

# **Analysis of the talus or astragalus bone of select squirrels for taxonomic diagnosis**

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## ABSTRACT

Reconstructions of past climates and landscapes are often performed through the analysis of the morphology of fossils deposited in rock and sediment. Commonly, these fossils are identified by their cranial anatomy, with little attention given to the postcranial elements. Here I will emphasize the use of the postcranial anatomy specifically, the astragalus. I have evaluated twelve different characters on the astragali of five different squirrel species. Only one character (the convexity of the navicular articular surface) was found to be diagnostic for the prairie dog (*Cynomys ludovicianus*) but suites of characters could be used to identify the other four species. As a preliminary study, the goal of this project is to provide a foundation for future research to confirm that actual potential for utilization of these characters in taxonomic identifications.

## INTRODUCTION

Paleoecological reconstructions are available through numerous proxies within naturally occurring data sets (Veltre et al, 2008). Fossils as a proxy for this purpose are such that if the observer can determine the taxonomic placement of a fossil organism, and the organism's preferred environment is known, then the environment in which the fossil was deposited can be inferred.

The cranial anatomy of rodents deposited within a talus cone in the Parker's Pit cave system in South Dakota has been used for paleoecological inferences. This sediment at Parker's Pit is analyzed by screen washing samples taken from the talus cone, with individual fossils being picked out of the washed sediment later. This method has recently only been used to target the teeth, jaws, and skulls of small mammals. While effective, this method relies solely on the preservation of these skeletal elements. The use of teeth has offered a vast array of reliable methods for diagnosing different organisms even to the species level, as well as for determining paleoecological reconstructions (Veltre et. al., 2008; Vennemann, Hegner, 1998), but may not be the only reliable method. Little research has been performed on the potential for accurate diagnosis of taxonomy through the observation of the postcranial anatomy (e.g. vertebrate limb bones, foot bones, etc.); the goal of this project is to evaluate the utilization of the tali of these rodents for that purpose.

Within the post-cranial anatomy, several bones may be available for the purpose of diagnosing taxonomic placement. This project is based on the astragalus or talus, a bone joining the distal tibia and proximal calcaneus, which allows for the hinge-like motion of the ankle in tetrapods. The talus may be much more structurally dense and therefore may have a much greater potential for preservation than many other bones of the body due to its integral

placement within the anatomy and physiology of an organism. It may be intuitive that the talus would form quickly with the anatomical elements of an organism at a very young age, due to the importance of locomotion within organism to escape potential predation. This may make the talus a reliable diagnostic tool when extracted from an organism at any stage in its life cycle, whereas under-developed or deciduous teeth may be more difficult to identify.

This project will observe the morphological attributes of the tali of some modern squirrels from different lifestyles, on the basis that different styles of locomotion would result in the necessity of different talar phenotypes. The goal of this project is to provide preliminary determination of diagnostic characteristics within the morphology of these bones and develop a key from them which is to be utilized in the basic identification of these organisms to at least a genus level. There may also be new taphonomic information to arise, if the numbers reported through post-cranial identification do not agree with the numbers reported through dentitions. This key is to provide a foundation for a new mode of insight into previous studies which have gained information only through the teeth of these fossil rodents.

## **MATERIALS AND METHODS**

There was little difficulty in deciding how to go about this research. It was decided to be potentially fruitful to take on a project which would observe potentially diagnostic characteristics within the tali of squirrel species related to those found in the sediment at Parker's Pit. There are many bones within this sediment, and deciding which bone to observe was dependent both on the potential for reliable diagnostic characters to be present within the bone, and on the time constraint of graduation allowing these characters to be observed and reported. The talus was chosen due to its ease of identification among other bones within the sediment, and its high preservation potential. This was to be the observed portion of postcranial anatomy within squirrels of differing genera and lifestyles.

The specimens used are of modern mammals which were collected in affiliation with the vertebrate paleontology lab and maintained at the Earth and Mineral Sciences Museum at The Pennsylvania State University. Because they were collected in the modern day, there is 100% certainty in the identification of these specimens, which allows for immediate knowledge of their taxonomic placement and their natural locomotive habit. The small sample sizes ( $n=1$ ) of these specimens creates the largest source of potential error. With the morphology of each specimen only being represented by one individual from each species, the reliability of this research is greatly decreased. However, this entire project is intended as a foundation for future research, and not as an end-all for taxonomic identification of squirrels.

The lifestyle of each specimen is known (Higgins et al, 2002; Kays, Wilson, 2002), and is used in conjunction with objective observation of the tali of the organisms. Two of the observed specimens, *Sciurus niger* and *Tamiasciurus hudsonius* are arborescent; two other specimens *Cynomys ludovicianus* and *Spermophilus franklinii* are terrestrial and burrow-dwelling; the fifth observed species, *Tamias striatus* is an intermediate and may display attributes present for both lifestyles. It is the assumption of this project that a different lifestyle and utilization of the surrounding environment will result in a different phenotypic response than that of any other lifestyle. In this regard, a postcranial feature which would be heavily utilized from birth such as the talus may prove to be extremely reliable in taxonomic diagnosis from the same bone found isolated within an unknown fossil sample.

The methods used for determination of the reliability of these characters were simple and straightforward, which allows for easy understanding, interpretation and review of this work. Optical microscopy was the most utilized method of observation, and the most straightforward. Talus specimens were placed individually under a microscope and observed in dorsal, medial, plantar, and lateral positions, with a record of the observed differentiations between all of them kept. In addition to microscopic observation, resolute photographs were taken of each specimen in the same four positions in order to capture still images of the characters. These photographs were used to accurately trace the dimensions of the specimens onto illustration board, at which point illustrations were made representing each bone (with the exception of *S. niger*) in dorsal, medial, plantar and lateral views. These illustrations will be used to accurately depict the key morphological characters, and to supplement the descriptions and the table of descriptive characters.

Through the standardized observation techniques, and knowledge of terminology made available through related literature (Whitehead et al, 2005), this project has the necessary means to objectively report the differentiating aspects of the tali of modern day rodents. With this osteological research comes a foundation for future research into the use of postcranial anatomy for the diagnosis of any vertebrate organism.

#### ANATOMICAL ABBREVIATIONS and DESCRIPTIONS

The following description focuses on the right tali of five squirrel genera: *Sciurus*, *Tamiasciurus*, *Cynomys*, *Spermophilus*, and *Tamias*, supplemented by the illustrated views of each specimen (excluding *Sciurus*). Comparisons are based purely within these five individuals, with nomenclature being greatly derived from Paul F. Whitehead et al in "A Photographic Atlas for Physical Anthropology" (2005). The descriptions will first take account of characters present on the terrestrial species, then on the arboreal species, and finally on the intermediate species, *Tamias striatus*.

Abbreviations for features on the tali of these organisms are as follows: **acs**, anterior calcaneal articular surface; **atp**, anterior trochlear pit; **lms**, lateral malleolar articular surface; **mcs**, medial calcaneal articular surface; **mms**, medial malleolar articular surface; **ns**, navicular articular surface; **pcs**, posterior calcaneal articular surface; **ptrc**, plantar trochlea; **slc**, talar (astragalar) sulcus; **trc**, trochlea; **mtrc/ltrc**, medial and lateral trochlear borders.

## RESULTS AND DISCUSSION

With the observation of the anatomy of these individuals, the goal is to develop a key of likely definitive characters within the genera in order to test them on unknown tali with the Parker's Pit sediment. The results show that there are distinctive characters within the tali of these animals that would indeed separate them taxonomically, at least to an individual level within the vertebrate paleontology lab here at Penn State, unless otherwise stated. Whether or not this key holds up across the genera is a matter of future research and much larger sample sizes. As previously stated, the sample sizes of this study are grossly diminished both by availability of the specimens at the EMS museum, and by the time allowance for completion of research and shipment of specimens from other equipped museums.

### *Cynomys ludovicianus*

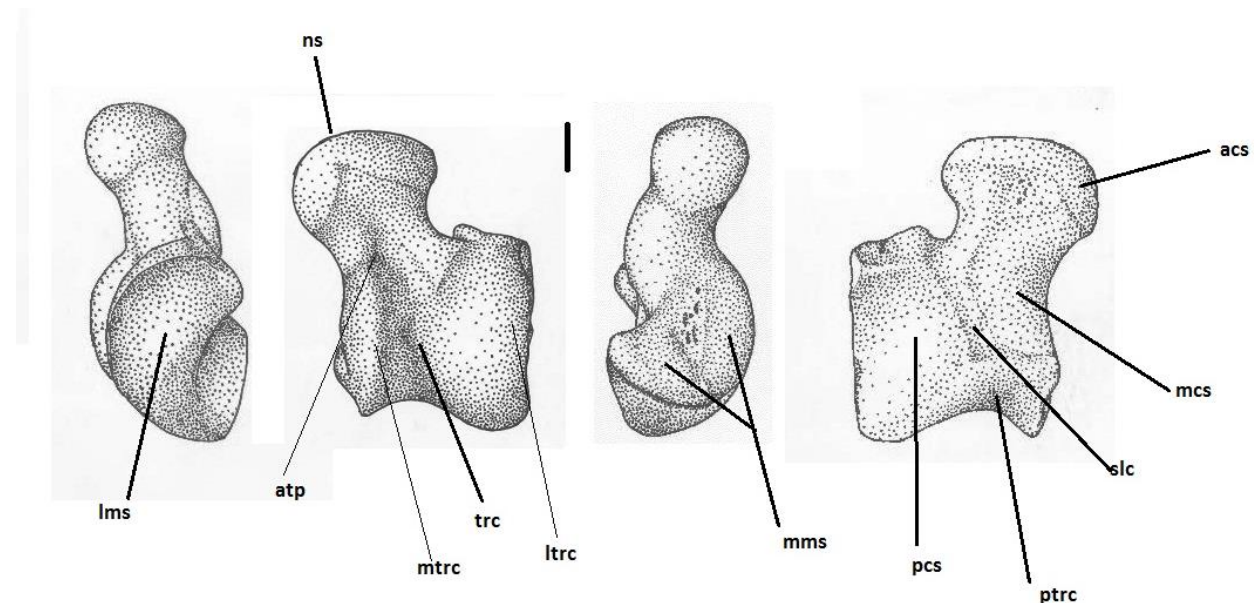


Figure 1. R. talus of *Cynomys ludovicianus*, Scale Bar= 1mm. Labels present are intended to show generalized synapomorphic features throughout each individual described. They will not be present on the remaining illustrations. The illustrations are all arranged in lateral, dorsal, medial and plantar views, respective to their appearance in this paper.

The right talus of *Cynomys ludovicianus* is squat in character and has an overall smoothness to the surface features. The smoothness did not hinder the capability of noticeable features, and was instead used as a defining character itself. A high medial trochlea border allows for a full view of the plantar surface, due to its evenness with the commonly higher lateral trochlea border (Fig. 1). The navicular articular surface is rounded and convex, with great distinction between its surface and the medial calcaneal articular surface. There is great differentiation between the anterior calcaneal articular surface and the medial calcaneal articular surface, as well as between the medial calcaneal articular surface and the talar sulcus, and between the talar sulcus and the posterior calcaneal articular surface. A feature originally thought to have promise as a defining character of *Cynomys* and possibly all terrestrial squirrels was a notch present on the latero-anterior trochlea and extending into the lateral neck. This feature however, was discovered within arboreal species as well. While it can still be used to describe *Cynomys*, it must be used with caution when describing an entire group of these organisms.

### ***Spermophilus franklinii***

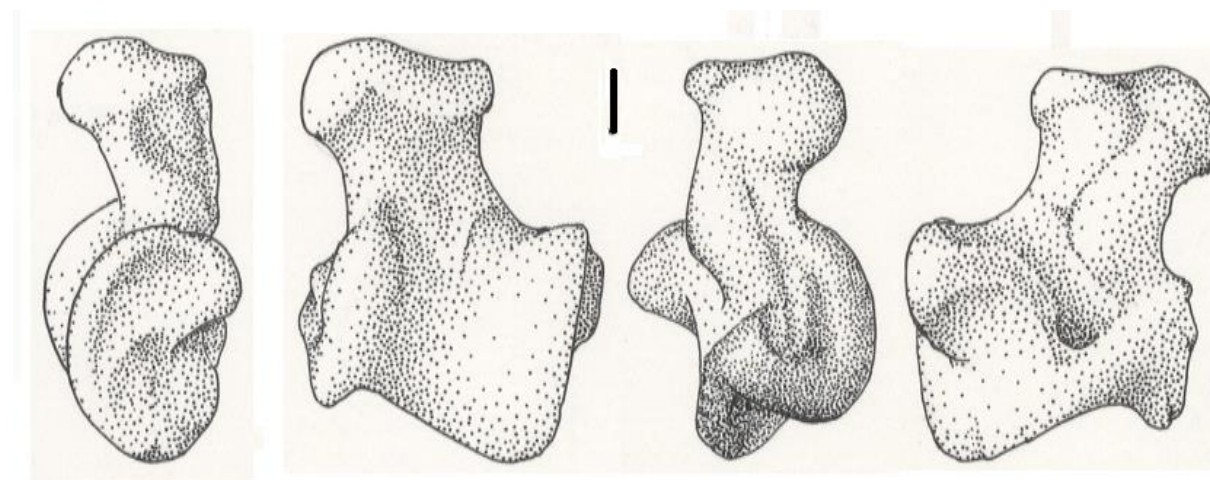


Figure 2. Right talus of *Spermophilus franklinii*, Bar= 1mm.

The right talus of *Spermophilus franklinii* shows many feature comparable to both terrestrial and arboreal genera of squirrels. It shares the same overall smoothness and squat, stocky form as *Cynomys*, as well as a high medial trochlea border. The differentiation between the anterior, medial, and posterior calcaneal articular surfaces is highly comparable to that of the other terrestrial species observed as well. There are other features present though,

including the concavity, lateral extension, and overall lateral flare of the navicular articular surface. Visible in both dorsal and plantar view, there is concavity of the posterior trochlea; and, only visible in plantar view, there is a medial extension of the plantar trochlea. Also present in plantar view is a depression of the medial sulcus latero-posteriorly. It is note-worthy that *Spermophilus franklinii* seems to share a feature present on the arboreal species; located on the antero-lateral neck, just posterior to the lateral navicular articular surface, is a notch for accepting an antero-dorsal protuberance on the calcaneus. While this paper does not go into detail on the functional morphology of these characters, it did seem promising at first that this feature would mainly define those species with an arboreal lifestyle; however this is not purely the case.

### ***Sciurus niger* (illustration not shown)**

The talus of *Sciurus niger* is the largest in the sampled group, and for this reason was not illustrated, in order to save time and space upon scaling of all images. The concavity, lateral extension, and overall antero-lateral flare of the navicular articular surface is of first mention, as it seems proportionately greater within *Sciurus niger* than in those other species in which the feature is present. Also present is the anterior trochlear depression, which is of great relief within the arboreal species. The differentiation between the anterior, medial, and posterior calcaneal articular surfaces is present here, though not as easily definable as in the terrestrial species. Another trait present seems to be the overall acute angle made by the neck to the rest of the bone body. This acuteness is likely a diagnostic feature of many species (Carrano, 1996), and may be the most reliable diagnostic feature present within arboreal species of squirrel. The notch on the latero-anterior neck just posterior to the navicular articular surface is present and of great relief within *Sciurus niger*.

### ***Tamiasciurus hudsonicus***

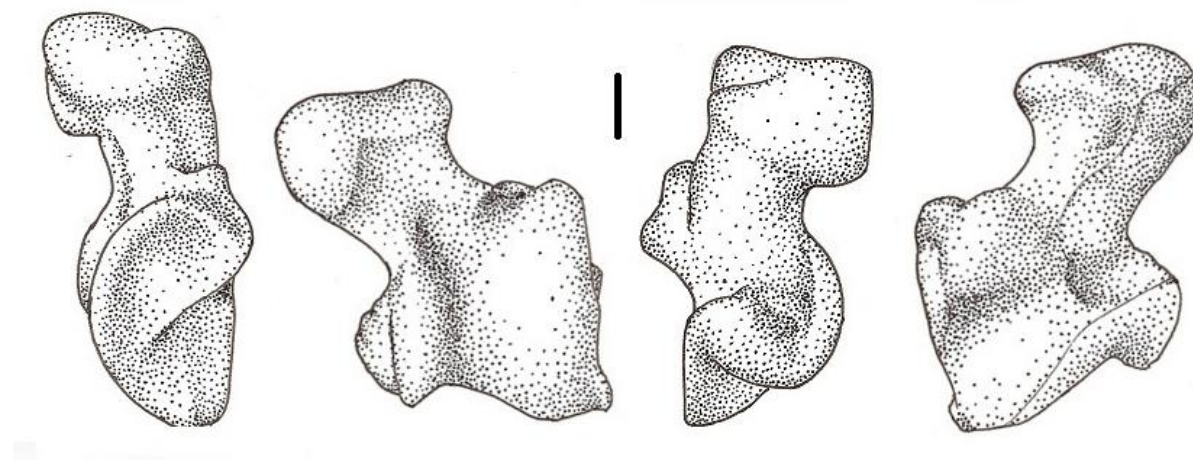


Figure 3. Right talus of *Tamiasciurus hudsonicus*, Bar= 1mm



This talus shows the concavity and overall flare of the navicular articular surface, but shows less lateral extension of the surface within *Tamiasciurus* (Figure 3). The notch posterior to the navicular articular surface is also present in *Tamiasciurus*; however its relief is smoothed, though this may be a result of specimen storage or a feature in the individual. The notch on the latero-anterior trochlea is present here as well as in *Cynomys*, which makes it less useful for taxonomic placement from this level of observation. There is noticeable differentiation of the anterior, medial, and posterior calaneal articular surfaces, as well as a familiar latero-posterior depression of the medial sulcus. Concavity of the trochlea in dorsal and plantar views is present, as well as a medial extension of the plantar trochlea. The angle of the neck is greatly acute even in comparison to those other species with an acute neck, and especially in comparison to those terrestrial species with a less acute angle.

### ***Tamias striatus***

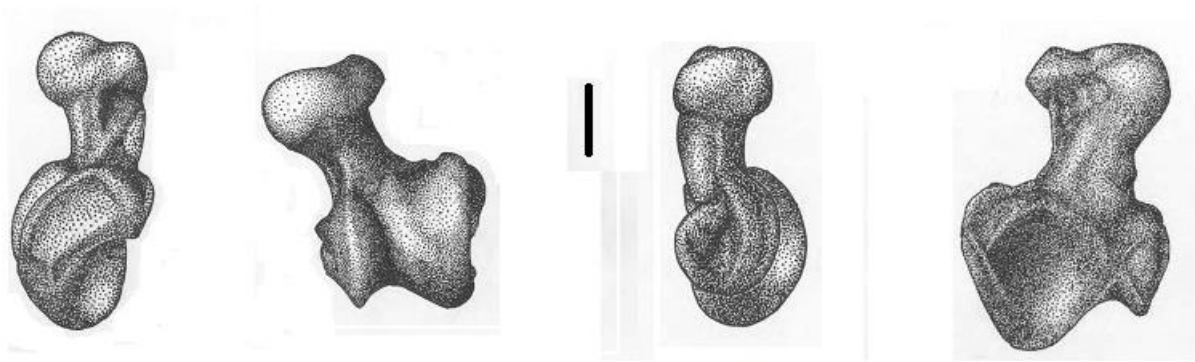


Figure 4. Right talus of *Tamias striatus*, Bar= 1mm

The intermediate species within the sampled group, *Tamias striatus*, is the smallest of the group and also the greatest sampled. This specimen shows a great deal of concavity of the navicular articular surface, as well as lateral extension and the antero-lateral flare present in the other species. The depression in the anterior trochlea is present in *Tamias* and was first observed in this specimen. Also first observed in this genera was the latero-anterior notch present on the neck just posterior to the lateral navicular articular surface; within *Tamias striatus*, this notch presents with a great deal of relief and a sharper ridge dorsally. There is medial extension of the plantar trochlea, however to a lesser degree than that of the other species sampled, and the latero-posterior depression of the medial sulcus is present as well to an approximate proportional equivalence. The angle of the neck is definitely acute in *Tamias striatus*, however not to as great of a degree as in the other arboreal species, confirming, for the purposes of this project, the choice of *Tamias striatus* as a reliable intermediate species.

These features, summarized in Table 1, were the most observable characters across the spectrum of sampled species within the scope of this project. While it is likely that with further



research and observation and larger sample sizes of the bones of squirrels from varying lifestyles, there would be an emergence of recurring characters that could be considered more reliable and defining within genera, the purposes of this project have been fulfilled in that a foundation for future research has been constructed. After cataloging the features described, I hope to see utilized the following key of features for all of these species. This key may be used by any interested party, and may hold in it a valuable first step for determining the classification of a fossil rodent species.

	<i>Cynomys</i>	<i>Spermophilus</i>	<i>Tamias</i>	<i>Tamiasciurus</i>	<i>Sciurus</i>
Squat/stocky	x	x			
High med trochlea border	x	x			
Convex ns	x				
Differentiation of mcs, acs, slc	x	x		x	x
anterio-lateral notch, trochlea	x			x	
Lateral ns flare		x	x	x	x
Medial sulcus depressed		x	x	x	
Plantar trochlea med. Extension		x	x	x	
Cancave trochlea		x	x	x	
Posterior ns notch		x	x	x	x
Concave ns		x	x	x	x
Lateral ns extension		x	x		x
Anterior trochlear pit				x	x
Acute angle of neck			x	x	x

**Table 1.** Observed defining characters across the five genera of squirrels researched. The first two columns are that of terrestrial species, the middle is of the intermediate *Tamias striatus*, and the final two columns are of the arboreal squirrels. The x's refer to the presence of the feature within the respective individual.

## CONCLUSIONS

Within the sample sizes and the allotted time, there were particular characters that were seen as potentially diagnostic for each genus:

- *Cynomys* featured a squat and stocky form, as well as a high medial trochlea border. *Cynomys* also exclusively features the convexity seen in the navicular articular surface. The taxonomic diagnosis of this genus may come when these features are observed in conjunction with the differentiation between the medial and anterior calcaneal articular surface and plantar sulcus, as well as the antero-lateral notch present on the trochlea.

- *Spermophilus* also displays the squat and stocky form seen in *Cynomys*, also sharing the high medial trochlea border. The potential for diagnosis lies in observing these characters together with a concave navicular articular surface, and a more extreme extension and flare of the lateral navicular articular surface than seen in *Cynomys*. The neck of *Spermophilus* is straight relative to *Tamiasciurus*, diminishing the potential for misidentification between the two genera.
- *Tamias* shares many features with terrestrial and arboreal species. Being the smallest of the samples, its size may be the first indicator of its origin. In addition to small size, the acute angle of the neck, subtle differentiation between plantar articular surfaces, and concavity of the navicular articular surface will assist in differentiating this genus from the others.
- *Tamiasciurus* displays a similar antero-lateral notch to that present on *Cynomys*. This feature will be diagnostic for *Tamiasciurus* if seen in conjunction with an acute angle of the neck, a pit on the anterior trochlea, concavity of the navicular articular surface, and differentiation of the plantar articular surfaces with the sulcus.
- *Sciurus* displays the largest size of the group. The size of this specimen, as well as the differentiation of the plantar surfaces with the sulcus, pit on the anterior trochlea, acute neck angle, and the extension and flare of the lateral navicular articular surface will help to differentiate this genus from the others sampled.

This analysis has shown that there is potential in the use of the postcranial anatomy of squirrels for the diagnosis of lifestyle, and possibly genera. As a preliminary study, this work will serve as a foundation for future work with identification of unknown species from their preserved astragali. We have shown here that it is indeed possible to determine taxonomic placement through anatomical characters other than the teeth and jaws of these specimens. With this possibility may eventually come new data sets describing paleoecological reconstructions, reworking our view of the Earth in its past.

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