The Morrison Formation sauropod consensus: A freely accessible online spreadsheet of collected sauropod specimens, their housing institutions, contents, references, localities, and other potentially useful information

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Abstract

The Morrison Formation has been explored for dinosaurs for more than 150 years, in particular for large sauropod skeletons to be mounted in museum exhibits around the world. Several long-term campaigns to the Jurassic West of the United States produced hundreds of specimens, ranging from isolated, fragmentary bones to nearly complete skeletons of these enormous herbivorous animals. Given the sheer number of specimens, keeping track of what is housed in which institution is paramount to study variability, taxonomy, and consequently geographic and temporal distribution of the various species and genera recognized from the Morrison Formation. In an attempt to facilitate these studies, we have compiled an online spreadsheet intended to combine all the available information on sauropod specimens from collection databases, published literature, and personal observations. These include lists of contents of the specimens, in what institution the material is housed, references mentioning, describing, figuring, providing measurements and/or 3D scans, locality data and stratigraphy, as well as other potentially useful data for research purposes. The spreadsheet is openly accessible, but editing is currently restricted to the authors of this study, in order to ensure high-quality data curation to keep the file as useful as possible.

Introduction

The Morrison Formation is one of the best-known Mesozoic terrestrial ecosystems, with thousands of vertebrate, invertebrate, and plant specimens recovered over more than 150 years of paleontological exploration (Gee et al., in press; Tschopp et al., in press; Chure et al., 2006; Foster, 2007; Whitlock et al., 2018). It therefore provides a unique study case where we can address questions regarding ecosystem structure and functioning. This study case is particularly interesting because of its

surprisingly high diversity of megaherbivores, with potentially more than 20 species of sauropod dinosaurs, living alongside smaller, but still large herbivorous ornithischians, as well as other, small-sized herbivores (Tschopp et al., in press, 2015; Whitlock et al., 2018). Studies concerning distribution of species through space and time of Morrison Formation deposition are both hampered and facilitated by the fact that specimens have been excavated or acquired by numerous institutions from around the world. This facilitates studies through easier access to specimens for researchers that are not in North America (one does not necessarily have to travel to the USA to study Morrison Formation sauropods, as there is often material housed in some institution close-by; Fig. 1). However, it also hampers study, because it is difficult to keep track of where which specimen is housed, and what institution may hold those specimens that would be paramount to study first-hand for a particular research question. First-hand study of material in collections is crucial for the understanding of morphological details, as well as in order to score specimens into phylogenetic matrices, because small features on the bones, broken edges, or bilaterally asymmetric characters can often not be detected or identified in figures (Tschopp et al., 2018), but may be useful for phylogenetic inference (Tschopp and Upchurch, 2019) or functional morphology studies. Many institutions do have most of their collections searchable online, but rarely are there online resources that let you search multiple databases simultaneously. Although considerable efforts to facilitate and make uniform these searches are now underway in most institutions, we are still far from simple online searches for that particular specimen one needs for his or her research. The Morrison Formation sauropod consensus is an attempt to facilitate such a search. It has been compiled over the past 10 years. Given the continued exploration, preparation, and study of material from the Morrison Formation, this spreadsheet will never be complete – however, with the combined efforts of several sauropod specialists working on the Morrison Formation, this curated spreadsheet will be a useful tool for future research on these enigmatic and popular animals. We hope that it might also inspire other efforts to compile and publish similar spreadsheets for different taxa, geological units, and geographic regions.

Methods

The spreadsheet has evolved over the last 10 years to include a number of columns with data that proved useful for selecting specimens for particular analyses and planning collection visits. It is available throughout the following link: https://docs.google.com/spreadsheets/d/1OazMLgm6rZe7SaNP3YexbqS9Vo-FsqFyFoJktcr2H8Q/edit?usp=sharing. The columns are taxonomic identification, specimen number, contents, references (with subcategories for who only mentioned it, and who provided description, figures, measurements, or 3D scans), information on ontogeny, locality, stratigraphy, current repository, and other potentially useful information. Below, we will explain in more detail what these columns contain and how they are organized.

Taxonomy

Taxonomic identification of the specimens is of course the first information that researchers generally look for. Here, we usually follow the latest taxonomic assessment based on a detailed study, where these exist. In many cases, particularly in incomplete fossils, there has never been a detailed, published scientific assessment of their taxonomy, so we copied the information from the collection databases of the particular institutions. In other cases, taxonomy has changed over time. These changes are generally not recorded in this column, but in the column “further info” (see below).

Specimen Number

Other than taxonomy, specimen numbers should generally remain the same, as long as the institution does not change. Even if a specimen has been traded or sold to another institution, the original collection numbers are usually preserved with the specimens, and new catalog numbers could be added in the new institution. One such case is the holotype specimen of the diplodocid *Galeamopus hayi*, which was collected by the Carnegie Museum crew in 1902 and 1903, cataloged as CM 662, later traded to the Cleveland Museum of Natural History, where it got the number CMNH 10670, and again sold to the Houston Museum of Nature and Science, where it is currently mounted and cataloged as HMNS 175 (Tschopp et al., in press; McIntosh, 1981). We attempted to have every specimen in the list with its current, most recent catalog number, so in the case of the holotype of *G. hayi*, we used HMNS 175. The older specimen numbers are mentioned under “further info” (see below). There are also cases, where specimens got renumbered while remaining in the same institution (e.g., the holotype scapulacoracoid of the diplodocid *Supersaurus*; Jensen 1985; Curtice & Stadtman 2001; Lovelace et al. 2007); we also recorded the old specimen numbers in the column “further info” here.

Contents

The contents of a specimen list the single bones preserved. This appears to be fairly straight forward, but complete information is not always available from collection databases, which sometimes only list “partial forelimb”, or “nearly complete specimen”. For some of these, we were able to add information after personally visiting collections and seeing the specimens first-hand. In most cases, however, we just had to copy the information from the collection databases. Hence, if somebody would need all the metacarpals from Morrison Formation sauropods for a particular study, specimens that preserve “forelimbs”, or a “manus” instead of “metacarpals” specifically would have to be searched for as well.

References

We intend to list every study that mentioned a particular specimen, be it in the text, in a figure, in a table, as an operational taxonomic unit in a phylogenetic matrix, or as comparative material. We then subdivide this information in the subcategories of references actually describing (parts of) the specimen, figuring it, providing measurements, and we mention references that produced 3D models of elements of the specimen.

Ontogeny

Body size and ontogenetic stage can be interesting traits to understand ecological and evolutionary aspects, such as community structure, age segregation, and body size evolution. Being such an important factor, it deserves its own column. We note general size (where reported from collection databases or publications), as well as assessments of Histological Ontogenetic Stages (HOS; see Klein and Sander, 2008), and other subdivisions proposed in the literature (e.g., H-MOS; Woodruff et al., 2017).

Further info

Comments, or information not covered in other columns, are mentioned here. These can include changes in taxonomic interpretation, old specimen numbers, the presence of tooth traces, if the specimen is a type, information on the preservation of the bone, association with other specimens, and other potentially useful information for research.

Locality

Locality information is obviously crucial for studies of temporal and spatial ranges of species and genera. However, not in all cases is locality data publicly available, for a variety of reasons including protection from fossil poaching (e.g., in the case of the *Suuwassea* type locality and the northern-most occurrence of *Camarasaurus*; Harris and Dodson, 2004; Woodruff and Foster, 2017). Therefore, we do not provide exact GPS data here, and only include the names of the quarries and localities if these are already published. Qualified researchers can generally access more precise locality data (based on locality name) from the repositing institutions.

Stratigraphy

The stratigraphy of the Morrison Formation is extremely complex, and changes considerably throughout its enormous geographical extent. Thus, geological members such as the Brushy Basin Member are not recognized throughout the entire formation, and long-distance correlations are very difficult (e.g., (Tschopp et al., in press; Trujillo, 2006; Maidment et al., 2017). Here, we note identified geological members where reported, exact ages if known, and attribution to the Systems Tracts reported by Maidment et al. (2017). In absence of other stratigraphic data, we aim to include position relative to formation and/or member boundaries, if available.

Current Repository

Not much explanation is needed for the column listing the current repository. However, it is interesting to note that some of the specimen numbers do not correspond to the current repository because some institutions have traded or given away specimens in the past, and new specimen numbers from the current repositories are unknown to us. In some cases, specimens have also been split, with parts being sent to one institution, and other parts to another, or kept in the original institution (e.g., CM 662, now HMNS 175, see above; and some specimens from

Bone Cabin Quarry given away or traded by the American Museum of Natural History).

Work in Progress

As mentioned above, ongoing excavation and study of these specimens makes it impossible that a list like this will ever be completed. Not just this, but having it assembled over a long time span, and combining information from several databases and researchers, data standardization is an issue, which is being tackled over time. For instance, in the contents column, bones are sometimes abbreviated, the side of the element is mentioned before or after the element, and some entries are in all capitals. Also, having added some of the columns over time (in particular the subcategories of the references for the descriptions, figures, etc., and the ontogeny and stratigraphy columns), some of the information that belongs into these newer columns might still be hidden in other columns (stratigraphic information was initially recorded in the locality or further info columns, for example). Nonetheless, we think that the currently available information in the spreadsheet is highly useful for exploratory analyses to find particular bones, specimens from a particular geographic area or stratigraphic level, or potentially juvenile individuals, as well as any reference that might mention them. Qualified researchers who would like to contribute in curating the spreadsheet are welcome to contact the lead author, and can be easily added as spreadsheet editors.

A future, very useful step would be to add links to the mentioned references. At this time, references are only mentioned as in-text references, with no added bibliography. Many of these papers are well-known among people working on Morrison Formation sauropods, but for students or other researchers entering the field, finding them may be difficult. Given the huge task of adding link to the thousands of mentioned references, however, will be extremely time-consuming, and has therefore been postponed. Generally, however, a search for the specimen number on Google Scholar, restricted to the year of the particular publication, should find the reference

Discussion and Conclusion

In order to provide a more complete picture of the information currently available, we conducted some quick and basic data exploration. In its current state, the spreadsheet lists 3226 specimens housed in more than 60 institutions on six continents (Fig. 1). About 240 specimens have associated information on ontogeny. Approximately a third has associated locality data. The only 16 entries in the stratigraphy column are because this was one of the last added columns, so that much of this information is still contained in other columns, or has yet to be extracted from collection databases and published literature. This short data exploration shows that thousands of sauropod specimens from the Morrison Formation are available for study around the world and indicates the potential of such a spreadsheet for planning and conducting future research projects.

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References

Chure, D. J., R. Litwin, S. T. Hasiotis, E. Evanoff, and K. Carpenter. 2006. The fauna and flora of the Morrison Formation: 2006. New Mexico Museum of Natural History and Science Bulletin 36:233–249.

Foster, J. R. 2007. Jurassic West: The Dinosaurs of the Morrison Formation and Their World. Indiana University Press, Bloomington and Indianapolis, USA, pp.

Gee, C. T., H. M. Anderson, J. M. Anderson, S. R. Ash, D. J. Cantrill, J. H. A. van Konijnenburg-van Cittert, and V. Vajda. in press. Postcards from the Mesozoic: Forest landscapes with giant flowering trees, enigmatic seed ferns, and other

naked-seed plants; pp. in E. Martinetto, E. Tschopp, and R. Gastaldo A. (eds.), Nature through Time. Springer, Berlin, Germany.
Harris, J. D., and P. Dodson. 2004. A new diplodocoid sauropod dinosaur from the Upper Jurassic Morrison Formation of Montana, USA. Acta Palaeontologica Polonica 49:197–210.
Klein, N., and M. Sander. 2008. Ontogenetic stages in the long bone histology of sauropod dinosaurs. Paleobiology 34:247–263.
Maidment, S. C. R., D. Balikova, and A. R. Muxworthy. 2017. Magnetostratigraphy of the Upper Jurassic Morrison Formation at Dinosaur National Monument, Utah, and prospects for using magnetostratigraphy as a correlative tool in the Morrison Formation; pp. 280–298 in K. Ziegler and W. Parker (eds.), Deciphering Complex Depositional Systems. Elsevier, Amsterdam, The Netherlands.
McIntosh, J. S. 1981. Annotated catalogue of the dinosaurs (Reptilia, Archosauria) in the collections of Carnegie Museum of Natural History. Bulletin of Carnegie Museum of Natural History 18:1–67.
Trujillo, K. C. 2006. Clay mineralogy of the Morrison Formation (Upper Jurassic-? Lower Cretaceous), and its use in long distance correlation and paleoenvironmental analysis. New Mexico Museum of Natural History and Science Bulletin 36:17–23.
Tschopp, E., and P. Upchurch. 2019. The challenges and potential utility of phenotypic specimen-level phylogeny based on maximum parsimony. Earth and Environmental Science Transactions of The Royal Society of Edinburgh 109:301–323.
Tschopp, E., O. Mateus, and R. B. J. Benson. 2015. A specimen-level phylogenetic analysis and taxonomic revision of Diplodocidae (Dinosauria, Sauropoda). PeerJ 3:e857.
Tschopp, E., O. Mateus, and M. Norell. 2018. Complex overlapping joints between facial bones allowing limited anterior sliding movements of the snout in diplodocid sauropods. American Museum Novitates 1–16.
Tschopp, E., S. C. R. Maidment, M. C. Lamanna, and M. A. Norell. in press. Sauropod dinosaurs from the Jurassic of Wyoming are not all what we thought – a reassessment of a historical collection from the northern Morrison Formation, with implications for our understanding of the geographical distribution of sauropod taxa. American Museum Novitates.
Tschopp, E., D. E. Barta, W. Brinkmann, J. R. Foster, F. M. Holwerda, S. C. R. Maidment, S. F. Poropat, T. M. Scheyer, A. G. Sellés, B. Vila, and M. Zahner. in press. How to Live with Dinosaurs: Ecosystems across the Mesozoic; pp. in E. Martinetto, E. Tschopp, and R. A. Gastaldo (eds.), Nature through Time. Springer, Berlin, Germany.
Whitlock, J. A., K. C. Trujillo, and G. M. Hanik. 2018. Assemblage-level structure in Morrison Formation dinosaurs, Western Interior, USA. Geology of the Intermountain West 5:9–22.
Woodruff, D. C., and J. R. Foster. 2017. The first specimen of *Camarasaurus* (Dinosauria: Sauropoda) from Montana: The northernmost occurrence of the genus. PLOS ONE 12:e0177423.
Woodruff, D. C., D. W. Fowler, and J. R. Horner. 2017. A new multi-faceted framework for deciphering diplodocid ontogeny. Palaeontologia Electronica 20:1–53.

Figure

Fig. 1: Map showing the approximate locations of the museums and institutions housing sauropod specimens from the Morrison Formation. Map © d-maps.com, modified with permission. Original available here: https://d-maps.com/carte.php?num_car=126802&lang=en.