

Supplemental Appendix 4. The specimens used :

Taxon	OUT
<i>Archaeopteryx lithographica</i>	<i>Archaeopteryx_lithographica</i>
<i>Protopteryx fengningensis</i>	<i>Protopteryx_fengningensis</i>
<i>Pengornis houi</i>	<i>Pengornis_houi</i>
<i>Apsaravis ukhaana</i>	<i>Apsaravis_ukhaana</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Gansus yumenensis</i>	<i>Gansus_yumenensis</i>
<i>Enaliornis sedgwicki</i>	<i>Enaliornis</i>
<i>Enaliornis sedgwicki</i>	<i>Enaliornis</i>
<i>Enaliornis sedgwicki</i>	<i>Enaliornis</i>
<i>Enaliornis seeleyi</i>	<i>Enaliornis</i>
<i>Enaliornis seeleyi</i>	<i>Enaliornis</i>
<i>Enaliornis seeleyi</i>	<i>Enaliornis</i>
<i>Enaliornis seeleyi</i>	<i>Enaliornis</i>
<i>Enaliornis barretti</i>	<i>Enaliornis</i>
<i>Enaliornis barretti</i>	<i>Enaliornis</i>
<i>Enaliornis barretti</i>	<i>Enaliornis</i>
<i>Enaliornis barretti</i>	<i>Enaliornis</i>
<i>Enaliornis barretti</i>	<i>Enaliornis</i>
<i>Enaliornis barretti</i>	<i>Enaliornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis tankei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>

<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Pasquiaornis hardiei</i>	<i>Pasquiaornis</i>
<i>Chupkaornis kerai</i>	<i>Chupkaornis_keraorum</i>
<i>Brodavis americanus</i>	<i>Brodavis</i>
<i>Brodavis bairdi</i>	<i>Brodavis</i>
<i>Brodavis varneri</i>	<i>Brodavis</i>
<i>Baptornis advenus</i>	<i>Baptornis_advenus</i>
<i>Baptornis advenus</i>	<i>Baptornis_advenus</i>
<i>Baptornis advenus</i>	<i>Baptornis_advenus</i>
<i>Fumicollis hoffmani</i>	<i>Fumicollis_hoffmani</i>
<i>Paraesperornis alexi</i>	<i>Paraesperornis_alexi</i>
<i>Paraesperornis alexi</i>	<i>Paraesperornis_alexi</i>
<i>Hesperornis regalis</i>	<i>Hesperornis_regalis</i>
<i>Hesperornis regalis</i>	<i>Hesperornis_regalis</i>
<i>Hesperornis regalis</i>	<i>Hesperornis_regalis</i>
<i>Hesperornis regalis</i>	<i>Hesperornis_regalis</i>
<i>Hesperornis regalis</i>	<i>Hesperornis_regalis</i>
<i>Hesperornis regalis</i>	<i>Hesperornis_regalis</i>
<i>Hesperornis gracilis</i>	<i>Hesperornis_gracilis</i>
<i>Hesperornis gracilis</i>	<i>Hesperornis_gracilis</i>
<i>Hesperornis gracilis</i>	<i>Hesperornis_gracilis</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Ichthyornis dispar</i>	<i>Ichthyornis_dispar</i>
<i>Lithornis</i>	<i>Lithornis</i>
<i>Crypturellus undulatus</i>	<i>Crypturellus_undulatus</i>
<i>Chauna torquata</i>	<i>Chauna_torquata</i>
<i>Vegavis iaai</i>	<i>Vegavis_iaai</i>
<i>Anas platyrhynchos</i>	<i>Anas_platyrhynchos</i>
<i>Gallus gallus</i>	<i>Gallus_gallus</i>
<i>Crax pauxi</i>	<i>Crax_pauxi</i>

for coding are listed. The type specimens are indicated in bold. Anat

Specimen ID
NHMUK 37007; MB. 188081
IVPP V11665
IVPP V15336
IGM 100/1017
CAGS-04-CM-003 CAGS-04-CM-004 CAGS-06-CM-011 CAGS-07-CM-006 CAGS-05-CM-014 CAGS-07-CM-011 CAGS-07-CM-009 CAGS-04-CM-002 CAGS-04-CM-001 CAGS-04-CM-018 CAGS-04-CM-031
NHMUK 479; CAMSM 55287, 55288, 55289, 55295, 55300, 55302, 55310 NHMUK 480; CAMSM 55314 , 55315; YORYMG 581 NHMUK 41790; CAMSM 55320, 55332
CAMSM 55283 NHMUK 484, 5801; CAMSM 55290, 55293, 55307, 55299, 55307, 55308; BGS 87935; NHMUK 478, 481; CAMSM 55317; YORYMG 587, 588 NHMUK 485a; CAMSM 55318, 55319, 55321; YORYMG 589
NHMUK 5308; YORYMG 507 CAMSM 55277 BGS 87936; NHMUK 5310; CAMSM 55282 NHMUK 163, 479, 482, 483, 5305, 5306, 5803, 5805, 41792; CAMSM 550 NHMUK 5304, 5307; CAMSM 55312, 55313, 55316; YORYMG 587 NHMUK 477 , 5309; BGS 87932; CAMSM 55331
RSM P2985.10, P2986.2, P2988.1, P2988.11, P2989.21, P2995.4, P2995. RSM P2626.15, P2957.16, P2957.17, P2987.13, P2987.14, P2989.24, P29 RSM P2989.23, P2957.15, P2985.3, P2989.22 RSM P2997.62 RSM P2988.9 RSM P2997.58, 2997.59 RSM P2077.4, 2487.4, 2995.1, 2989.11 RSM P2831.4, 2989.34 RSM P2989.17, 2997.30 RSM P2626.27, 2997.56 RSM P2077.10, 2077.108, 2997.2, 2997.3 RSM P2957.22, 2957.21, 2997.44 RSM P2997.80 RSM P2077.63 , 2077.79, 2957.27 RSM P2989.27, 2989.41, 2997.68, 3015.9
RSM P2831.18, P2831.6, P2957.12, P2985.9, P2989.19 RSM P2831.8 RSM P2626.18, P2989.25 RSM P2831.54

RSM P2985.8
RSM P2487.3, 2995.1, 2989.15
RSM P2831.20
RSM P2077.59, 2077.60, 2487.3, 2997.4
RSM P2995.1, 2997.42, 2997.46
RSM P2988.21
RSM P2077.117 , 2997.18, 2997.81
MCM.A773
RSM P2315.1
UNSM 50665
SDSM 68430
AMNH 5101
FMNH 395
KUVP 2290
UNSM 20030
KUVP 2287
KUVP 24090
YPM 1200
YPM 1206
YPM 1476
KUVP 71012
FHSM VP-2069
UNSM 1212
YPM 1473
YPM 1478
YPM 1679
YPM 1450
YPM 1732
YPM 1733
YPM 1755
YPM 1773
YPM 1741
YPM 1724
YPM 1463
YPM 1739
YPM 1771
YPM 1796
multiple specimens
multiple specimens
multiple specimens
MLP 93-I-3-1
multiple specimens
multiple specimens
multiple specimens

tomical abbreviations: cav, caudal vertebrae; cor, coracoid; crn, cranial elements; c

Material	Specimen Reference
complete skeletons	Wellnhofer 2009
complete skeletons	Zhang & Zhou 2000
complete skeletons	Zhou et al. 2008
nearly complete skeletons without skull	Norell & Clarke 2001; Clarke & Norell 2002
nearly complete skeletons without skull	You et al. 2006
cvt, tvt, rib, fur, cor, hum, uln, rad, cmc, mph	You et al. 2006
stn	Wang et al. 2014
hum, uln, rad, cmc	Wang et al. 2014
hum, uln, rad, cmc, mph, fmr, tib, fib, tmt, pph	Wang et al. 2014
stn, plv, fmr, tbt, fib, tmt, pph	Wang et al. 2014
plv	Wang et al. 2014
cvt, tvt, plv, sys, cav, fmr, tbt, fib, tmt, pph	You et al. 2006
tbt, fib, tmt, pph	You et al. 2006
tbt	Wang et al. 2014
tmt	Wang et al. 2014
fmr	Galton & Martin 2002a, b
tbt	Galton & Martin 2002a, b
tmt	Galton & Martin 2002a, b
plv	Galton & Martin 2002a, b
fmr	Galton & Martin 2002a, b
tbt	Galton & Martin 2002a, b
tmt	Galton & Martin 2002a, b
cvt	Galton & Martin 2002a, b
tvt	Galton & Martin 2002a, b
plv	Galton & Martin 2002a, b
fmr	Galton & Martin 2002a, b
tbt	Galton & Martin 2002a, b
tmt	Galton & Martin 2002a, b
crn	Sanchez 2011
cvt	Sanchez 2011
tvt	Sanchez 2011
sys	Sanchez 2011
cor	Sanchez 2011
sca	Sanchez 2011
hum	Tokaryk et al. 1997; Sanchez 2011
cmc	Sanchez 2011
uln	Sanchez 2011
plv	Sanchez 2011
fmr	Tokaryk et al. 1997; Sanchez 2011
tbt	Sanchez 2011
fib	Sanchez 2011
tmt	Tokaryk et al. 1997; Sanchez 2011
pph	Sanchez 2011
crn	Sanchez 2011
cvt	Sanchez 2011
sys	Sanchez 2011
cor	Sanchez 2011

sca	Sanchez 2011
hum	Sanchez 2011
rad	Sanchez 2011
fmr	Tokaryk et al. 1997; Sanchez 2011
tbt	Sanchez 2011
fib	Sanchez 2011
tmt	Tokaryk et al. 1997; Sanchez 2011
cvt, tvf, fmr, fib	Tanaka et al. 2017
tmt	Martin et al. 2012
tmt	Martin et al. 2012
cvt, tvf, plv, fmr, fib, tbt, tmt	Martin & Cordes-Person 2004; Martin et al.
cvt, tvf, cav, sys, plv, tbt, tmt	Martin & Tate 1976
crn, cvt, sys, fmr, tbt, tmt, pph	Martin & Tate 1976
cvt, tvf, sys, sca, cor, hum, uln, rad, fmr, pat,	Martin & Tate 1976
cvt, tvf, cav, cor, stn, plv, fmr, fib, tbt, tmt, p	Martin & Tate 1976; Bell & Chiappe 2015b
nearly complete skeletons	Martin 1988
cvt, tvf, cav, stn, sca, cor, fmr, tbt	Bell 2013
tvf, cav, fmr, tbt, pat, tmt, fib, pph	Marsh 1880; Bell & Ciappe 2015a
nearly complete skeletons	Marsh 1880; Bell & Ciappe 2015a
stn, plv, fmr, pat, tbt, tmt, pph	Marsh 1880; Bell & Ciappe 2015a
crn, cvt, tmt	Buhler et al. 1988; Bell & Ciappe 2015a
nearly complete skeletons	Bell & Ciappe 2015a
cvt, tvf, sys, plv, fmr, tmt	Everhart 2011
tmt	Marsh 1880; Bell & Ciappe 2015a
cvt, tvf, fmr, tbt, tmt, pph	Marsh 1880; Bell & Ciappe 2015a
rib, plv, fmr, pat, tbt, fib, tmt, pph	Marsh 1880; Bell & Ciappe 2015a
crn, stn, cor, scp, hum, uln, rad, cmc, plv, fmr	Clarke 2004
tvf, plv	Clarke 2004
cvt, cor	Clarke 2004
fur	Clarke 2004
scp	Clarke 2004
rad	Clarke 2004
cmc	Clarke 2004
mph	Clarke 2004
tmt	Clarke 2004
tmt	Clarke 2004
tmt	Clarke 2004
nearly complete skeletons	Houde 1988
complete skeletons	
complete skeletons	
cvt, tvf, sys, cor, sca, hum, uln, rad, plv, fmr,	Clarke et al. 2005
complete skeletons	
complete skeletons	
complete skeletons	

;mc, carpometacarpus; crn, cranial elements; cvt, cervical vertebrae; fib, fibula;

2012

fmr, femur; fur, furcula; hum, humerus; mph, manual phalanges; pat, patella;

plv, pelvis (any combination of the pubis, ilium and/or ischium); pph, pedal ph:

alanges; rad, radius; scp, scapula; stn, sternum; sys, synsacrum; tvt, thoracic ve

artebrae; tmt, tarsometatarsus; uln, ulna;