Larval Fish Laboratory, Fort Collins, Technical Publication No. 42.

Snyder, D. E., K. R. Bestgen, and S. C. Seal. 2005. Native cypriniform fish larvae of the Gila River Basin—morphological descriptions, comparisons, and computer-interactive key. Final report submitted by the Larval Fish Laboratory to the Bureau of Reclamation, Phoenix, Arizona.

Stevens, D. L., and A. R. Olsen. 1999. Spatially restricted surveys over time for aquatic resources. Journal of Agricultural, Biological, and Environmental Statistics 4:415–428.

Stevens, D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. Environmental Metrics 14:593–610.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Tyus, H. M., and C. A. Karp. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River basin of Colorado and Utah. Southwestern Naturalist 35:427–433.

Wick, E. J., C. W. McAda, and R. V. Bulkley. 1982. Life history and prospects for recovery of the razorback sucker. Pages 120–126 in Fishes of the upper Colorado River system: present and future (W. H. Miller, H. M. Tyus, and C. A. Carlson, editors). American Fisheries Society, Western Division, Bethesda, Maryland.

Submitted 15 December 2016. Accepted 3 August 2017.
Associated Editor was Ingo Schlupp.

The Southwestern Naturalist 62(3): 232–234

PRELIMINARY PALEODIET OF A SPECIMEN OF THE PLIOCENE RHINOCEROS (*TELEOCERAS FOSSIGER*) FROM MICHOACÁN, MÉXICO

Víctor Adrián Pérez-Crespo,* Joaquín Arroyo-Cabrales, Pedro Morales-Puente, Edith Cienfuegos-Alvarado, and Francisco J. Otero

Instituto de Geología, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica S/N, Ciudad Universitaria, Del. Coyoacán, 04510 México, CdMx, México (VAPC, PMP, ECA, FJO)
Laboratorio de Arqueozoología "M. en C. Ticul Álvarez Solórzano", Subdirección de Laboratorios y Apoyo Académico, INAH. Moneda 16 Col. Centro, 06060, México, CdMx, México (JAC)
**Correspondent: vapc79@gmail.com*

Abstract—Using the isotopic carbon and oxygen ratios present in dental enamel, the diet and the habitat of an individual of the Pliocene rhinoceros *Teleoceras fossiger* from San Francisco de los Reyes, Michoacán, México, were inferred. The values of $\delta^{13}C$ and $\delta^{18}O$ indicate that this animal fed on C_3 plants and lived in enclosed areas similar to those found in some Florida specimens. However, because only one specimen was analyzed, it is not possible to determine if these rhinoceroses in Mexico were specialists or generalists in their diet.

Resumen—Usando las relaciones isotópicas de carbono y oxígeno presentes en el esmalte dental, se infiriirieron la dieta y el hábitat de un individuo de rinoceronte del Plioceno *Teleoceras fossiger* proveniente de San Francisco de los Reyes, Michoacán, México. Los valores de $\delta^{13}C$ y $\delta^{18}O$ indican que este animal se alimentó de plantas C_3 y vivió en zonas cerradas similar a lo hallado en algunos ejemplares de Florida. Sin embargo, dado que se analizó un sólo ejemplar, no es posible determinar si estos rinocerontes en México eran especialistas o generalistas en su dieta.

Teleoceras was a genus of rhinoceros (Perissodactyla, Rhinocerotidae) that inhabited México during the Late Hemphillian; their remains have been found in several localities (Carranza-Castañeda, 1989, 2006). This animal has been the subject of multiple studies to identify species within the genus that lived in Mexico during the Late Hemphillian. *Teleoceras fossiger* has been found in Chihuahua, Jalisco, and Hidalgo (Carranza-Castañeda, 2006; Carbot-Chanona et al., 2009), Guanajuato (Carranza-Castañeda and Ferrusquía-Villafranca, 1978), Sinaloa (Maldonado-Köerdell, 1954), and Michoacán (Brunet, 1968). A specimen of *Teleoceras guymonense* was found in Jalisco (Lucas, 2008).

In Mexico there have been no paleobiological studies of the genus, whereas in the United States there have been taxonomic (Prothero, 2005), ethologic (Mead, 1999; Mihlbachler, 2005), taphonomic (Voorhies, 1985), and paleoecologic studies of this genus (MacFadden,

1998; Ayoub and Mihlbachler, 2012). Because of the lack of paleoecologic studies in Mexico, we inferred the diet and habitat based on one specimen of *T. fossiger*, found in San Francisco de los Reyes, Michoacán, using carbon and oxygen stable isotopes. San Francisco de los Reyes is located in the State of Michoacán, México, at 19°46′18″N and 100°13′37″W and 2,650 m above sea level. The geology of the area is dominated by Neogene (Miocene and Pliocene) rhyolites, conglomerates, and limestone (Brunet, 1968).

One sample of dental enamel was taken from the fourth upper left premolar of a rhinoceros of *T. fossiger*, catalogue number DP-217 from the Paleontological Collection, Archaezoology Lab, Subdirección de Laboratorios y Apoyo Académico, National Institute of Anthropology and History (INAH), México. The sample was processed and isotopically analyzed in the Stable Isotopes Lab at the Instituto de Geología, Universidad Nacional Autonóma de México (UNAM).

We prepared samples following the method proposed by Koch et al. (1997). We determined sample isotopic ratios through assays in a Finnigan MAT 253 (Thermo Fisher Scientific [Bremen] GmbH, Germany) mass spectrometer with a dual inlet system and GasBench auxiliary equipment with a GC Pal autosampler with a temperature-controlled aluminum plate adjoined to the mass spectrometer (Révész and Landwehr, 2002). Results were normalized using NBS-19, NBS-18, and LSVEC and reported as $\delta^{18}O_{VPDB}$ and $\delta^{13}C_{VPDB}$ using the Vienna Pee Dee Belemnite (VPDB) scale in accordance with the corrections described by Coplen (1988), Coplen et al. (2006), and Werner and Brand (2001). For this technique, standard deviation was 0.2‰ for oxygen and 0.2‰ for carbon.

Once we obtained a carbon isotopic value for the sample, the value was compared with those obtained by MacFadden and Cerling (1996). We determined the percentage of C_4 plants ($\%C_4$) consumed by using an equation proposed by Koch et al. (2004): (100) $\delta^{13}C_{sample} = (100 - X)\ \delta^{13}C_{100\%\ C3enamel} + (X)\ \delta^{13}C_{100\%\ C4enamel}$, where $\delta^{13}C_{enamel}$ of an animal consuming a diet of 100% $C_{3plants}$ is −12.6‰ or less and $\delta^{13}C_{enamel}$ of an animal consuming a diet of 100% $C_{4\ plants}$ is 2.4‰ or more. These values correspond to those estimated before the Glacial Maximun (Koch et al., 2004). Then, $\delta^{13}C$ and $\delta^{18}O$ values of our specimen were plotted and compared with those reported by MacFadden (1998) for specimens of *Teleoceras* from a series of localities of Late Hemphillian age (late Miocene to early Pliocene) in Bone Valley, Florida, USA (Bone Valley-0, Bone Valley-Tiger Bay, Bone Valley-Palmetto, and U Bone Valley).

The carbon isotopic value of −10‰ from the DP-217 individual lies within the range of values observed for Floridian rhinos, being similar to an individual from BV Tiger Bay (Fig. 1). The value corresponds to a diet based predominantly in C_3 plants with only 17.33% of C_4 plants,

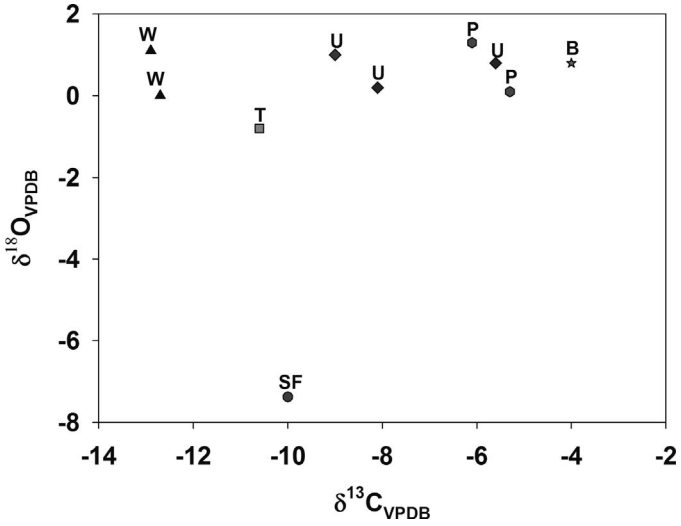

Fig. 1—Comparisons between carbon and oxygen isotopic values for rhinoceros from Michoacán, Mexico, and Florida, USA. Abbreviations: SF = San Francisco de los Reyes; B = Bone Valley O; P = BV Palmetto; T = BV Tiger Vay; U = U Bone Valley; W = Withlacooche 4A.

which suggests that C_4 plants were not an important component in the individual's diet. Prothero (1998) indicated that rhinoceros of *Teleoceras* were flexible in their feeding habits, as Floridian specimens showed, with animals that exclusively fed on C_3 plants while others were mixed feeders with an important C_4 component (MacFadden, 1998). On the other hand, Ayoub and Mihlbachler (2012), using mesowear and microwear assays, found that specimens from Kansas, USA, of the same genus were browsers. However, given that there was only one specimen in our study, it is not advisable to generalize that all *T. fossiger* in Mexico were specialists in consumption of C_3 plants or if there existed some mixed feeder specimens.

On the other hand, the oxygen isotopic value $\delta^{18}O$ of the individual DP-217 from Michoacán is −7.4‰, which is different from those exhibited by Floridian specimens (Fig. 1) as would be expected owing to their different ecological settings, that is, because of differences in temperature, altitude, latitude, or amount of rainfall in the sites where these animals lived, all of which affect the oxygen isotopic values of the rainfall (Yann et al., 2013), and more importantly because of their different ages.

The habitat for this individual probably was an enclosed zone such as forest or jungle, similar to that of some Floridian rhinoceros (Fig. 1). Also, because there was only one study specimen, we are not concluding that all *T. fossiger* from Mexico lived in enclosed zones.

Finally, we can say that the rhinoceros from San Francisco de los Reyes was a browser as shown by the $\delta^{13}C$ value from its dental enamel and that it lived in an enclosed zone. However, to better understand the feeding habits and habitat for this species in Mexico, it will be

necessary to assay a large number of specimens from this and other species within the genus *Teleoceras* that inhabited the country, possibly finding any specific ecological data depending upon the study species.

We thank Consejo de Arqueología from INAH for granting the permit to obtain the enamel sample. Also, thanks to Consejo Nacional de Ciencia y Tecnología (CONACYT no. 132620) and Programa de Apoyo a Proyectos de Investigación e Innovación Tecnológica (PAPIIT IN104017) for support for this study and to Laboratorio de Isótopos Estables from the Institute of Geology, UNAM, as well as R. Puente M. for analyzing the samples. O. Carranza-Castañeda kindly reviewed and enriched this manuscript and I. Casar, Instituto de Física-UNAM, reviewed the English translation.

Literature Cited

Ayoub, M., and M. C. Mihlbachler. 2012. Dental wear and feeding ecology in North American Late Miocene Rhinocerotidae, *Aphelops* and *Teleoceras*. Journal of Vertebrate Paleontology 72:58.

Brunet, J. 1968. The Pliocene rhinoceroses of Mexico. Geological Society of America 12:1–2.

Carbot-Chanona, G., J. Juárez-Woo, and R. Guzmán-Guittierez. 2009. Contribución al conocimiento de los rinocerontes fósiles de la Cuenca de Tecolotlán, en el estado de Jalisco, México. Boletín de la Sociedad Geología Mexicana 61:277–286.

Carranza-Castañeda, O. 1989. Rinocerontes de la fauna del Rancho El Ocote, Mioceno tardío (Henfiliano tardío) del Estado de Guanajuato. Universidad Nacional Autónoma de México, Instituto de Geología, Revista 8:88–99.

Carranza-Castañeda, O. 2006. Late Tertiary fossil localities in central México, between 19°–23°N. Pages 45–60 in Advances in late Tertiary vertebrate paleontology in México and the Great American Biotic Interchange (O. Carranza-Castañeda and E. H. Lindsay, editors). Universidad Nacional Autónoma de México, Instituto de Geología and Centro de Geociencias, Publicación Especial 4.

Carranza-Castañeda, O., and I. Ferrusquía-Villafranca. 1978. Nuevas investigaciones sobre la fauna Rancho El Ocote, Plioceno medio de Guanajuato, México; informe preliminar. Universidad Nacional Autónoma de México, Instituto de Geología, Revista 2:163–166.

Coplen, T. 1988. Normalization of oxygen and hydrogen isotope data. Chemical Geology (Isotope Geoscience Section) 72:293–297.

Coplen, T., W. A. Brand, M. Gehre, M. Gröning, A. J. Meijer Harro, B. Toman, and R. M. Erkouteren. 2006. New guidelines for $\delta^{13}C$ measurements. Analytical Chemistry 78:2439–2441.

Koch, P. L., N. S. Diffenbaugh, and K. A. Hoppe. 2004. The effects of late Quaternary climate and $_{P}CO_2$ change on C_4 plant abundance in the south-central United States. Palaeogeography, Palaeoclimatology, Palaeoecology 207:331–357.

Koch, P. L., N. Tuross, and M. L. Fogel. 1997. The effects of sample treatment and diagenesis on the isotopic integrity of carbon in biogenic hydroxylapatite. Journal of Archaeological Science 24:417–429.

Lucas, S. G. 2008. The rhinoceros *Teleoceras* from the Miocene of Jalisco, México. New México Museum of Natural History and Science Bulletin 44:65–70.

MacFadden, B. J. 1998. Tale of two rhinos: isotopic ecology, paleodiet, and niche differentiation of *Aphelops* and *Teleoceras* from Florida Neogene. Paleobiology 24:274–286.

MacFadden, B. J., and T. E. Cerling. 1996. Mammalian herbivore communities, ancient feeding ecology, and carbon isotopes: a 10 million-year sequence from the Neogene of Florida. Journal of Vertebrate Paleontology 16:103–115.

Maldonado-Köerdell, M. 1954. Sobre un rinoceronte fósil de Sinaloa, México. Sociedad Mexicana de Historia Natural 5:141–146.

Mead, A. J. 1999. Enamel hypoplasia in Miocene rhinoceroses (*Teleoceras*) from Nebraska: evidence of severe physiological stress. Journal of Vertebrate Paleontology 19:391–397.

Mihlbachler, M. C. 2005. Linking sexual dimorphism and sociality in rhinoceroses: insights from *Teleoceras proterum* and *Aphelops malacorhinus* from the Late Miocene of Florida. Bulletin of Florida Museum Natural History 45:495–520.

Prothero, D. R. 1998. Rhinocerotidae. Pages 595–605 in Evolution of Tertiary mammals of North America. Volume 1. Terrestrial carnivores, ungulates and ungulate-like mammals (M. C. Janis, K. M. Scott, and J. L. Jacobs, editors). Cambridge University Press, United Kingdom.

Prothero, D. R. 2005. The evolution of North American rhinoceros. Cambridge University Press, Cambridge, United Kingdom.

Révész, K. M., and J. M. Landwehr. 2002. $\delta^{13}C$ and $\delta^{18}O$ isotopic composition of $CaCO_3$ measured by continuous flow isotope ratio mass spectrometry: statistical evaluation and verification by application to Devils Hole core DH–11 calcite. Rapid Communications in Mass Spectrometry 16:1012–2114.

Voorhies, M. R., 1985. A Miocene rhinoceros herd buried in volcanic ash. National Geographic Society Research Reports 19:671–688.

Werner, R. A., and W. A. Brand. 2001. Referencing strategies and techniques in stable isotope ratio analysis. Rapid Communications in Mass Spectrometry 15:501–519.

Yann, T. L., L. R. G. Desantis, R. J. Haupt, J. L. Romer, S. E. Corapi, and D. J. Ettenson. 2013. The application of an oxygen isotope aridity index to terrestrial paleoenvironmental reconstructions in Pleistocene North America. Paleobiology 39:576–590.

Submitted 2 December 2016. Accepted 8 August 2017.
Associate Editor was Troy Ladine.