The Paleontograph

A newsletter for those interested in all aspects of Paleontology
Volume 4 Issue 4 October, 2015

From Your Editor

Welcome to our latest issue. This issue is one of the final things I do before shutting down my office for my move west. With all that is going on, I've only managed 4 issues so far this year. My field season has suffered also although I did manage a few days of collecting dinosaur material in SD thanks to a friend that brought me along on one of his trips. I met a bunch of nice people and had a good time playing in the dirt for a few days.

I set my booth up at the Denver Coliseum show again this year and had an extremely successful show. For those of you that don't go to shows, I recommend it even if you are not a buyer. There are always cool things to see and cool people to meet. I went to shows for years before I started my business because I was always fascinated by what the commercial market brings to light that the scientific community just misses due to lack of funding, time, storage and just plain lack of interest. The shame of it is that as many in that community try to shut down the fossil marketplace, there are fossils out there just eroding away into dust. Anyone that spends time in the field as opposed to time at a desk can attest to this. The desk people also don't realize the chilling effect this will have on the pursuit of knowledge. Commercial and amateurs are responsible for many great finds as well as small finds that help round out the picture of what ancient times were like. **Once again, thanks to Bob Sheridan for continuing to produce the quality writing you are about to read.** I hope you enjoy this all Dinosaur edition.

The Paleontograph was created in 2012 to continue what was originally the newsletter of The New Jersey Paleontological Society. The Paleontograph publishes articles, book reviews, personal accounts, and anything else that relates to Paleontology and fossils. Feel free to submit both technical and non-technical work. We try to appeal to a wide range of people interested in fossils. Articles about localities, specific types of fossils, fossil preparation, shows or events, museum displays, field trips, websites are all welcome.

This newsletter is meant to be one by and for the readers. Issues will come out when there is enough content to fill an issue. I encourage all to submit contributions. It will be interesting, informative and fun to read. It can become whatever the readers and contributors want it to be, so it will be a work in progress. TC, January 2012

Edited by Tom Caggiano and distributed at no charge

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Brontosaurus Resurrected?

Bob Sheridan, April 11, 2015

Sauropods are very large dinosaurs with long tails and long necks. They come in a number of families, most of which lived in the Late Jurassic, although some survived to the Cretaceous. The specific family we are talking about today are the Diplodocidae ("double beams"). Diplodocids generally have longish necks, whip-ended tails, and shortish legs. They also have long heads with nostrils at the top of the skull and peg-like teeth. The group contains some very well known genera such as Diplodocus (for which the group is named), Apatosaurus, and Barosaurus, as well as some obscure ones such as Galeomopus and Leinkupal. Most diplodocids are excavated from the Morrison Formation of North America.

As with any type of dinosaur, the assignments of specimens to genera is always in flux. For example, "Supersaurus" and "Seismosaurus", once their own genera, were later assigned to Diplodocus. The oldest and most famous reassignment is "Brontosaurus." The great nineteenth century paleontologist O.C. Marsh described *Apatosaurus ajax* in 1877, and then gave a different name "Brontosaurus" to a separate specimen of a very similar dinosaur two years later. He also mistakenly assigned to Brontosaurus the skull of Camarasaurus, an unrelated sauropod. Elmer Riggs, in reviewing the literature on sauropods known up to 1903, thought Brontosaurus was not sufficiently different from Apatosaurus to deserve its own genus, and the older name took precedence. By that time, however, the blunt-skulled, tail-dragging, semi-aquatic image of "Brontosaurus" was an icon of popular culture. It was not until the 1970's that Apatosaurus was finally assigned the correct long Diplodocus-like skull. AMNH didn't revise its "Brontosaurus" mount until the refurbishment of the Dinosaur Halls in the mid-1990's.

It is quite common for paleontologists to reanalyze groups of dinosaurs to take into account new specimens, with more powerful computational techniques for generating cladograms, using ever-more specimens and more characters. The new work by Tschopp (2015) is an example of such a study. These authors included 81 individual specimens of sauropod, of which 49 are diplodocids. They noted 477 individual anatomical characters using all parts of the skeleton. It should be pointed out, of course, that all specimens are at least partially incomplete, and some are very fragmentary, e.g. are isolated skulls or femurs, so not every character can be coded for every specimen. However, computational methods handle this type of situation very well. There is an interesting chart in this paper showing which specimens can be coded for which characteristics. It should be noted that not every study of this type is at the level of individual specimens. Most use genera as the unit. The advantage of using individual specimens is that one can see whether the assignments of species and genera is self-consistent according to anatomical features.

The aim of such studies is to produce cladograms or "trees" that shows which "taxonomical units" (specimens, genera, etc.) are related to which others and how closely. The cladograms are sensitive to adjustable parameters and assumptions, so a prudent investigator produces cladograms several ways to see which conclusions will hold up. One result of the Tschopp et al. study seems robust: the two specimens originally named "Brontosaurus" cluster together, and seem similar to specimens named "Eubrontosaurus" and "Elosaurus". This group forms a sister group to three specimens named "Apatosaurus," plus two other specimens not yet assigned a genus. The differences between "Brontosaurus" and "Apatosaurus" could be enough to say they are different genera. Most of the distinction comes from the anatomical detail of the neck vertebrae.

The popular press has seized upon this finding with headlines about "Brontosaurus" returning. I am reminded of when, a couple of years ago, we heard that Archaeopteryx was "knocked off its perch" as the first bird, because it nested with dinosaurs instead of birds when Anchiornis was added to a cladistic study, but not when Anchiornis was left out. There is some hype involved with such headlines. You should keep the following in mind:

1. Such findings need to be repeated and checked against new specimens. Although, this is probably the best study so far, remember that we are dealing with incomplete information and mathematical methods that are never perfectly precise.

Since the sample sizes are so small, it may not be possible to truly know whether animals are truly distinct as genera or species or are just along a continuum. Also it is always possible mistake animals of different ages or sexes as different genera.

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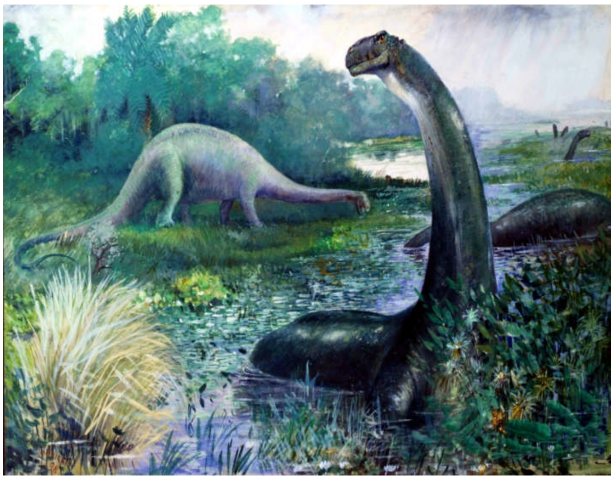
Brontosaurus Cont'd

3. It is not clear that "Brontosaurus" will ever be revived as a valid genus name. It may be decided that all these specimens should keep the name "Apatosaurus", but the species names need rearranging. The pre-1970s blunt-skulled, tail-dragging, iconic "Brontosaurus" will never come back since it is a mistake.



Finally, a side comment. When I first saw mention of the Tschopp et al. study in Science yesterday, I hadn't heard of the journal PeerJ in which the study appears. PeerJ is an open-access journal that has been around a few years, and I found at least three articles on paleontology. Anyone with an internet connection can read the articles in open-access journals, whereas you have to pay a yearly fee to read the articles in subscription journals. When I retire and stop having access to journals like Science, Nature, and PNAS through the company's subscriptions, there are at least four journals in which I can regularly find articles on paleontology: PLoS ONE, PLoS Biology, Palaeontographica Electronica, and PeerJ.

Sources:

Tschopp, E.; Mateus, O.; Benson, R.B.J.
"A specimen-level phylogenetic analysis and taxonomic revision of Diplodocidae (Dinosauria, Sauropoda)."
PeerJ 2015 3:e857.

Ontogeny of Centrosaurus

Bob Sheridan, April 19, 2015

Ontogeny is the anatomical trajectory an animal takes as it ages. For a fossil animal, it is important to know something about its ontogeny because there is always the danger of confusing animals of different ages (or sexes) as different genera or species. This is especially an issue with dinosaurs. For example, the issue of whether Nanotyrannus is a juvenile Tyrannosaurus or a separate dwarf species is still open, after 30 years of debate. More recently we have the debate over whether Torosaurus is really just a very old Triceratops. Generally speaking, unless there is a complete "growth series," where one can see various intermediate steps in an animal growing, which differences are ontological and which differences represent different species will never be so obvious that such debates can be avoided. Off the top of my head, I can think of only one dinosaur species *Protoceratops andrewsi* for which we have anything like a complete growth series.

Nowadays, it is a common practice to estimate the age of a dinosaur specimen by sectioning its long bones. Most dinosaurs have concentric "lines of arrested growth" (LAGs), which indicate a time where the growth of the animal slowed. Assuming one LAG per year, one can read the age of the animal by counting LAGs in the bones, much as we estimate the age of a tree by counting rings. So it is common to use LAGs as part of the argument whether one specimen is older than another, and it is also common to estimate the growth rate of dinosaurs using the ages and sizes of different specimens of the same species.

Today's story deals with how one can know what life-stage a dinosaur is in just by looking at its anatomy, and distinguishing age-related differences from variations among individuals. The species in question is *Centrosaurus apertus*. Centrosaurus ("pointy reptile") is a fairly large (20 ft. long) ceratopsian dinosaur with a large nasal horn and very small horns over the eyes. There is a large frill with largish fenestrae on either side. The frill is decorated with knobs along the edge, and two long horns on the top of the frill point forward and downward. Most known specimens of Centrosaurus are from Canada, where there are very large bonebeds of containing specimens of Centrosaurus of different sizes.

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Centrosaurus Cont'd

The usual explanation for the bonebeds is that herds of Centrosaurus were killed in a single event, such as being drowned while crossing a river during a flood. Centrosaurus is therefore a good animal to test "ontogeny by anatomy" methods, and Fredrickson and Tumarkin-Dratzian (2014) has undertaken the analysis.

These authors examined 47 Centrosaurus skulls and described them by a few hundred characters. The characters fall into three types: fusion state of bone joints, bone texture, and shape of horns and knobs. Interestingly, characteristics such as the overall shape of the skull and its size were omitted. The thought here is that many fossils are crushed or otherwise distorted, so the final shape is unreliable. Size is used only to determine the "polarity" of each characteristic under the assumption that the smallest individuals were the youngest. The overall aim of the analysis is to group together sets of skulls that are presumably the "same age", and find trends between the groups that would indicate increasing age. There are several ways to run the analysis: treating characters as "multistate" or "binary", including incomplete specimens or leaving them out, etc. In only certain treatments was a useful trend found. No one character is completely predictive of age, since there is much individual variation, but combinations of characters are indicative. These are the characteristics that seem most robustly correlated with age:

1. The tip of the nasal horn points backwards (recurved) in younger individuals, but forward (procurved) in older individuals.
2. The small horns over the eyes get smaller with age and bone in that region of the skull becomes more pitted.
3. The absolute size of the frill gets longer with age. This is a stronger trend in immature individuals than in older individuals. (We are familiar with this type of trend in humans. One can generally tell the age of children by size, but one cannot use the size of adults to determine age.) There is no indication of frills falling into two size classes at any given age. That is, there is no indication that the sexes were of different sizes.
4. Bones are more clearly fused in older individuals. Ornaments at the edge of the frill tend to be smaller in the very oldest.

Unexpectedly, the oldest individuals seem to form two different distinct groups based on anatomical characters. This can be explained in at least three different ways:

1. Mature males and mature females of *Centrosaurus apertus* look different.
2. There are actually two different species present, but we cannot tell the difference between species in the immature individuals.
3. Since there are fewer immature individuals, there is not enough data to distinguish two groups among them.

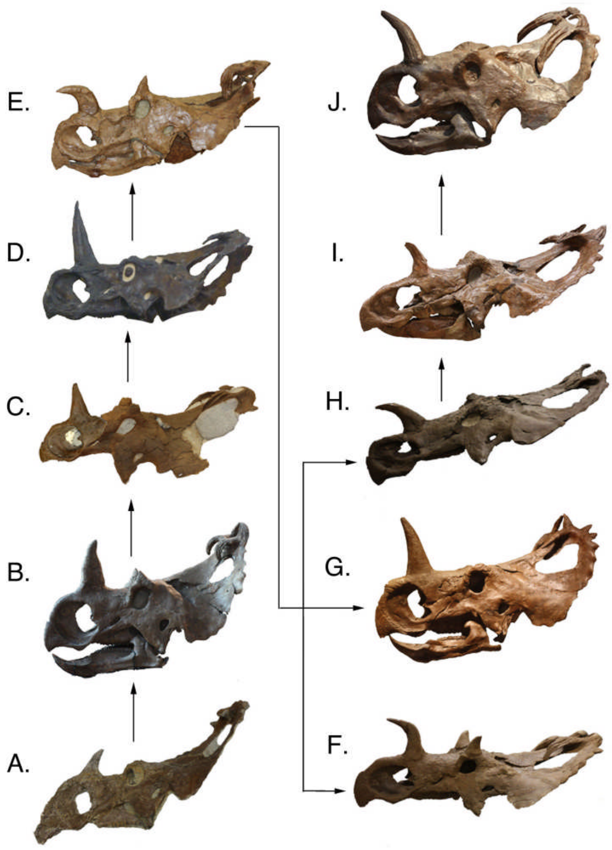
Bone histology was not used in this study for two reasons:

1. Data has not been published for Centrosaurus.
2. Skulls generally do not show LAGs.

The authors suggest that measuring the age of individuals Centrosaurus by histology (by counting LAGs for instance) could be use to test the trends they observed, with the caveat that absolute age is not the same as "maturity".

Sources:

Fredrickson, J.A. and Tumarkin-Dratzian, A.R. "Craniofacial ontogeny of *Centrosaurus apertus*" PeerJ 2014 2:e252.



Protoceratops: Can We Tell the Males from the Females?

Bob Sheridan, May 15, 2015

The topic of sexual dimorphism in dinosaurs, or in any other fossil animal, is important because we need to avoid assigning members of different sexes (or ages) as different species. My last article, for instance, discussed a study that proposed sexual dimorphism based on the shape of Stegosaurus plates. Ideally one would have enough adult specimens of any particular dinosaur to show that there were two distinct types. The number of dinosaurs for which this is true is fairly small, however. Even when the number of specimens is large, there can still be controversy. Errors can go both ways, and new information may make us change our mind. For example, there might be some confidence that two types of similar dinosaur represent "male" and "female" of the same species. However, if more precise dating reveals that all the"males" lived a million years later than "females", it seems likely that these two types do not represent different sexes but different species.

Today's story is about *Protoceratops andrewsi*, a Late Cretaceous ceratopsian dinosaur from Mongolia, that is very well known. Protoceratops is a sheep-size quadruped, with a beak, large thin frill, but no horns to speak of. We have a complete growth series for Protoceratops, from hatchling to adult. Many workers have supported the idea that there is clear sexual dimorphism in Protoceratops. There are criteria from Peter Dodson by which males and females might be distinguished, based on ratios of certain measurements. The "males" supposedly are wider in the back of the skull relative to the overall length of the skull, have a wider and taller frill, a taller nose, and a more curved beak.

A paper by Maiorino et al. (2015) reexamines this question. These authors looked at 29 complete skulls of Protoceratops and measured distances between landmarks in the skull. Distances were measured in 2D projection: dorsal and lateral. This is done because not all specimens can be measured directly in 3D because they are permanently in display cases. However, one can photograph them and measure the 2D photograph. Specimens that seemed distorted or restored with plaster were left out. The authors can confirm that, for the specimens Dodson looked at, one can separate Protoceratops skulls based on simple ratios. The ratio that looks best is frill length. One can plot log(frill length) vs. log(basal skull length), and find the best fit line through the data. There are large 11 skulls above the line, assigned to be "males" and 10 below the line, assigned as the "females." These groups are somewhat separated, i.e. there are few specimens lying on the line compared to above and below it. The authors also assign 4 skulls as "juveniles" based on size. These tend to be below the best-fit line, and in that the resemble the "females" in having a short, low frill and a small beak.

The question is whether the separation based on this one ratio will hold up when all the inter-landmark distance data is analyzed. The distances can be analyzed in a number of ways. The most used method in this study Principal Components Analysis, where the multiple measurements of can be projected into two dimensions. One can calculate the PCA using all the distances in the skull, just the frill, or everything but the frill. In any of these PCA projections, there is a clear separation of "juveniles" from "males" and "females", but no separation of "males" from "females". The only partly different feature is the shape of the beak. Moreover, the change in shape along the "female"->"male" trajectory is correlated with size. That is, the larger the animal is, the more it tends to resemble a "male." Thus, the evidence for shape changes with age is strong, but the evidence for a sexual dimorphism among Protoceratops adults unaccounted for by size is weak.

The authors, much to their credit, discuss reasons they have not completely eliminated the possibility that there is sexual dimorphism in Protoceratops:

1. The sample size is limited.
2. In animals like reptiles that continually grow it is hard to separate size effects from differences between sexes.
3. There could be a difference in parts of the animal other than the skull.
4. What was ruled out was one particular definition (Dodson's) of "male" and "female." Other definitions are possible.

Sources:

Maiorino, L.; Farke, A.A.; Kotsakis, T.; Piras, P. "Males resemble females: re-evaluating sexual dimorphism in *Protoceratops andrewsi* (Neoceratopsia, Protoceratopsidae)." PLoS ONE 2015, 10, e0126464

Sexual Dimorphism in Oviraptors?

Bob Sheridan, May 23, 2015

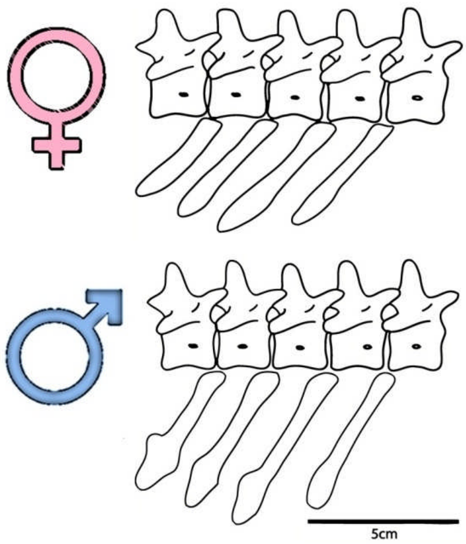
This is the third article about sexual dimorphism in dinosaurs I have written in a month. The topic of sexual dimorphism for any fossil animal is important because we need to avoid assigning members of different sexes (or ages) as different species. Telling the sexes apart in any fossil animal for which we do not have close analogs living today is difficult for a number of reasons:

1. We do not have any soft parts.
2. Skeletons are incomplete.
3. We usually do not have many examples of each species.

Today's story is about two specimens of dinosaur *Khaan mckennai*. Khaan is a medium-sized oviraptor. Oviraptors, which are found mostly in Asia, are unusual Late Cretaceous theropods that have short heads with toothless beaks, long arms, and shortish tails. Many oviraptors are preserved with long feathers. The two specimens of *Khaan mckennai* are MPC-D 100/1127 and MPC-D 100/1002. The two specimens were found in close proximity and it is thought they were killed together in a dune collapse. The first is complete and is the holotype specimen for *Khaan mckennai*. The second, slightly larger, is nearly complete. It is generally thought that these two represent adult animals based on the state of fusion of their vertebrae. The pair has nicknames, as unusual specimens often do: "Romeo and Juliet" or "Sid and Nancy," although no one before has claimed that the nicknames actually imply that the specimens are of opposite sexes.

Persons et al. (2015) pay particular attention to differences in the anterior tail chevrons of these specimens. Chevrons are finger-like projections that extend above or below the tail vertebrae in reptiles. In particular we are concerned about the chevrons at the base of the tail that point downward. For the past few decades, there has been some discussion whether extant reptiles like alligators have chevrons that are sexually dimorphic, and whether this applies to dinosaurs as well. One would expect the females to have shorter chevrons to allow the passage of eggs, and one might expect males to have longer chevrons to support the penis retractor muscles. Famously, sex assignments were made for Tyrannosaurus partly on this basis. Whether the expectations correspond to reality is controversial. So far no one has established chevron length as a reliable indicator of sex.

This is the main point: specimen MPC-D 100/1127 has straight finger-like anterior chevrons, but specimen MPC-D 100/1002 has slightly longer chevrons with spearhead-like tips. The authors therefore assign MPC-D 100/1002 as the "male" based on the argument in the previous paragraph. The authors also argue that since oviraptors probably used their feathered tails for sexual display, we might expect a difference in bones in the tail.



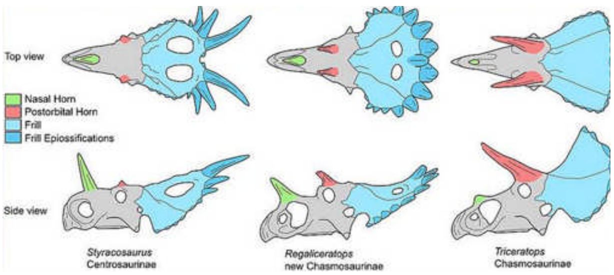
This is a pretty iffy assignment, as the authors admit (after all, the title includes the word "possible"):
1. Given that there are only two or three specimens of *Khaan mckennai*, it is hard to tell a sexual difference from a difference between individuals.
2. No other oviraptor shows this type of spearhead chevron shape.
3. The connection between displaying the end of a feathered tail and the required anatomy at the base of the tail is not clear.
At the end we have only a recommendation that other workers look for differences in chevrons in new specimens of dinosaur.
Sources:

Persons, W.S.; Funston, G.F.; Currie, P.J.; Norell, M.A.
"A possible instance of sexual dimorphism in the tails of two oviraptorosaur dinosaurs."
Scientific Reports 2015, 5: 9472.

Convergence in Ceratopsian Horn Styles?

Bob Sheridan, June 13, 2015

Ceratopsians are quadrupedal ornithiscian horned dinosaurs that lived in the Late Cretaceous. Triceratops is the most famous example. Except for the very primitive types like the sheep-size Protoceratops, ceratopsians vary from rhinoceros-size to elephant-size. Their specialized characteristics are in their very large heads, which have a sharp beaks, frills, and multiple horns. Ceratopsians overall come in two major groups: chasmosaurines and centrosaurines. Chasmosaurines (named for Chasmosaurus) have long forward-pointing brow horns (also called "postorbital" horns) and short nose ("nasal") horns. Triceratops is an example. Centrosaurines (named for Centrosaurus) have a long nose horn and short or nonexistent brow horns. Ceratopsians also have half a dozen or so bony processes at the edge of the frill (called "episossifications") on each side. These tend to be bigger in centrosaurines, the extreme example being Styracosaurus, which has three long curved spikes on each side. Within each class there is variation in the length of the frill, curve of the horns, etc. Given the large variation, the current thought is that the horns were used mostly as species or sexual display, and less often as weapons. One can distinguish chasmosaurines from centrosaurines on a number of skull characteristics separate from the horns.



Brown and Henderson (2015) describe a new species of ceratopsian they call *Regaliceratops peterhewski* ("royal horned face discovered by Peter Hews"), based on a nearly complete skull that was excavated from the St. Mary River Formation in Alberta, Canada. The likely date on this formation is 67-69 Myr. The skull, which is about 1.6 meters long is missing only the lower jaw and rostral bone (beak). The ends of the horns are missing, but enough remains that one can estimate their length.

Regaliceratops has an unusual horn configuration in that the brow horns are thin, short, and point straight up. The nose horn is somewhat thicker and points up as well. The epiossifications are large and spade-shaped. (To me they resemble Megalodon teeth in shape and size.) That is, overall the cranial ornamentation of Regaliceratops is more centrosaurine than chasmosaurine. The interesting part is that the other details of the skull, including the nose, eye, and frill tell a different story. A phylogenetic analysis would suggest that Regaliceratops is deeply nested among the advanced (and younger) chasmosaurines, somewhere in the branch that contains Triceratops. Also, Regaliceratops lived one or two million years after all known centrosaurines had gone extinct.

The obvious conclusion is that Regaliceratops is an advanced chasmosaurine that converged upon a centrosaurine-like ornamentation. This suggests that the ornamentation in ceratopsians is more "plastic" than previous suspected.

Sources:

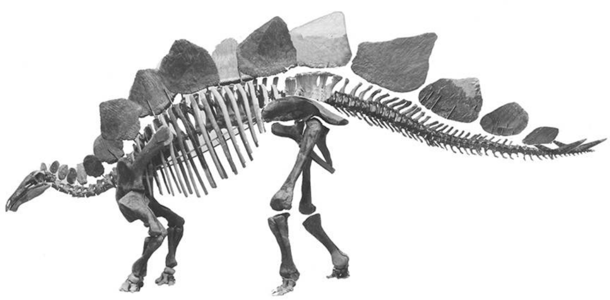
Brown, C.M.; Henderson, D.M.
"A new horned dinosaur reveals convergent evolution in cranial ornamentation in ceratopsidae."
Current Biology 2015, 25, 1-8.

Stegosaurus Plates Segregated by Sex?

Bob Sheridan, May 1, 2015

Stegosaurs are moderately large (5-9 meters) ornithiscians (herbivores) with small heads. Specimens come from the Upper Jurassic of North America, Asia, and Africa. The animal from which they are named, Stegosaurus ("roof reptile"), was described by O.C. Marsh in 1877. Classic dinosaur tropes about having "a brain the size of a walnut" or having "two brains" come from Stegosaurus.

It is hard to appreciate how bizarre stegosaurs are since we are so familiar with them. The most outstanding features are their "ornamentation", four bony spikes on the tail and a largish number of upward facing bony plates on the neck, back, and tail. From more recent specimens we know about pebbly armor on the underside of the neck. The back plates vary in shape from large and rounded to very spike-like, depending on the individual genus (rounder for Stegosaurus, more spikelike for Kentrosaurus). They also vary in size based on location on the back, the larger ones being over the hips. In the living animal, the plates were not attached to the rest of the skeleton, but were embedded in the skin. Thus the exact number and arrangement of the plates (two rows, a single row with plates alternately pointing left or right, etc.), may not be obvious if the bones of the specimen are jumbled. The presence of large blood vessel channels indicates that the plates were covered in skin. The function of the plates has been debated for 150 years. Suggestions are: protection from predators, thermoregulation, sexual display and species recognition. Given the wide variety of shape of plates among the stegosaur genera, the latter seems most likely.



Stegosaurus, from the Morrison Formation in the United States, is probably the largest and best known stegosaur. As mentioned before, the back plates (numbered 18) in Stegosaurus tend to be flat from left-to-right, but have a rounded or tear-drop shape as seen from the side. The plates have definite rugose base where they were embedded, so one can tell "top" from "bottom." One can also tell "front" from "back" where there is asymmetry: we know from articulated specimens that the most narrow part of the plate points backward.

A new paper (Saitta, 2015) suggests that Stegosaurus plates come in two "morphs" and that the morphs indicate a difference in sex. The study in question examined 40 plates from a particular species *Stegosaurus mjosi*. Five specimens of this species were found in a new bonebed in Montana. Other previously discovered specimens were also included. Specific measurements were taken for each plate and the measurements subjected to principal components (PCA) analysis. Histological specimens were taken from some plates, and CT-scanning was done on some plates and spikes.

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The PCA analysis shows there are two separable "morphs": "wider" and "taller". The wider plates are oval in shape and are longer from front-to-back, than top-to-bottom. The taller plates are generally rectangular or tear-drop shaped and are longer from top-to-bottom, than front-to-back. The wider plates also have about a 40% larger surface area on the average. The narrow plates have rougher bases and more prominent blood vessel channels. Both types of plates are seen in the new Montana bonebed: four wide, five tall. The rest are incomplete, so it is hard to tell.

The difference in shapes could be associated with a number of attributes:
1. Individuals of different ages.
2. Location on the back.
3. Individuals of different species.
4. Individuals of different sexes.

The authors argue that if the difference in plates is due to age, they ought to see some plates in-between the two extreme morphs. However, these are not seen. In articulated specimens of Stegosaurus, one can tell cervical, dorsal, and caudal plates based on variations in size. One can assign both wide and tall morphs to cervical, dorsal, and caudal types. To the authors, this suggests an individual animal possessed all wide or all tall plates. The authors argue that it would be unlikely that two different species would occur jumbled together in the new Wyoming bonebed. The histology of the plates examined here, compared to histology of other known Stegosaur, plus the characteristics of the blood vessel channels in the plates, suggest that all specimens were sexually mature adults.

If we can eliminate the other explanations, then a correlation between the morphs and sex remains. The authors point out a similarity in other animals, such as bovines, where one sex invests more energy in "ornamentation" (horns in the case of bovines) than the other. On the other hand, if both sexes of Stegosaurus retained plates, this could suggest a function of the plates other than display.

Sources:

Saitta, E.T.
"Evidence for sexual dimorphism in the dinosaur *Stegosaurus mjosi* (Ornithiscia Stegosauria) from the Morrison Formation (Upper Jurassic) of western USA."
PLoS ONE 2015,10, e0123504

Chilesaurus, Another Weird Theropod

Bob Sheridan, June 21, 2015

Theropods are a branch of bipedal non-avian dinosaurs. The more advanced ones, i.e. those that lived after the Triassic, generally have large heads with sharp teeth, shortish necks, smallish arms (usually with three fingers), and long legs. All have hollow long bones. Most of them are obvious predators. Think Allosaurus and Tyrannosaurus as prototypes. There are some variations from this plan, however. Ornithomimids (the ostrich mimics) have small heads on long necks. They have toothless beaks and long arms. Many gastroliths are preserved with their skeletons, so it is likely they were something other than obligate carnivores, perhaps herbivores or omnivores. Therizinosaurs are even more deviant in that they have a small head on a long neck, but also have leaf-shape teeth and enormous claws. The conclusion is inescapable that they are theropods that converged on a herbivorous lifestyle.

Note that I deliberately said "non-avian" in the above paragraph. Birds are theropods, and they would be considered ultra-weird by many criteria compared to the "Allosaurus" standard.

In the past year more complete specimens of previously known theropods have been turning up, proving them more unusual than expected. For example:

1. Spinosaurus, with its long notched snout and back sail, was thought to be unusual before, but last October we learned it also has very short legs and dense bones. This suggests it was the only known dinosaur that could swim.
2. Deinocheirus was known for decades only from a single arm. It was thought to be a very large ornithomimid. The complete specimen shows it to indeed be an ornithomimid, but one with a very heavy body and a back sail. Not a swift runner like most ornithomimids.

You may have noticed the weird non-avian theropods are all from the Cretaceous. A recent paper by Novas et al. (2015) describes a new, very unusual theropod from the Late Jurassic Toqui Formation of Chile.

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The paper is based on four specimens, which would have been anywhere from 1.2 to 3.2 meters in length as living animals. The best specimen, which appears to be a juvenile because its bones are not quite fused, would have been 1.6 meters long. It is nearly complete, missing only the tail and part of the skull. The authors have given this species the name *Chilesaurus diegosaurezi* ("Reptile from Chile"; honoring Diego Suarez who discovered the first bones in the Toqui Formation).

Image credit: Gabriel Lio

Overall, the silhouette of Chilesaurus resembles that of a prosauropod, the Triassic ancestors of sauropods. (Plateosaurus is the best-known example.) Of course, Chilesaurus is very different than prosauropods in detail.

Chilesaurus has a short roundish skull with columnar teeth that have serrations only at the crown. To me the teeth resemble the teeth of Iguanodon, a fairly advanced herbivore. Chilesaurus has a long slender neck. It has three fingers and four toes. The number of toes alone is very unusual for a Jurassic theropod.

The pubic bone of Chilesaurus points backwards. The significance of this requires an aside. Dinosaurs can be broadly divided into two types based on the orientations of the pelvic bone. In saurischians ("lizard-hipped" dinosaurus) the pubic bone points forward. Saurischians include prosauropods, sauropods, and theropods. In ornithischians ("bird-hipped" dinosaurs), the pubic bone points backwards. Since all ornithischians are herbivorous, one idea is that when the pubic bone points backwards, it makes more room for a large digestive tract, which is needed to digest plants. So we can say Chilesaurus converged on the hip design of herbivorous dinosaurs, as is true of Therizinosaurus the other known theropod herbivore, which also has a backward-pointing pubic bone.

The link between a backward pubic bone and herbivory has plenty of exceptions, however. The prosauropods and sauropods are super-herbivores and their pubic bone points forward, as is typical for saurischians. Also, in a few types of theropods, including birds, the pubic bone points backwards. The dromeosaurs were definitely predators, despite their backward pubic bones. (I have always found it confusing that birds actually do not belong to the "bird-hipped" dinosaurs, but these names were made up in 1888, long before anyone knew about the ancestry of birds.) So it might be possible to say that Chilesaurus anticipated the design of very advanced theropods.

Phylogenetic analysis places Chilesaurus firmly within the tetanurans, which is a fairly advanced group of theropods. Chilesaurus would fall somewhere between Ceratosaurus and Megalosaurus, which are also from the Jurassic. It should be noted that Chilesaurus does not fall near Therizinosaurus, which means that these two animals likely developed herbivory separately. While the spine, forelimb, and pelvis of Chilesaurus, is much like a typical tetanuran, the ankles, and feet are more primitive, resembling those of earlier theropods and prosauropods. The teeth, of course, are unique among theropods.

Sources:

Novas, F.E.; Salgado, L.; Suarez, M.; Agnolin, F.L.; Ezcurra, M.D.; Chimento, N.R.; de la Cruz, R.; Isasi, M.P.; Vargas, A.O.; Rubilar-Rogers, D.
"An enigmatic plant-eating theropod from the Late Jurassic period of Chile."
Nature, 2015, 522, 331-334.