QnAs with Juan Carrillo

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Paleobiologist Juan Carrillo has moved around the globe during his short research career, but his work has stayed solidly anchored in South America. A native of Colombia, Carrillo completed his undergraduate degree at National University of Colombia in Bogota. He moved to Panama for a research internship at the Smithsonian Tropical Research Institute. Later, he went to the University of Zurich in Switzerland for a doctorate in paleontology. Carrillo studied fossils and extant organisms, particularly mammals, with the goal of understanding the changes in faunal diversity through time and space in the American tropics. From Zurich, Carrillo moved once more, this time for a postdoctoral fellowship at University of Gothenburg in Sweden, where he began solving a long-standing mystery: Why was the Great American Biotic Interchange (GABI) asymmetrical? GABI started when the Isthmus of Panama connected North and South America during the Neogene period, allowing animals to migrate between the continents. However, the fossil record shows a stark asymmetry: Mammals of North American origin attained higher diversity in South America than vice versa. In a recent PNAS article (1), Carrillo and his colleagues laid out the potential causes of this asymmetry. PNAS spoke to Carrillo, now a research fellow at the Natural History Museum in Paris, about his findings.

PNAS: How did the study of GABI come about?

Carrillo: I have been interested in this since I was a student in Colombia. The GABI was a kind of natural experiment with these separate groups of mammals that started to move in both directions, and it had major implications in the evolution of fauna in the Americas. At the beginning, this interchange was relatively symmetrical, but, in the fossil record, during the Pleistocene time period, we see that in South America native mammals and North American immigrants are about 50–50. In contrast, in North America there are relatively few mammals from the south. I wanted to look in more detail how this asymmetry came to be. I talked to my colleagues in Sweden and the Smithsonian, and we designed this study.

PNAS: Paleontologists have long known about the asymmetry; what made it possible to do this study now?

Carrillo: There are multiple mechanisms that could explain this asymmetry. We wanted to evaluate four hypotheses, and we finally had the analytical tools and the data to test them properly. One reason I went to Sweden was to learn how to use some analytical tools they had developed to estimate from the fossil record the diversity trends, extinction patterns, and dispersal from one continent to another. We also now have access to large databases of fossils. We used one called the PaleoBiology Database. Many paleontologists

Juan Carrillo. Image credit: Christian Ziegler (photographer).

contribute records of mammals or fossils of mammals, giving us a huge amount of data. It allowed us to analyze around 20,000 fossil occurrences.

PNAS: How would you summarize what you now think happened to cause the asymmetry?

Carrillo: We started with four hypotheses. The asymmetry could result from a higher rate of movement of mammals from north to south; a relatively similar rate of movement, but the North American mammals in South America diversified more; the South American mammals had higher extinction rates; or the rate of movement was similar, but more mammals from North America moved south. In our analyses, we found that, during the Pliocene, there was a relatively high extinction of native South American mammals in South America. We call it a disproportionate extinction of these mammals during this time period. Consequently, the diversity of the native mammals from South America declined. Then, during the following time period, the Pleistocene, when there was more movement between the two continents, there were relatively fewer native mammals in South America; they went extinct and so there were fewer mammals that could migrate to North America.

PNAS: What might have caused the extinction?

Carrillo: That's the next question we'd like to answer. We have some hypotheses. We did this analysis based on the fossil data, most of which comes from higher latitudes, particularly the Pampas region of Argentina. We don't know if the extinction occurred across the continent because we have less data from other regions, like the tropics. What we do know is that in southern South America, during the Pliocene, the climate was cooling and becoming more dry, so that could have influenced extinctions. It also could have been interactions with some early new immigrants from the north. In particular, there were differences in the predators that came to the continent from North America. The predators in South America before the interchange were marsupials that went extinct, leaving an empty space for new predators to arrive, and they were possibly more effective. Or some of the immigrants could have had parasites or diseases that could have spread to the native animals. It was likely a combination of these different factors. We hope to look into all of these ideas.

PNAS: How surprising were your findings?

Carrillo: Many paleontologists, including us, thought that the asymmetry was likely because the immigrants from North America to South America radiated, or diversified, more than the immigrants from South America to North America [did]. But, when we accounted for differences in the sampling sizes, it was not the case. It was driven by this extinction. There are some groups that certainly did radiate. And not all of the groups were as well represented in the fossil record as others. But the evidence did not support the idea that the asymmetry was driven by radiation.

PNAS: What is the significance of this finding?

Carrillo: It's important to understand how this asymmetry came to be in order to understand the legacy of the GABI in the current patterns of diversity. In addition, it shifts the narrative, which was basically that the South American mammals were less competitive [than] the North American mammals. This is an oversimplified version of what happened. It was much more complex over a long time span.

1 J. D. Carrillo *et al.*, Disproportionate extinction of South American mammals drove the asymmetry of the Great American Biotic Interchange. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 26281–26287 (2020).