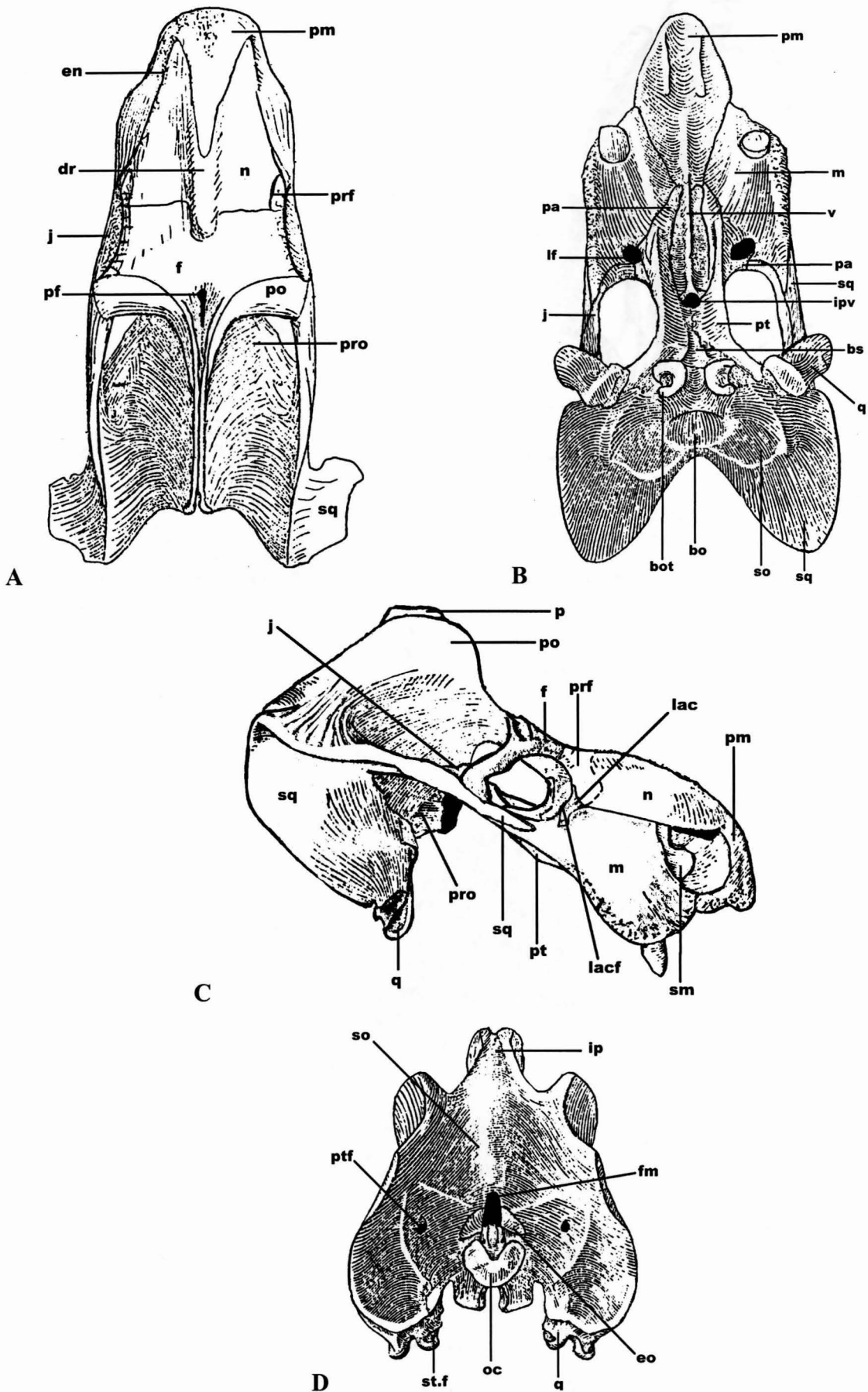


Figure 1. Cranial reconstructions of dorsal **A**, ventral **B**, lateral **C** and occipital **D** views of the genotype of *Kannemeyeria* modified from Pearson (1924a). Not drawn to same scale, abbreviations as on p. xii.

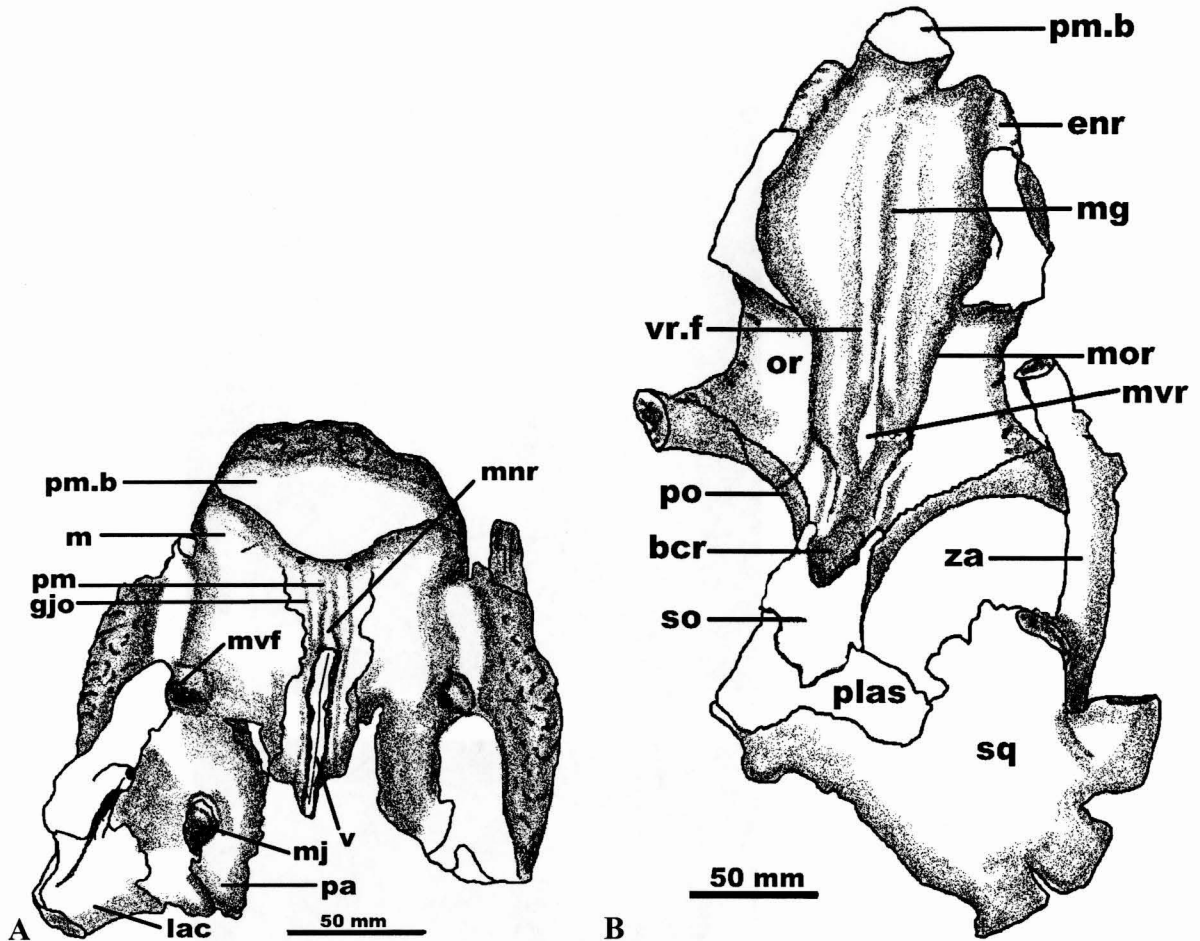


Figure 2. Drawing of the floor of the nasal cavity A, and ventral skull roof B of specimen BP/1/4648, abbreviations as on p. ix.

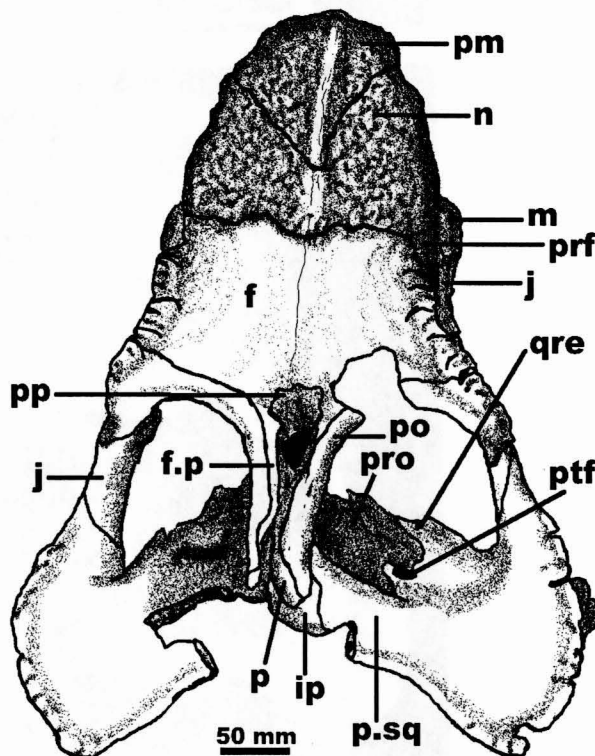
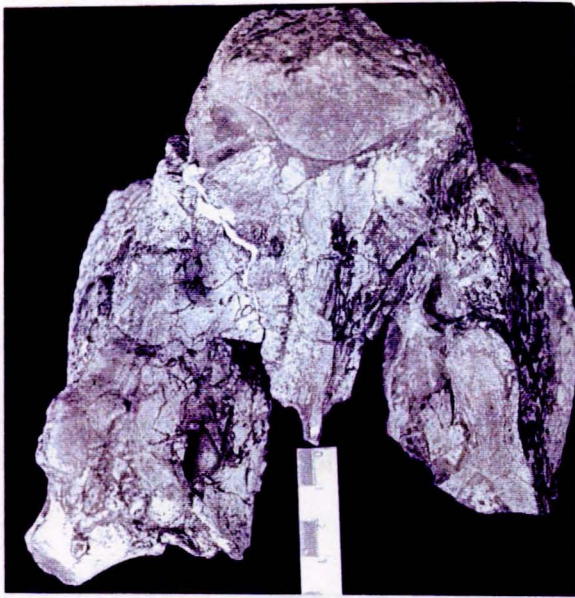


Figure 3. Dorsal view of specimen BP/1/5624, abbreviations as on p. ix.

A



B



C

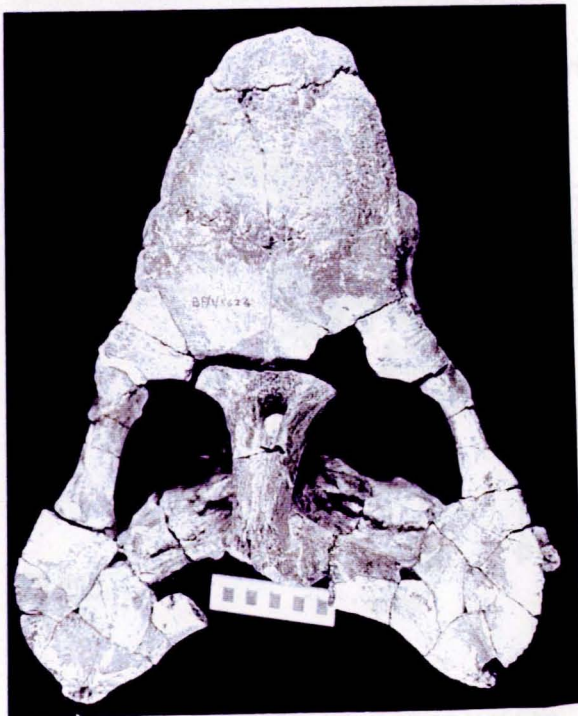


Figure 4. Photographs of the nasal cavity floor **A** and maxillary fovea of the right side of the nasal cavity **B** of BP/1/4648; and the dorsal view of BP/1/5624 **C**.

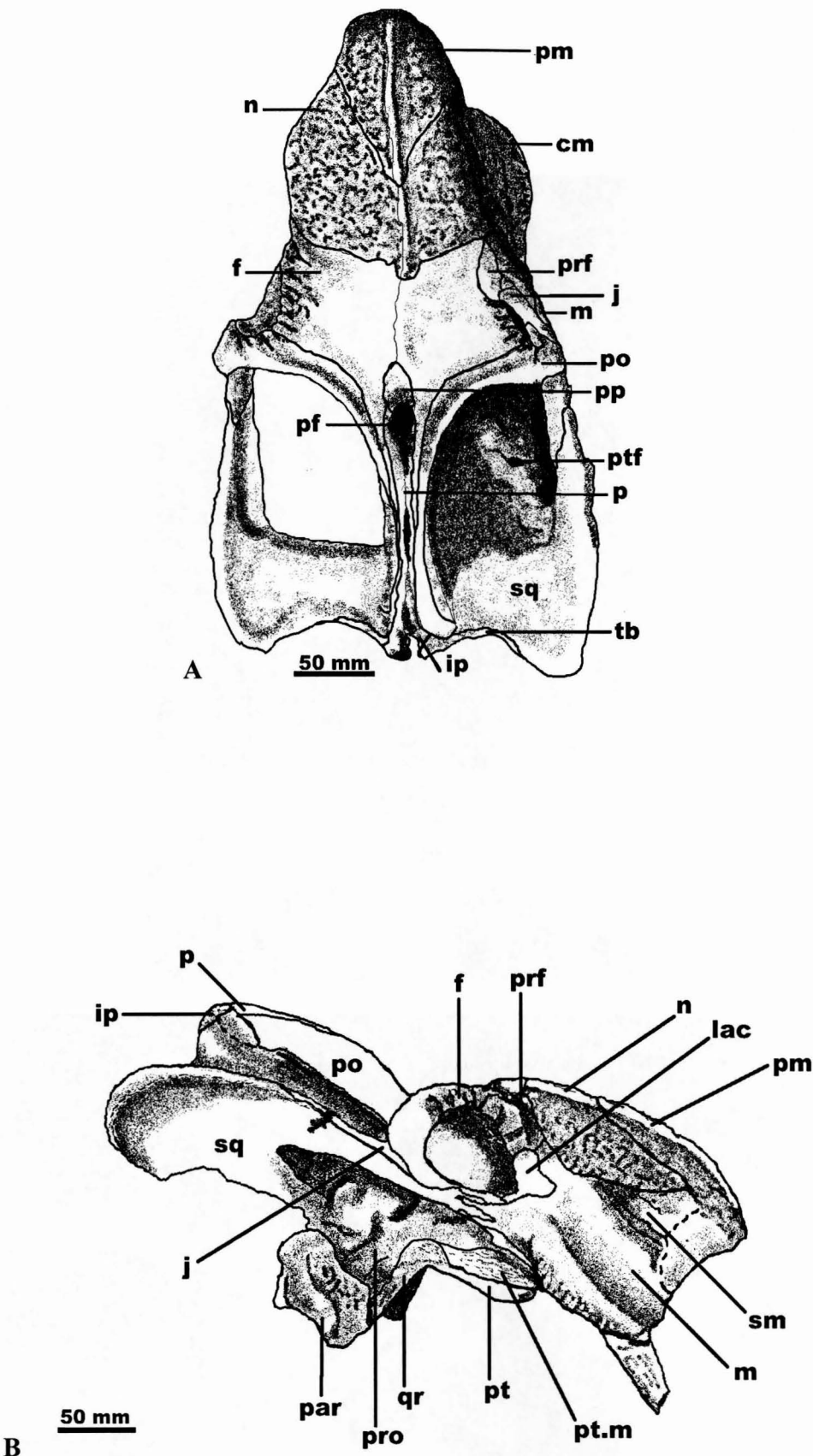


Figure 5. Dorsal A and lateral B views of BP/1/1168, abbreviations as on p. ix.

A



B



Figure 6. Photographs of the dorsal **A** and lateral **B** views of BP/1/1168.

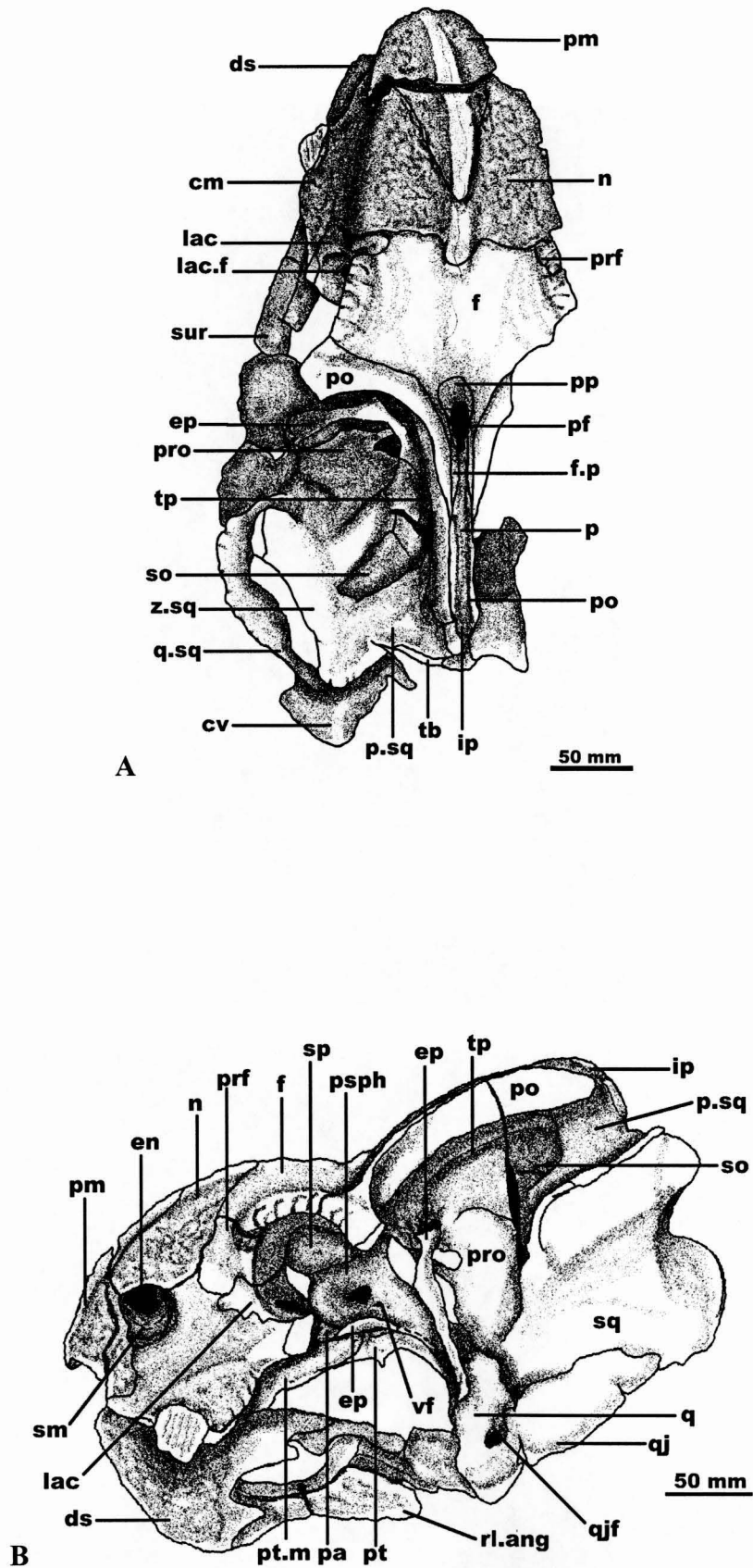


Figure 7. Dorsal A and lateral B views of SAM/PK/10555, abbreviations as on p. ix.

A



B

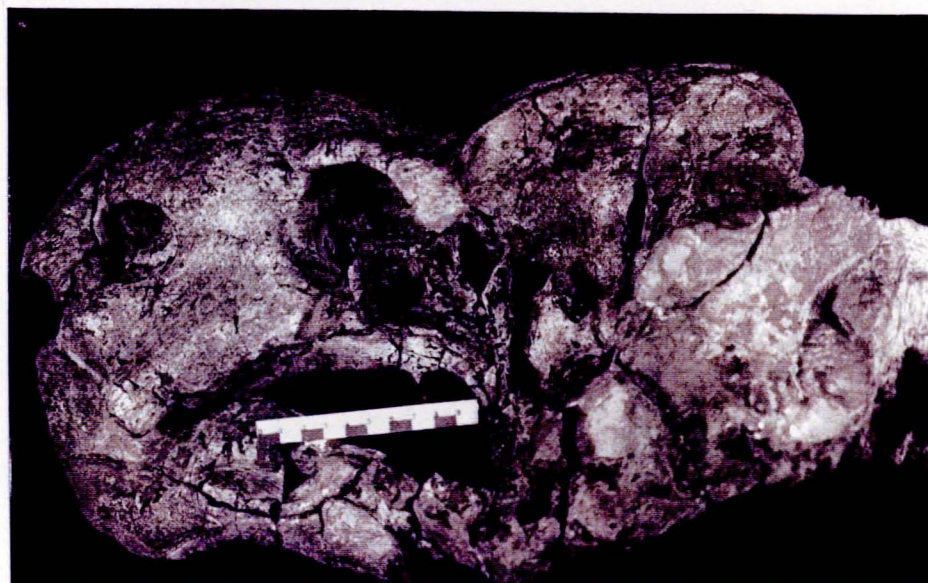


Figure 7. Photographs of the dorsal **A** and lateral **B** views of SAM/PK/10555.

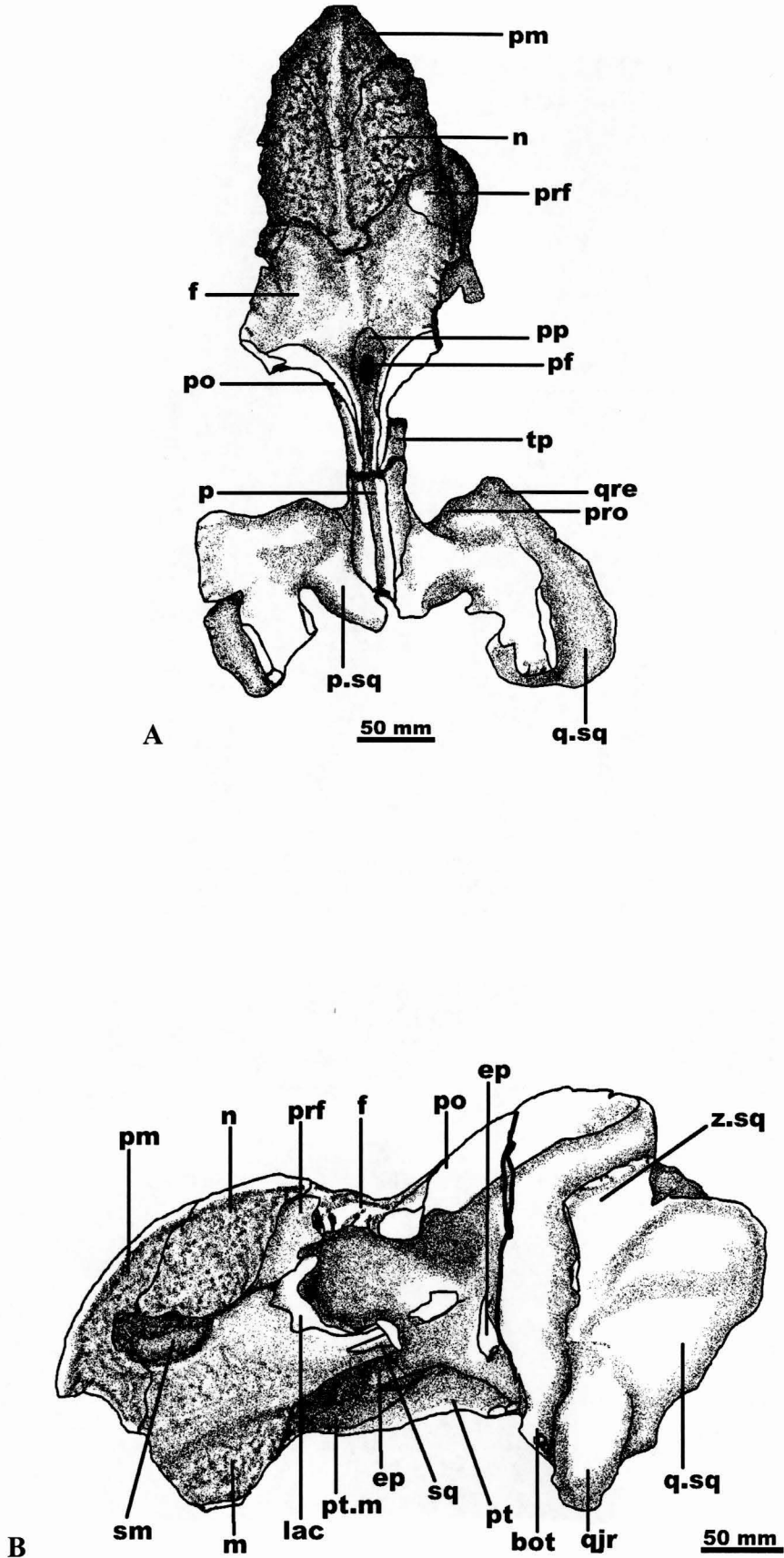


Figure 9. Dorsal A and lateral B views of NMQR/1127, abbreviations as on p. ix.

A



B

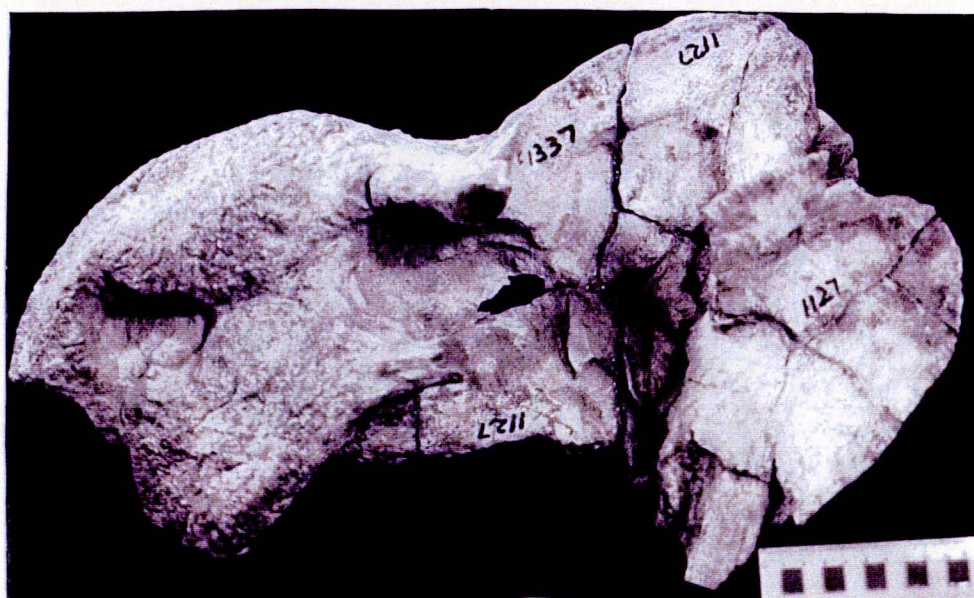


Figure 10. Photographs of the dorsal **A** and lateral **B** views of NMQR/1127

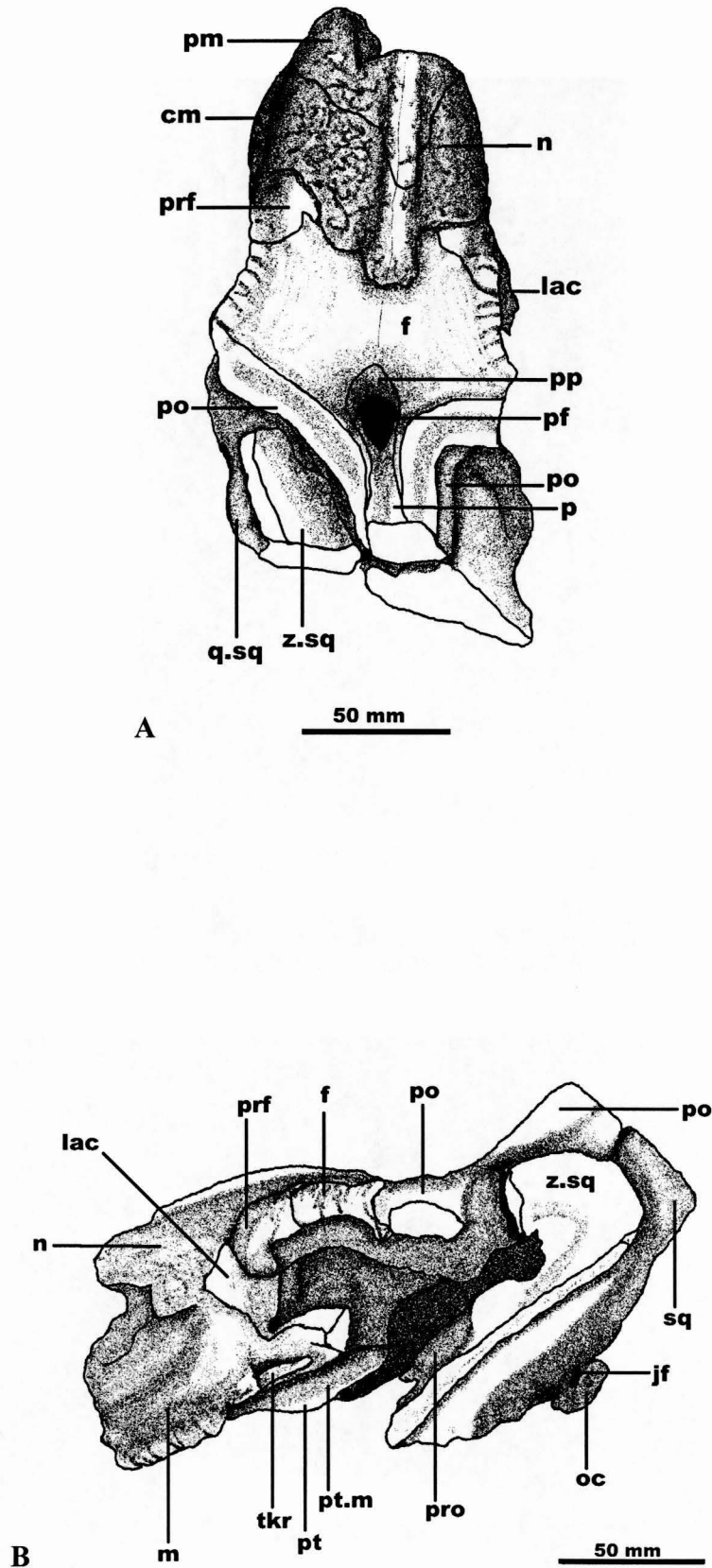
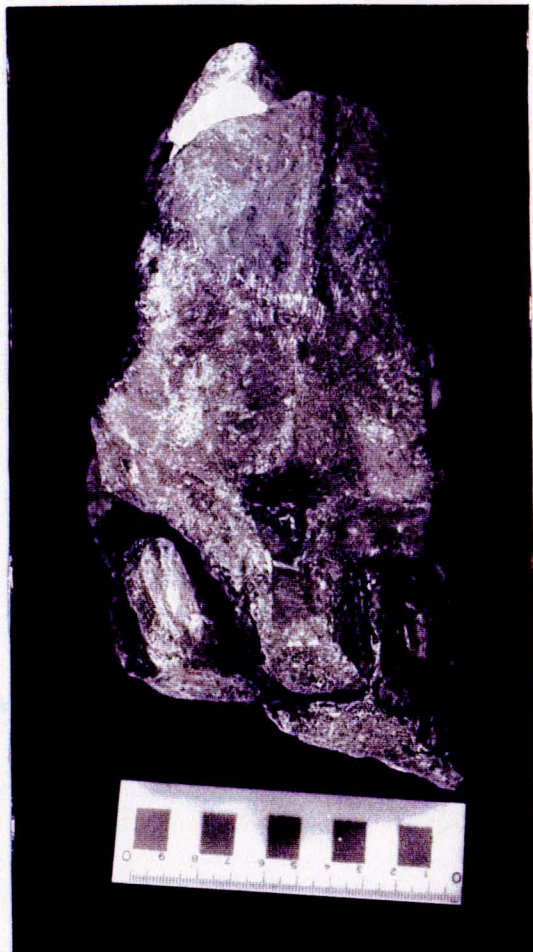


Figure 11. Dorsal **A** and lateral **B** views of PE/1199P (holotype of *K. latifrons* Broom 1913), abbreviations as on p. ix.

A



B

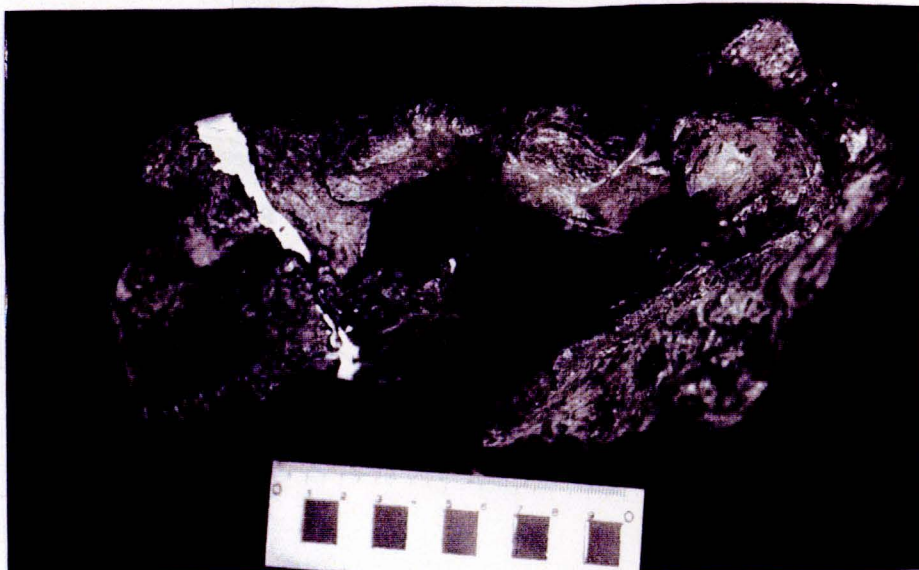


Figure 12. Photographs of the dorsal **A** and lateral **B** views of PE/1199P (holotype of *K. latifrons* Broom 1913)..

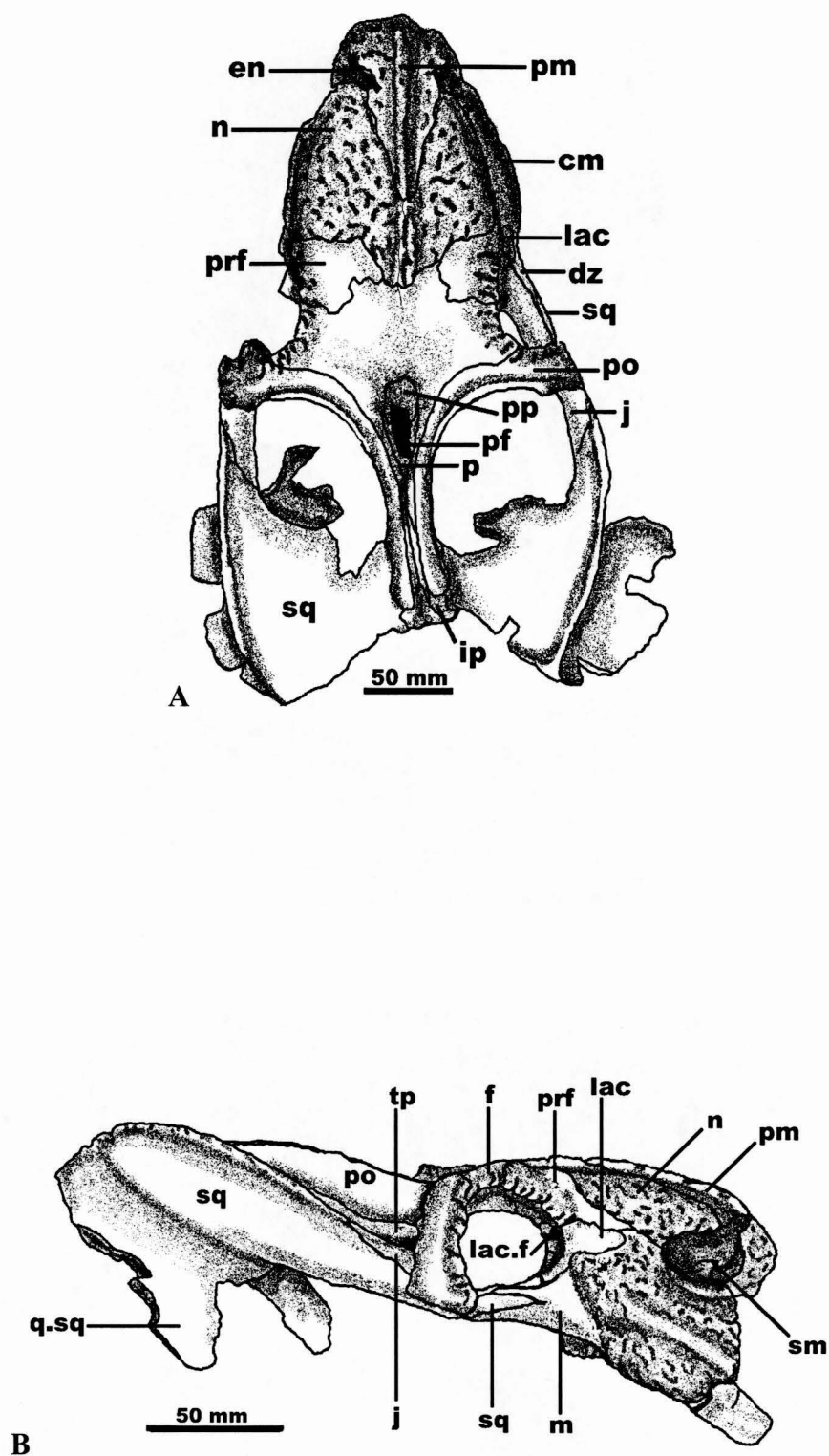


Figure 13. Dorsal **A** and lateral **B** views of BP/1/4648, abbreviations as on p. ix.

A

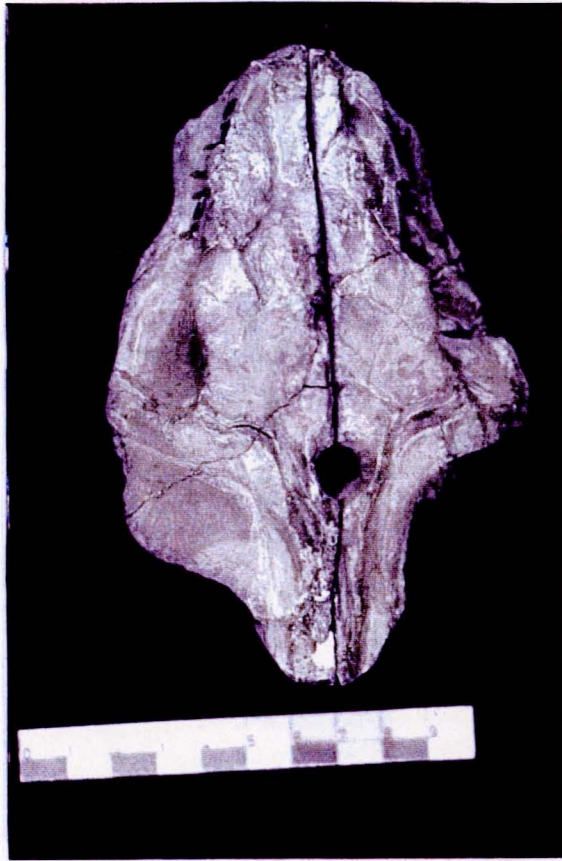


B



Figure 14. Photographs of the dorsal A and lateral B views of BP/1/4648.

A



B



Figure 15. Photographs of the dorsal **A** and lateral **B** views of BP/1/989.

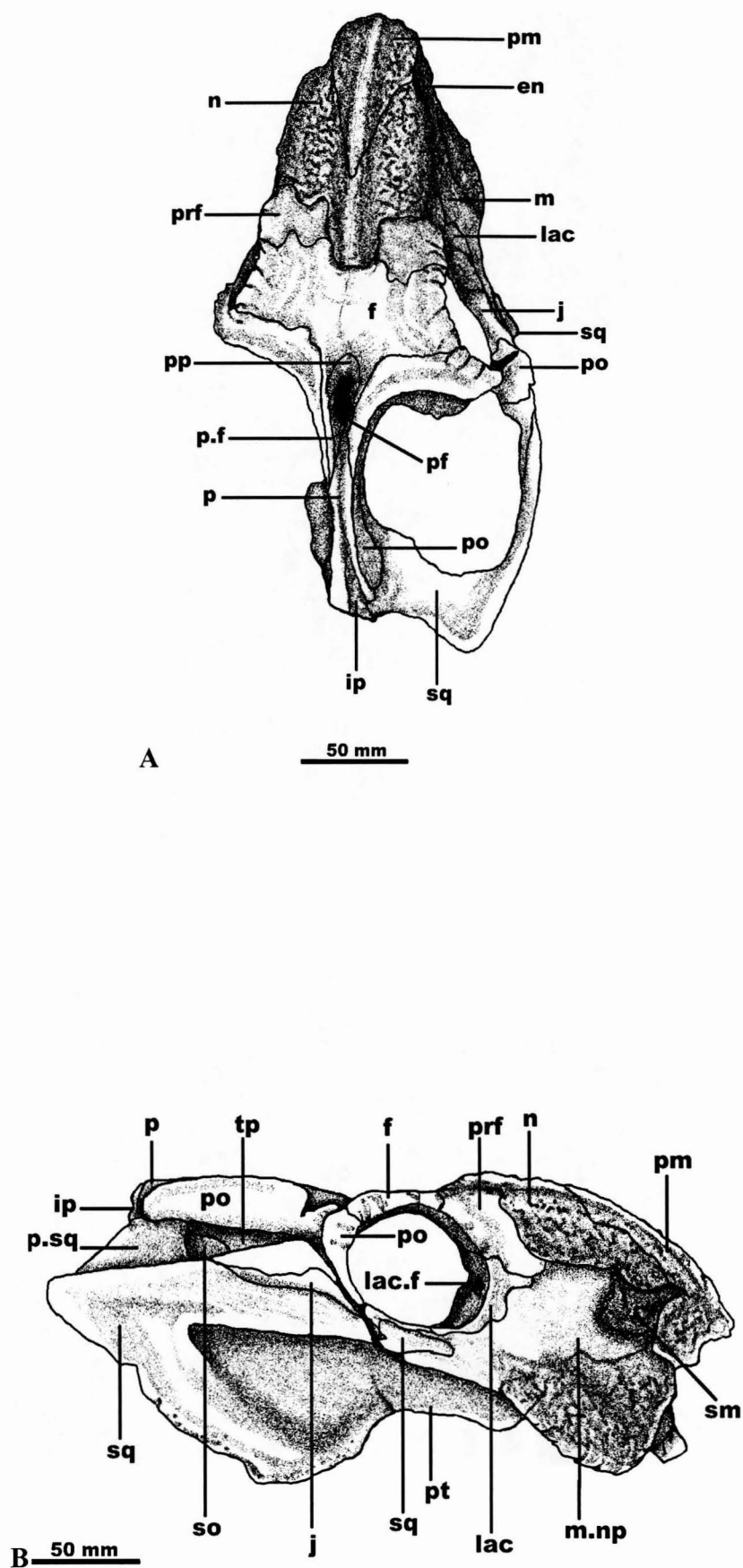


Figure 16. Dorsal **A** and lateral **B** views of BP/1/2092, abbreviations as on p. ix.

A



B

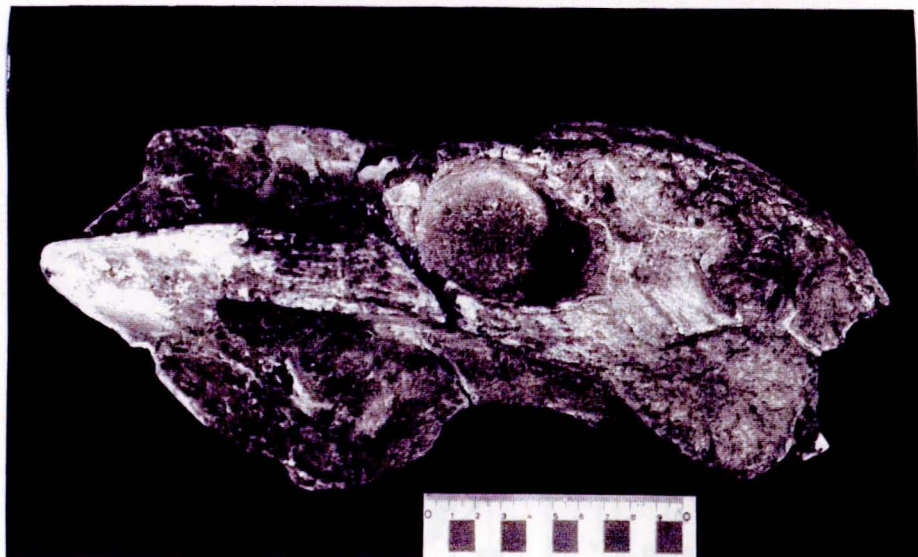


Figure 17. Photographs of the dorsal **A** and lateral **B** views of BP/1/2092.

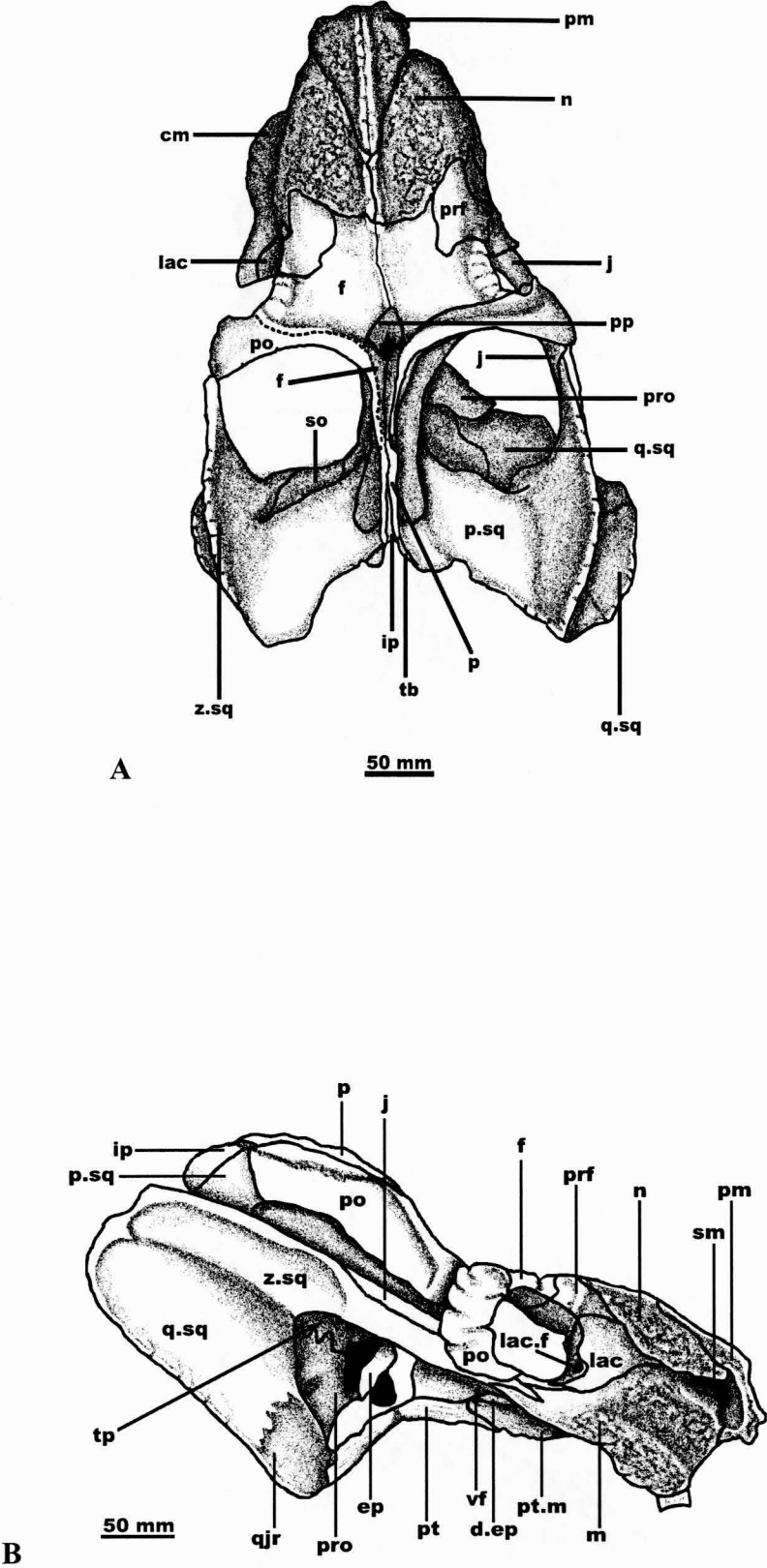


Figure 18. Dorsal **A** and lateral **B** views of SAM/PK/3017 (holotype of *K. erithrea* Haughton 1915), abbreviations as on p. ix.

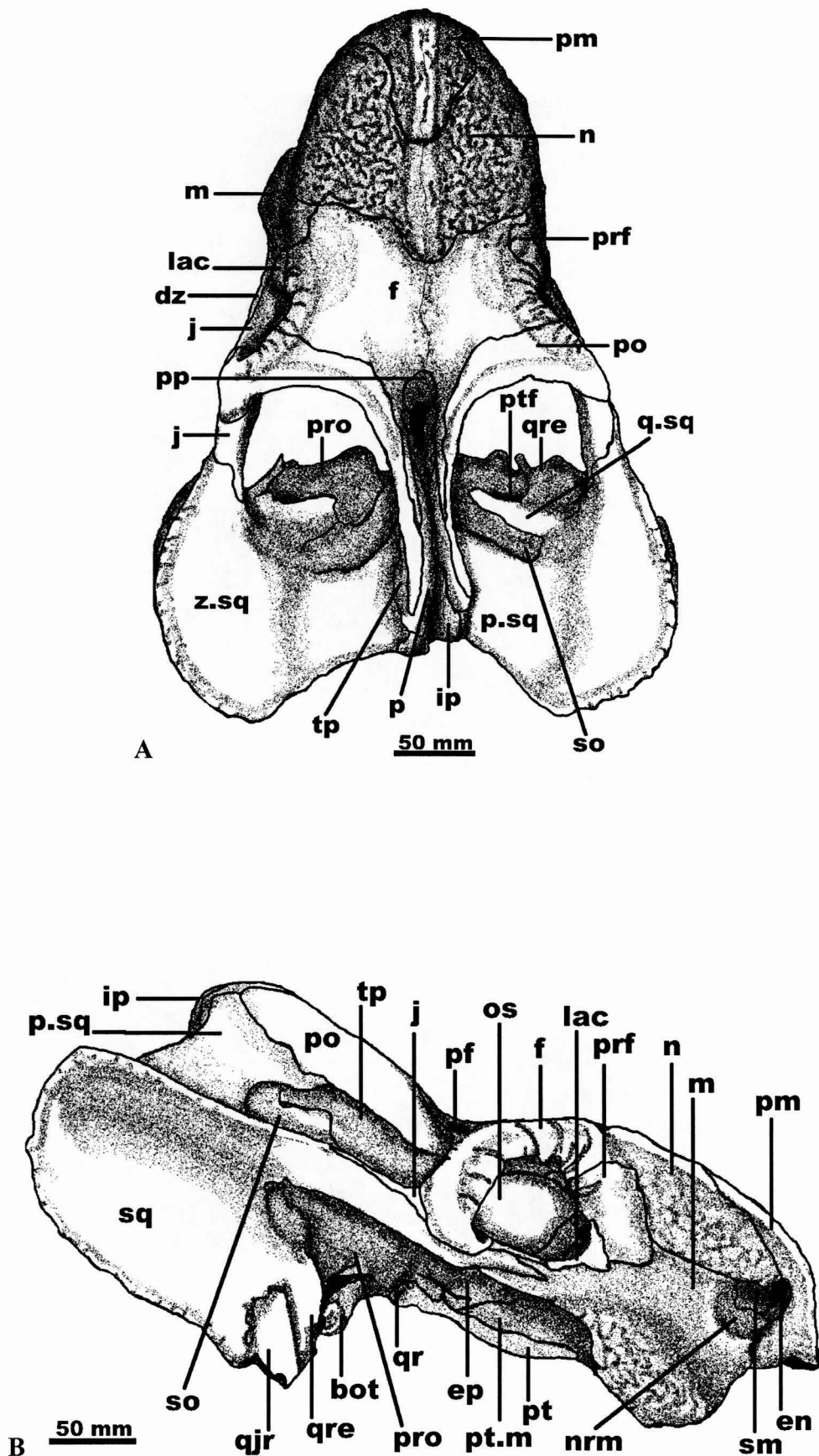


Figure 19. Dorsal A and lateral B views of BP/1/4523, abbreviations as on p. ix.

A



B

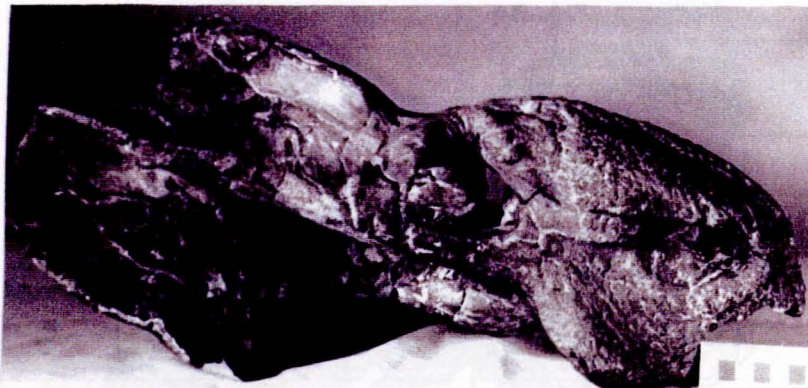


Figure 20. Photographs of the dorsal **A** and lateral **B** views of BP/1/4523.

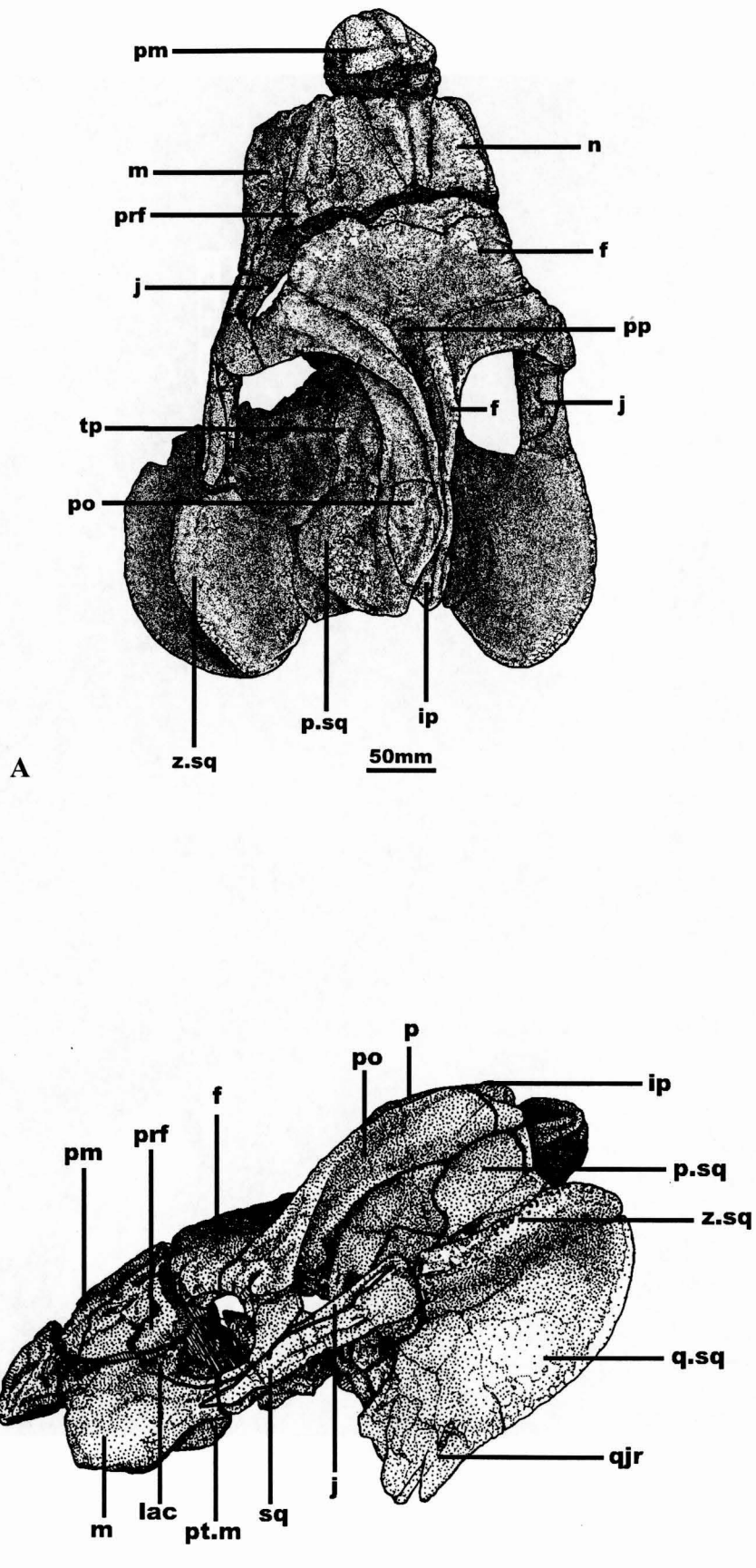


Figure 21. Dorsal **A** and lateral **B** views of EL/1 (holotype of *K. wilsoni* Broom 1937), abbreviations as on p. ix.

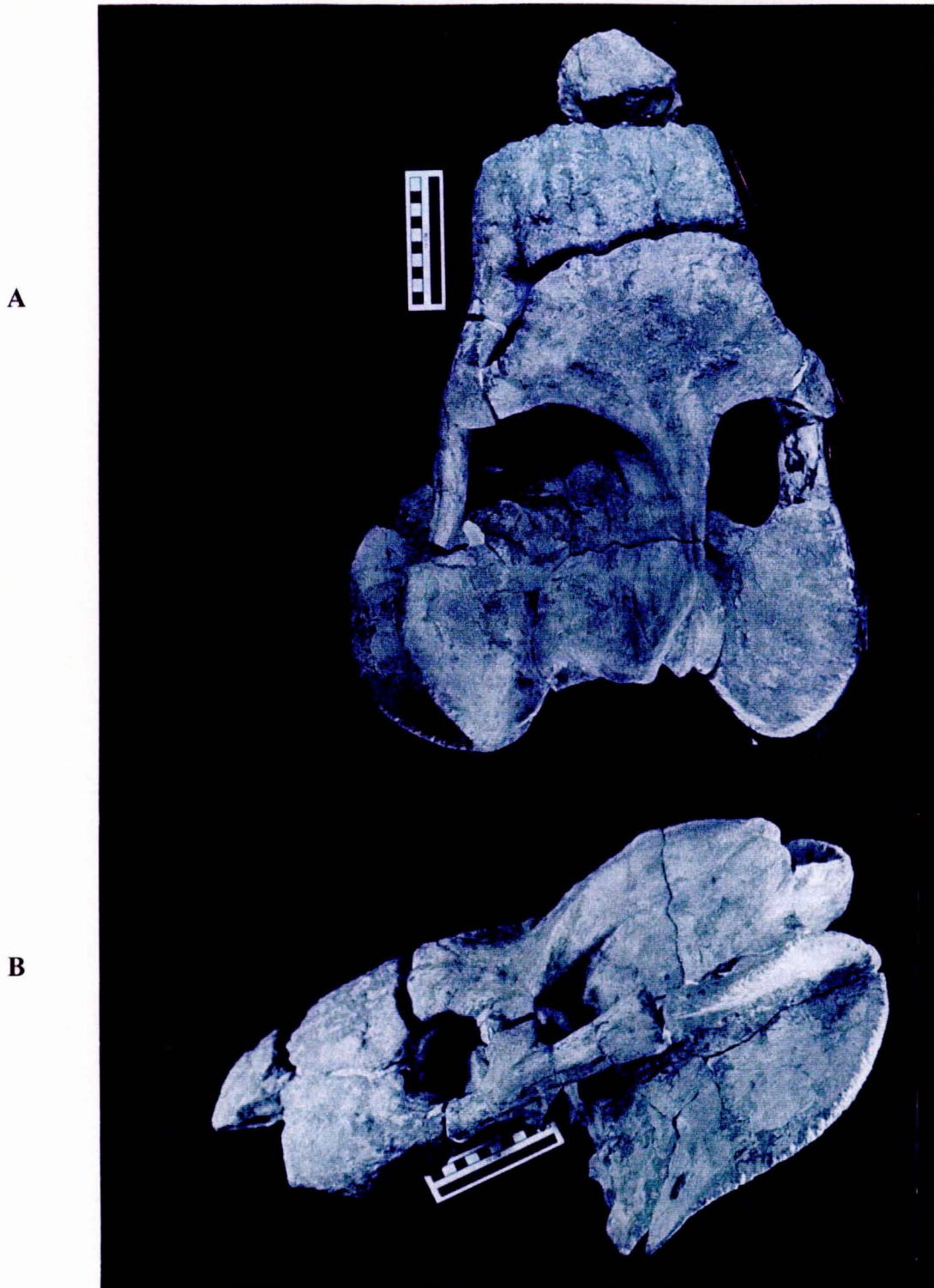


Figure 22. Photographs of the dorsal **A** and lateral **B** views of EL/1 (holotype of *K. wilsoni* Broom 1937).

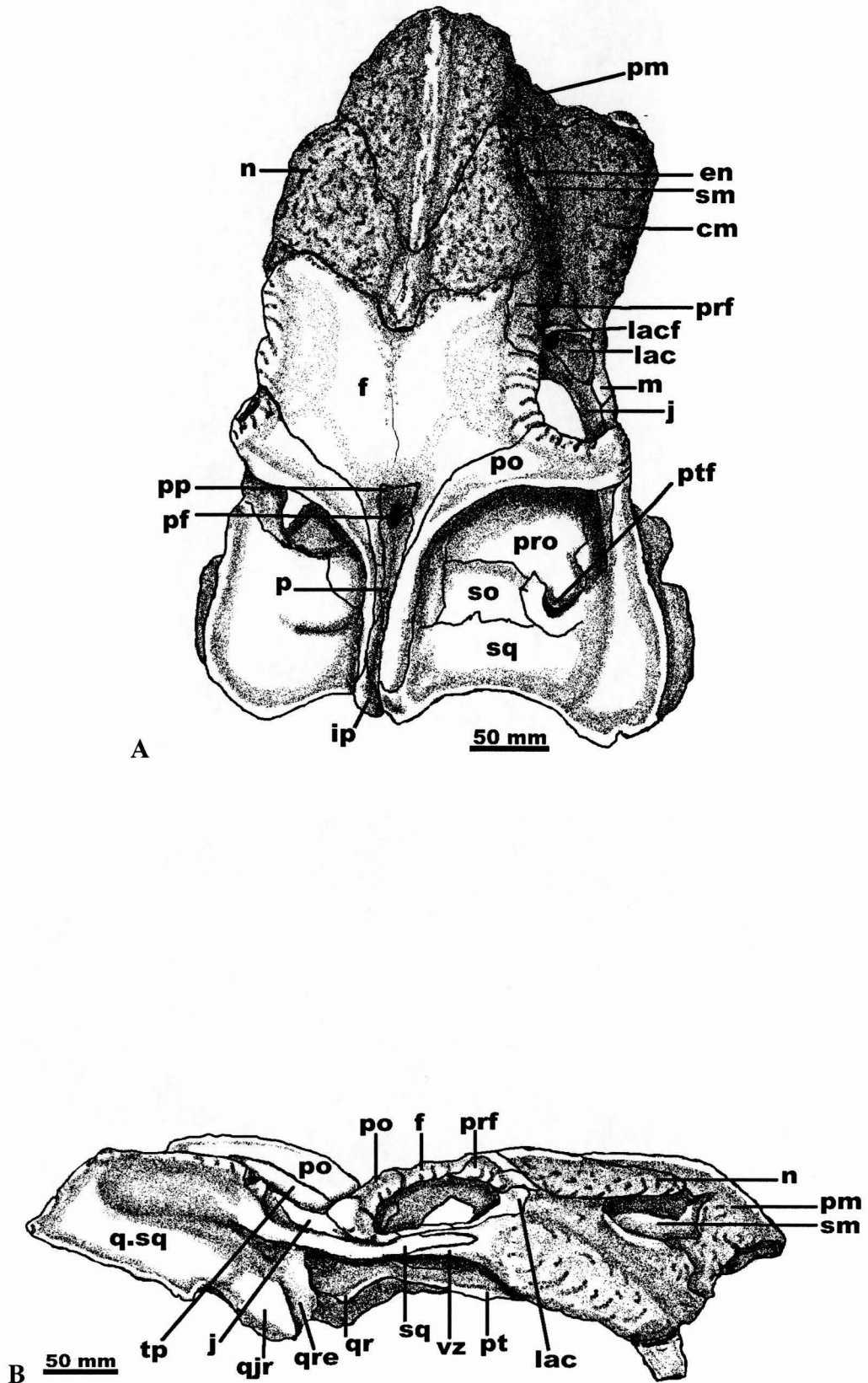


Figure 23. Dorsal A and lateral B views of BP/1/4524, abbreviations as on p. ix.

A



B

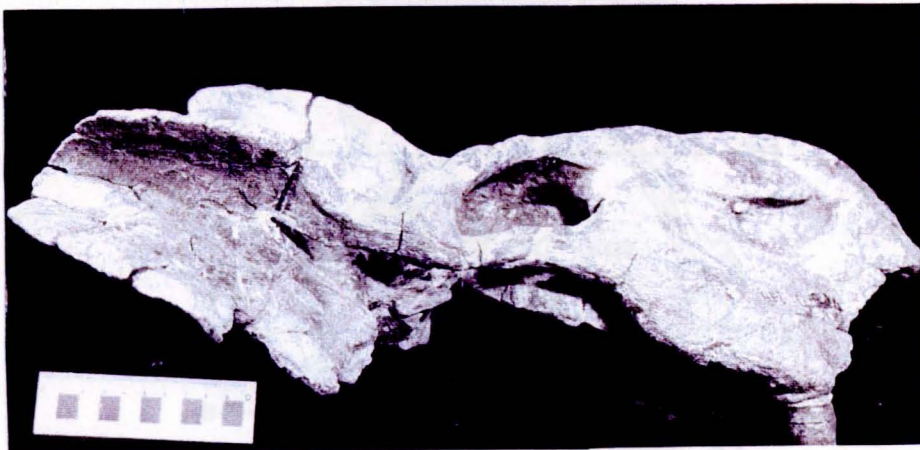


Figure 24. Photographs of the dorsal **A** and lateral **B** views of BP/1/4524.

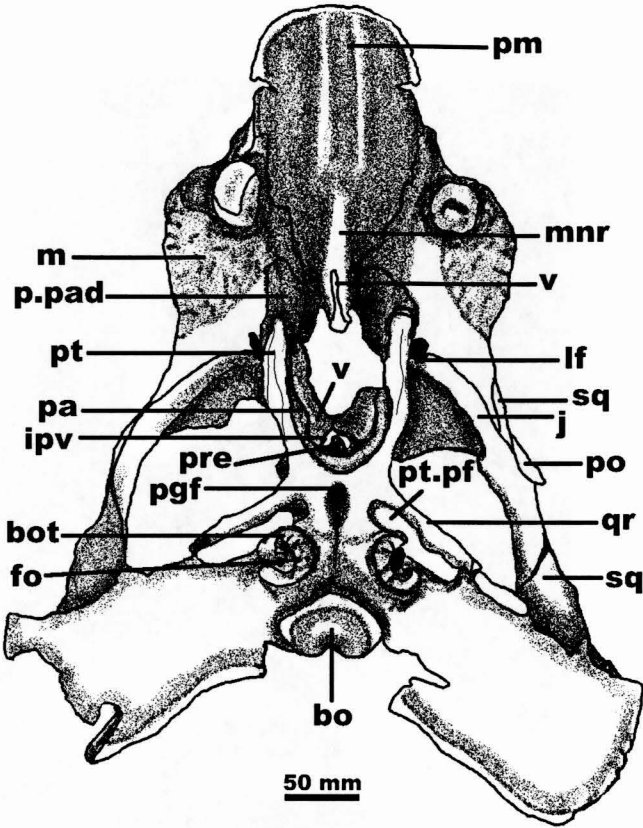


Figure 25. Ventral view of BP/1/5624, abbreviations as on p. ix.

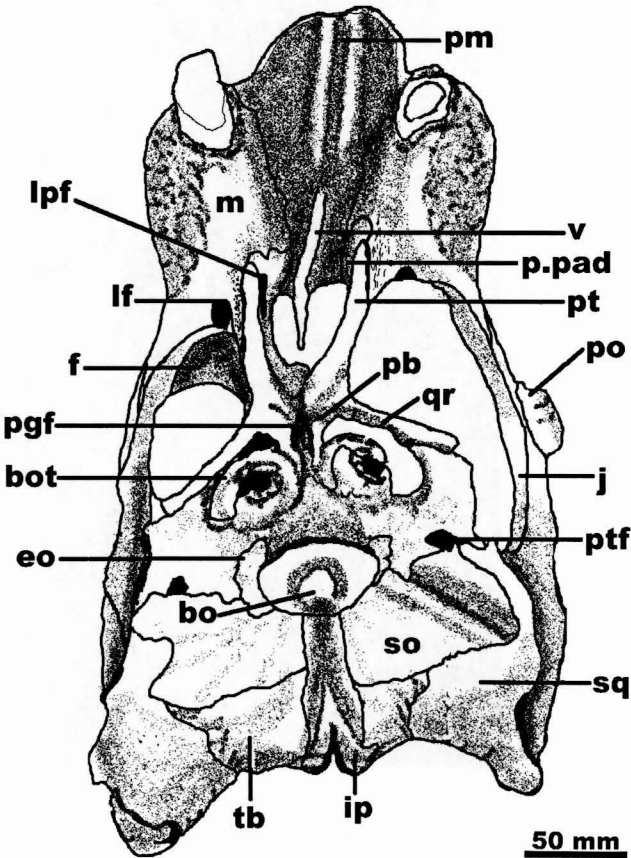
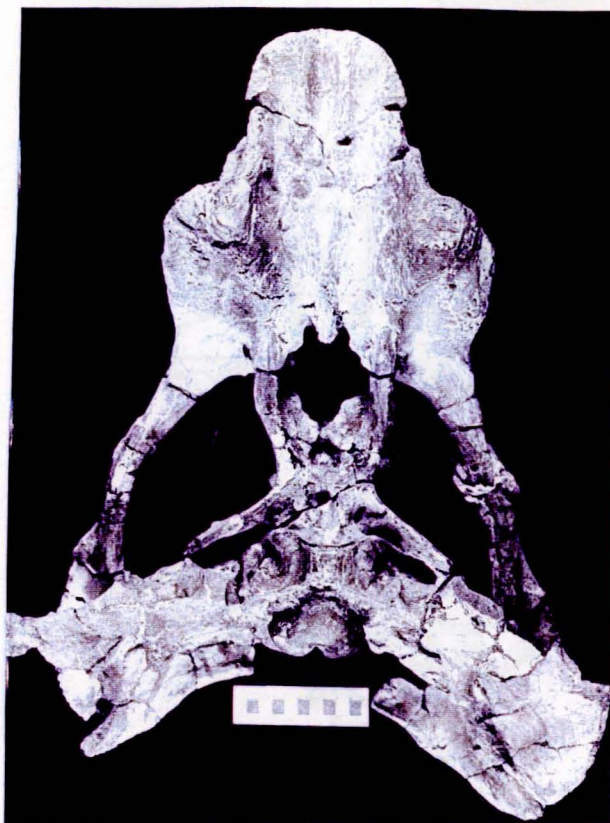


Figure 26. Ventral view of BP/1/1168, abbreviations as on p. ix.

A



B



Figure 27. Photographs of the ventral views of BP/1/5624 **A** and BP/1/1168 **B**.

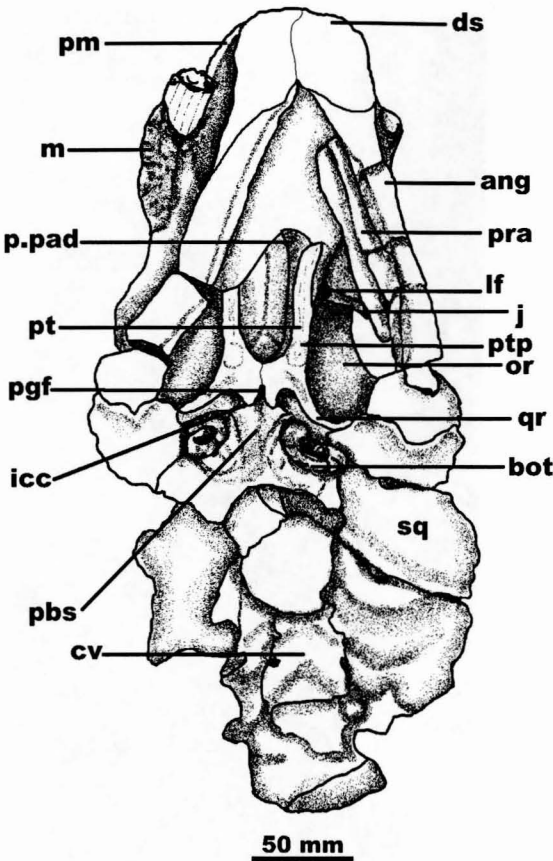


Figure 28. Ventral view of SAM/PK/10555, abbreviations as on p. ix.

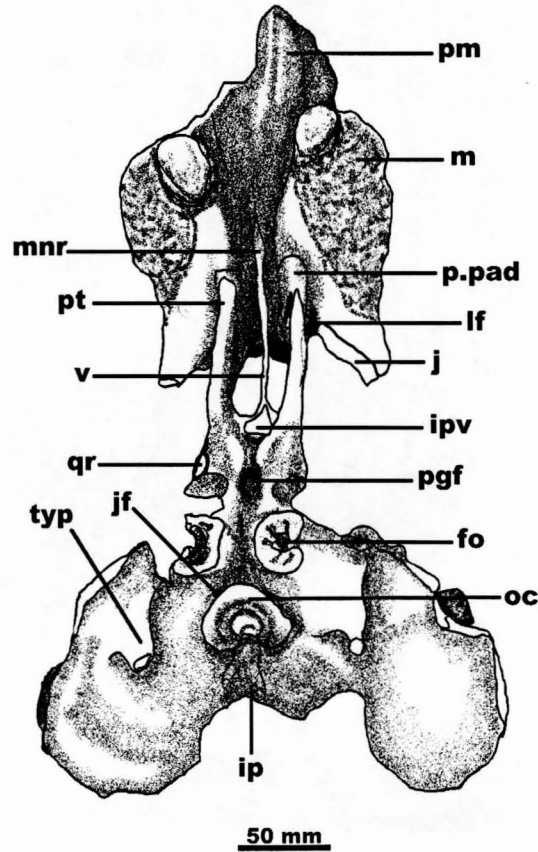


Figure 29. Ventral view of NMQR/1127, abbreviations as on p. ix

A



B



Figure 30. Photographs of the ventral views of SAM/PK/10555 A and NMQR/1127 B.

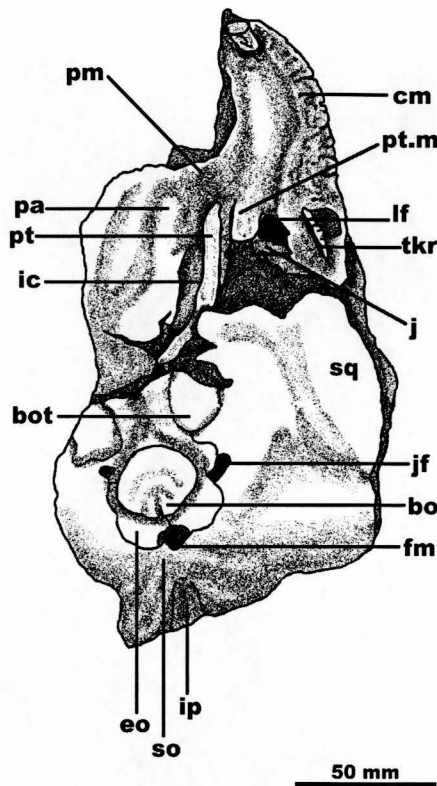


Figure 31. Ventral view of PE/1199P (holotype of *K. latifrons* Broom 1913), abbreviations as on p. ix.

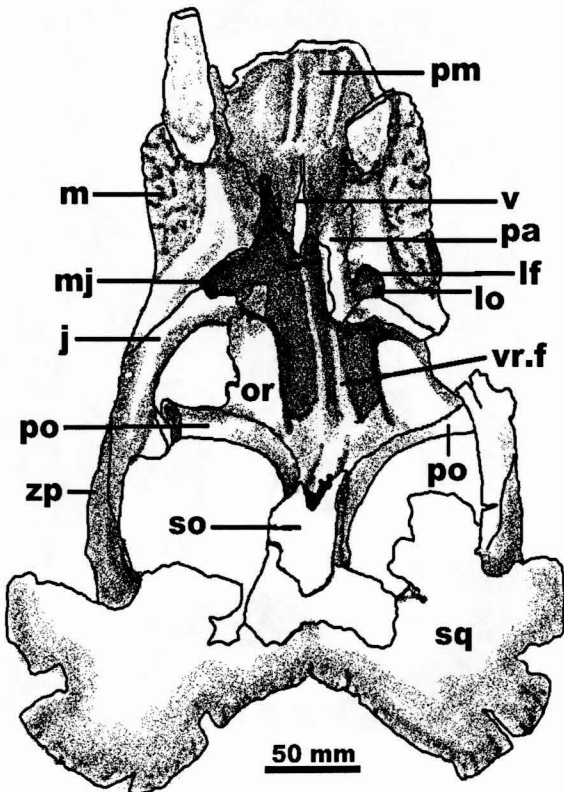


Figure 32. Ventral view of BP/1/4648, abbreviations as on p. ix.

A



B

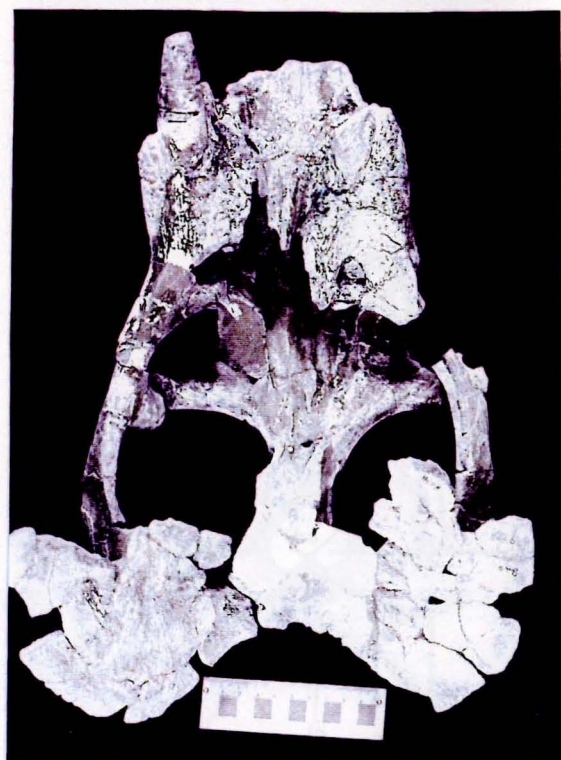


Figure 33. Photographs of the ventral views of PE/1199P **A** and BP/1/4648 **B**.

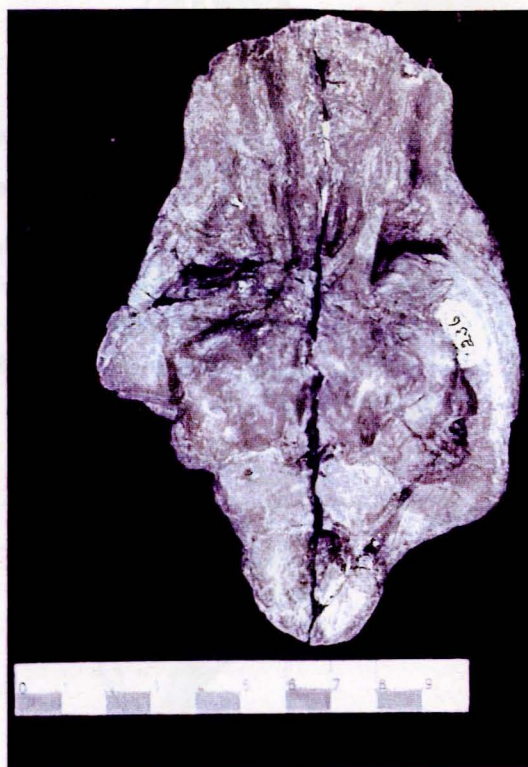


Figure 34. Ventral view of BP/1/989.

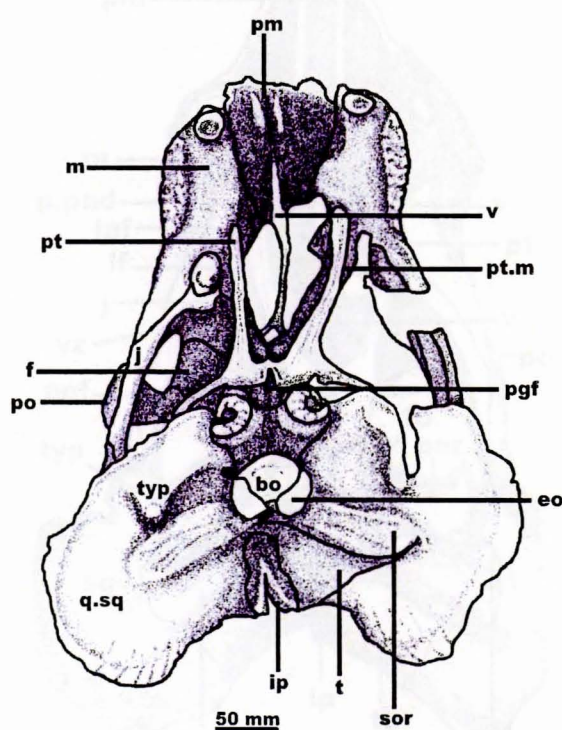


Figure 35. Ventral view of SAM/PK/3017 (holotype of *K. erithrea* Haughton 1915), abbreviations as on p. ix.

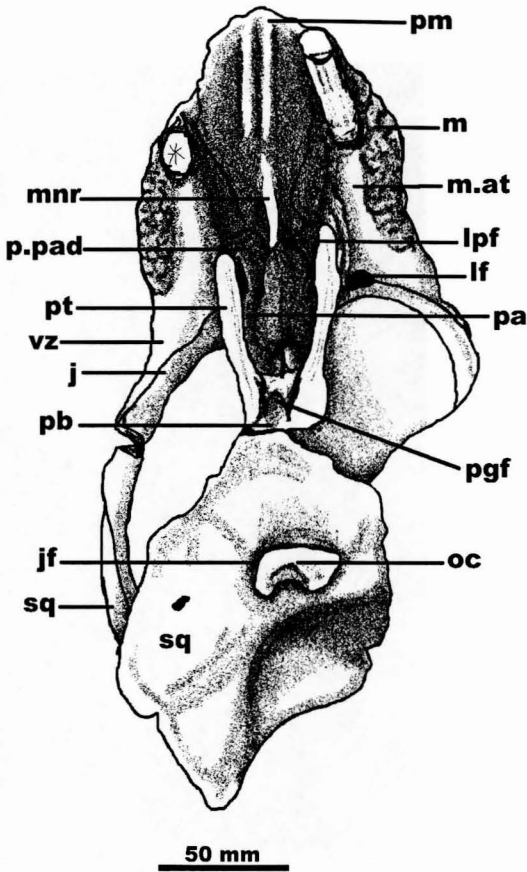


Figure 36. Ventral view of BP/1/2092, abbreviations as on p. ix.

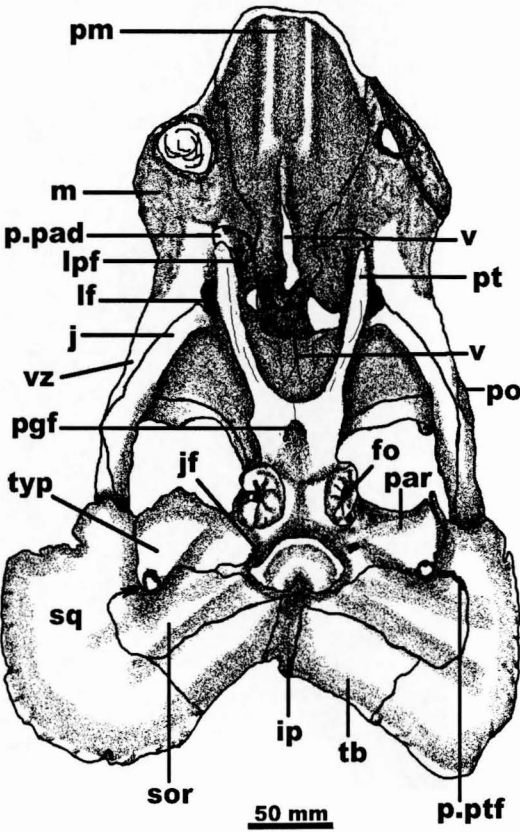


Figure 37. Ventral view of BP/1/4523, abbreviations as on p. ix.

A



B

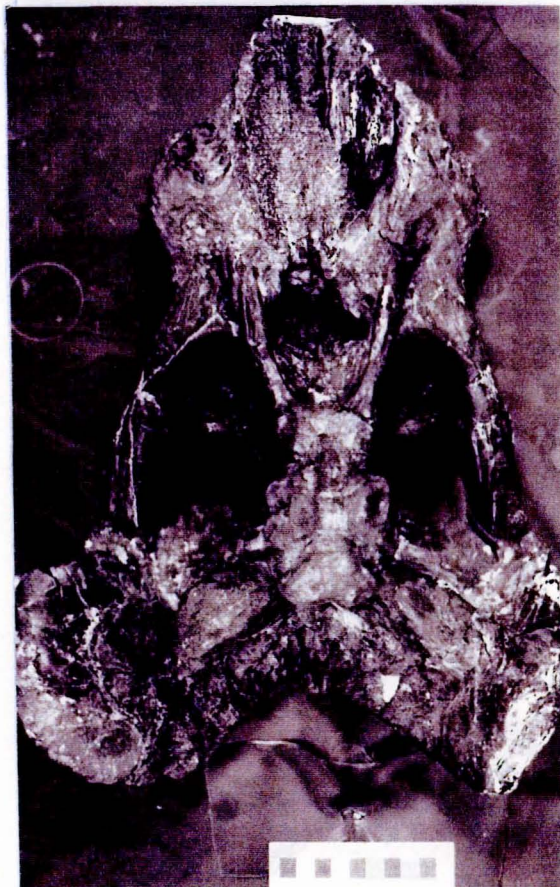


Figure 38. Photographs of the ventral views of BP/1/2092 **A** and BP/1/4523 **B**.

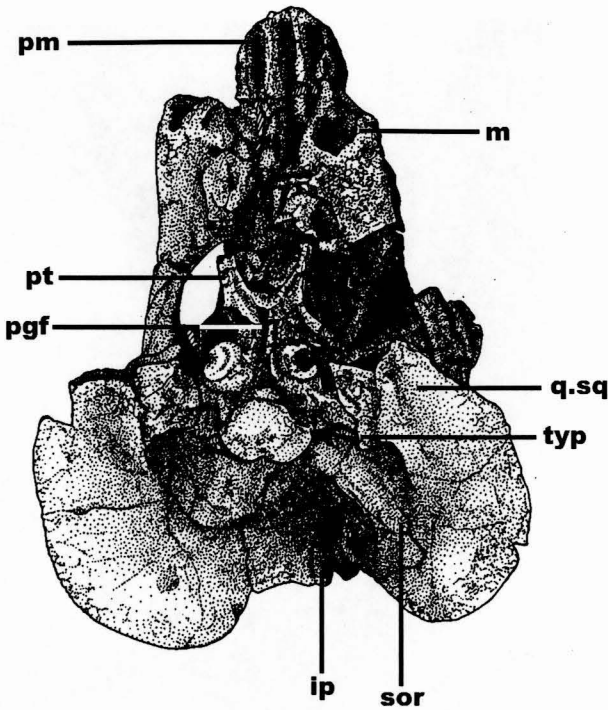


Figure 39. Ventral view of EL/1 (holotype of *K. wilsoni* Broom 1937), abbreviations as on p. ix.

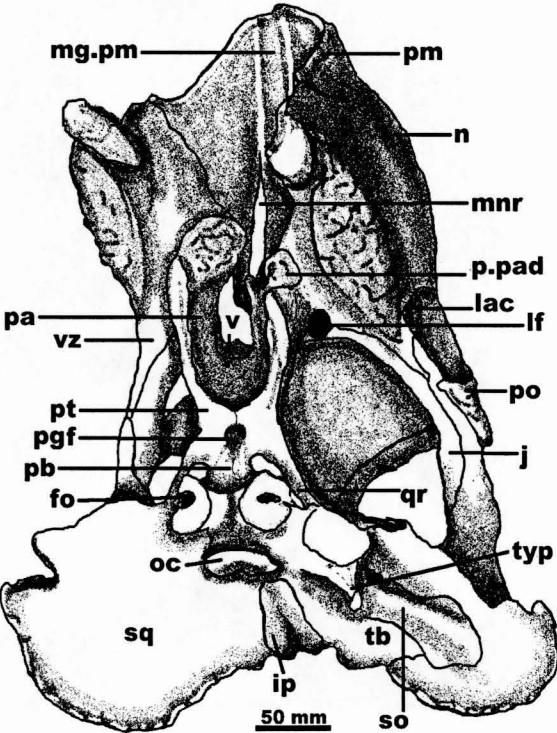
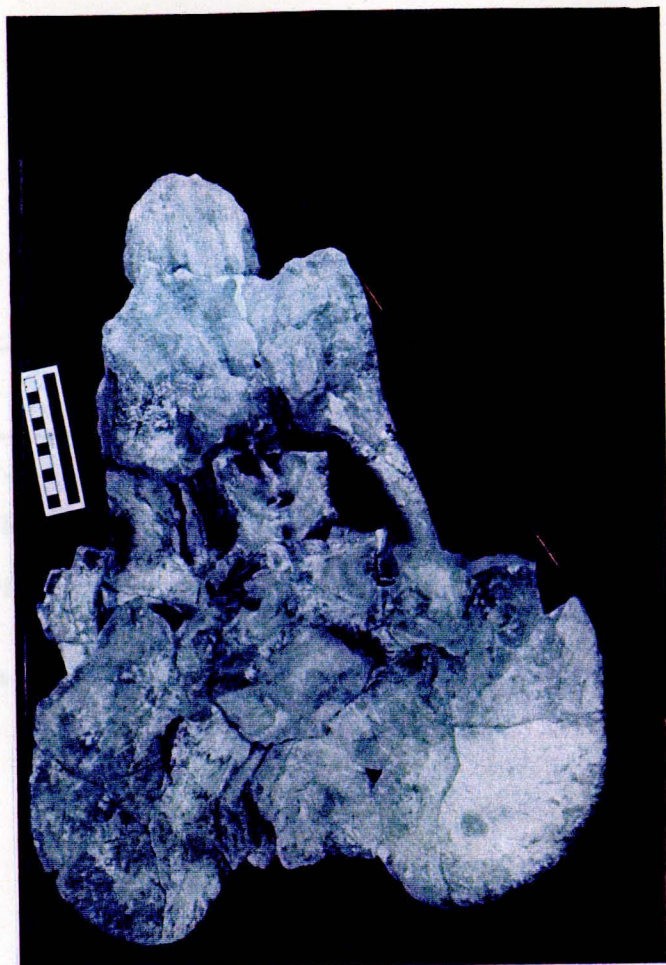


Figure 40. Ventral view of BP/1/4524, abbreviations as on p. ix.

A



B



Figure 41. Photographs of the ventral views of EL/1 A and BP/1/4524 B.

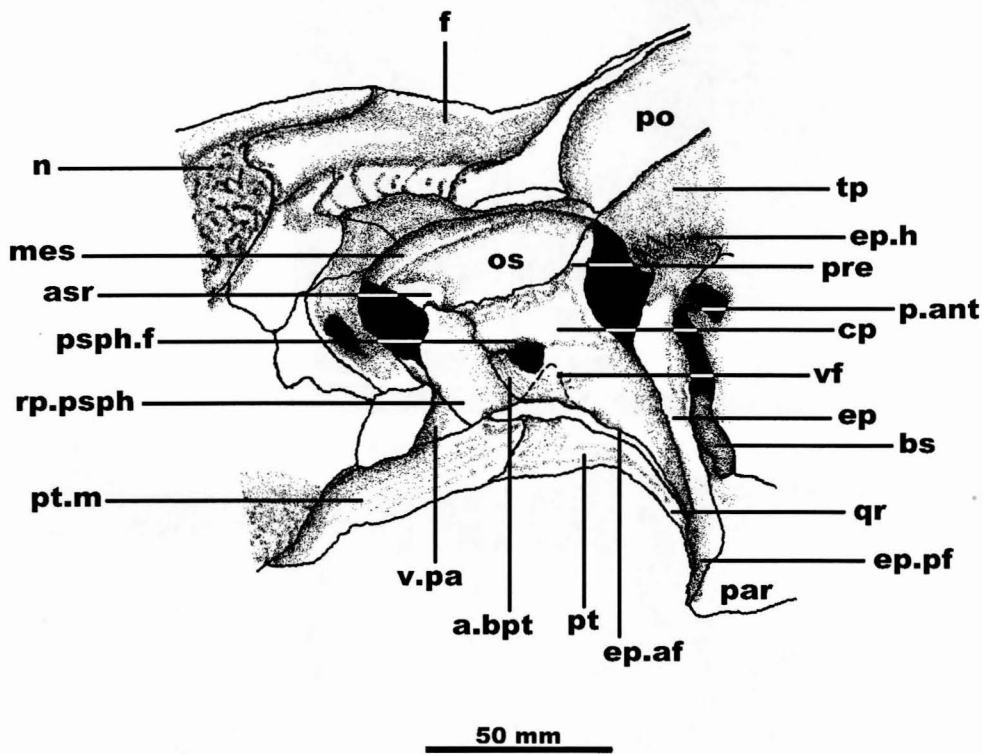


Figure 42. Sphenethmoid region of SAM/PK/3017, abbreviations as on p. ix.

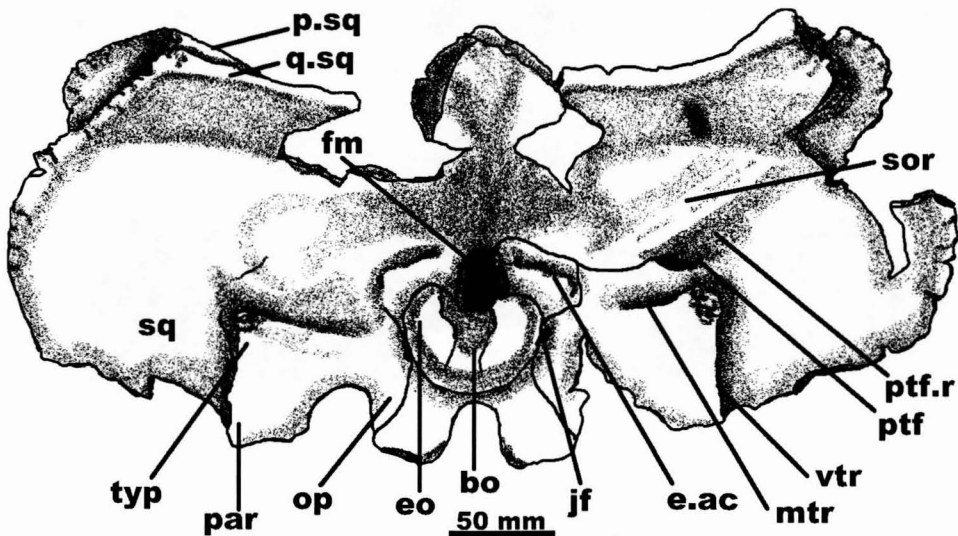


Figure 43. Occipital view of BP/1/5624, abbreviations as on p. ix.

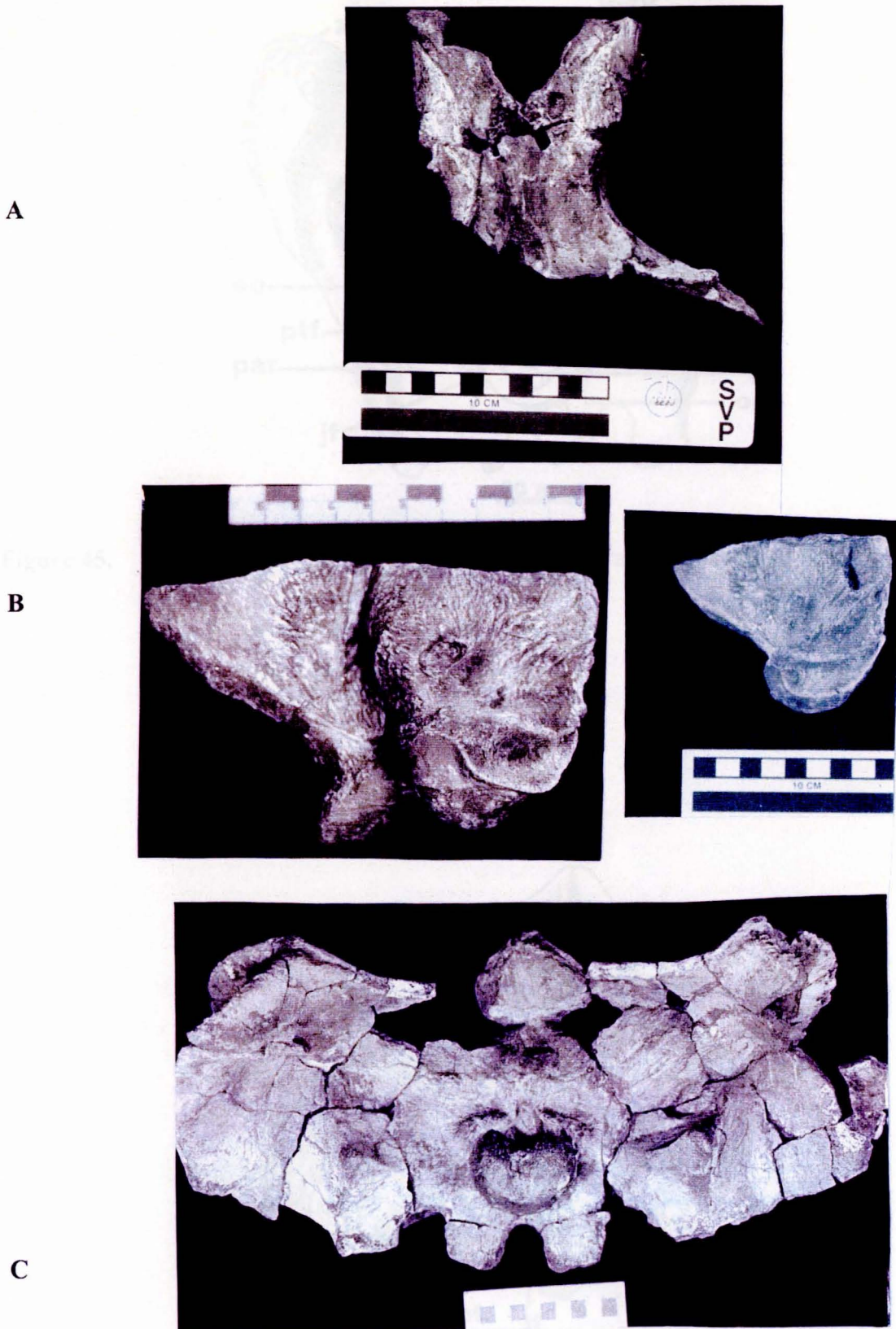


Figure 44. Photographs of the dorsal surface of the basisphenoid **A** of BP/1/5624 showing the dorsal trough and the exit of the internal carotid canals; and the distal end of the quadrate complex of BP/1/5624 showing the stapedial facet and ligament attachment area **B**; and the occiput **C** of BP/1/5624.

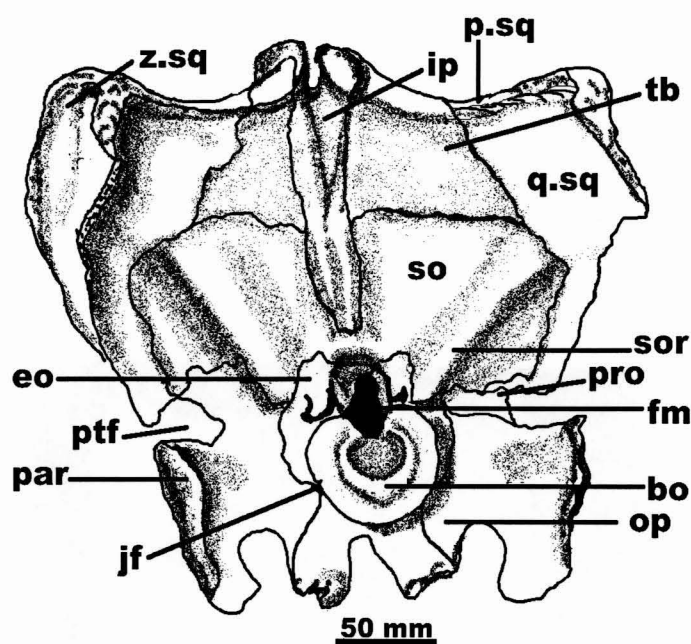


Figure 45. Occipital view of BP/1/1168, abbreviations as on p. ix.

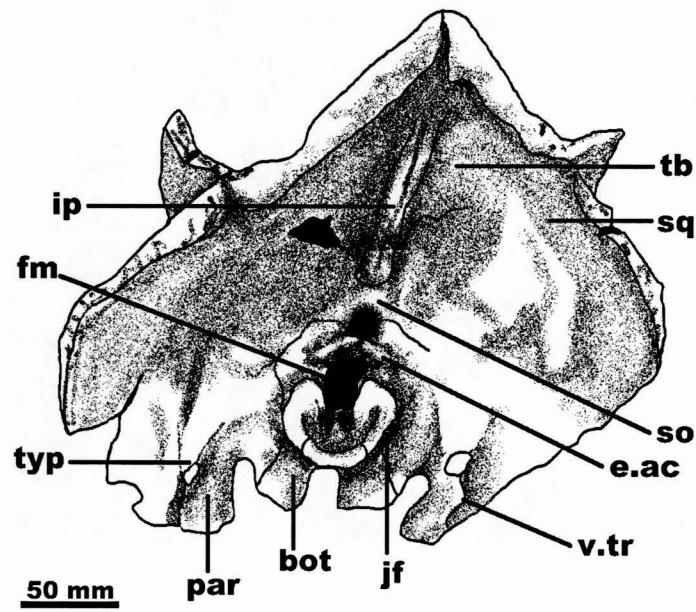
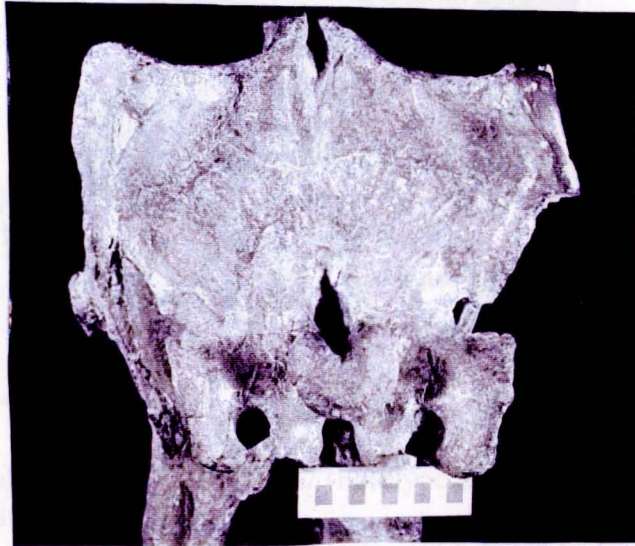


Figure 46. Occipital view of NMQR/1127, abbreviations as on p. ix.

A



B



Figure 47. Photographs of the occipital views of BP/1/1168 A and NMQR/1127 B.

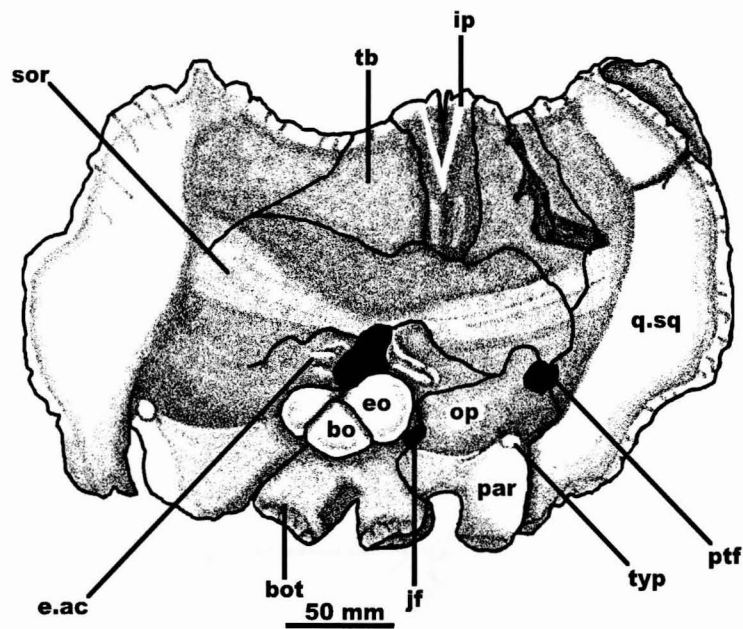


Figure 48. Occipital view of SAM/PK/3017 (holotype of *K. erithrea* Haughton 1915), abbreviations as on p. ix.

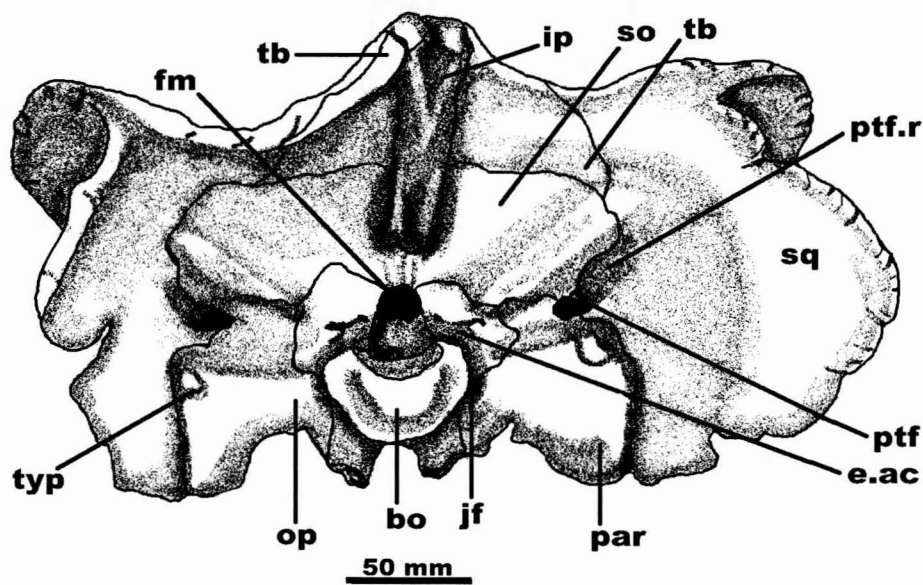


Figure 49. Occipital view of BP/1/4523, abbreviations as on p. ix.

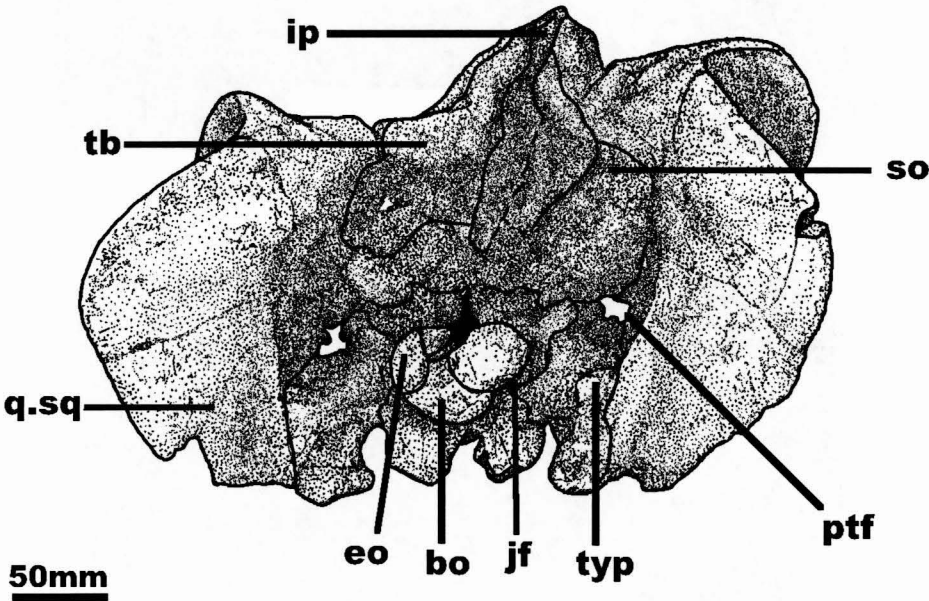
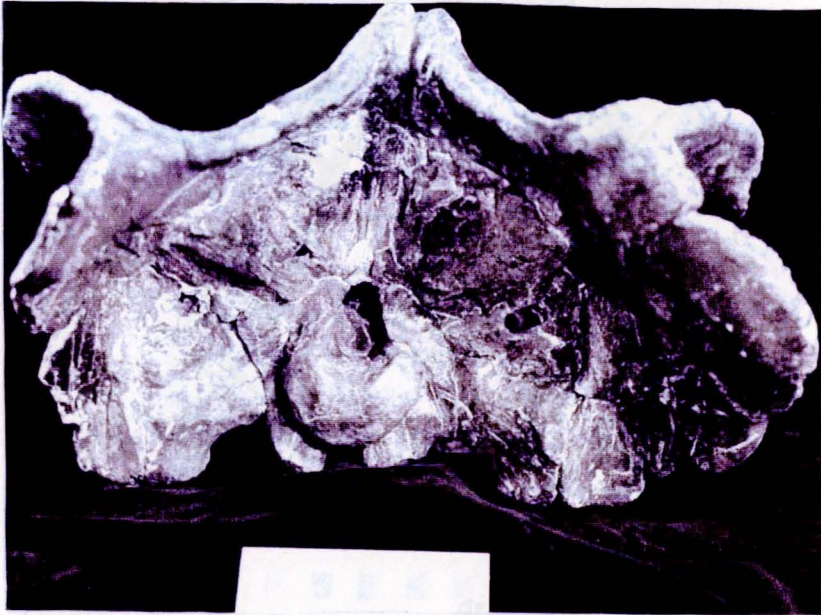


Figure 50. Occipital view of EL/1 (holotype of *K. wilsoni* Broom 1937), abbreviations as on p. ix.

A



B



Figure 51. Photographs of the occipital views of BP/1/4523 A and EL/1 B.

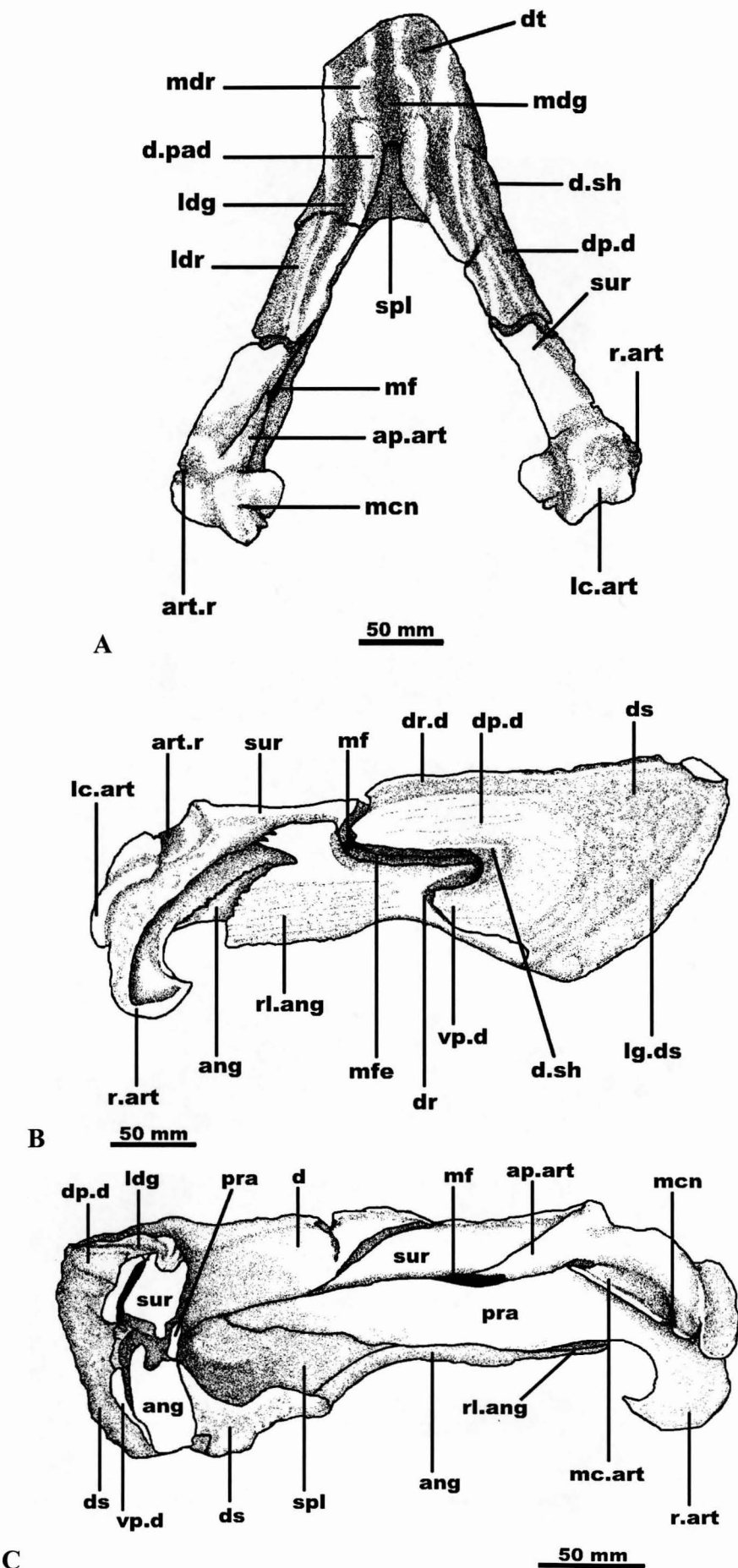


Figure 52. Dorsal **A**, lateral **B** and lingual **C** views of the lower jaw of BP/1/5624, abbreviations as on p. ix

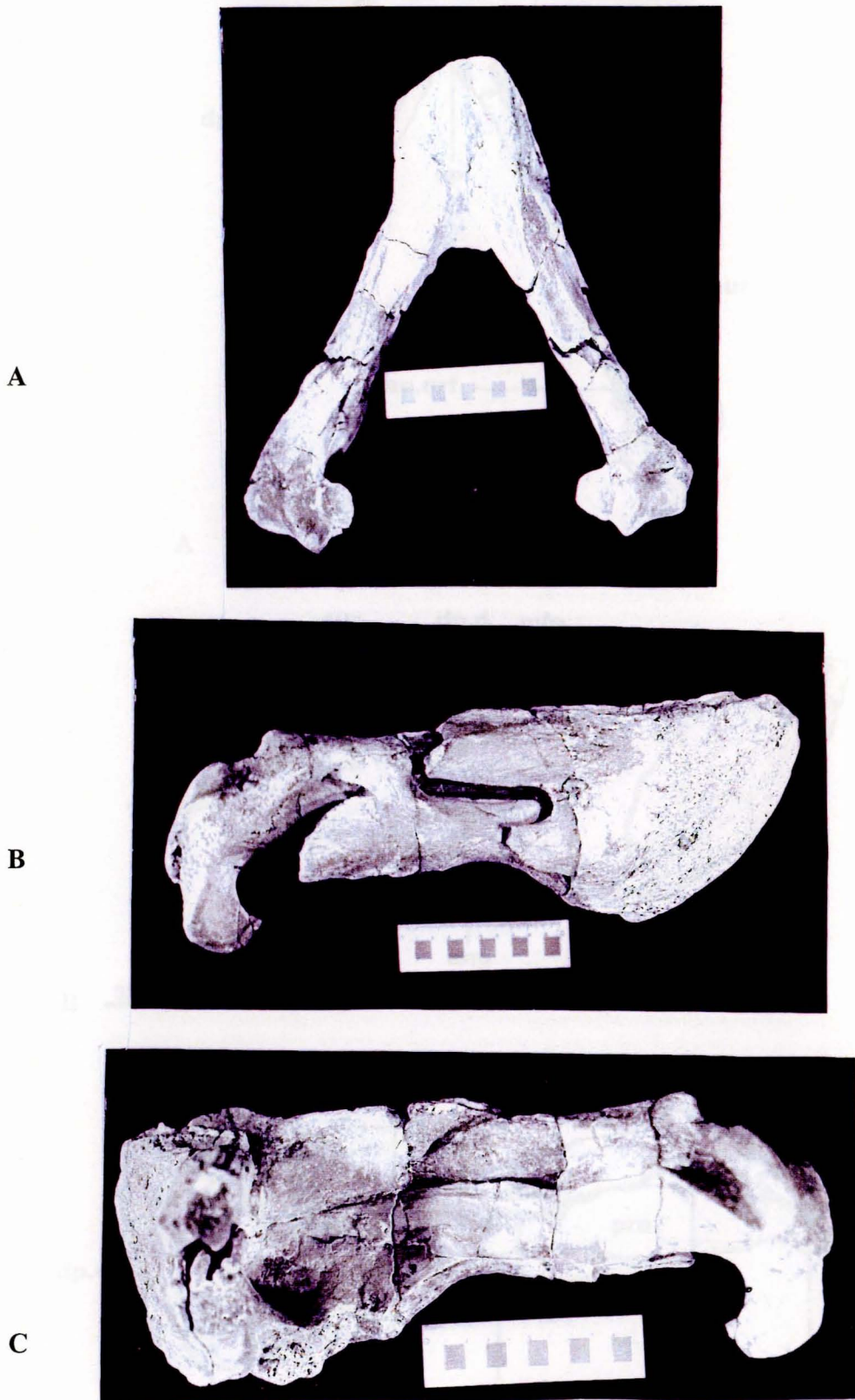


Figure 53. Photographs of the dorsal **A**, lateral **B** and lingual **C** views of the lower jaw of BP/1/5624.

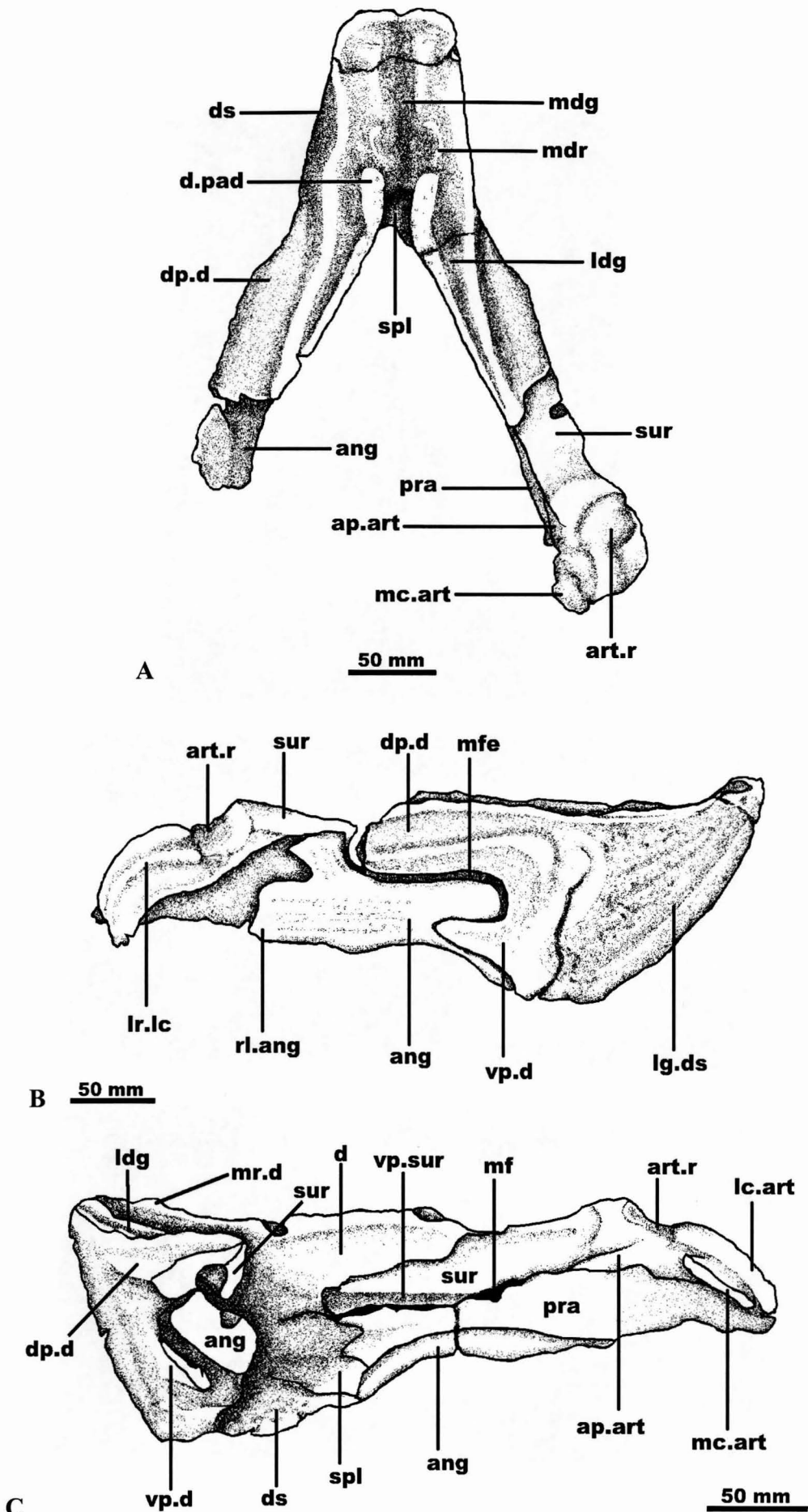


Figure 54. Dorsal A, lateral B and medial C views of the lower jaw of BP/1/4524, abbreviations as on p. ix.

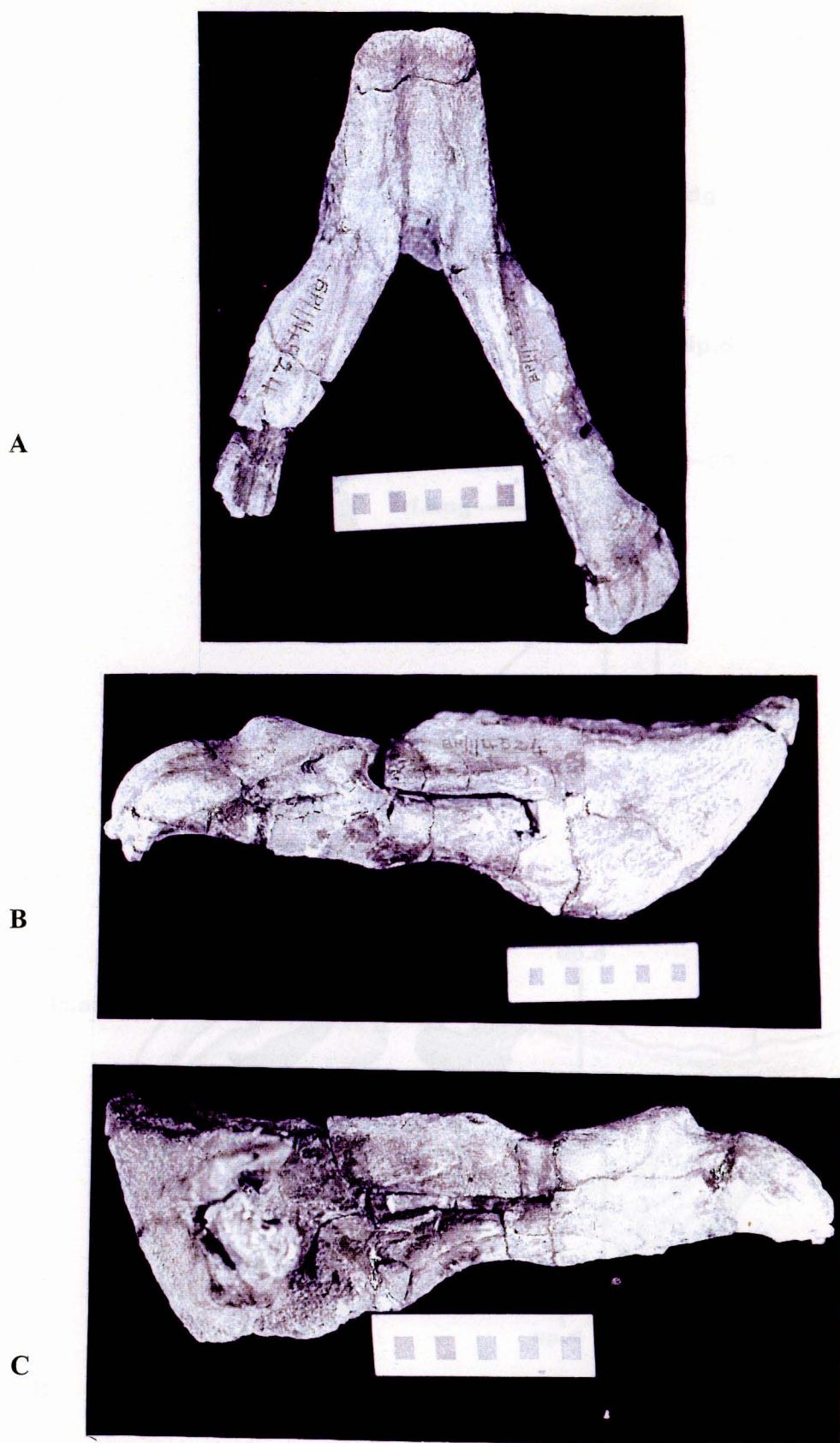


Figure 55. Photographs of the dorsal **A**, lateral **B** and medial **C** views of the lower jaw of BP/1/4524.

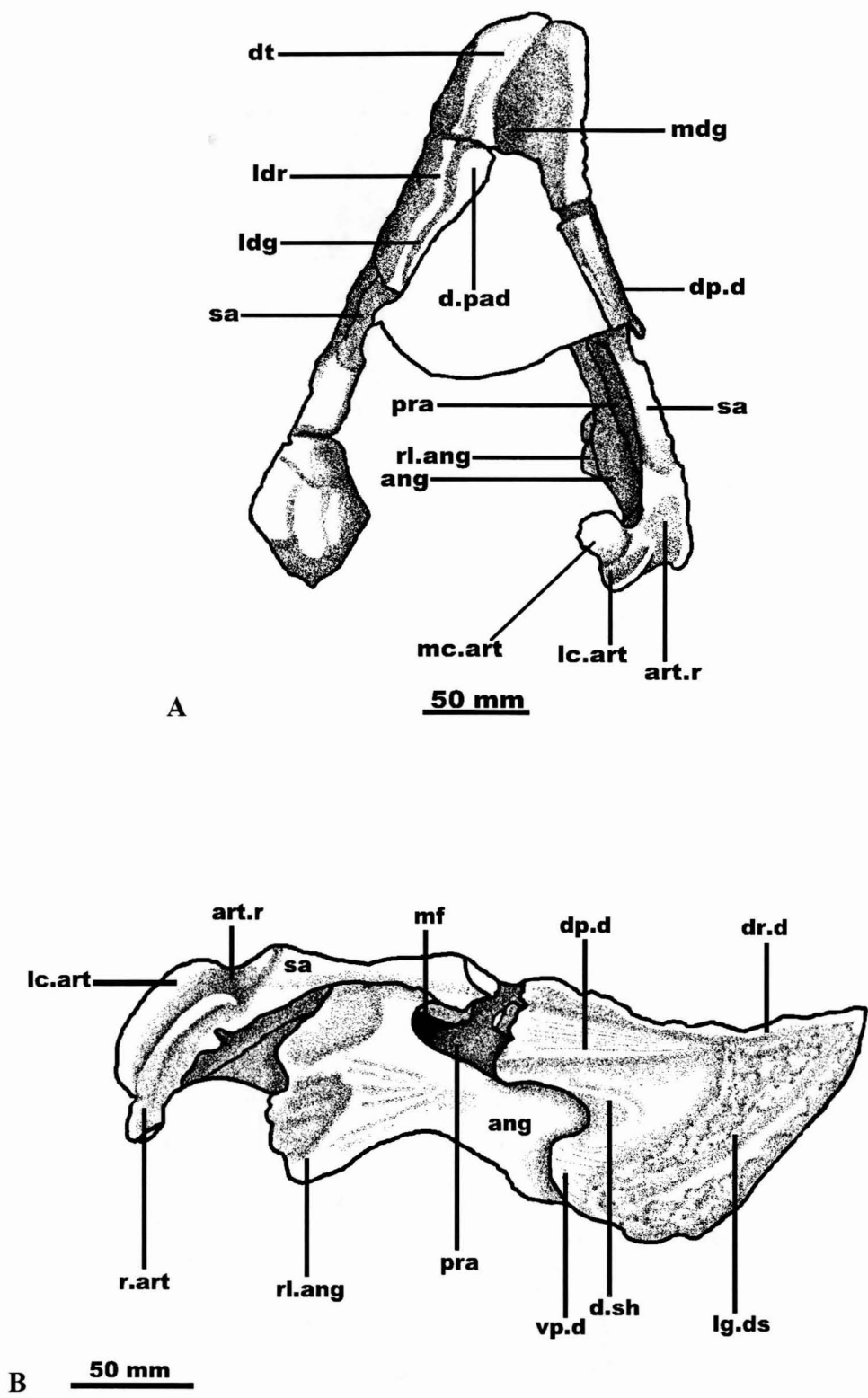


Figure 56. Dorsal **A** and lateral **B** views of the lower jaw of SAM/PK/3017 (holotype of *K. erithrea* Haughton 1915), abbreviations as p. ix.

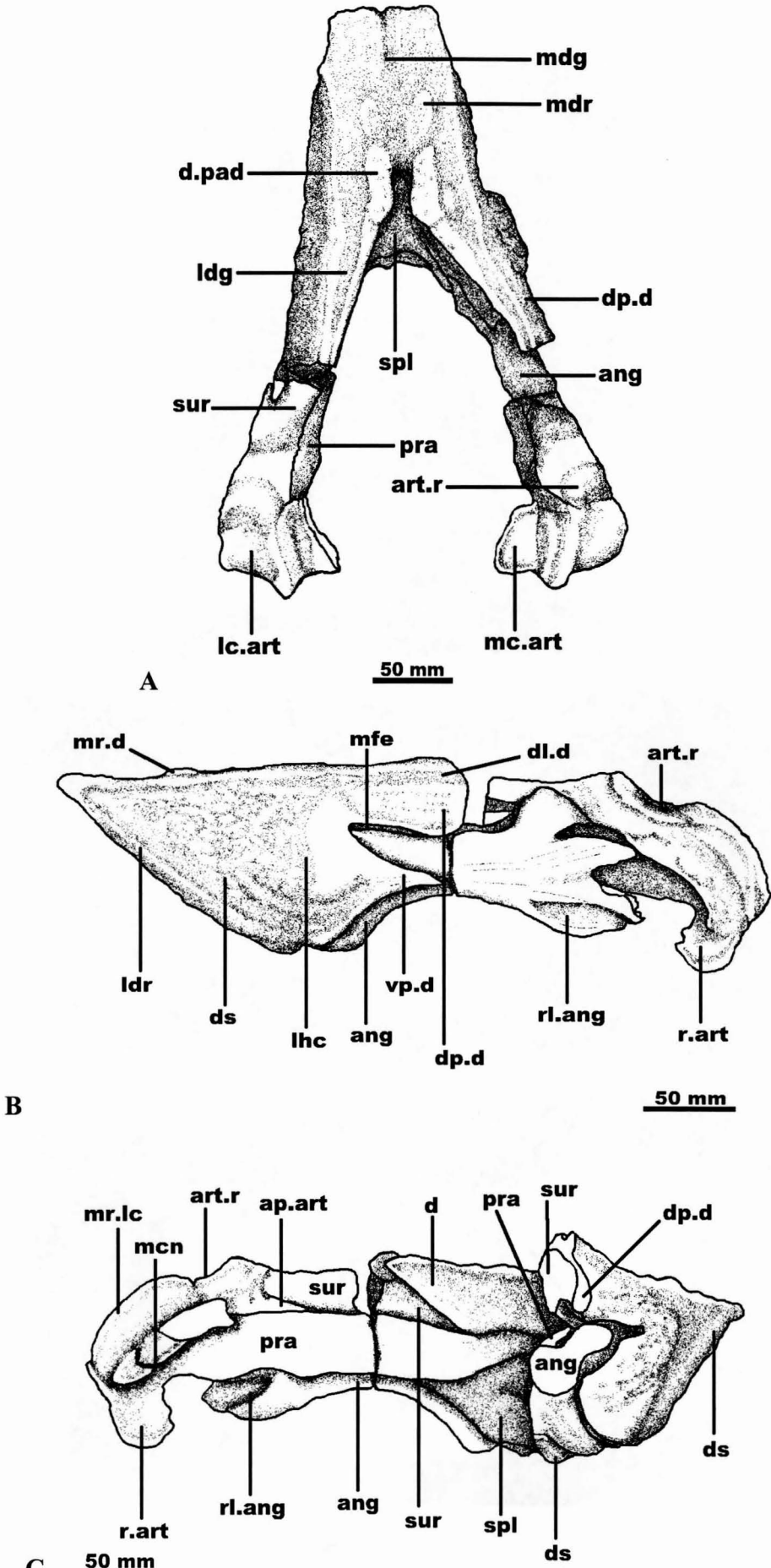
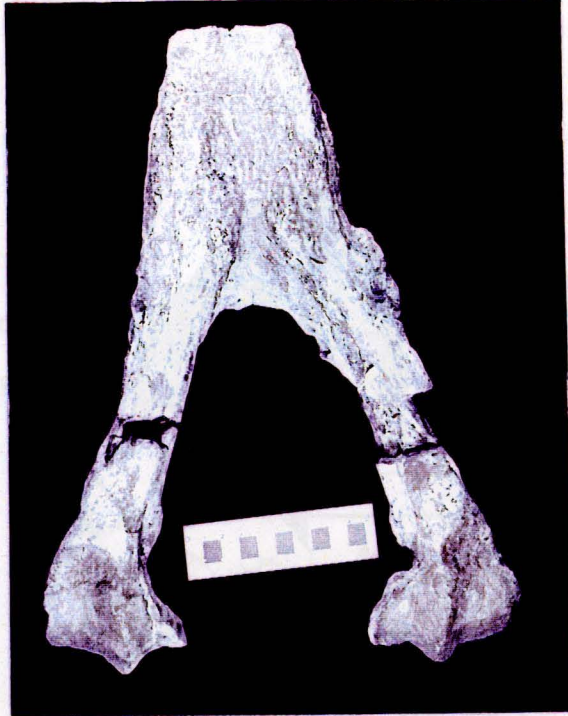


Figure 57. Dorsal **A**, lateral **B** and medial **C** views of the lower jaw of EL/1 (holotype of *K. wilsoni* Keyser & Cruickshank), abbreviations as on p. ix.

A



B



C



Figure 58. Photographs of the dorsal **A**, lateral **B** and medial **C** views of the lower jaw of EL/1.

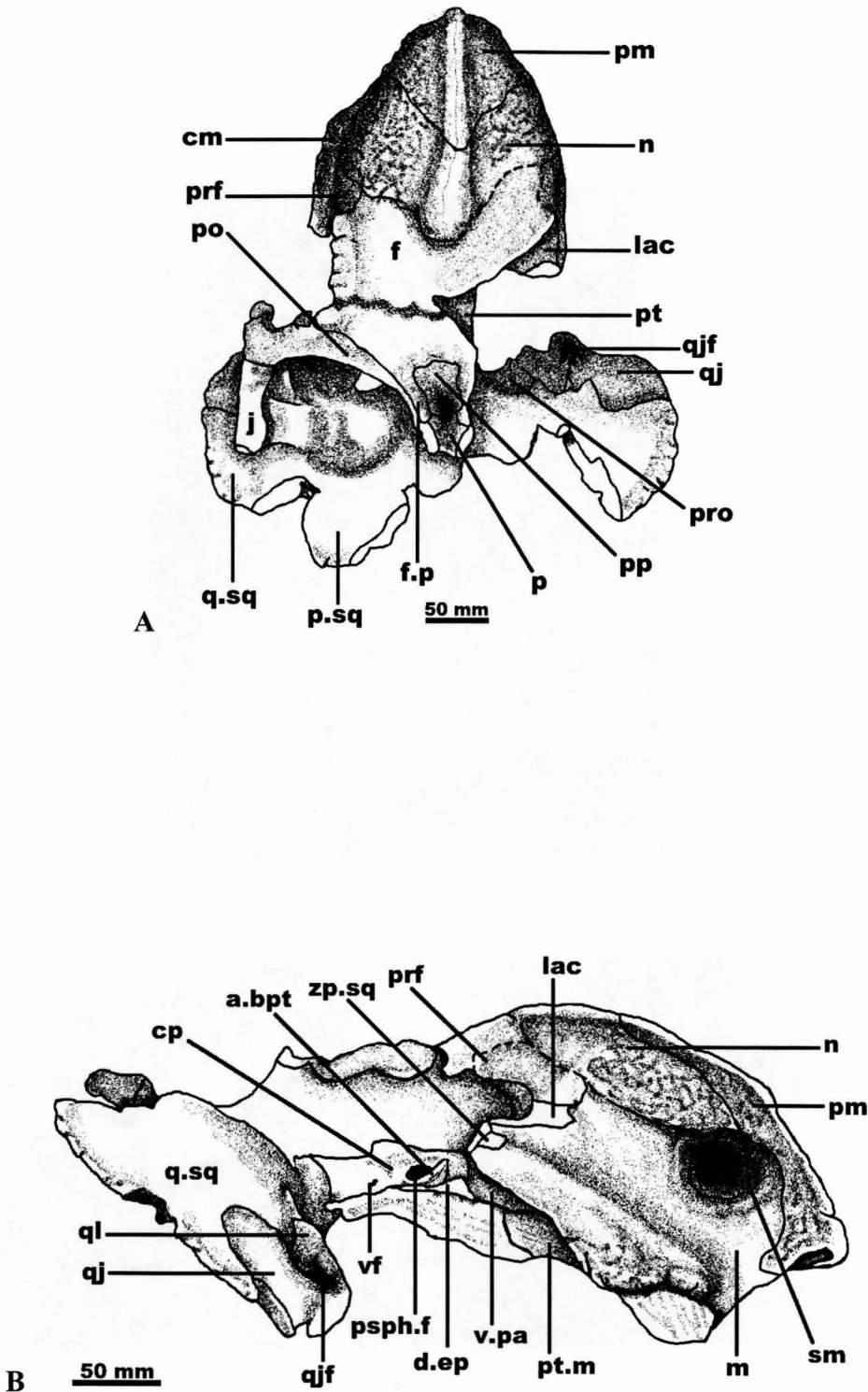
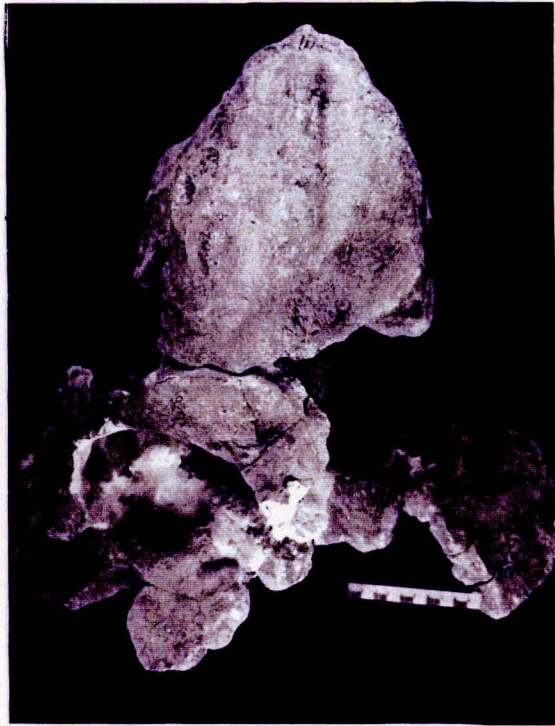


Figure 59. Dorsal A and right lateral B view of BP/1/3638 (holotype *K. cristarhynchus* Keyser & Cruickshank 1979), abbreviations as on p. ix.

A



B



Figure 60. Photographs of the dorsal **A** and right lateral **B** views of BP/1/3638.

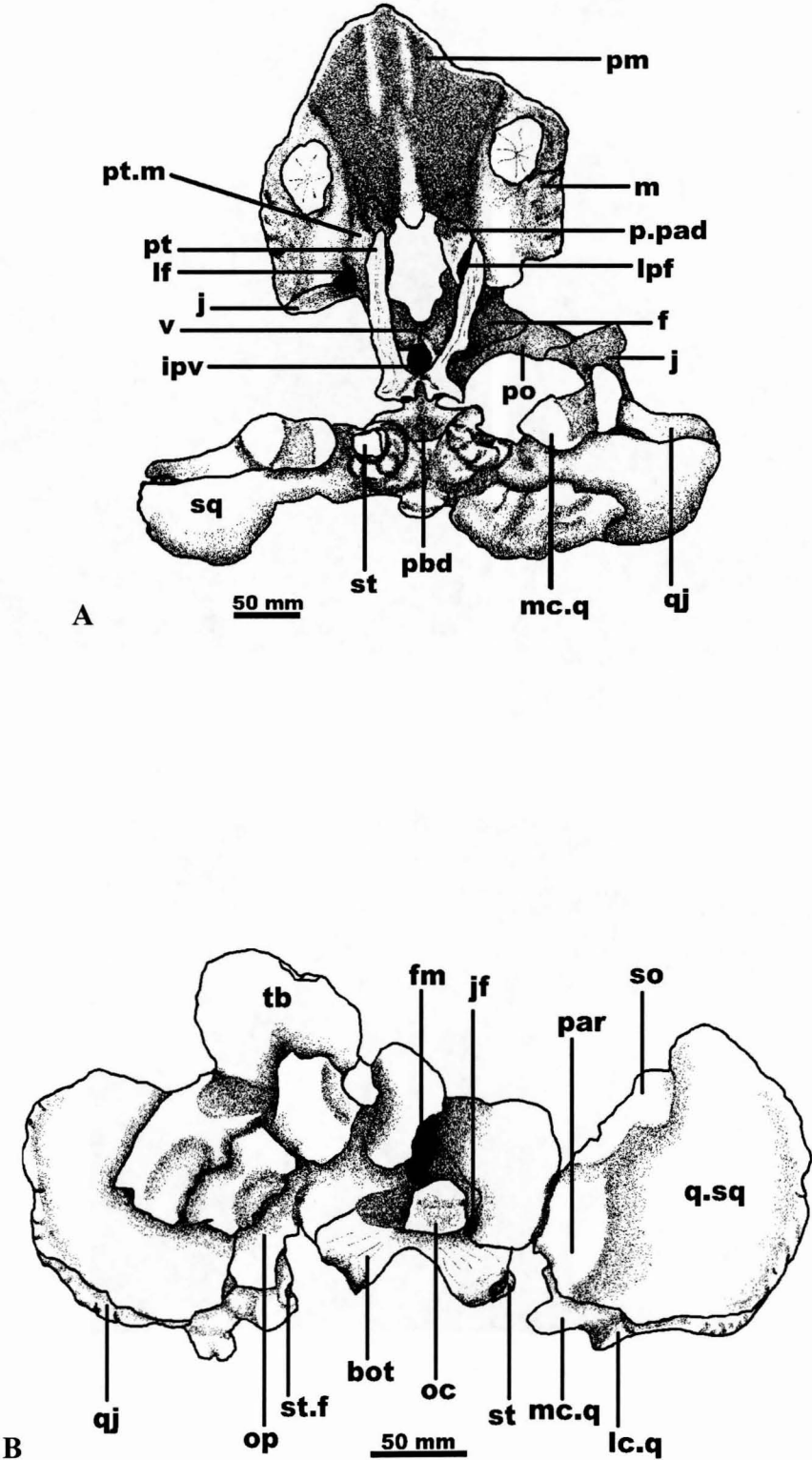


Figure 61. Ventral A and occipital B views of BP/1/3638 (holotype of *K. cristarhynchus* Keyser & Cruickshank 1979), abbreviations as on p. ix.

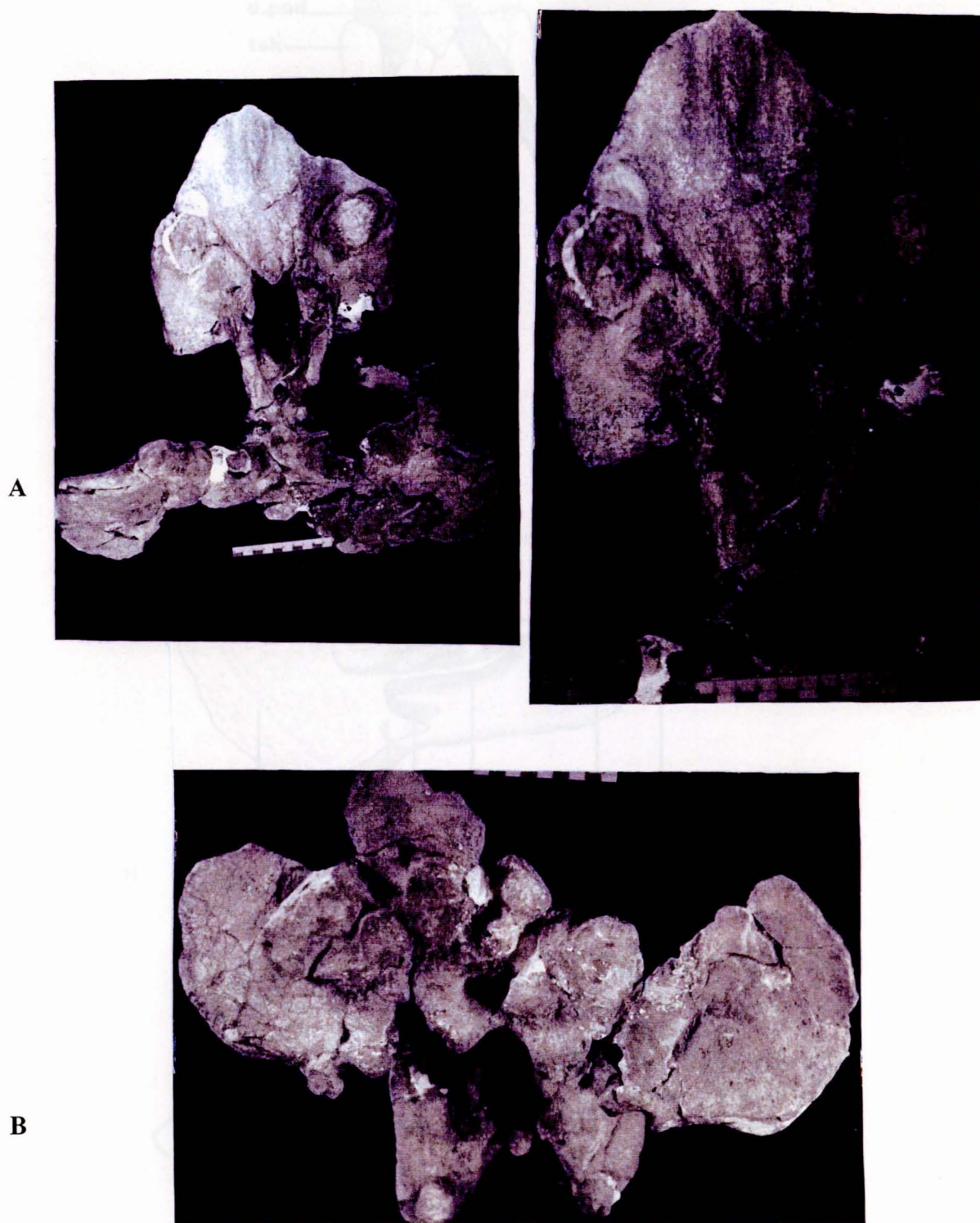


Figure 62. Photographs of the ventral **A** and occipital **B** views of BP/1/3638.

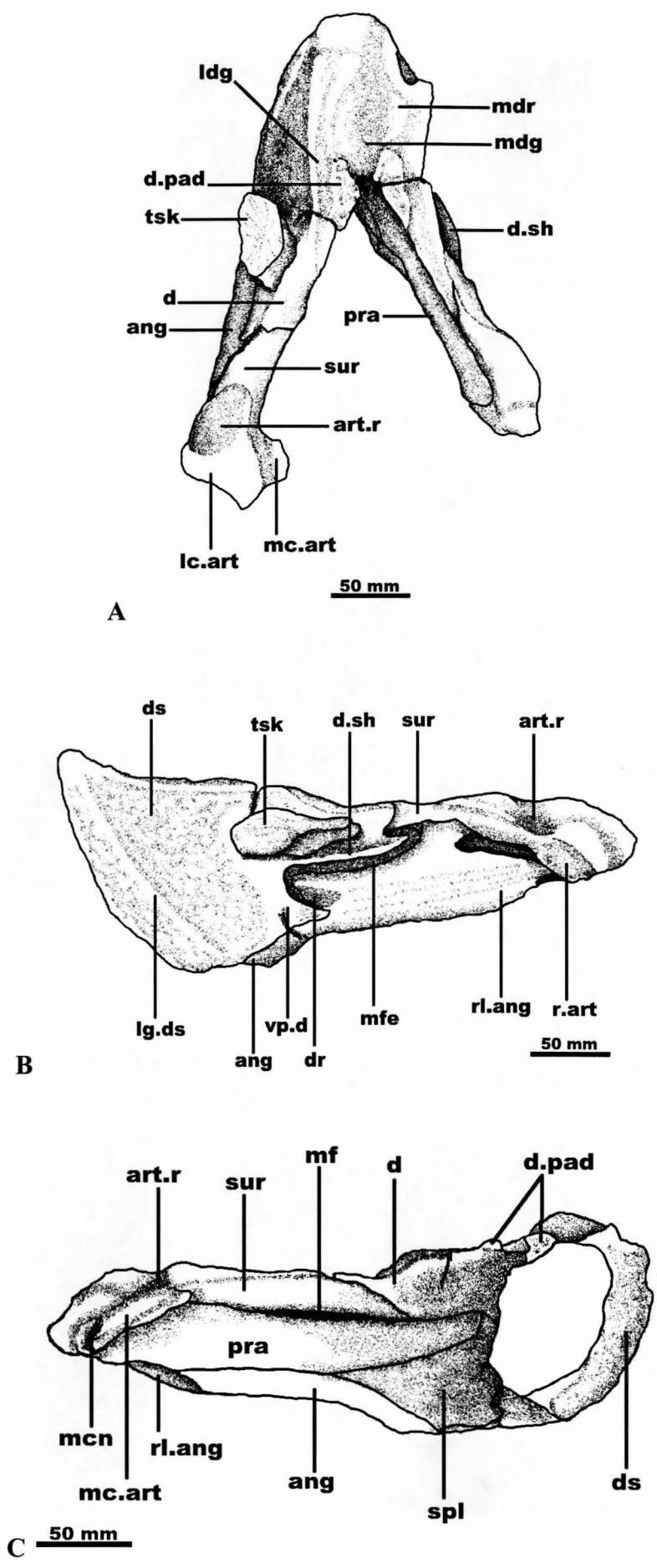


Figure 63. Dorsal A, lateral B and medial C views of the lower jaw of BP/1/3638 (holotype of *K. cristarhynchus* Keyser & Cruickshank 1979), abbreviations as on p. ix.

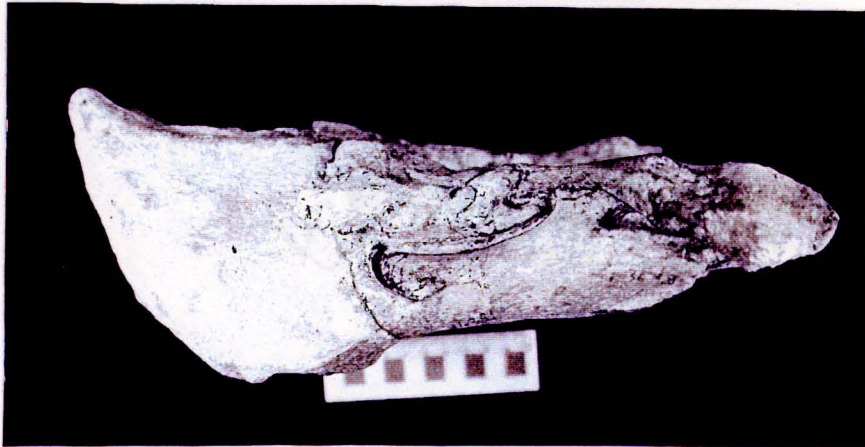
A**B****C**

Figure 64. Photographs of the dorsal **A**, lateral **B** and medial **C** views of the lower jaw of BP/1/3638.

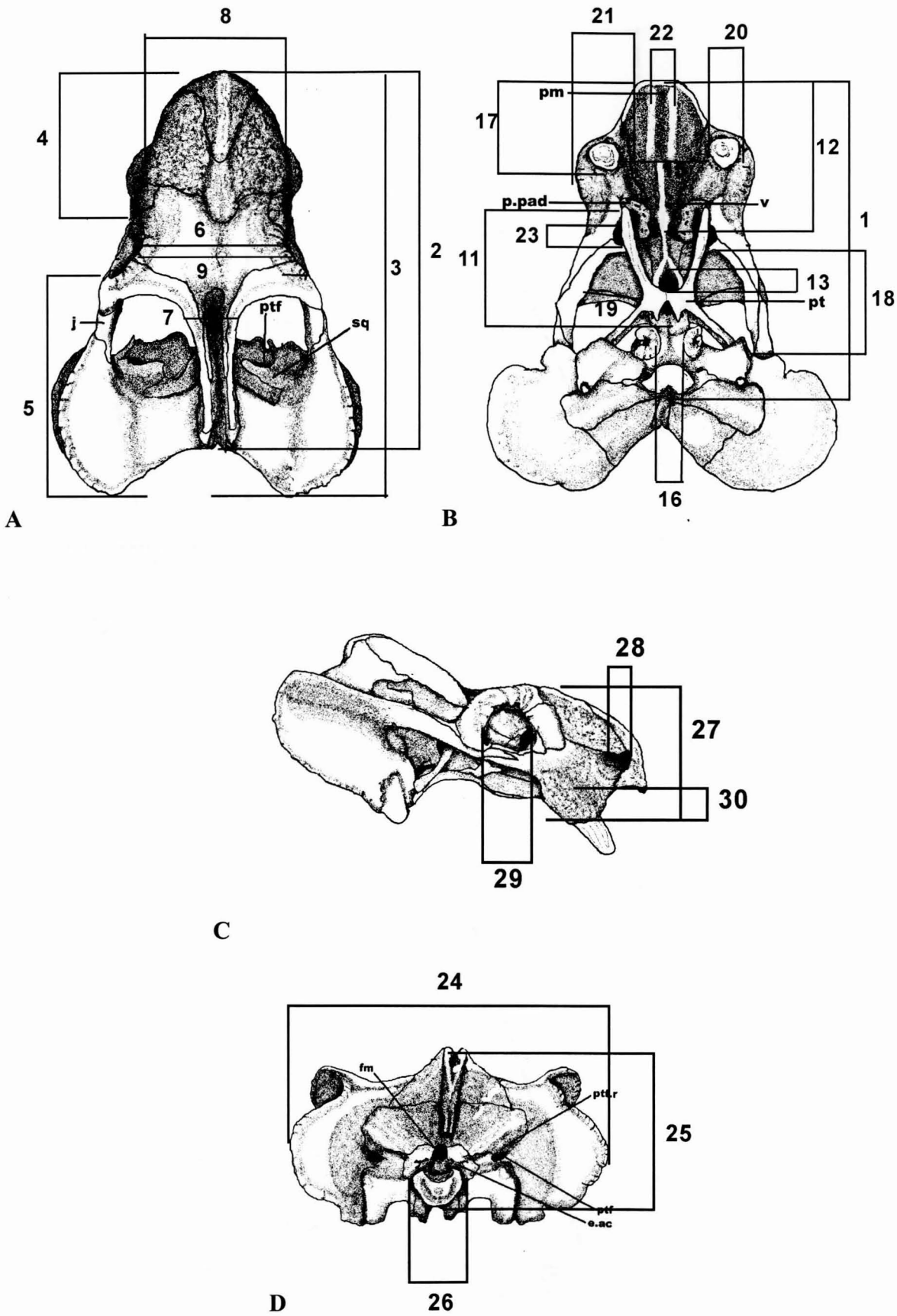


Figure 65. *Kannemeyeria* skull measurements. A - dorsal view, B - ventral view, C - lateral view, D - occipital view. Views not drawn to the same scale, and not all variables are shown.

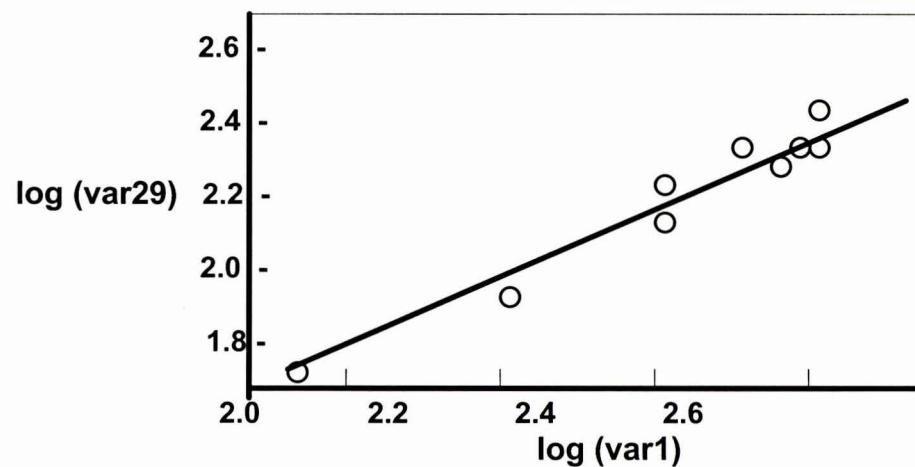
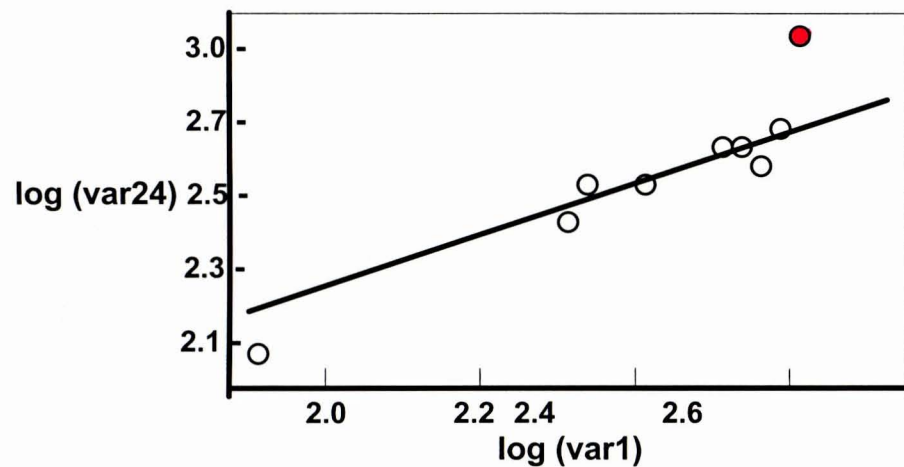
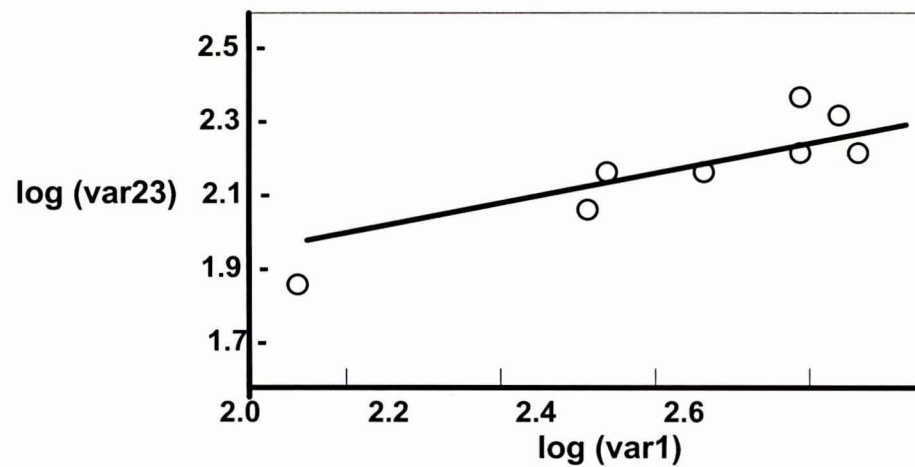
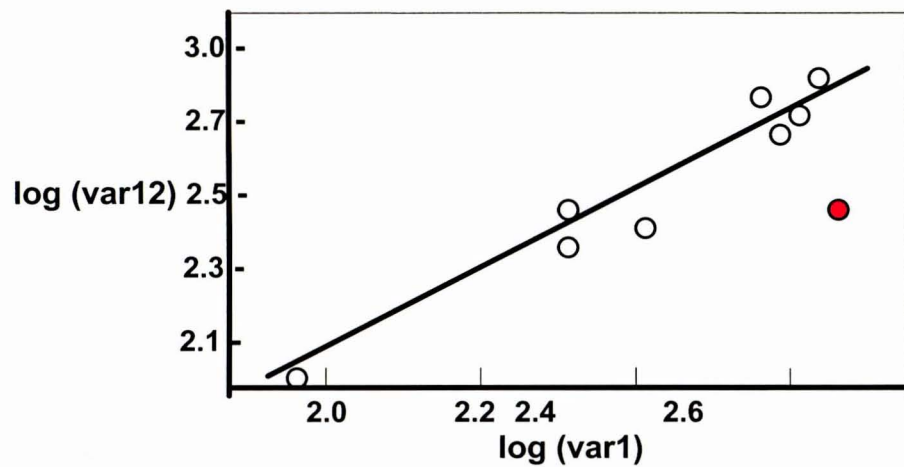
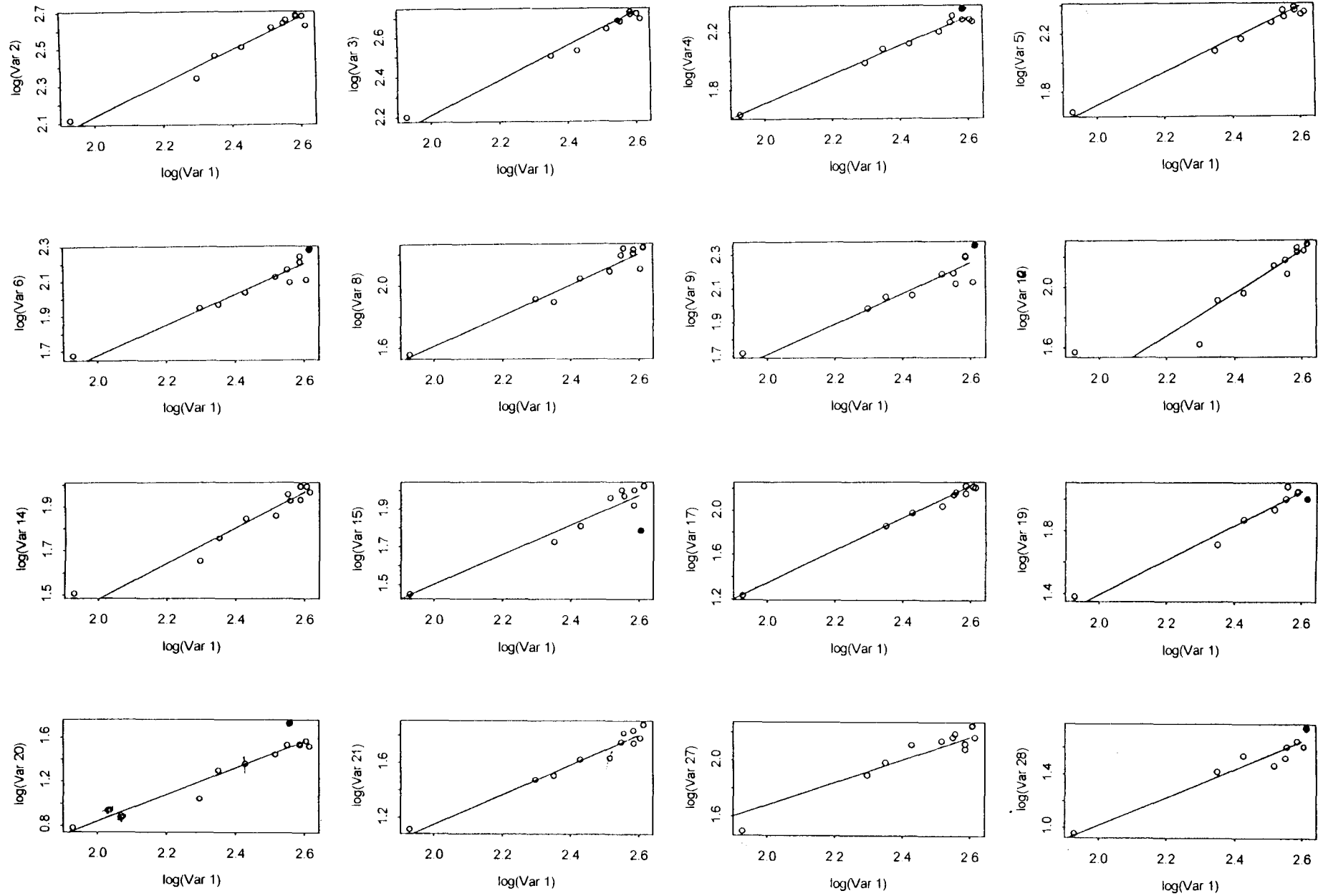


Figure 66. Selected bivariate plots of taxonomic significance, or demonstrating the effects of specific ontological growth patterns.

Figure 67.

Further selected bivariate plots showing allometric-growth trends of the genus *Kannemeyeria*.



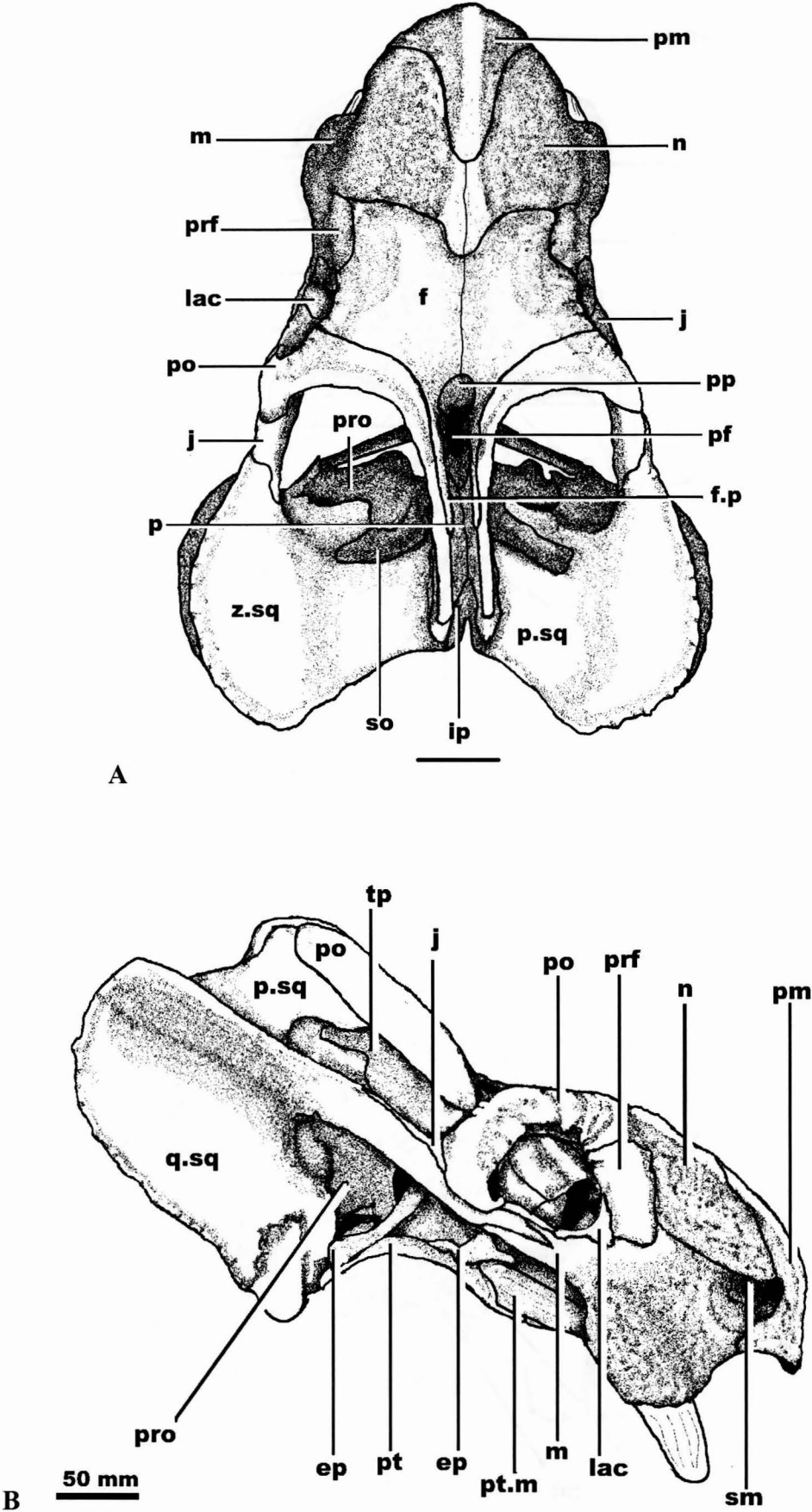


Figure 68. Cranial reconstructions of the skull of *Kannemeyeria simocephalus*. **A**-dorsal view, **B** - lateral view in revised orientation considered valid for this taxon (refer to Chapter 8). Abbreviations as on p. ix.

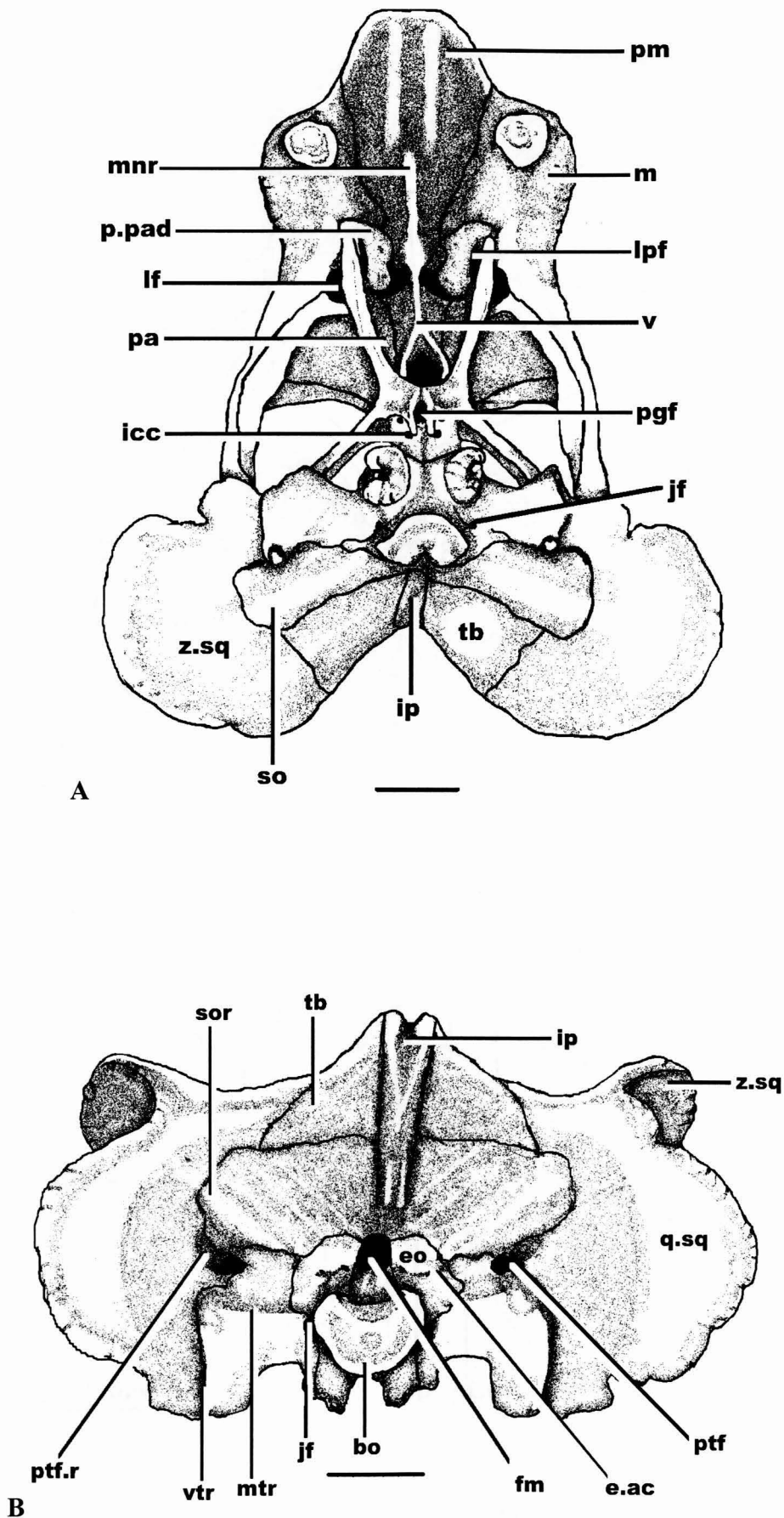


Figure 69. Cranial reconstructions of the skull of *Kannemeyeria simocephalus*. **A** - ventral view, **B** - occipital view, scale - 50mm. Abbreviations as on p. ix.

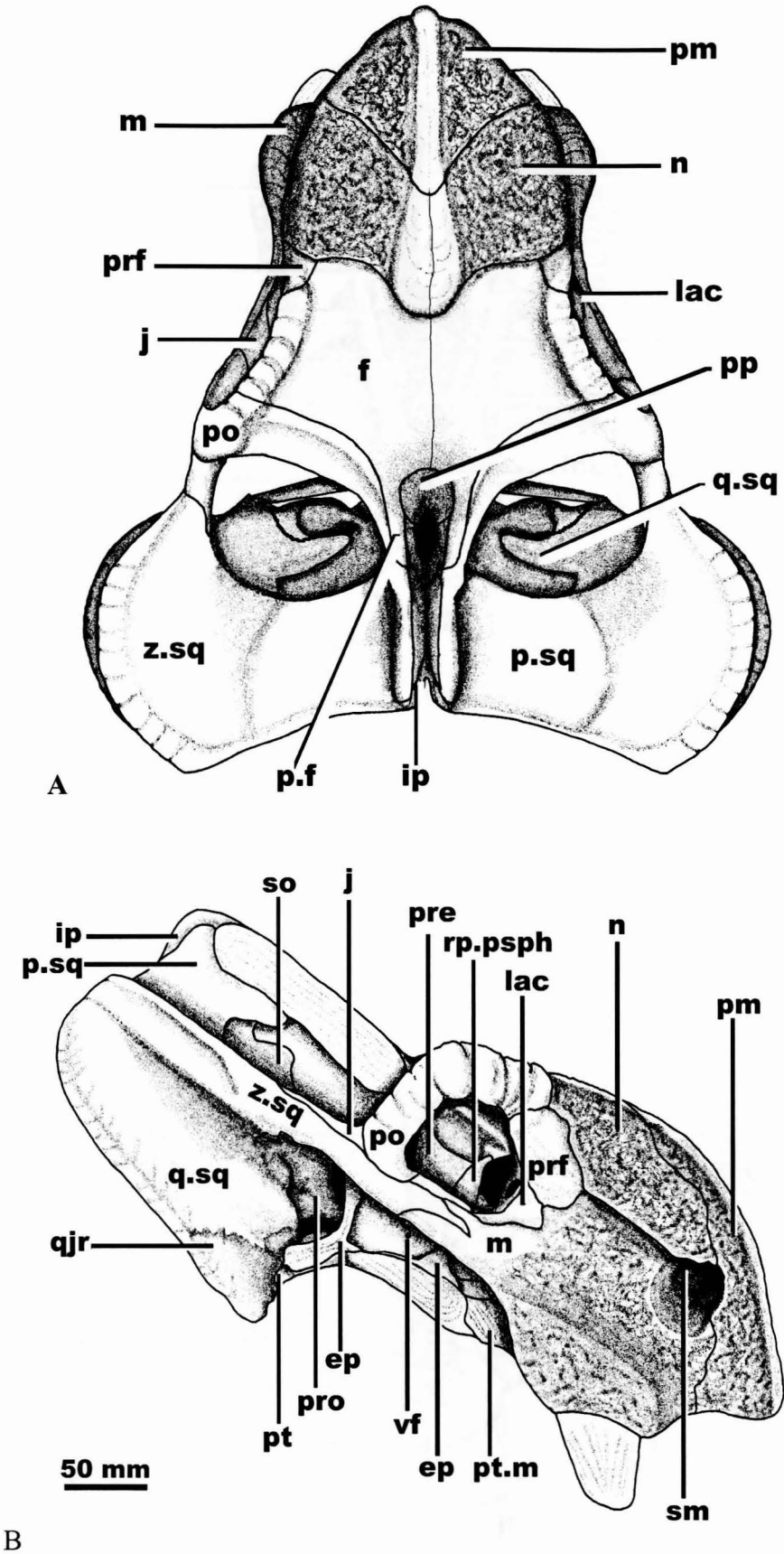


Figure 70. Cranial reconstruction of the dorsal - **A** and lateral - **B** views of the skull of *Kannemeyeria cristarhynchus*. Lateral view in revised orientation considered valid for this taxon (refer to Chapter 8). Abbreviations as on p. ix.

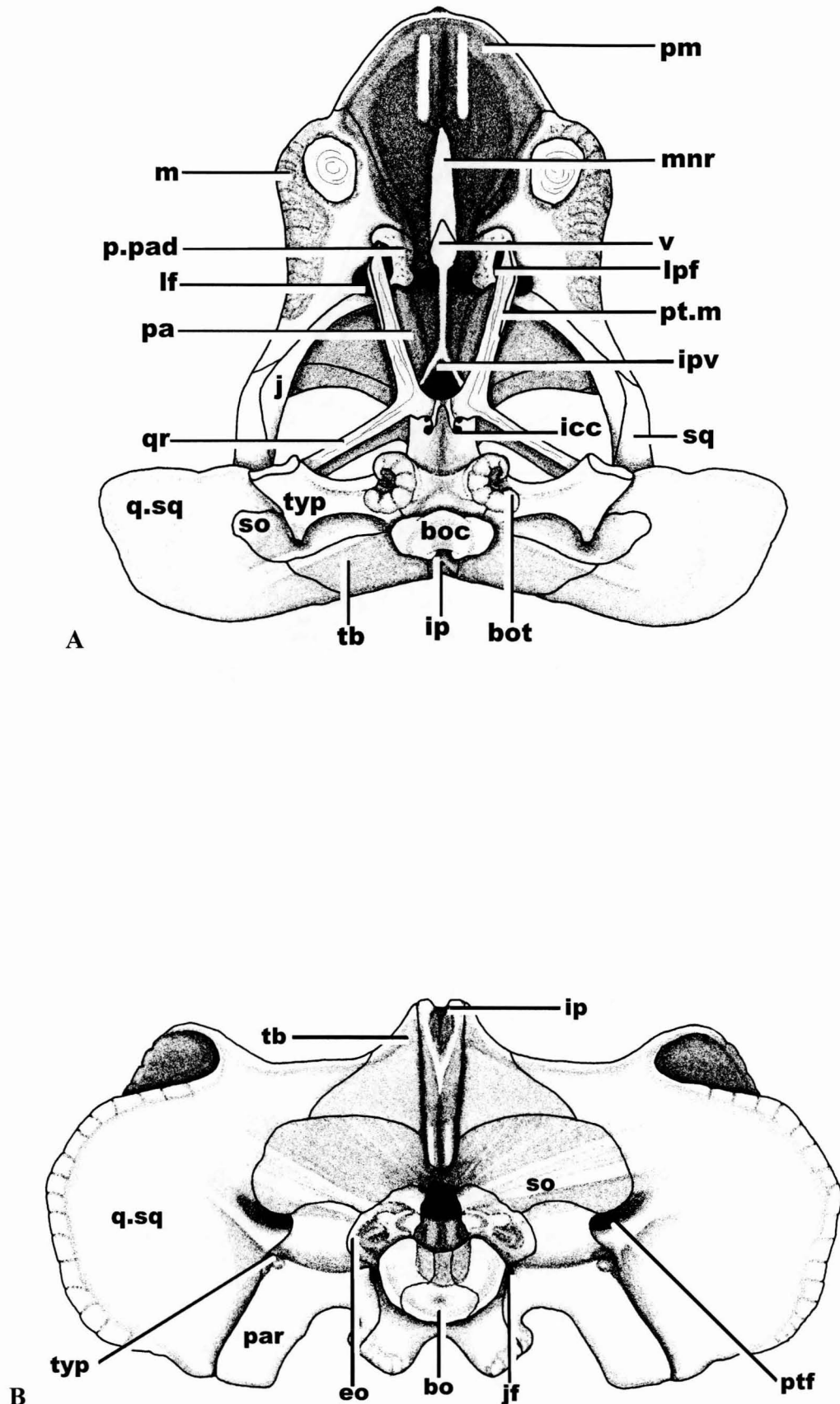


Figure 71. Cranial reconstructions of the skull of *Kannemeyeria cristarhynchus* **A** - ventral view, **B** - occipital view. Abbreviations as on p. ix.

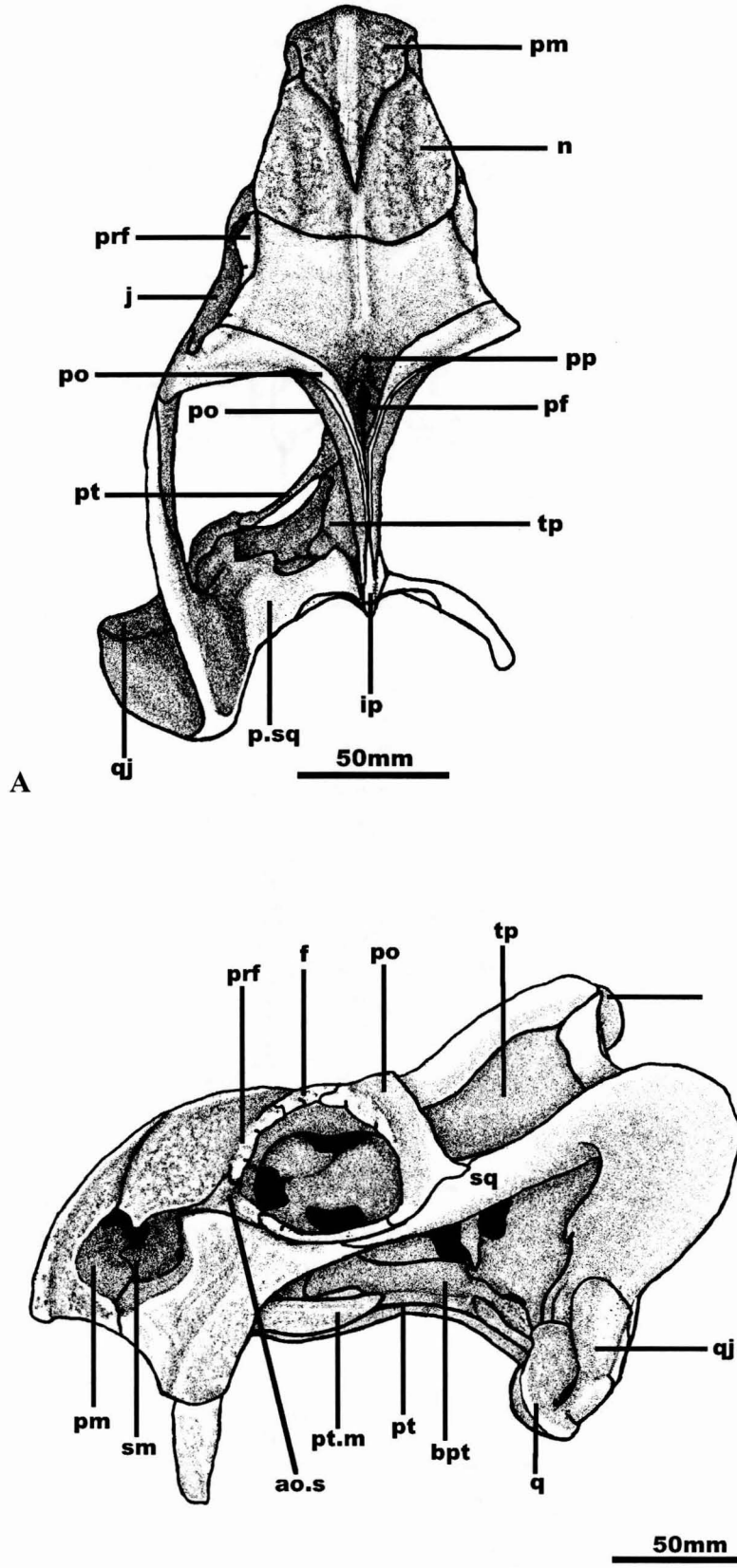


Figure 72. Dorsal **A** and lateral **B** views of PVL/3465 (holotype of *K. argentinensis* Bonaparte 1966), abbreviations as on p. ix.

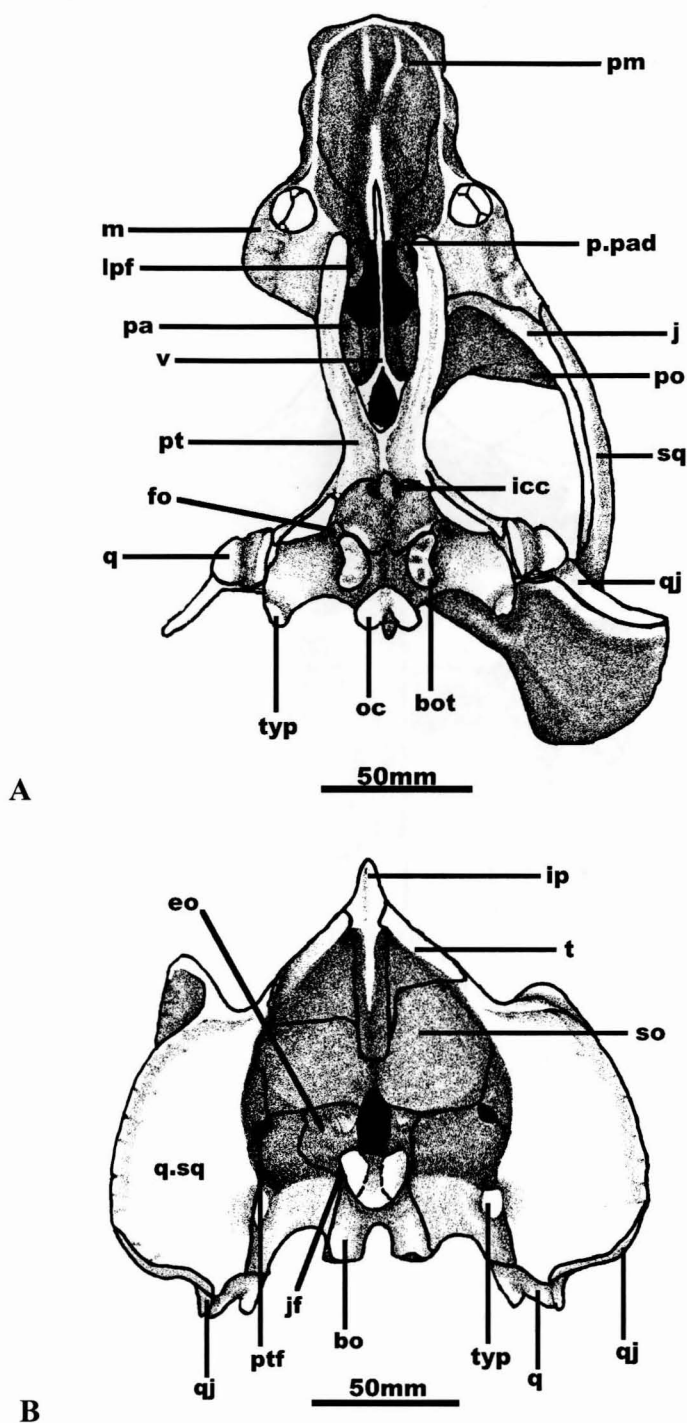


Figure 73. Ventral **A** and occipital **B** views of PVL/3465 (holotype of *K. argentinensis* Boneparte 1966), abbreviations as on p. ix.

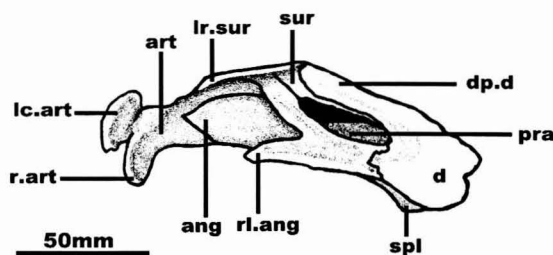


Figure 74. Lateral views of the lower jaw of PVL/3465 (holotype of *K. argentinensis* Boneparte 1966), abbreviations as on p. ix.

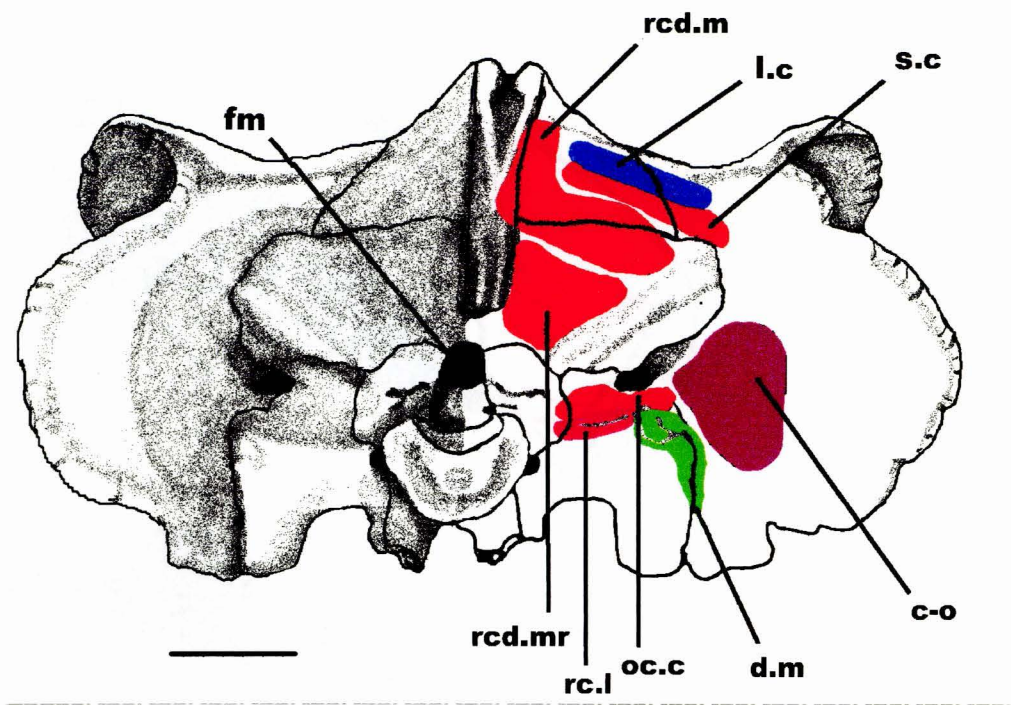


Figure 75. Occiput of *Kannemeyeria* demonstrating major muscle insertion sites, illustrated as functional units.

rcd.m - rectus capitis dorsalis major, rcd.mr - rectus capitis dorsalis minor, s.c - semispinalis capitis, l.c - longissimus capitis, oc.c - obliquus capitis cranialis, rc.l - rectus capitis lateralis, d.m - depressor mandibulae, c-o - cleido-occipitalis.

Scale - 50mm.

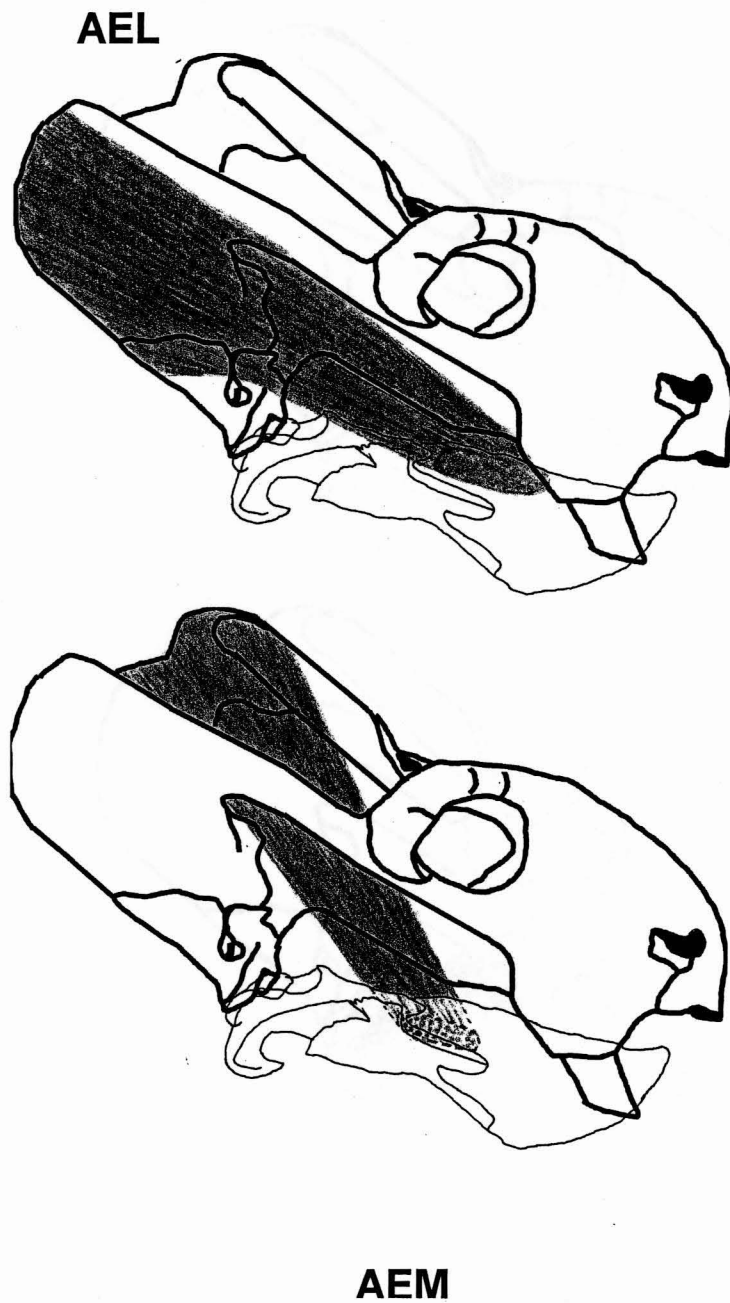


Figure 76. Diagrammatic representation of the *Kannemeyeria* external adductor musculature. AEL - lateral external adductor, AEM - medial external adductor.

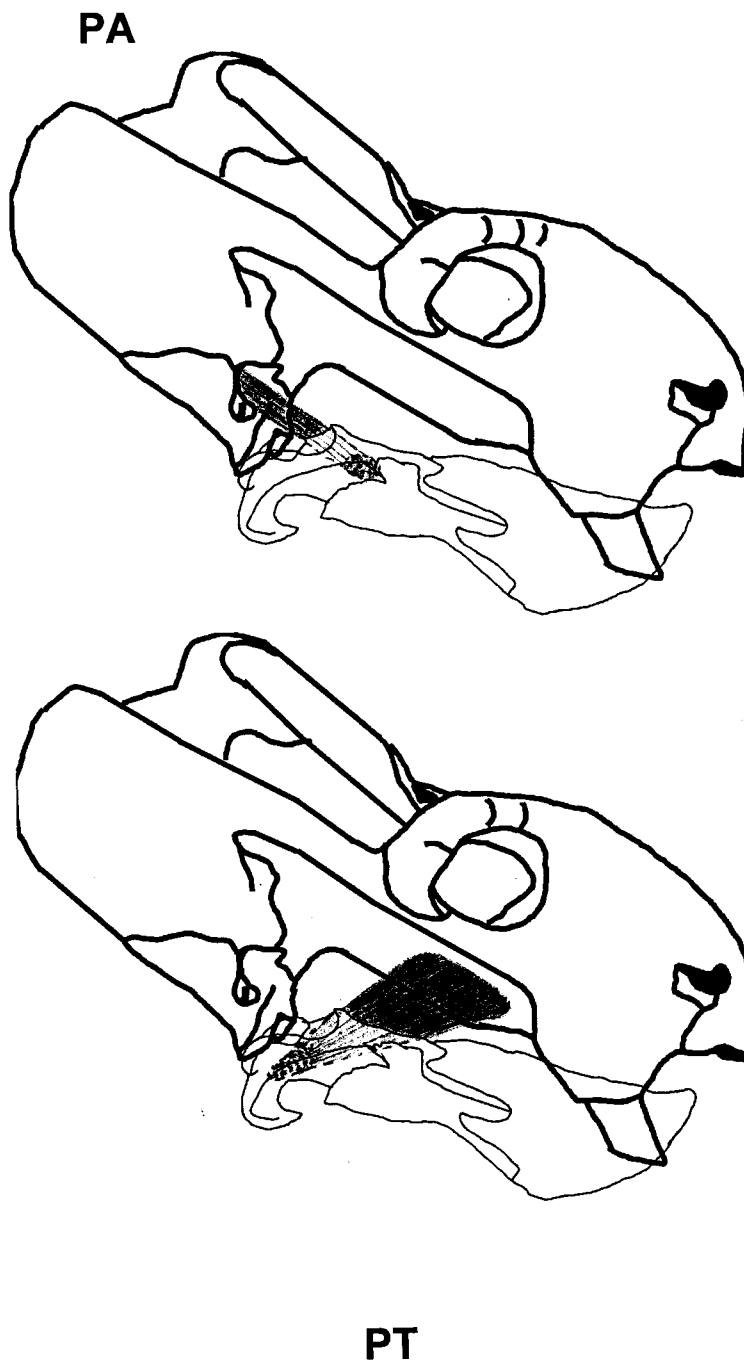


Figure 77. Diagrammatic representation of the posterior adductor (PA), and the internal adductor musculature. PT - pterygoideus muscle.

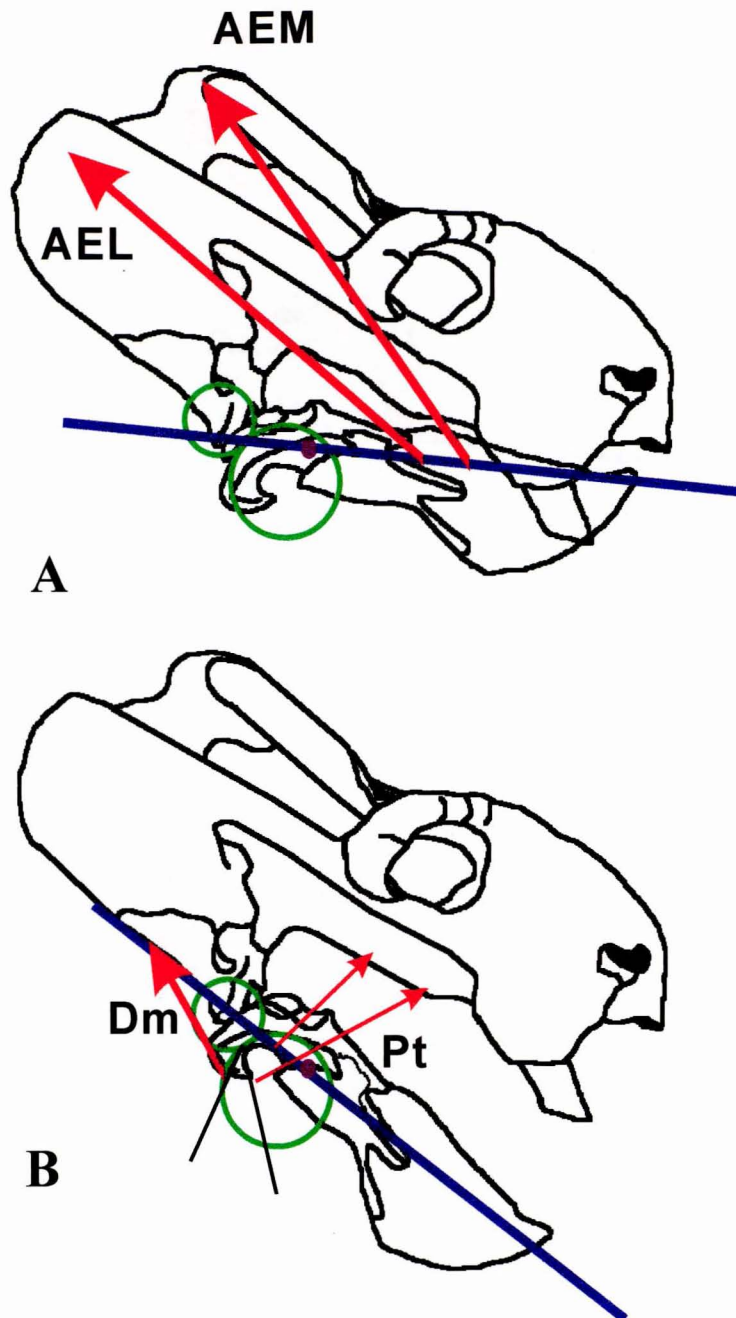


Figure 78. Phase One of the *Kannemeyeria* masticatory cycle.

A - elevation: primarily performed by the contraction of the external adductor muscles (AEL and AEM) to achieve the beak-bite between the anterior ends of the dentary and the alveolar border of the snout. **B - depression:** achieved by gravity and the contraction of the m. depressor mandibulae (Dm). Partial muscular control of the action is provided by a minor contribution from the pterygoideus musculature (Pt). **Red arrows** - traction lines indicating the muscle forces involved in the production of jaw movement during Phase One. Traction lines show maximal force at, or near, the main lever arm of the lower jaw (blue line). **Green circles** - arc described by the articulating surfaces of the lateral quadrate and articular condyles, and are apt to change their position determined by the position of the lower jaw during the cycle. **Purple dot** - actual pivot point of the entire lower jaw, which remains static regardless of the position the jaw assumes.

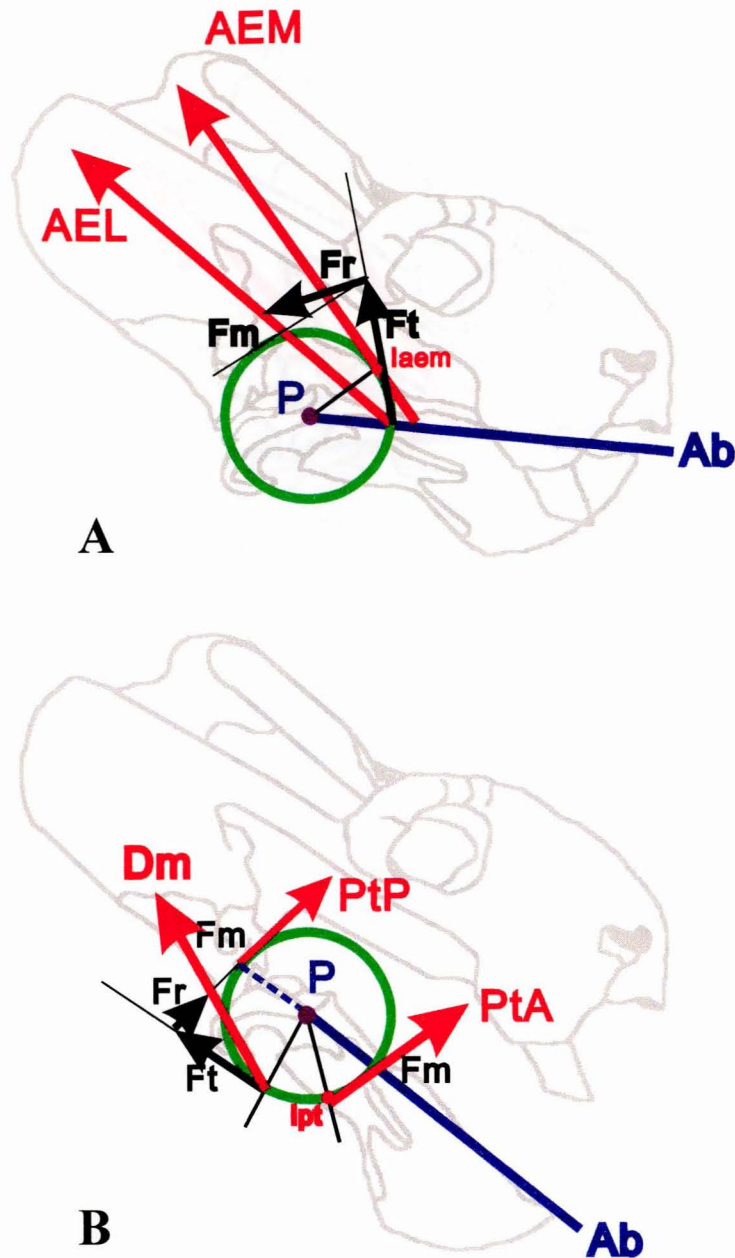


Figure 79. Force diagrams depicting the movements of the lower jaw during Phase One of the *Kannemeyeria* masticatory cycle.

A - elevation, **B** - depression. **Green circle** - radius of bell-crank curve, determined by the point of action of the traction line of the depressor mandibulae (**Dm**, see text). The arc of action of the bell-crank circle matches the arc of action of the anterior end of the alveolar border of the lower jaw (**Ab**). **P** - pivot point of the lower jaw, around which the bell-crank circle operates. All traction lines (**red arrows**) are redrawn according to the pivot point and the bell-crank circle. They lie either tangential to this circle or pass through the circle and their force needs to be described via the Pythagorean Theorem (see text). In actuality all muscle force is translated at the joint articulation but to a lesser or greater degree as shown by the force diagram. **PtP** - posterior pterygoideus fibres, **PtA** - anterior pterygoideus fibres, **Iaem** - interception point of the medial external adductor muscle, **Ipt** - interception point of the anterior pterygoideus muscle fibres.

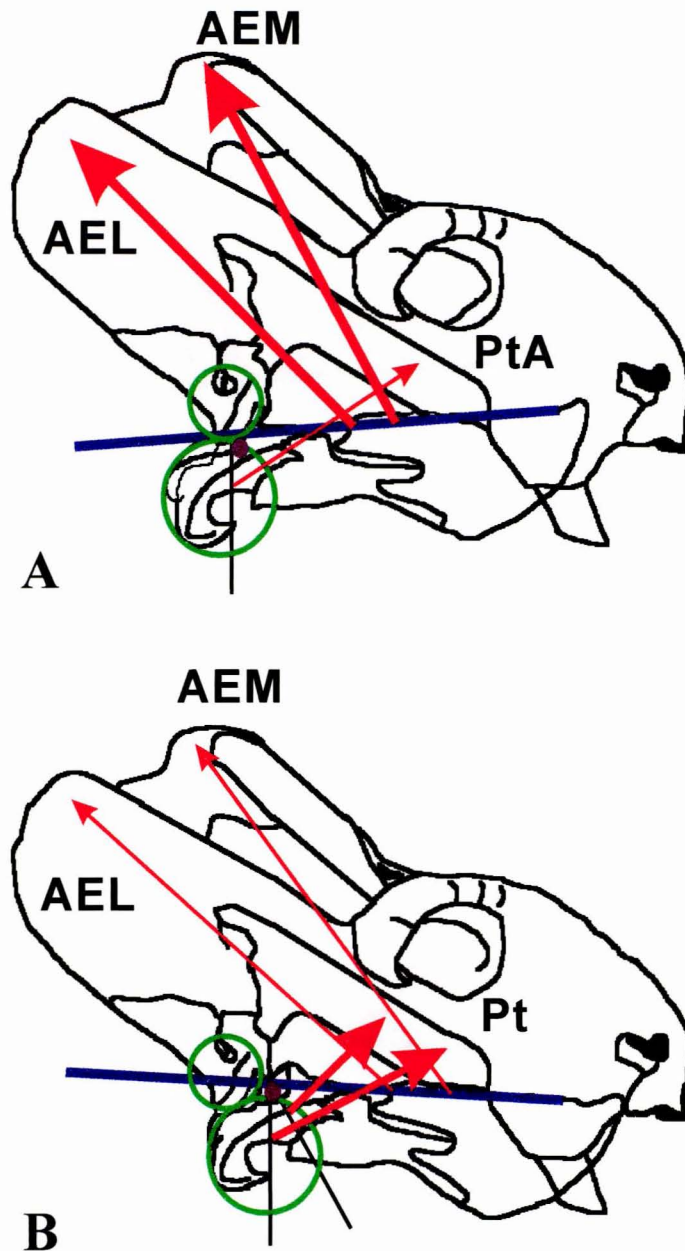


Figure 80. Phase Two of the *Kannemeyeria* masticatory cycle.

A - postero-dorsal crushing and grinding action, resulting from the vertical force applied by the external adductor musculature (AEM and AEL), mediated by a small antero-medial component from the pterygoideus musculature (PtA). **B - antero-dorsal** crushing and grinding action, resulting from the vertical force applied by the pterygoideus musculature (Pt), functionally subdivided into anterior and posterior fibre units. Mediated by a small posterior contribution from the external adductor muscles. The pivot point (**purple dot**) closely corresponds to the point of contact of the quadrate condyle with the articular recess.

Red arrows - traction lines of the muscle forces involved in the movement of the lower jaw relative to the upper jaw when the mouth is effectively closed.

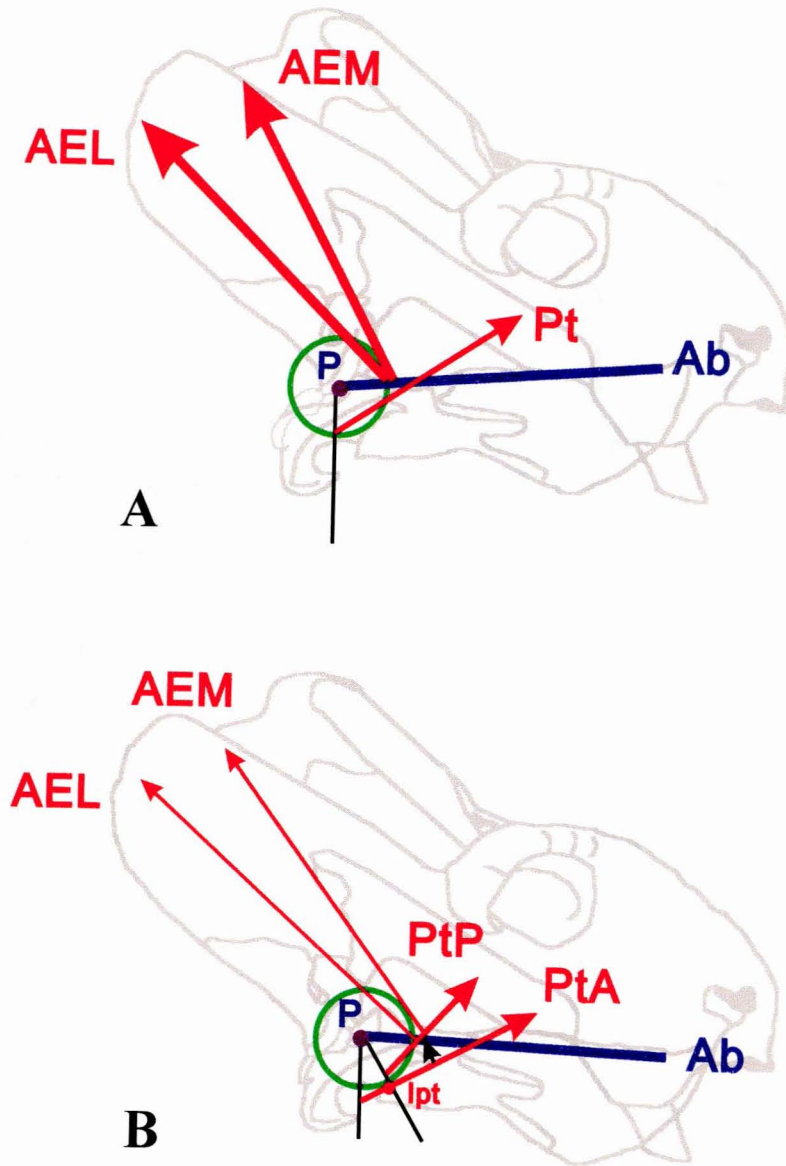


Figure 81. Force diagrams depicting the movements of the lower jaw during Phase Two of the *Kannemeyeria* masticatory cycle.

A - postero-dorsal stroke, the traction lines of the external adductor muscles (**red arrows**) both lie nearly tangential to the circle around the pivot point (P) which reflects the smaller arc of action of the lower jaw of Phase 2. This radius is determined by the anterior fibres of the pterygoideus musculature (PtA). The upward and backward force of AEM and AEL pulls the lever arm of the lower jaw (P - Ab) firmly against the palatal pads of the upper jaw. **B - antero-dorsal stroke**, most of the force is exerted by the anterior and posterior (PtP) fibres of the pterygoideus musculature. The anterior fibres are nearly tangential to the bell-crank curve, whilst the traction line of the posterior fibres runs through the circle and is described by the Pythagorean Theorem, which matches the path of the traction line of the anterior fibres. The insertion point (Ipt) marks the point of action of the anterior fibres.

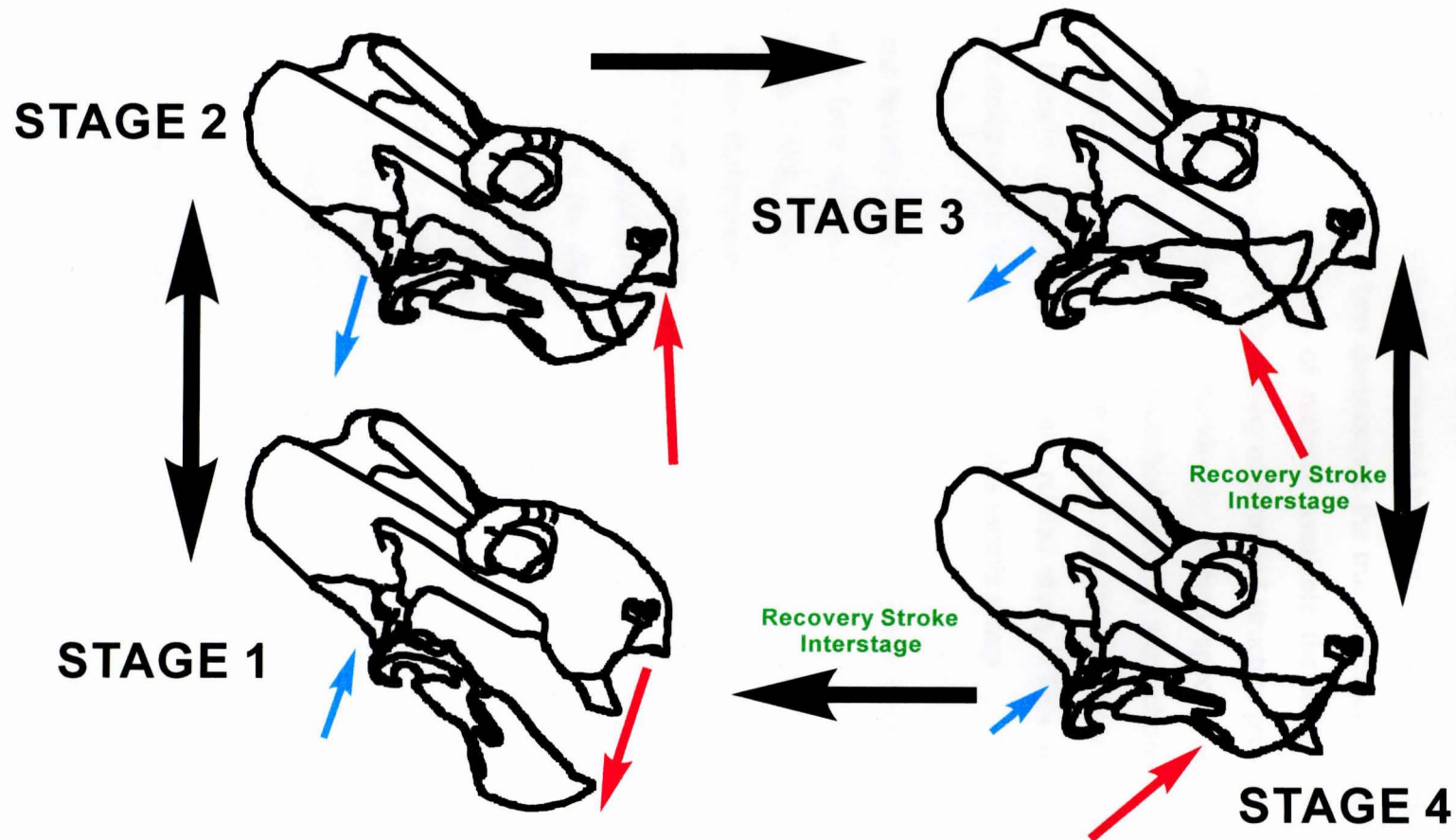


Figure 82. Masticatory cycle of *Kannemeyeria*.
Blue arrow - direction of movement of jaw joint, **red arrow** - direction of maximum applied force and thus direction of movement of the entire lower jaw, **black arrows** - progression of masticatory cycle from depression (Stage 1) to elevation (Stage 2) to orthal jaw action (Stages 3 & 4), and finally back to depression.

APPENDIX A

A.1 Materials and Methods

A vast number of specimens, in various institutions, can be reliably attributed to the genus *Kannemeyeria*, but this study has attempted to produce an accurate rendering of the genus based on those specimens which best demonstrate the true characteristics of the genus. This means that from the large collection of material available the least distorted and best preserved specimens, which still reflect the variety of form and structure present in the genus, were chosen for examination. Holotypes of previously erected species, including those which were subsequently synonymised with established species, were chosen for study. A final factor influenced the composition of the sample size was the attempt to obtain as many specimens as possible from a single area, or closely related areas. This is of particular importance if allometric studies are to be performed on this sample group.

Specimens broadly identifiable as belonging to the genus *Kannemeyeria* were determined and recognised from the genotype of *Kannemeyeria simocephalus* (HNV/8178), described by Weithofer in 1888, from Dwarsvlei farm Aliwal North District, South Africa, and currently housed in the Hofmuseum, Vienna. Although this holotype specimen was not available for study, a museum cast and photographs of the specimen was used for comparison and examination. The cast (BP/11/129) revealed that this specimen was very incomplete lacking the entire left half of the skull, and much of the palate and braincase. Consequently, most observations of the elements of the palatal surface, nasal cavity and braincase of skulls diagnosed as *Kannemeyeria* have previously relied on descriptions of other dicynodonts (Pearson, 1924a). A meaningful description of the morphology of this genus must, therefore, be founded on the examination of well preserved referred material. As part of the recognition of a specimen as a member of the genus *Kannemeyeria* it is critical to investigate the nature and extent of the distortion suffered, these description are included in this section.

Mechanical means of preparation of the specimen refers to the use of air-scribe tools tipped with a tungsten needle point, whereas occasional acid preparation is described in detail for those specimens where it was used.

A.2 List of Reference Specimens

Specimen No.	Taxon	Description
BP/1/296	<i>Lystrosaurus</i>	Small, complete & well preserved skull & lower jaw.
BP/1/300	<i>Aulacephalodon</i>	<i>A. baini</i> Large well preserved and undistorted skull.
BP/1/315	<i>Pristerodon</i>	Small, complete skull.
BP/1/555	<i>Dicynodon</i>	Holotype of <i>D. daptocephaloides</i> Toerien 1955. Medium sized well preserved & complete skull.
BP/1/766	<i>Aulacephalodon</i>	Large well preserved & complete lower jaw.
BP/1/878	<i>Lystrosaurus</i>	Holotype of <i>L. primitivus</i> Small, complete skull & lower jaw.
BP/1/2188	<i>Dicynodon</i>	= <i>Daptocephalus</i> . Large skull, bilaterally compressed, but complete.
BP/1/2642	<i>Pristerodon</i>	Small, well preserved & complete skull & lower jaw. Used by Crompton & Hotton (1967) to establish their model on dicynodont jaw cycle.
BP/1/3532 ₅	<i>Shansiodon</i>	A small to medium sized skull & lower jaw, identified as a <i>Shansiodon</i> sp. by Hancox, 1998.
BP/1/4233	<i>Dicynodon</i>	Large, well preserved & complete skull.
BP/1/4545	<i>Kannemeyeria</i>	Right caniniform process & tusk.
BP/1/4675	<i>Kannemeyeria</i>	Large, right caniniform & tusk.
BP/1/4798	<i>Lystrosaurus</i>	Small, well preserved & complete skull & lower jaw.
BP/1/5287	<i>Dicynodon</i>	= <i>Daptocephalus</i> . Large, complete skull with partial lower jaw.
MACN/18.055	<i>Ischigualastia</i>	Holotype of <i>I. jenseni</i> Cox 1965. Large, nearly complete skull, partial lower jaw (uncatalogued).
PVL/3831	<i>Vinceria</i>	Holotype of <i>V. andina</i> Boneparte 1967. Small, complete skull & lower jaw. Rio Mendoza Formation, Argentina.
PVL/3832	<i>Vinceria</i>	Small, sub-adult complete skull.
R/313	<i>Kannemeyeria</i>	<i>K. cristarhynchus</i> large, well preserved & complete skull.
RC/9	<i>Dinanomodon</i>	Holotype of <i>D. rubidgei</i> Broom 1938. Large, near complete skull.

APPENDIX B

B.1 Log-Transformed Data for Allometric Analysis

Variable	Speciment										
	BP/1/989	PE/1199P	BP/1/2092	BP/1/4648	SAM/10555	BP/1/4523	BP/1/3638	EL/1	BP/1/4524	QR/1127	BP/1/5624
var1	1.92941893	2.29666619	2.350248	2.42813479	2.51687384	2.550228353	2.5563026	2.58546073	2.5865873	2.60530606	2.61489722
var2	2.1172713	2.34242268	2.462398	2.51054501	2.6180481	2.643452676	2.6580114	2.68574174	2.67760695	2.68124124	2.62838893
var3	2.19865709		2.50515	2.53147892	2.64147411	2.685741739	2.67669361	2.72835378	2.71600334	2.7201593	2.6946052
var4	1.63346846	1.98227123	2.079181	2.11394335	2.19589965	2.260071388	2.31175386	2.2787536	2.35410844	2.2787536	2.26717173
var5	1.66275783		2.079181	2.15836249	2.2764618	2.361727836	2.31597035	2.38381537	2.36361198	2.33445375	2.35218252
var6	1.67209786	1.94939001	1.968483	2.0374265	2.1271048	2.167317335	2.09342169	2.20951501	2.24303805	2.10720997	2.2787536
var7	1.50514998	1.63346846	1.556303	1.67209786	1.71600334	1.77815125	1.80617997	1.90308999	1.8920946	1.78532984	1.83250891
var8	1.5563025	1.91381385	1.892095	2.04139269	2.08635983	2.184691431	2.23044892	2.19865709	2.22271647	2.10037055	2.23552845
var9	1.71600334	1.98227123	2.049218	2.06069784	2.18752072	2.190331698	2.13033377	2.28555731	2.29225607	2.13672057	2.35218252
var10			2.271842	2.11394335	2.40483372	2.431363764	2.38916608	2.52113808	2.37106786	2.26481782	2.46982202
var11	1.47712125	1.53147892	1.832509	1.84509804	2.09691001	2.096910013	2.19589965	2.1271048	2.13033377	2.1271048	2.15228834
var12	1.56820172	1.62324929	1.913814	1.95904139	2.13987909	2.178976947	2.08635983	2.25527251	2.23044892	2.2380461	2.2787536
var13	0.90308999		1.041393		1.30103	1.342422681	1.25527251	1.34242268	1.32221929	1.38021124	1.38021124
var14	1.50514998	1.65321251	1.755875	1.84509804	1.8573325	1.954242509	1.92427929	1.92941893	1.99122608	1.99122608	1.96378783
var15	1.44715803		1.724276	1.80617997	1.95904139		2	1.96848295	1.91907809	2	1.78532984
var16	1.17609126	1.20411998	1.431364		1.36172784	1.342422681	1.69019608	1.49136169	1.44715803	1.34242268	1.44715803
var17	1.23044892		1.857332	1.97312785	2.03342376	2.136720567	2.16435286	2.21748394	2.1430148	2.2121876	2.20411998
var18			2.041393	1.93951925	2.1271048	2.190331698	1.89762709	2.13987909	2.24551267	2.08990511	2.10037055
var19	1.38021124		1.70757	1.86923172	1.93449845		2	2.08278537	2.04139269	2.05307844	2
var20	0.77815125	1.04139269	1.30103	1.36172784	1.44715803	1.531478917	1.72427587	1.54406804	1.53147892	1.56820172	1.51851394
var21	1.11394335	1.47712125	1.50515	1.62324929	1.63346846	1.748188027	1.81291336	1.83250891	1.74036269	1.77815125	1.87506126
var22	0.84509804	0.95424251	1.079181	1.04139269	1.34242268	1.361727836	1.43136376	1.38021124	1.36172784	1.07918125	1.34242268
var23	1	1.14612804	1.230449	1.30103	1.25527251	1.342422681	1.39794001	1.32221929	1.36172784	1.25527251	1.30103
var24				2.42160393		2.509202522	2.64836001	2.55870857	2.60314437	2.46538285	2.5797836
var25		2.08990511		2.1271048	2.32014629	2.346352974		2.37106786	2.33041377	2.45939249	2.32633586
var26		1.63346846				1.785329835		1.83250891	1.75587486	1.76342799	1.80617997
var27	1.49136169	1.8920946	1.982271	2.11058971	2.13672057	2.164352856	2.18752072	2.11394335	2.07918125	2.24303805	2.161368
var28	0.95424251		1.414973	1.53147892	1.462398	1.51851394	1.60205999		1.64345268	1.60205999	1.74036269
var29	1.5797836	1.69897	1.792392	1.77815125	1.85125835	1.851258349	1.95904139	1.90848502	1.93951925	1.81291336	1.87506126
var30	0.60205999	1.41497335	1.518514	1.59106461	1.64345268	1.602059991	1.77815125	1.70757018	1.71600334	1.69897	1.71600334

mean.X1	2.251116732
mean.X2	2.540801566
mean.X3	2.598062574

B.2 Statistical Results of Allometric Analysis: Bartlett's 'Best-Fit' Procedure

Variable	N	B	a	Sxx	Sxy	Syy	s(B)	t	d.f.	reject	95% Conf. Int(B)		95% Conf. Int(a)	
											LCL.B	UCL.B	LCL.a	UCL.a
var1	11													
var2	11	0.893758	0.3524167	0.1483034	0.114085	0.095331	0.035121	-1.252883	8	FALSE	0.80409	0.983425518	0.339151	0.365682006
var3	10	0.873388	0.4645424	0.1483034	0.099005	0.072672	0.04298	-0.862176	7	FALSE	0.798075	0.948701662	0.452857	0.476227899
var4	11	0.98713	-0.265093	0.1483034	0.145124	0.156312	0.042293	-0.910252	8	FALSE	0.917288	1.056972251	-0.27542	-0.254760327
var5	10	1.129135	-0.544624	0.1483034	0.142859	0.149084	0.047131	-1.710429	7	FALSE	0.964835	1.293435219	-0.57012	-0.519131018
var6	11	0.872701	-0.065986	0.1483034	0.106681	0.096889	0.054358	1.0797861	8	FALSE	0.992321	0.753080301	-0.08368	-0.04828951
var7	11	0.753723	-0.116778	0.1483034	0.040468	0.030249	0.081774	1.0235508	8	FALSE	0.583136	0.924310857	-0.14201	-0.091542037
var8	11	0.975418	-0.335687	0.1483034	0.135441	0.150822	0.058843	-1.106656	8	FALSE	0.842701	1.10813531	-0.35532	-0.316053508
var9	11	0.906861	-0.101771	0.1483034	0.106177	0.105381	0.065825	1.3293281	8	FALSE	0.72825	1.085470735	-0.12819	-0.075347953
var10	10	0.616289	0.845996	0.1483034	0.011175	0.07262	0.127819	-0.806923	7	FALSE	0.40608	0.826498454	0.81338	0.878611861
var11	11	1.333511	-1.310686	0.1483034	0.102845	0.120425	0.117184	-1.188106	8	FALSE	1.049754	1.617268296	-1.35266	-1.26870708
var12	11	1.396626	-1.387598	0.1483034	0.105954	0.124318	0.121263	0.5670248	8	FALSE	1.25649	1.536763126	-1.40833	-1.366866184
var13	10	1.106872	-1.466763	0.1483034	0.111526	0.088937	0.05824	1.0890196	7	FALSE	0.977607	1.236137441	-1.44671	-1.486819134
var14	11	0.804393	-0.123923	0.1483034	0.091776	0.071423	0.049668	0.4241459	8	FALSE	0.761458	0.847328548	-0.13027	-0.117570914
var15	10	0.784545	-0.063992	0.1483034	0.100683	0.10819	0.07699	-1.70712	7	FALSE	0.516676	1.052413909	-0.10555	-0.022429815
var16	10	0.465491	0.2500246	0.1483034	0.043299	0.123443	0.128323	-1.063784	7	FALSE	0.187276	0.743705761	0.206857	0.29319214
var17	10	1.461991	-1.573844	0.1483034	0.214405	0.340133	0.065855	-0.858944	7	FALSE	1.347002	1.576980396	-1.59169	-1.556002877
var18	10	0.442319	0.9992761	0.1483034	0.007573	0.081737	0.12192	0.938916	7	FALSE	0.209013	0.675625627	0.963077	1.035475606
var19	9	1.09283	-0.78777	0.1483034	0.131412	0.136747	0.066634	-0.9578	6	FALSE	0.962755	1.222903691	-0.80904	-0.766495844
var20	11	1.210535	-1.578193	0.1483034	0.167128	0.255946	0.092629	-2.010597	8	TRUE	0.830961	1.590109487	-1.63435	-1.522039728
var21	11	1.085631	-1.017516	0.1483034	0.145479	0.172177	0.062342	0.3977491	8	FALSE	1.035093	1.136168329	-1.02499	-1.010039067
var22	11	0.896126	-0.999415	0.1483034	0.062924	0.097318	0.113818	-2.358525	8	TRUE	0.349016	1.443235298	-1.08035	-0.918476273
var23	11	0.405425	0.269023	0.1483034	0.082788	0.066536	0.054525	-1.595764	8	FALSE	0.228095	0.582756112	0.242789	0.295256932
var24	7	0.375133	1.61945	0.1483034	0.005348	0.014399	0.088398	-1.109894	4	FALSE	0.17517	0.575096171	1.582367	1.655533161
var25	8	0.758901	0.4322637	0.1483034	0.0241	0.042311	0.136015	0.0615572	5	FALSE	0.741962	0.775839805	0.429325	0.435202118
var26	6	0.449723	0.6581513	0.1483034	0.019253	0.015381	0.09671	0.0756437	3	FALSE	0.434813	0.464632498	0.655165	0.66113788
var27	11	0.807917	0.0666583	0.1483034	0.176532	0.230733	0.072706	-1.587728	8	FALSE	0.572646	1.04318714	0.031853	0.101463775
var28	9	1.042603	-1.064314	0.1483034	0.163613	0.206305	0.066265	1.9499261	6	TRUE	0.779257	1.30594907	-1.10738	-1.021242996
var29	11	0.494805	0.6070575	0.1483034	0.06162	0.045049	0.060472	-1.206924	8	FALSE	0.370663	0.618946883	0.588692	0.625422849
var30	11	1.233575	-1.485572	0.1483034	0.302948	0.548614	0.125932	-0.545504	8	FALSE	1.093566	1.373584162	-1.50628	-1.464859386

B.3 Cranial Measurements. Variables (Var) 1 to 30 are explained in the text (Volume 1 Chapter 7). All measurements are in millimetres, and represent the average of three independent readings.

Variable	Specimen										
	BP/1/989	BP/1/2092	BP/1/3638	BP/1/4523	BP/1/4524	BP/1/4648	BP/1/5624	PE/1199P	QR/1127	EL/1	SAM/PK/10555
var1	85	224	360	355	386	268	412	198	403	385	328
var2	131	290	455	440	476	324	425	220	480	485	415
var3	158	320	475	485	520	340	495		525	535	438
var4	43	120	205	182	226	130	185	96	190	190	157
var5	46	120	207	230	231	144	225		216	242	189
var6	47	93	124	147	175	109	190	89	128	162	134
var7	32	36	64	60	78	47	68	43	61	80	52
var8	36	78	170	153	167	110	172	82	126	158	122
var9	52	112	135	155	196	115	225	96	137	193	154
var10		187	245	270	235	130	295		184	332	254
var11	30	68	157	125	135	70	142	34	134	134	125
var12	37	82	122	151	170	91	190	42	173	180	138
var13	8	11	18	22	21		24		24	22	20
var14	32	57	84	90	98	70	92	45	98	85	72
var15	28	53	93	100	100	64	105		61	83	91
var16	15	27	49	22	28		28	16	22	31	23
var17	17	72	146	137	139	94	160		163	165	108
var18		110	79	155	176	87	126		123	138	134
var19	24	51	121	100	113	74	100			110	86
var20	6	20	53	34	34	23	33	11	37	35	28
var21	13	32	65	56	55	42	75	30	60	68	43
var22	7	12	27	23	23	11	22	9	12	24	22
var23	10	17	25	22	23	20	20	14	18	21	18
var24			445	323	401	264	380		292	362	
var25				222	214	134	212	123	288	235	209
var26				61	57		64	43	58	68	
var27	31	96	154	146	120	129	145	78	175	130	137
var28	9	26	40	33	44	34	55		40		29
var29	38	62	91	71	87	60	75	50	65	81	71
var30	4	33	60	40	52	39	52	26	50	51	44