DETERMINING INDIVIDUAL *EDMONTOSAURUS* FROM A DISARTICULATED BONE BED USING PRINCIPAL COMPONENTS ANALYSIS

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ABSTRACT - Caudal vertebrae from numerous individuals of *Edmontosaurus* were examined for morphological variation using Principal Components Analysis (PCA). The vertebrae were from a disarticulated, monospecific bone bed in Corson County, South Dakota. Results of the PCA showed a minimum of 50 parallel lines which are interpreted to represent the existence of complete sections of tails from individual animals within the bone bed. These lines showed a range in size from large to small animals, as well as large to small vertebrae. This arrangement also facilitated examining fusion characteristics between the vertebral centrum and associated processes. The results suggest that the fossil assemblage represents an accumulation over a short, rather than long period of time, as well as a possible method for identifying individual animals or numbers of animals in other disarticulated bone beds.

INTRODUCTION - The findings presented in this poster were part of a study done for the Masters Thesis "The Hadrosaurid Genus *Edmontosaurus* from the Cretaceous Hell Creek Formation of South Dakota" (Mink [Gould], 2007, North Dakota State University). At the time of the study, Concordia College of Moorhead Minnesota had an immense collection of *Edmontosaurus* bones from a monospecific bone bed, from Corson County, SD. In that collection were hundreds of caudal vertebrae from adult and sub-adult animals (no juveniles were found in the bone bed). It was initially thought that by running a Principal Components Analysis (PCA) looking at the morphology of the bones, that different age groups of animals (adult, sub-adult) might clump together, or sexual dimorphism might become revealed in that section of post-crania.

MATERIALS & METHODS - Over 1600 caudal vertebrae were housed in the Concordia College collection, 888 of which were prepared at the time of study. Of those, 577 were complete enough to be consistently measured. Bones included ranged from just posterior to the sacrum, to the terminal end of the tail. All measurements were made to the nearest millimeter using digital calipers. Length, anterior medial height, and anterior width were taken (Figure 1). After measurement, each bone was also assigned a value representing the amount of fusion present between the centrum and spinous process. Those completely fused were noted as a 1, partially fused as 2, and unfused as 3 (Figure 1).

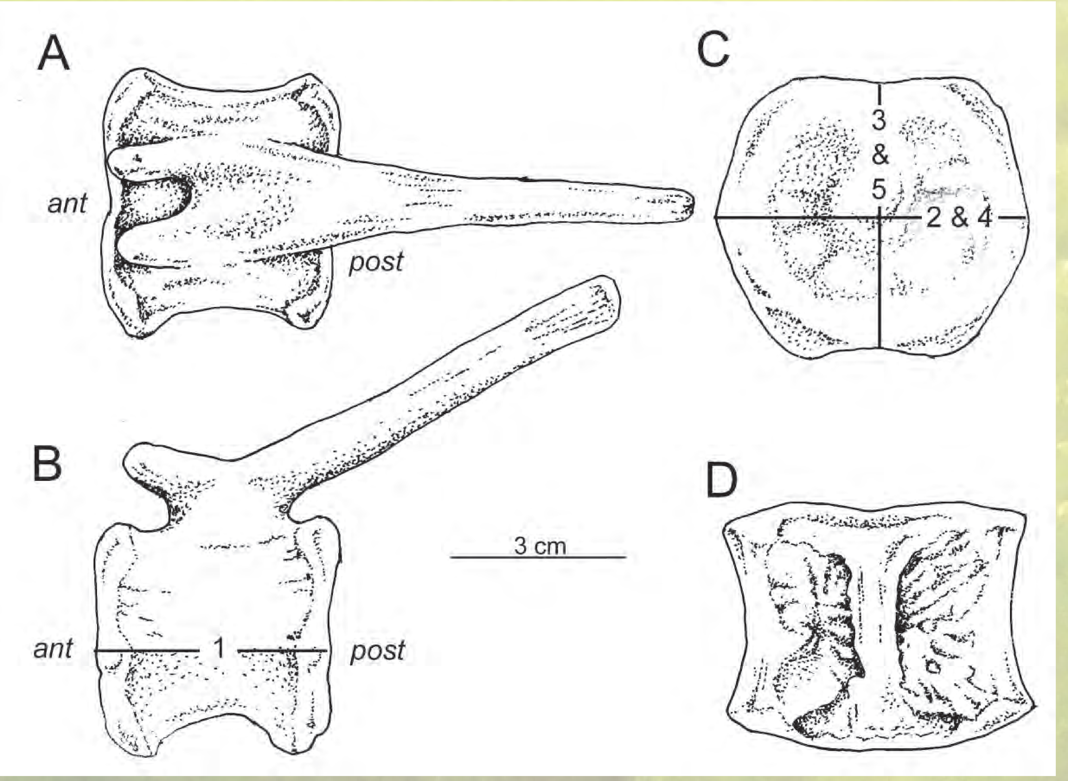

Figure 1: *Edmontosaurus* caudal vertebrae A) dorsal view of mid-caudal vertebra. B) Lateral view of mid-caudal vertebra, showing fusion between centrum and spinous process. C) Anterior view of mid-caudal vertebra; numbers correspond with order of measurements taken (4 & 5 later discarded). D) Dorsal view of mid-caudal vertebra, showing unfused sutures between centrum (visible) and spinous process (removed).

RESULTS - In the PCA, the caudal vertebrae were arranged in a linear continuum, with bones closer to the sacrum more positive along the PC2 axis (Figure 2). There is a change in shape in the bones over the length of the tail. Bones closest to the sacrum held a more heart-shaped appearance on the anterior and posterior surface (or more tall than wide). Bones closer to the end of the tail were more hexagonal on the anterior and posterior surface, with height approaching an equal width. The curve seen along the continuum could be due to this change in shape, but the exact cause is unknown.

To examine point location not explained by size, the middle of the initial curvature was reexamined (Figure 3). A series of distinct, parallel rows were found obliquely oriented to the overall trend of large-to-small seen in axis PC1. Each secondary row was separated by size along axis PC1, and morphological variation along axis PC2.

To explain the parallel trends observed in the rows, we hypothesized that each row represented either 1) individual tails or 2) numerical placement of vertebrae within tails. Upon examination of the bones from individual rows, it became apparent that they represented sequential vertebrae from the tails of individual animals. The vertebrae of one of the tail rows is shown in Figure 4.

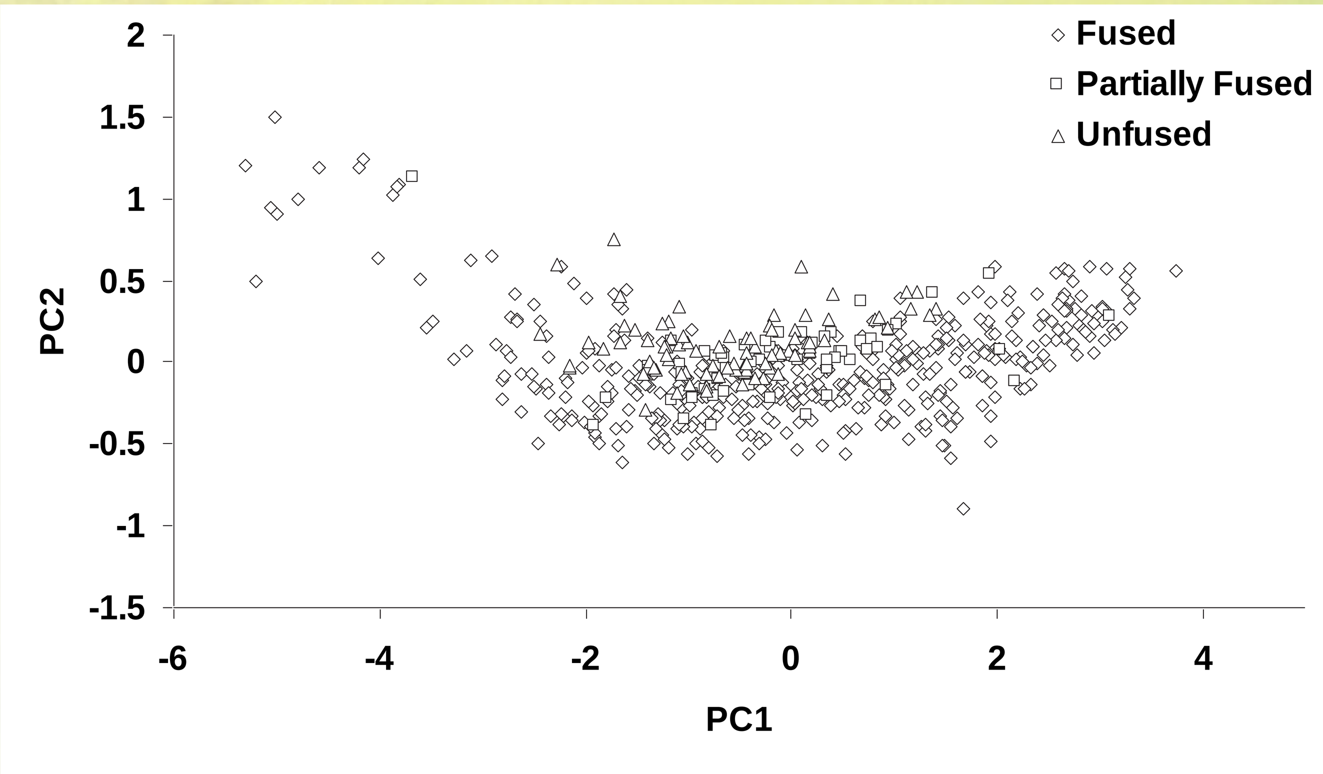

Figure 2: PCA results of axis PC1 and PC2. PC1 exhibits change in shape of the bones, from more hexagonal (positive) to heart-shaped(negative). PC2 exhibits change in size, with larger bones more positive, and smaller bones more negative.

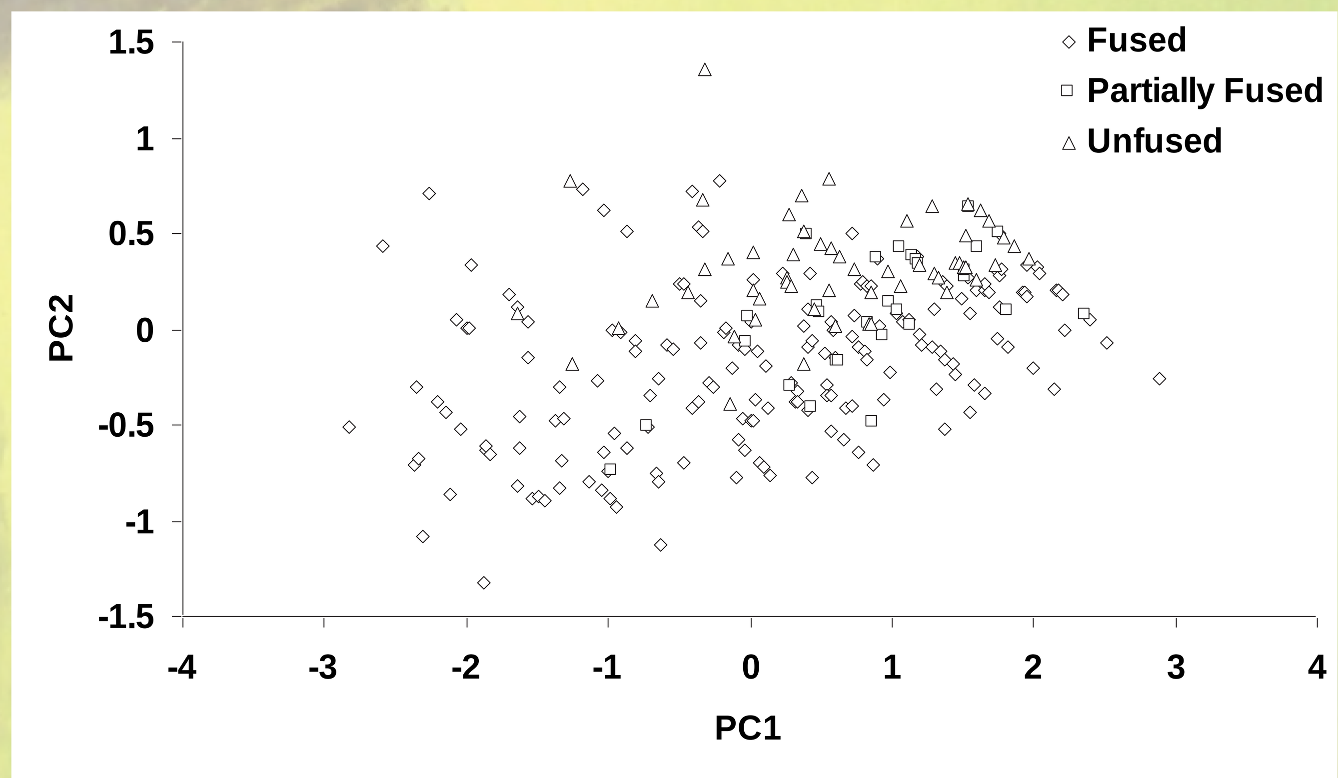

Figure 3: Reexamined portion of original results. Each parallel line represents an individual animal's tail, with smaller animals more positive along axis PC1, and larger, older animals more negative.

Figure 4: Reconstructed tail using results in Figure 3. Caudal vertebrae were pulled out and organized according to their placement in the parallel lines. Minus missing elements, the sections fit together as hypothesized.

DISCUSSION - The rows of individual tails making up the larger linear continuum represent gradation from smaller to larger tails, or younger to older animals. Tails from young individuals exhibited a combination of fused and unfused vertebrae, whereas the largest tails showed complete fusion between centrum and processes. Few smaller or terminal caudal vertebrae were unfused while larger mid-to-anterior vertebrae showed a wide range of fused and unfused specimens. Only the primary axis PC1 eigenvalue (1569.67) was greater than the Broken-stick eigenvalue (1011.57), with the other axes non-significant. The trends within the plot indicate separation along axis PC2, even if statistically non-significant.

SUMMARY - The various states of fusion seen in the vertebrae, once organized into individual tails, show that the bones in the tail of an individual begin to fuse first towards the tip of the tail, progressing towards the sacrum, rather than all at the same time. The smaller the vertebrae in the collection, the less likely one is to find an unfused sample, thus fusion begins at a relatively early age. Lack of small unfused juvenile bones is most likely due to the general age of the animals deposited, rather than sorting (Colson et al., 2004; Mink, 2007).

Based on the results of the PCA analysis, a minimum of 50 individual tails were present in the collection. This method of identifying individual tails from within a bone bed may be applicable to other bone beds, especially those with disarticulated remains. Estimations of the numbers of individuals found within a bone bed can be made using caudal vertebrae, rather than with teeth or jaws (Badgley, 1986).

LITERATURE CITED

Badgley, C. 1986. Counting individuals in mammalian fossil assemblages from fluvial environments. PALAIOS 1:328-338.

Colson, M.C., R. O. Colson, and R. Nellemoe. 2004. Stratigraphy and depositional environments of the upper Fox Hills and lower Hell Creek Formations at the Concordia Hadrosaur Site in northwestern South Dakota. Rocky Mountain Geology 39(2):93-111.

Mink [Gould], R. 2007. The Hadrosaurid genus *Edmontosaurus* from the Cretaceous Hell Creek Formation of South Dakota. Masters Thesis, North Dakota State University, Fargo, ND, 141pp.

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