

= Parasaurolophus =

Parasaurolophus (/ ˈpær?s??r?l?f?s / PARR @-@ ? @-@ saw @-@ ROL @-@ ? @-@ f?s or / ˈpær?s??r??lo?f?s / PARR @-@ ?- SAWR @-@ ? @-@ LOH @-@ f?s ; meaning " near crested lizard " in reference to Saurolophus) is a genus of ornithomimid dinosaur that lived in what is now North America during the Late Cretaceous Period , about 76 @. @ 5 ? 74 @. @ 5 million years ago . It was a herbivore that walked both as a biped and a quadruped . Three species are recognized : P. walkeri (the type species) , P. tubicen , and the short @-@ crested P. cyrtocristatus . Remains are known from Alberta (Canada) , and New Mexico and Utah (USA) . The genus was first described in 1922 by William Parks from a skull and partial skeleton found in Alberta .

Parasaurolophus was a hadrosaurid , part of a diverse family of Cretaceous dinosaurs known for their range of bizarre head adornments . This genus is known for its large , elaborate cranial crest , which at its largest forms a long curved tube projecting upwards and back from the skull . Charonosaurus from China , which may have been its closest relative , had a similar skull and potentially a similar crest . Visual recognition of both species and sex , acoustic resonance , and thermoregulation have been proposed as functional explanations for the crest . It is one of the rarer hadrosaurids , known from only a handful of good specimens .

= = Description = =

Like most dinosaurs , the skeleton of Parasaurolophus is incompletely known . The length of the type specimen of P. walkeri is estimated at 9 @. @ 5 m (31 ft) , and its weight is estimated at 2 @. @ 5 tonnes (2 @. @ 8 short tons) . Its skull is about 1 @. @ 6 m (5 ft 3 in) long , including the crest , whereas the type skull of P. tubicen is over 2 m (6 ft 7 in) long , indicating a larger animal . Its single known forelimb was relatively short for a hadrosaurid , with a short but wide shoulder blade . The thighbone measures 103 cm (41 in) long in P. walkeri and is robust for its length when compared to other hadrosaurids . The upper arm and pelvic bones were also heavily built .

Like other hadrosaurids , it was able to walk on either two legs or four . It probably preferred to forage for food on four legs , but ran on two . The neural spines of the vertebrae were tall , as was common in lambeosaurines ; tallest over the hips , they increased the height of the back . Skin impressions are known for P. walkeri , showing uniform tubercle @-@ like scales but no larger structures .

= = = Skull = = =

The most noticeable feature was the cranial crest , which protruded from the rear of the head and was made up of the premaxilla and nasal bones . William Parks , who named the genus , hypothesized that a ligament ran from the crest to the notch to support the head , and cited the presence of possibly pathological notch as evidence . Although this idea seems unlikely , Parasaurolophus is sometimes restored with a skin flap from the crest to the neck . The crest was hollow , with distinct tubes leading from each nostril to the end of the crest before reversing direction and heading back down the crest and into the skull . The tubes were simplest in P. walkeri , and more complex in P. tubicen , where some tubes were blind and others met and separated . While P. walkeri and P. tubicen had long crests with only slight curvature , P. cyrtocristatus had a short crest with a more circular profile .

= = Classification = =

As its name implies , Parasaurolophus was initially thought to be closely related to Saurolophus because of its superficially similar crest . However , it was soon reassessed as a member of the lambeosaurine subfamily of hadrosaurids ? Saurolophus is an hadrosaurine . It is usually interpreted as a separate offshoot of the lambeosaurines , distinct from the helmet @-@ crested Corythosaurus , Hypacrosaurus , and Lambeosaurus . Its closest known relative appears to be Charonosaurus , a

lambeosaurine with a similar skull (but no complete crest yet) from the Amur region of northeastern China , and the two may form a clade Parasaurolophini . *P. cyrtocristatus* , with its short , rounder crest , may be the most basal of the three known *Parasaurolophus* species , or it may represent subadult or female specimens of *P. tubicen* .

The following cladogram is after the 2007 redescription of *Lambeosaurus magnicristatus* (Evans and Reisz , 2007) :

= = Discovery and naming = =

Meaning " near crested lizard " , the name *Parasaurolophus* is derived from the Greek para / " beside " or " near " , saurus / " lizard " and lophos / " crest " . It is based on ROM 768 , a skull and partial skeleton missing most of the tail and the hind legs below the knees , which was found by a field party from the University of Toronto in 1920 near Sand Creek along the Red Deer River in Alberta , Canada . These rocks are now known as the Campanian @-@ age Upper Cretaceous Dinosaur Park Formation . William Parks named the specimen *P. walkeri* in honor of Sir Byron Edmund Walker , Chairman of the Board of Trustees of the Royal Ontario Museum . *Parasaurolophus* remains are rare in Alberta , with only one other partial skull from (probably) the Dinosaur Park Formation , and three Dinosaur Park specimens lacking skulls , possibly belonging to the genus . In some faunal lists , there is a mention of possible *P. walkeri* material in the Hell Creek Formation of Montana , a rock unit of late Maastrichtian age . This occurrence is not noted by Sullivan and Williamson in their 1999 review of the genus , and has not been further elaborated upon elsewhere . It is possible that the fossil specimen could be an undescribed lambeosaurine .

In 1921 , Charles H. Sternberg recovered a partial skull (PMU.R1250) from what is now known as the slightly younger Kirtland Formation in San Juan County , New Mexico . This specimen was sent to Uppsala , Sweden , where Carl Wiman described it as a second species , *P. tubicen* , in 1931 . The specific epithet is derived from the Latin *t?b?c?n* " trumpeter " . A second , nearly complete *P. tubicen* skull (NMMNH P @-@ 25100) was found in New Mexico in 1995 . Using computed tomography of this skull , Robert Sullivan and Thomas Williamson gave the genus a monographic treatment in 1999 , covering aspects of its anatomy and taxonomy , and the functions of its crest . Williamson later published an independent review of the remains , disagreeing with the taxonomic conclusions .

John Ostrom described another good specimen (FMNH P27393) from New Mexico as *P. cyrtocristatus* in 1961 . It includes a partial skull with a short , rounded crest , and much of the postcranial skeleton except for the feet , neck , and parts of the tail . Its specific name is derived from the Latin *curtus* " shortened " and *cristatus* " crested " . The specimen was found in either the top of the Fruitland Formation or , more likely , the base of the overlying Kirtland Formation . The range of this species was expanded in 1979 , when David B. Weishampel and James A. Jensen described a partial skull with a similar crest (BYU 2467) from the Campanian @-@ age Kaiparowits Formation of Garfield County , Utah . Since then , another skull has been found in Utah with the short / round *P. cyrtocristatus* crest morphology .

= = = Species = = =

Parasaurolophus is known from three certain species , *P. walkeri* , *P. tubicen* , and *P. cyrtocristatus* . All of them can be distinguished from each other , and have many differences . The first named species , therefore the type , is *P. walkeri* . One certain specimen , from the Dinosaur Park Formation is referred to it , but many more are almost certainly referable . Like stated above , it is different from the other two species , with it having a simpler internal structure than *P. tubicen* , a straighter crest and different internal structuring than *P. cyrtocristatus* .

The next named species is *P. tubicen* , which is the largest of the *Parasaurolophus* species . It lived in New Mexico , where three specimens are known , and can be differentiated from its other species . It possesses a long and straight crest , with a very complex interior compared to the other species . All known specimens of *P. tubicen* come from the De @-@ Na @-@ Zin Member of the Kirtland

Formation .

In 1961 , the third species , *P. cyrtocristatus* was named by John Ostrom . Its three known specimens , have been found in the Fruitland and Kaiparowits formations from Utah and New Mexico . The second specimen , the first known from the Kaiparowits Formation , was originally unassigned to a specific taxon . Of the *Parasaurolophus* species , *P. cyrtocristatus* it is the smallest , and has the most curved crest . Because of its possession of the two above features , it has often been speculated that it was a female of *P. walkeri* or *P. tubicen* , which were males , although *P. tubicen* lived approximately a million years later . As noted by Thomas Williamson , the type material of *P. cyrtocristatus* is about 72 % the size of *P. tubicen* , close to the size at which other lambeosaurines are interpreted to begin showing definitive sexual dimorphism in their crests (~ 70 % of adult size) . Even though many scientists have supported the possible fact of *P. cyrtocristatus* being a female , many other studies have found that it is not , because of the differences in age , distribution , and the large differences in the crest and its internal structure .

A study published in PLoS ONE in 2014 found that one more species could be referred to *Parasaurolophus* . This study , led by Xing , found *Charonosaurus jiayensis* was actually nested deeply inside *Parasaurolophus* , which created the new species *P. jiayensis* . If this species is indeed inside *Parasaurolophus* , then the genus lasted until the K @-@ Pg extinction , and is known from two continents .

= = Paleobiology = =

= = = Diet and feeding = = =

As a hadrosaurid , *Parasaurolophus* was a large bipedal / quadrupedal herbivore , eating plants with a sophisticated skull that permitted a grinding motion analogous to chewing . Its teeth were continually being replaced ; they were packed into dental batteries containing hundreds of teeth , only a relative handful of which were in use at any time . It used its beak to crop plant material , which was held in the jaws by a cheek @-@ like organ . Vegetation could have been taken from the ground up to a height of around 4 m (13 ft) . As noted by Bob Bakker , lambeosaurines have narrower beaks than hadrosaurines , implying that *Parasaurolophus* and its relatives could feed more selectively than their broad @-@ beaked , crestless counterparts .

= = = Growth = = =

Parasaurolophus is known from many adult specimens , and a juvenile described in 2013 . The juvenile was discovered in the Kaiparowits Formation in 2009 . Excavated by the joint expedition by The Webb Schools and Raymond M. Alf Museum of Paleontology (RAM) , the juvenile has been identified as around only one year old when it died . Referred to *Parasaurolophus* sp . , the juvenile , under specimen number RAM 14000 , is the most complete , as well as youngest *Parasaurolophus* ever found , and measures 2 @.@ 5 m (8 @.@ 2 ft) . This individual fits neatly into the currently known *Parasaurolophus* growth stages , and lived approximately 75 million years ago . Even though no complete skull of the intermediate age between RAM 14000 and adult *Parasaurolophus* has been found yet , a partial braincase of about the right size is known . At 25 % of the total adult size , the juvenile show that crest growth of *Parasaurolophus* began sooner than in related genera , such as *Corythosaurus* . It has been suggested that *Parasaurolophus* adults bore such large crests , especially when compared to the related *Corythosaurus* , because of this difference in age between when their crests started developing . Its age also means that *Parasaurolophus* had an very fast growth , which took place in about a year . The crest of the juvenile is not long and tubular like the adults , but low and hemispherical .

The skull of RAM 14000 is almost complete , with the left side only lacking a piece of the maxilla . However , the skull was split down the middle by erosion , possibly when it was resting on the bottom of a river bed . The two sides are displaced slightly , with some bones of the right being

moved off the main block , also by erosion . After reconstruction , the skull viewed from the side resembles other juvenile lambeosaurines found , being roughly a trapezoid in shape .

A partial cranial endocast for RAM 14000 was reconstructed from CT scan data , the first ever for a *Parasaurolophus* of any ontogenetic stage . The endocast was reconstructed in two sections , one on the portion of the braincase articulated with the left half of the skull and the remainder on the disarticulated portion of the braincase . Their relative position was then approximated based on cranial landmarks and comparison with other hadrosaurids . Because of weathering , many of the smaller neural canals and foramina could not be identified for certain .

= = = Cranial crest = = =

Many hypotheses have been advanced as to what functions the cranial crest of *Parasaurolophus* performed , but most have been discredited . It is now believed that it may have had several functions : visual display for identifying species and sex , sound amplification for communication , and thermoregulation . It is not clear which was most significant at what times in the evolution of the crest and its internal nasal passages .

= = = Differences in crests = = =

As for other lambeosaurines , it is believed that the cranial crest of *Parasaurolophus* changed with age and was a sexually dimorphic characteristic in adults . James Hopson , one of the first researchers to describe lambeosaurine crests in terms of such distinctions , suggested that *P. cyrtocristatus* , with its small crest , was the female form of *P. tubicen* . Thomas Williamson suggested it was the juvenile form . Neither hypothesis became widely accepted . As only six good skulls , one juvenile braincase , and one recently discovered juvenile skull are known , additional material will help clear up these potential relationships . Williamson noted that in any case , juvenile *Parasaurolophus* probably had small , rounded crests like *P. cyrtocristatus* , that probably grew faster as individuals approached sexual maturity . Recent restudy of a juvenile braincase previously assigned to *Lambeosaurus* , now assigned to *Parasaurolophus* , provides evidence that a small tubular crest was present in juveniles . This specimen preserves a small upward flaring of the frontal bones that was similar to but smaller than what is seen in adult specimens ; in adults , the frontals formed a platform that supported the base of the crest . This specimen also indicates that the growth of the crest in *Parasaurolophus* and the facial profile of juvenile individuals differed from the *Corythosaurus* @-@ *Hypacrosaurus* @-@ *Lambeosaurus* model , in part because the crest of *Parasaurolophus* lacks the thin bony ' coxcomb ' that makes up the upper portion of the crest of the other three lambeosaurines .

= = = Rejected function hypotheses = = =

Many early suggestions focused on adaptations for an aquatic lifestyle , following the hypothesis that hadrosaurids were amphibious , a common line of thought until the 1960s . Thus , Alfred Sherwood Romer proposed it served as a snorkel , Martin Wilfarth that it was an attachment for a mobile proboscis used as a breathing tube or for food gathering , Charles M. Sternberg that it served as an airtrap to keep water out of the lungs , and Ned Colbert that it served as an air reservoir for prolonged stays underwater .

Other proposals were more physical in nature . As mentioned above , William Parks suggested that it was joined to the vertebrae with ligaments or muscles , and helped with moving and supporting the head . Othenio Abel proposed it was used as a weapon in combat among members of the same species , and Andrew Milner suggested that it could be used as a foliage deflector , like the helmet crest (called a ' casque ') of the cassowary . Still other proposals made housing specialized organs the major function . Halszka Osmólska suggested that it housed salt glands , and John Ostrom suggested that it housed expanded areas for olfactory tissue and much improved sense of smell of the lambeosaurines , which had no obvious defensive capabilities . One unusual suggestion , made

by creationist Duane Gish , is that the crest housed chemical glands that allowed it to throw jets of chemical " fire " at enemies , similar to the modern @-@ day bombardier beetle .

Most of these hypotheses have been discredited or rejected . For example , there is no hole at the end of the crest for a snorkeling function . There are no muscle scars for a proboscis and it is dubious that an animal with a beak would need one . As a proposed airlock , it would not have kept out water . The proposed air reservoir would have been insufficient for an animal the size of *Parasaurolophus* . Other hadrosaurids had large heads without needing large hollow crests to serve as attachment points for supporting ligaments . Also , none of the proposals explain why the crest has such a shape , why other lambeosaurines should have crests that look much different but perform a similar function , how crestless or solid @-@ crested hadrosaurids got along without such capabilities , or why some hadrosaurids had solid crests . These considerations particularly impact hypotheses based on increasing the capabilities of systems already present in the animal , such as the salt gland and olfaction hypotheses , and indicate that these were not primary functions of the crest . Additionally , work on the nasal cavity of lambeosaurines shows that olfactory nerves and corresponding sensory tissue were largely outside the portion of the nasal passages in the crest , so the expansion of the crest had little to do with the sense of smell .

===== Temperature regulation hypothesis =====

The large surface area and vascularization of the crest also suggests a thermoregulatory function . The first to propose the cranial crests of lambeosaurines related to temperature regulation was Wheeler (1978) . He proposed that there was a nerve connection between the crest and the brain , so that the latter could be cooled by the former . The next people to publish a related idea were Maryanska and Osmólska , who realized that like modern lizards , dinosaurs could have possessed salt glands , and cooled off by osmo @-@ regulation . In 2006 Evans published an argument about the functions of lambeosaurine crests , and supported why this could be a causing factor for the evolution of the crest .

===== Behavioural hypotheses =====

Parasaurolophus is often hypothesized to have used its crest as a resonating chamber to produce low frequency sounds to alert other members of a group or its species . This function was originally suggested by Wiman in 1931 when he described *P. tubicen* . He noted that the crests internal structures are similar to those of a swan , and theorized that an animal could use its elongated nasal passages to create noise . However , the nasal tubes of *Hypacrosaurus* , *Corythosaurus* , and *Lambeosaurus* are much more variable and complicated than the airway of *Parasaurolophus* . A large amount of material and data supports the hypothesis that the large , tubular crest of *Parasaurolophus* was a resonating chamber . Weishampel in 1981 suggested that *Parasaurolophus* made noises ranging between the frequencies 55 and 720 Hz , although there was some difference in the range of individual species because of the crest size , shape , and nasal passage length , most obvious in *P. cyrtocristatus* (interpreted as a possible female) . Hopson found that there is anatomical evidence that hadrosaurids had strong hearing . There is at least one example , in the related *Corythosaurus* , of a slender stapes (reptilian ear bone) in place , which combined with a large space for an eardrum implies a sensitive middle ear . Furthermore , the hadrosaurid lagena is elongate like a crocodilian 's , indicating that the auditory portion of the inner ear was well @-@ developed . Based on similarity of hadrosaurid inner ears to those of crocodiles , he also proposed that adult hadrosaurids were sensitive to high frequencies , such as their offspring might produce . According to Weishampel , this is consistent with parents and offspring communicating .

Computer modeling of a well @-@ preserved specimen of *P. tubicen* , with more complex air passages than those of *P. walkeri* , has allowed the reconstruction of the possible sound its crest produced . The main path resonates at around 30 Hz , but the complicated sinus anatomy causes peaks and valleys in the sound . The other main behavioural theory is that the crest was used for intra @-@ species recognition . This means that the crest could have been used for species

recognition , as a warning signal , and for other , non @-@ sexual uses . These could have been some of the reasons crests evolved in *Parasaurolophus* and other hadrosaurids . Instead , social and physiological functions have become more supported as function (s) of the crest , focusing on visual and auditory identification and communication . As a large object , the crest has clear value as a visual signal , and sets this animal apart from its contemporaries . The large size of hadrosaurid eye sockets and the presence of sclerotic rings in the eyes imply acute vision and diurnal habits , evidence that sight was important to these animals . If , as is commonly illustrated , a skin frill extended from the crest to the neck or back , the proposed visual display would have been even showier . As is suggested by other lambeosaurine skulls , the crest of *Parasaurolophus* likely permitted both species identification (such as separating it from *Corythosaurus* or *Lambeosaurus*) and sexual identification by shape and size .

== Paleopathology ==

Parasaurolophus walkeri is known from one specimen which might contain a pathology . The skeleton shows a v @-@ shaped gap or notch in the vertebrae at the base of the neck . Originally thought to be pathologic , Parks published a second interpretation of this , as a ligament attachment to support the head . The crest would attach to the gap via muscles or ligaments , and be used to support the head while bearing a frill , like predicted to exist in some hadrosaurids . One other possibility , is that during preparation , the specimen was damaged , creating the possible pathology . The notch , however , is still considered more likely to be a pathology , even though some illustrations of *Parasaurolophus* restore the skin flap .

Another possible pathology was noticed by Parks , and from around the notch . In the fourth , fifth , and sixth vertebrae , directly anterior to the notch , the neural spines were damaged . The fourth had an obvious fracture , with the other two possessing a swelling at the base of the break .

== Paleoecology ==

== Alberta ==

Parasaurolophus walkeri , from the Dinosaur Park Formation , was a member of a diverse and well @-@ documented fauna of prehistoric animals , including well @-@ known dinosaurs such as the horned *Centrosaurus* , *Chasmosaurus* , and *Styracosaurus* ; fellow duckbills *Gryposaurus* and *Corythosaurus* ; tyrannosaurid *Gorgosaurus* ; and armored *Edmontonia* , *Euoplocephalus* and *Dyoplosaurus* . It was a rare constituent of this fauna . The Dinosaur Park Formation is interpreted as a low @-@ relief setting of rivers and floodplains that became more swampy and influenced by marine conditions over time as the Western Interior Seaway transgressed westward . The climate was warmer than present @-@ day Alberta , without frost , but with wetter and drier seasons . Conifers were apparently the dominant canopy plants , with an understory of ferns , tree ferns , and angiosperms .

Some of the less common hadrosaurs in the Dinosaur Park Formation of Dinosaur Provincial Park , such as *Parasaurolophus* , may represent the remains of individuals who died while migrating through the region . They might also have had a more upland habitat where they may have nested or fed . The presence of *Parasaurolophus* and *Kritosaurus* in northern latitude fossil sites may represent faunal exchange between otherwise distinct northern and southern biomes in Late Cretaceous North America . Both taxa are uncommon outside of the southern biome , where , along with *Pentaceratops* , they are predominate members of the fauna .

== New Mexico ==

In the Fruitland Formation of New Mexico , *P. cyrtocristatus* shared its habitat with other ornithischians and theropods . Specifically , its contemporaries were the ceratopsian *Pentaceratops*

sternbergii ; the pachycephalosaur *Stegoceras novomexicanum* ; and some unidentified fossils belonging to Tyrannosauridae , ? Ornithomimus , ? Troodontidae , ? Saurornitholestes langstoni , ? Struthiomimus , Ornithopoda , ? Chasmosaurus , ? Corythosaurus , Hadrosaurinae , Hadrosauridae , and Ceratopsidae . When *Parasaurolophus* existed , the Fruitland Formation was swampy , positioned in the lowlands , and close to the shore of the Cretaceous Interior Seaway . The lowermost part of the Fruitland Formation is just younger than 75 @. @ 56 ± 0 @. @ 41 mya , with the uppermost boundary dating to 74 @. @ 55 ± 0 @. @ 22 mya .

Existing slightly later than the species from the Fruitland Formation , *P. tubicen* is also found in New Mexico , in the Kirtland Formation . Numerous vertebrate groups are from this formation , including fishes , crurotarsans , ornithischians , saurischians , pterosaurs , and turtles . The fishes are represented by the two species *Melivius chauliodon* and *Myledalphus bipartitus* . The crurotarsans include *Brachychampsia montana* and *Denazinosuchus kirtlandicus* . Ornithischians from the formation are represented by the hadrosaurids *Anasazisaurus horneri* , *Naashoibitosaurus ostromi* , *Kritosaurus navajovius* , and *P. tubicen* ; the ankylosaurids *Achillesaurus minor* and *Nodocephalosaurus kirtlandensis* ; the ceratopsians *Pentaceratops sternbergii* and *Titanoceratops ouranos* ; and the pachycephalosaurs *Stegoceras novomexicanum* and *Sphaerotherium goodwini* . Saurischians include the tyrannosaurid *Bistahieversor sealeyi* ; the ornithomimid *Ornithomimus* sp . ; and the troodontid " *Saurornitholestes* " *robustus* . One pterosaur is known , named *Navajodactylus boerei* . Turtles are fairly plentiful , and are known from *Denazinemys nodosa* , *Basilemys nobilis* , *Neurankylus baueri* , *Plastomenus robustus* . and *Thescelus hemispherica* . Unidentified taxa are known , including the crurotarsan ? *Leidyosuchus* , and the theropods ? *Struthiomimus* , *Troodontidae* and *Tyrannosauridae* . The beginning of the Kirtland Formation dates to 74 @. @ 55 ± 0 @. @ 22 mya , with the formation ending at around 73 @. @ 05 ± 0 @. @ 25 mya .

= = = Utah = = =

Argon @-@ argon radiometric dating indicates that the Kaiparowits Formation was deposited between 76 @. @ 6 and 74 @. @ 5 million years ago , during the Campanian stage of the Late Cretaceous period . During the Late Cretaceous period , the site of the Kaiparowits Formation was located near the western shore of the Western Interior Seaway , a large inland sea that split North America into two landmasses , Laramidia to the west and Appalachia to the east . The plateau where dinosaurs lived was an ancient floodplain dominated by large channels and abundant wetland peat swamps , ponds and lakes , and was bordered by highlands . The climate was wet and humid , and supported an abundant and diverse range of organisms . This formation contains one of the best and most continuous records of Late Cretaceous terrestrial life in the world .

Parasaurolophus shared its paleoenvironment with other dinosaurs , such as dromaeosaurid theropods , the troodontid *Talos sampsoni* , ornithomimids like *Ornithomimus velox* , tyrannosaurids like *Albertosaurus* and *Teratophoneus* , armored ankylosaurids , the duckbilled hadrosaur *Gryposaurus monumentensis* , the ceratopsians *Utahceratops gettyi* , *Nasutoceratops titusi* and *Kosmoceratops richardsoni* and the oviraptorosaurian *Hagryphus giganteus* . Paleofauna present in the Kaiparowits Formation included chondrichthyans (sharks and rays) , frogs , salamanders , turtles , lizards and crocodilians . A variety of early mammals were present including multituberculates , marsupials , and insectivorans .