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MAMMALIAN PALEONTOLOGY ON A GLOBAL STAGE: PAPERS IN HONOR OF MARY R. DAWSON

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Cover illustration: Artist's depiction of the living Laotian rodent *Laonastes aenigmamus* standing upon lacustrine strata containing a well-preserved skeleton of the early Miocene rodent *Diatomys shantungensis.* Mary Dawson and her colleagues were the first to recognize that *Laonastes* is a surviving member of the otherwise extinct rodent clade Diatomyidae (see contribution by Flynn in this volume). Original art of Mark A. Klingler.

Frontispiece: Portrait of Mary R. Dawson painted by Gina Scanlon.

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THE MIOCENE MAMMAL MAPPING PROJECT (MIOMAP): AN ONLINE DATABASE OF ARIKAREEAN THROUGH HEMPHILLIAN FOSSIL MAMMALS

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ABSTRACT

The Miocene Mammal Mapping Project (MIOMAP), a relational database of all published mammalian vertebrate localities between 30 and 5 million years old from the western United States, is now online for use by the paleontological community. The database is housed at the University of California at Berkeley, served through the Berkeley Natural History Museums, and accessible via the University of California Museum of Paleontology website. Here we outline the salient features of the database to facilitate its use and provide the information needed for users to adapt the data to their own needs. Online queries of the database can be accessed via http://www.ucmp.berkeley.edu/miomap and made through HTML forms or an interactive map created using open source MapServer 4.0 software and Google Earth™. We also highlight past work done using the database and some of its potential applications.

INTRODUCTION

The evolution of vertebrate paleocommunities and faunas can only be understood through the meticulous collection and comparison of numerous types of data including the location, age, and taxonomic composition of faunas. Compiling and analyzing such data have traditionally been difficult because of the nature of the fossil record—discoveries are geographically disparate, record distinct ages and unique sedimentological units, and are published over many decades. Hay (1902) was one of the first to attempt to compile an exhaustive account of vertebrate fossil organisms in his *Bibliography and Catalogue of the Fossil Vertebrates of North America*. A revised version (Hay 1929) comprised two volumes and later, building on the work of Hay, the *Bibliography of Fossil Vertebrates* (Camp and VanderHoof 1940) was born.

In the last two decades, the development of computerized database programs and, more recently, the World Wide Web has provided a means for vertebrate paleontologists to easily organize and disseminate data from diverse sources through the creation of both collections databases [e.g., University of California Museum of Paleontology (UCMP), American Museum of Natural History (AMNH), Smithsonian Institution] and research databases [e.g., Miocene Mammal Mapping Project (MIOMAP), FAUNMAP, The Paleobiology Database, Evolution of Terrestrial Ecosystems]. Collections databases are created with the primary goal of keeping track of the fossil specimens within a single museum. They are site-specific and contain only basic taxonomic (often not updated), chronologic, and stratigraphic information. On the other hand, research databases are usually created in an attempt to address particular research questions, contain updated systematic and chronologic information for a particular subset of organisms (e.g., mammals), and are based primarily on information from the published literature. Many research databases allow users to relate various categories of data within the database (e.g., location as it relates to age, taxonomy, depositional environment, etc.). Integration of relational research databases with Geographic Information Systems offers a powerful means to analyze data bearing on fossil vertebrates both temporally and spatially.

Here we introduce the Miocene Mammal Mapping Project (MIOMAP), a relational database of Arikareean through Hemphillian (30 to 5 Ma) fossil mammals from western North America, which is now on-line at http://www.ucmp.berkeley.edu/miomap/ as a resource to the vertebrate paleontology community and other users. MIOMAP is housed at the University of California, Berkeley and served through the UCMP website. The data are available for full download, or for searching and analysis using the MIOMAP toolkits. Our purpose here is to document the salient features of the database in order to facilitate its use for a wide variety of potential applications in studies of mammalian evolution, biogeography, and paleoecology, and to provide the information needed for users to adequately adapt the data to their own needs. Additional details are available in the metadata portion of the MIOMAP website.

Abbreviations include the following: **AMNH**, American Museum of Natural History, New York, New York; **FGDC**, Federal Geographic Data Committee; **MIOMAP**, Miocene Mammal Mapping Project; **NALMA**, North American Land Mammal Age; **PDN**, Paleontology Database Network; **UCMP**, University of California Museum of Paleontology, Berkeley, California; **USGS**, United States Geological Survey.

DATA ACQUISITION METHODS

MIOMAP was developed to test hypotheses concerning how major disruptions to the physical environment affected species richness, evolutionary patterns, and biogeographic patterns in mammals. Environmental disruptions of most interest included middle Miocene tectonism in the northern Rocky Mountains and Great Basin, and climatic warming events of the late Oligocene and mid-Miocene.

Database creation began in 2000 and continues today. The database encompasses over 3200 georeferenced localities and 15,000 taxonomic occurrences (Fig. 1). Currently all data from states west of the Mississippi River (excluding the Texas Gulf Coast) are included; these were the states with the most complete fossil collections where we could address the major research questions. However, current efforts are being focused on completing the database for all fifty states. As a result of the vagaries of the fossil record, distribution of localities is patchy. Nebraska, California, and Oregon account for more than half of all the localities in the database, whereas states with the fewest localities include Utah, Washington, and North Dakota. The majority of sites in the database were recovered from the published literature, including selected theses. To warrant inclusion, localities had to be described well enough to be placed within a county, represented by a voucher specimen, and assigned to a biochronologic age derivable from the information provided in the publication. A limited number of localities utilized information from unpublished specimens (Hepburn's Mesa, Montana; Railroad Canyon, Idaho; the state of Nevada). These specimens were typically from areas in which one of us had worked extensively (Hepburn's Mesa, Railroad Canyon) or for which primary field notes and examination of key specimens was possible (Nevada). In addition, specimen counts of some taxa were enhanced through the use of online museum databases maintained by the AMNH and UCMP.

Data acquisition began with extraction of primary bibliographic references, specimen information, and locality information for the relevant time periods from Appendix 1 (Tertiary mammal localities) of Janis et al. (1998). Additional localities were discovered by following the paper trail from one bibliography to another, and by using the University of California Berkeley library system to keep abreast of literature that appeared from 1998 to the present. The information we found by searching the primary literature was compared with the locality and taxon lists compiled by John Alroy in the Paleobiology Database to ensure all principal localities and taxa were included. In the end, however, the taxonomic composition, locality designations/subdivisions, and chronologic assignments were made based only on the most current published primary literature and, therefore, frequently differed from those presented in either the Janis et al. (1998) volume or the Paleobiology Database.

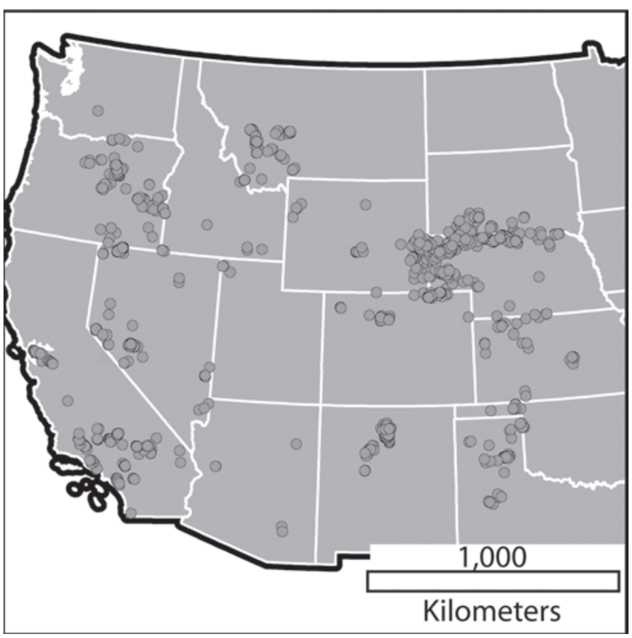

Fig. 1.—Distribution of all fossil localities present in the MIOMAP database as of January, 2006.

DATABASE STRUCTURE

The relational database was created using Corel PARADOX 9.0™ software. In total, six different tables were produced: Locality, Faunal, Synonymy, Relative Age, Absolute Age, and Reference. In addition, an electronic bibliography was created using Endnote 7.0.0.

All sites in the database contain entries in the Locality, Faunal, Relative Age, and Reference tables as well as the electronic bibliography. It was not always possible to fill all of the data fields in these or the other tables, but as much information as was available from the published literature was utilized.

The structure of these tables closely parallels the structure of the tables used for FAUNMAP and outlined by the FAUNAMP Working Group (1994). One exception is the Synonymy Table, which was not included in FAUNMAP. The Synonymy Table tracks the taxonomic changes for a particular taxon from a single locality. Note that the synonymies listed for any given locality are taken only from those publications that have specifically discussed that locality and do not include taxonomic synonyms from other sites.

The database structure, seen in Figure 2, revolves around the Locality Table. All localities have a machine number (a

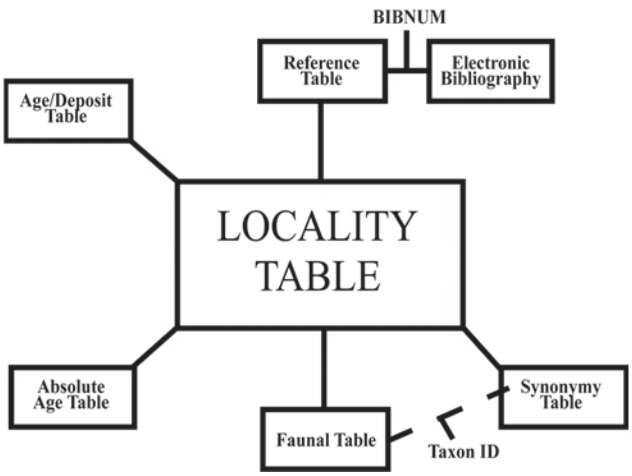

Fig. 2.—MIOMAP database structure. Each table is joined to all other tables via a unique identifier number (called a machine number) and analysis unit originally found in the Locality Table.

number identifier) and some are further divided into analysis units (e.g., Unit 1, Unit 2, Upper, Lower). The combination of machine number and analysis unit for each locality serves as a unique identifier and is used to link the data from all other tables. A detailed account of the types of information contained within each table can be found at the MIOMAP homepage. In addition, links can be found there to both the FGDC-Style as well as the PDN-Style metadata for the database.

Positional Accuracy

Latitudes and longitudes of localities are those interpolated from the publications that reported the fossil sites. In most cases these are not exact. Rarely were latitudes and longitudes reported, especially in older literature. Commonly, geographic positions were given in USGS section, township and range. These coordinates were converted to latitude and longitude by using the conversion routines at http://www.esg.montana.edu/gl/trs-data.html or http://www.topozone.com. Latitudes and longitudes were recorded using the WGS84/NAD83 coordinate datum. In some cases only a geographic description was given in publications; these localities were assigned a latitude and longitude that corresponded with the geographic description, thus are only approximations of their true positions, and in the worst cases are plotted at the center of the county in which they occur. In general, sites based on published latitude and longitude or USGS township coordinates imply that the locality is within a 1 km radius of the latitude and longitude in the database, those clearly assigned to a given USGS quadrangle within about a 5 km radius, and sites with only an approximate quadrangle designation within about a 10 km radius. Options that can be turned on in the online interactive mapping interfaces highlight the positional accuracy of each locality.

Temporal Structure

Age assignments were taken from the original publications, and updated to conform to Tedford et al. (2004), based on the trail of information that could be followed through the literature regarding the stratigraphic position of specimens. Every attempt was made to place each locality within one of the fifteen subdivisions of the NALMAs listed in Tedford et al. (2004) and shown in Table 1. Inasmuch as possible, actual stratigraphic context was considered in making age assignments. Tedford et al. (2004) provides the biochronologic scheme and correlation to the radiometric and magnetostratigraphic time scales that are used in the current version of the MIOMAP database.

Taxonomic Structure

Genus and species names and biochronologic occurrences from earlier papers were updated to conform to Janis et al. (1998) for large mammals and Korth (1994) for rodent taxa. When subsequent publications supplant the taxonomy or biochronology used in the Janis et al. (1998) volume or the Korth (1994) book, the more recent treatment was used. In situations where continual conflict in the taxonomy of a given taxon existed, every attempt was made to use the taxonomy from the most recent, comprehensive discussion of the taxon. An exception to this was the taxonomic identifications of the Oreodontoidea. Because of the continuing uncertainty in oreodont classification, in most cases oreodont taxonomy remained that proposed by Lander (1998), even when more recent publications presented a different taxonomic identification. The reason for this decision was that Lander (1998) presented a detailed synonomy list for all oreodont taxa, and it was unclear how later systematic changes affected this taxonomy. Nevertheless, more recent oreodont designations were included in the database in the

Table 1. Subdivisions of the NALMAs into which, when possible, localities in the MIOMAP database were assigned. These subdivisions are based on those used by Tedford et al. (2004).

NALMA Subdivision	Age Boundaries
Late Late Hemphillian	5.9–4.7 Ma
Early Late Hemphillian	6.7–5.9 Ma
Late Early Hemphillian	7.5–6.7 Ma
Early Early Hemphillian	9–7.5 Ma
Late Clarendonian	10–9 Ma
Middle Clarendonian	12–10 Ma
Early Clarendonian	12.5–12 Ma
Late Barstovian	14.8–12.5 Ma
Early Barstovian	15.9–14.8 Ma
Late Hemingfordian	17.5–15.9 Ma
Early Hemingfordian	18.8–17.5 Ma
Late Late Arikareean	19.5–18.8 Ma
Early Late Arikareean	23.8–19.5 Ma
Late Early Arikareean	27.9–23.8 Ma
Early Early Arikareean	30–27.9 Ma

Synonomy Table so that future researchers would still be able to track the classification discrepancies in the published literature. The taxonomic standard above the species level generally followed McKenna and Bell (1997).

WORLD WIDE WEB ACCESS

For web access, the database was transferred to MySQL. To simplify the transfer process, the Relative Age Table was appended onto the Locality Table. The database is accessible directly via http://miomap.berkeley.edu or through the general MIOMAP home page at http://www.ucmp.berkeley.edu/miomap/. Queries of the database can be made through HTML forms or through an interactive mapping interface that utilizes open source MapServer 4.0 software. Two types of HTML forms can be accessed: a simple query list form containing single line entries for criteria such as taxonomic designation, locality name, and age, and an advanced form where users can query via multiple entries of a single criterion (e.g., multiple species). The mapping interface allows the user to create downloadable, customized maps using a variety of background templates (e.g., airphoto vs. topographic) and magnifications (Fig. 3). All search results or the entire dataset can be downloaded in Microsoft® Excel format. Bibliographic information is available in three formats: Microsoft Word, Rich Text, or Endnote.

The general MIOMAP web page also contains links to relevant UCMP type specimen records and catalog card images. In addition, many of the UCMP type specimens listed contain links to photos of the specimen and their published diagnosis. There are plans to augment the type photos and diagnoses of UCMP specimens with type specimens from other institutions.

RESULTS AND APPLICATIONS

Previous Work

As discussed previously, MIOMAP was designed to test questions about how major physical disturbances such as

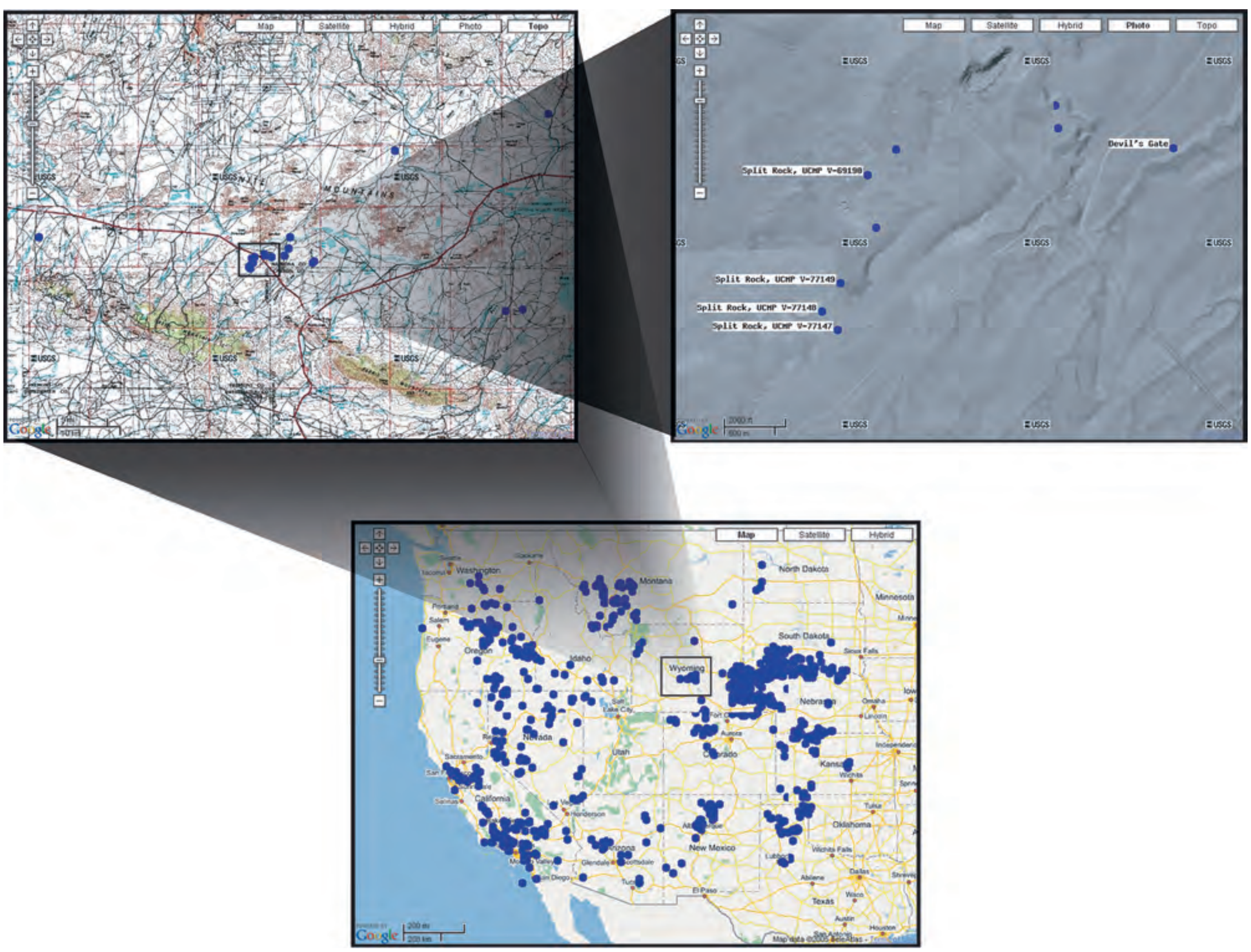

Fig. 3.—These maps, generated using the Berkeley Mapper and Google Earth, summarize the fossil bearing localities in the MIOMAP database for the Hemingfordian NALMA (bottom map) and illustrate how users can utilize the web interface to zoom in on specific geographic regions (as shown in the top two maps for the Split Rock localities, Wyoming). Map scales range from continental down to 1:10000.

climate change and tectonic change influence biotic patterns. Research on the MIOMAP database assembled so far has progressed towards testing these questions in a stepwise fashion. First, a theoretical groundwork was laid that considered what geographic and temporal scale was most appropriate for detecting the effects of climate change on species richness and other attributes of biota. Preliminary data suggested to us that if climate changes were to affect species richness, the relevant scales to examine would be the regional scale geographically and the hundred-thousand to million-year time scale temporally (Barnosky 2001).

We then looked to determine whether or not the climatic perturbations of the Oligocene and Miocene—the late Oligocene Warming and the mid-Miocene Climatic Optimum—were far enough above the background noise of climatic change through time to suggest they should influence biotic change. Our research (Barnosky et al. 2003) indicated that while these climatic events plot at the high end of normal rates of climate change, they do not fall outside of the "normal" window. This suggests that any biotic responses to climate change at these times reflect normal variability that is built into biotic systems, rather than response to an abnormal event. Therefore, study of these climatic events holds much promise for understanding how evolution and community dynamics proceed in natural systems.

Given this theoretical framework, we next analyzed our data under varying assumptions to assess the effects of employing different metrics to compute species richness (Carrasco and Barnosky 2000; Barnosky 2001; Barnosky and Carrasco 2002) and gauge the impact of the species-area effect on estimates of paleodiversity (Barnosky et al. 2005). In all of these studies, it became clear that choice of metric heavily influenced the estimate of diversity. In addition, Barnosky et al. (2005) revealed that previously undocumented biases resulting from the species-area effect could have a significant effect on paleodiversity.

Potential Applications

While previous research has focused on understanding large-scale patterns in mammalian history, the MIOMAP database can serve as an invaluable resource for more focused research avenues such as systematic and biogeographic studies of individual taxonomic groups as well as aid in field research. For example, what if a researcher is embarking on a study of the rodent family Heteromyidae? As a preliminary step, one could first query the database using the family taxonomic entry in the query list form. The localities retrieved could then be searched either online or from a downloaded data file to determine: what papers documented these heteromyid occurrences; what museums held type specimens or had abundant collections of heteromyids that one might want to inspect; or in what time intervals the specimens occurred? If one's interest were in the biogeography of the Heteromyidae, one could query MIOMAP by entering a familial designation and land mammal age into the query list form and repeat the process for successive land mammal ages. The results of each search could be used to create maps of all heteromyid occurrences for each time period to evaluate how their geographic distribution has changed through time. Alternatively, if one wanted to visit the field sites where various heteromyids had been reported in the published literature, one could zoom in on the customized maps, save and print detailed topographic or satellite photos of the regions of interest to take into the field, and download summaries of published information about the locality, such as other taxa found at the site, the depositional environment, the geology, and approximate published location.

The above example serves to illustrate only a few of the numerous possible applications of the MIOMAP database. We welcome any comments or suggestions concerning the database and web interface as researchers begin to use it. Hopefully, by making the database fully downloadable and accessible via the World Wide Web and integrating it with a mapping system, MIOMAP will stimulate further research on the late Oligocene and Miocene, an interval in earth history critical to understanding how long term tectonic and climatic changes affect mammalian diversity.

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