Birth of a Continent

Pioneering laboratory helps reconstruct the geological history of South America by determining the age of rocks

Igor Zolnerkevic

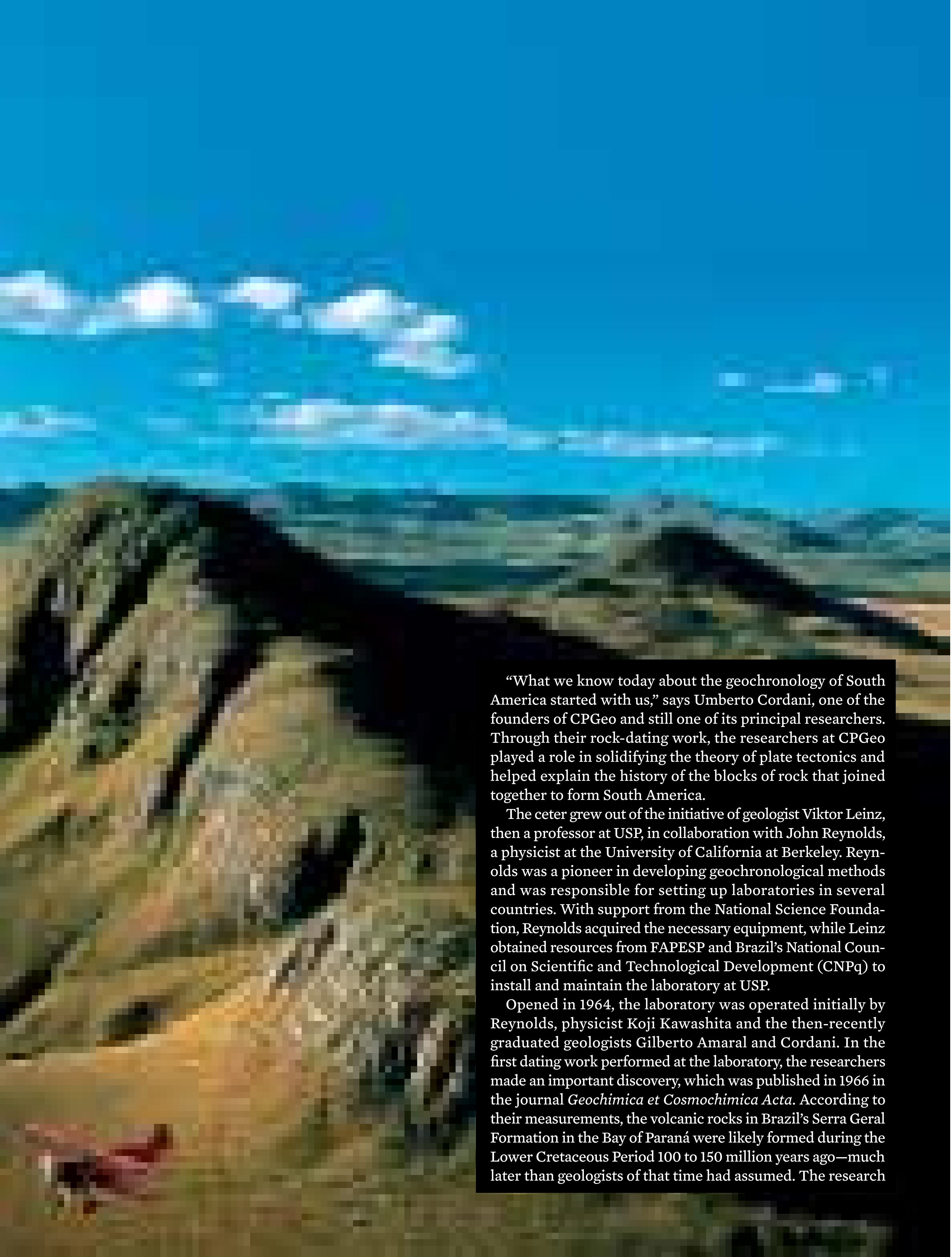
It is difficult to imagine that the rocky foundations holding up the continents are anything but eternal and static. During the course of the second half of the twentieth century, however, it became clear to geologists that the continents are slowly moving about, opening and closing oceans around them, and that their internal structure is the product of a complex collage of enormous blocks of rock that have grown and been shuffled around on the surface of the planet for over four billion years.

Thrust around by heat in the Earth's core, these blocks sometimes fragmented into smaller units and other times merged into supercontinents, constantly altering the features on the map of the world. That tumultuous dynamic, explained by the so-called theory of plate tectonics, pushed up several mountain ranges, now completely eroded, that were once as high as the present-day Andes and Himalayas. It also created and destroyed countless ancestral oceans before sculpting the current shape of the continents.

Sorting out each step in that history is literally a jigsaw puzzle of global proportions, the pieces of which are yet to be fully understood. In operation for nearly 50 years, the Geochronological Research Center (CPGeo) of the Geosciences Institute (IGc) at the University of São Paulo (USP) was Latin America's pioneer in mastering the art of geochronology—the exact determination of the age of geological events carved into the rocks—that is essential for reconstructing the evolution of the continents.

Chapada dos Veadeiros Plateau in northern Goiás state, Brazil

LALO DE ALMEIDA



“What we know today about the geochronology of South America started with us,” says Umberto Cordani, one of the founders of CPGeo and still one of its principal researchers. Through their rock-dating work, the researchers at CPGeo played a role in solidifying the theory of plate tectonics and helped explain the history of the blocks of rock that joined together to form South America.

The ceter grew out of the initiative of geologist Viktor Leinz, then a professor at USP, in collaboration with John Reynolds, a physicist at the University of California at Berkeley. Reynolds was a pioneer in developing geochronological methods and was responsible for setting up laboratories in several countries. With support from the National Science Foundation, Reynolds acquired the necessary equipment, while Leinz obtained resources from FAPESP and Brazil’s National Council on Scientific and Technological Development (CNPq) to install and maintain the laboratory at USP.

Opened in 1964, the laboratory was operated initially by Reynolds, physicist Koji Kawashita and the then-recently graduated geologists Gilberto Amaral and Cordani. In the first dating work performed at the laboratory, the researchers made an important discovery, which was published in 1966 in the journal *Geochimica et Cosmochimica Acta*. According to their measurements, the volcanic rocks in Brazil’s Serra Geral Formation in the Bay of Paraná were likely formed during the Lower Cretaceous Period 100 to 150 million years ago—much later than geologists of that time had assumed. The research


Diamantina Plateau, Bahia, Brazil, 1.4 billion years old

FABIO COLOMBINI

triggered discussions of the evolution of the Bay of Paraná—a subject that, according to Cordani, remains an open question in the geology of Brazil.

In 1967, the journal *Science* published the scientific article that Cordani regards as CPGeo's principal contribution to science. Although continental drift had been proposed in 1912 by German geoscientist Alfred Wegener, until the early 1960s geologists widely adhered to verticalist theory. This was the idea that the continents had always inhabited the same place, and that the structure of rocks, with their folds and fissures, could be explained only by the sinking and rising of the blocks of rock. Between 1964 and 1968, however, a series of published scientific articles presented the principal evidence for, and first proposal of, what were likely the mechanisms behind the theory of plate tectonics.

The evolution of the Bay of Paraná remains an open question in the geology of Brazil

The article in *Science* was the product of collaboration between a team from the Massachusetts Institute of Technology (MIT) led by geologist Patrick Hurley, and USP researchers Fernando de Almeida, Geraldo Melcher, Paul Vandoros, Kawashita and Cordani. In the paper, the researchers compared the ages of several rock formations in Northeastern Brazil with similar formations in West Africa, helping to demonstrate that the two continents used to be one before the birth of the Atlantic Ocean began to separate them a little over 100 million years ago. "We contributed to a paradigm shift in the geosciences," Cordani says.

GEOLOGICAL CHRONOMETERS

Geochronology is based on the measurement of very small quantities of certain chemical elements trapped within rock minerals. These elements, known as radioactive isotopes, transform into other elements over a period of billions of years. For example, with the first method developed at CPGeo, known as potassium-argon dating, researchers know exactly how long it takes for a given quantity of the radioactive isotope potassium-40 to transform into the argon-40 isotope. Consequently, the ratio between quantities of potassium-40 and argon-40 works as a kind of chronometer by marking the amount of time since the argon was formed and trapped in the mineral containing potassium.

To accomplish that task, geochronologists use instruments known as mass spectrometers, which are capable of separating and measuring abundances of different isotopes of chemical elements. Samples are heated to high temperatures inside a mass spectrometer, releasing their elements, whose atoms lose their electrons and become ionized. Magnetic fields then separate these ionized nuclei according to their mass and electrical charge, and conduct them towards sensors that count them.

In addition to the potassium-argon method, the laboratories at the Center currently use nearly all of the rock-dating methods that were developed over the years in which its researchers conducted studies in other countries to learn new methods or received visiting researchers from abroad who helped introduce them—exchanges that were made possible through research grants from FAPESP. "Today we are one of the most complete geochronology centers in the world," declares Benjamin Bley de Brito Neves, a researcher at CPGeo. "Each method has its own qualities, deficiencies, and purposes," he explains.

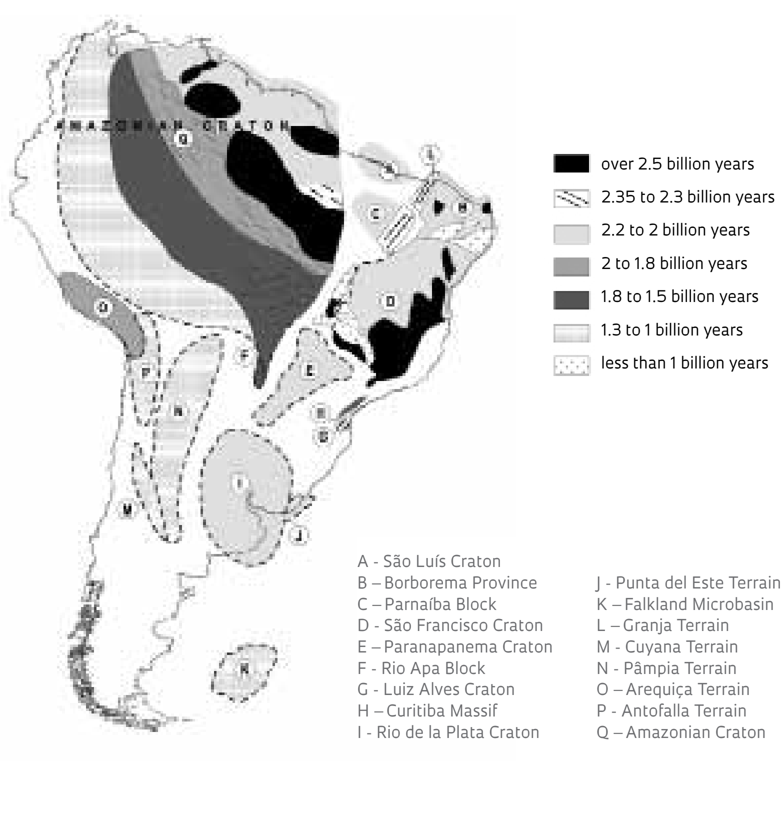
The potassium-argon method dates from episodes when the rocks went through temperature changes at the time of their formation. The rubidium-strontium method, introduced in the 1970s, provides the age of movements that deformed the rocks. In the 1990s, through the purchase of additional equipment financed by FAPESP, other techniques were introduced such as the samarium-neodymium method, which determines when the magma from which the rock was formed rose upward to the Earth's crust, and the uranium-lead method, which indicates when the magma cooled and crystallized in rock. There are still other methods (e.g., argon-argon, lead-lead, rhenium-osmium), each one ideal for determining the date of a certain geological event recorded in a certain type of rock.

Cordani explains that the first 30 years of CPGeo's existence were devoted to extensive mapping of the ages of the rocks that form the continental crust of South America. These are the old, immense, and stable blocks of rock known as cratons, most of which were formed between 500 million and 4 billion years ago. The largest of these is the Amazonian craton, which contains 52% of the territory of Brazil, followed by the São Francisco and Rio de la Plata cratons, and smaller continental fragments, in addition to the recent Andean belt, still continually growing as a result of the collision between the oceanic Nazca tectonic plate and the South American continental plate.

This decades-long effort received continuous support from FAPESP, particularly during its final phase, by way of two thematic projects coordinated by Cordani— *Tectonic evolution of South America* from 1993 to 1996, and *Crustal evolution of South America* from 1996 to 2000. The work culminated in the publication of the book *Tectonic Evolution of South America* during the 31st International Geological Congress in Rio de Janeiro in 2000. Written in collaboration with dozens of researchers from several universities in Brazil and other countries, the volume presented the most complete synthesis to date of the evolution of each of the continent's rock cores, and delineated the history of how they grew and joined together.

Vestiges of Rodinia

Fragments are scattered throughout South America



BENJAMIN BLEY BRITO NEVES / USP

A NEW LEVEL

Although the broad outlines of the formation of South America are now well understood, there are still important details to be uncovered. "Geology lives by interpreting the information available at the time," explains Miguel Basei of CP-Geo, who coordinated the Center's most recent thematic project, "South America in the Context of the Supercontinents," begun in 2005 and concluded in 2011.

Thanks to the renovation and expansion of CP-Geo during the project, its researchers obtained a record amount of data on the age and chemical composition of rocks. Thousands of dating tests performed each year made it possible to confirm or refute a series of hypotheses on the evolution of the blocks that merged to form South America, as well as its ancient connections to blocks on other continents, especially in Africa.

"The level of our understanding changed," says Colombo Tassinari of CP-Geo. The new perspectives of geological history were published in book chapters and about two hundred scientific articles. Among those publications were the 2011 special issues of the *International Journal of Earth Science* and the *Journal of South American Earth Sciences*, which were devoted entirely to the findings of the project.

The biggest revolution came with the installation of a sensitive high-resolution ion microprobe (SHRIMP), a type of mass spectrometer designed mainly to carry out the uranium-lead dating method in extreme detail. There are only 16 of these instruments in operation in the world, and USP has the only one in Latin America. Made by Australia Scientific Instruments, it was purchased in 2005 with funding from FAPESP (US$1.5 million) and Petrobras (US$1.5 million). In 2010 a new building specially constructed to house the SHRIMP and its peripheral devices opened alongside IGc.

One such device is a cathodoluminescence microscope, which obtains images of zircon crystals (the mineral contained in uranium) varying in size from 30 to 300 micrometers (thousandths of a millimeter). The images reveal the internal structure of the zircon, which holds the record of the various episodes of growth and modification to which it was subjected after its initial crystallization. Like the layers of an onion, each outer layer of the grain corresponds to an episode that melted and then recrystallized the mineral. "A single zircon grain can sometimes tell the complete history of a region," Tassinari explains.

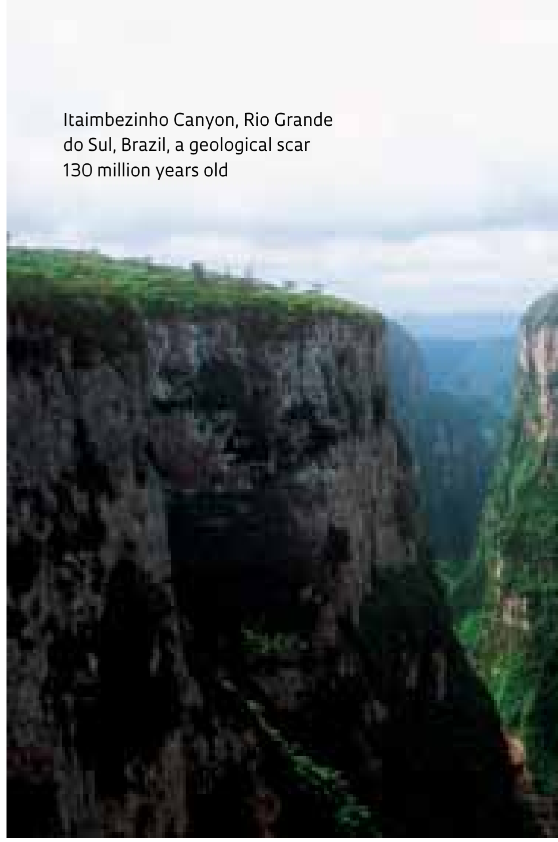
The SHRIMP operates by focusing an oxygen ion beam capable of targeting a specific point on the zircon grain, as chosen by the researchers, with a precision of up to five micrometers. The beam releases the atoms of uranium and lead trapped in that point on the grain so they can be analyzed in the mass spectrometer. In this way, it is possible to determine the age of each recrystallization event.

Petrobras' interest in financing the purchase of the SHRIMP lies in the instrument's usefulness in searching for oil. Using detailed dating measurements performed by this instrument, geologists discover how the sedimentary rocks of a certain region were formed and what changes of temperature they underwent during the course of their history—important data for determining their potential for holding oil reserves.

While each isotope analysis performed by the SHRIMP takes about 15 minutes, researchers often choose to do 50-second measurements, which are a little less precise but reduce operating costs by one-third. This is done using a Neptune laser ablation mass spectrometer acquired in 2009 with funding from the Brazilian Innovation Agency (Finep) and installed with FAPESP support.

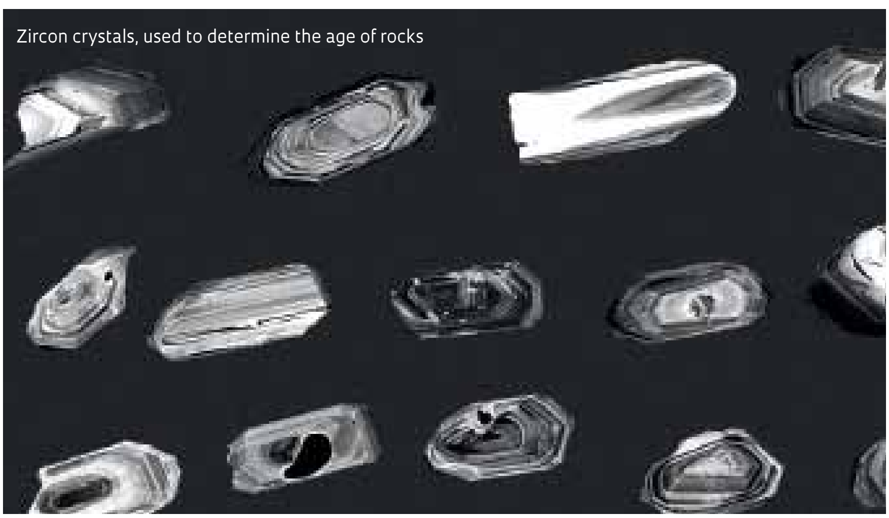
The Neptune is one of four instruments of this type operating in Brazil. Instead of an oxygen beam, it uses a beam of laser light to ablate 20- to 30-micron pieces from the zircons for analysis by the spectrometer. In addition, the Neptune's nine isotope collectors make it possible to measure the quantity of several different chemical elements at the same time. The instrument's speed enables geologists to date over 60 zircons in one day—an ideal pace for preliminary recognition studies and for dating sedimentary rocks formed from the detritus of other rocks.

Under the thematic project, CPGeo obtained a third, conventional Triton mass spectrometer. The Triton is a simpler but latest-generation apparatus that analyzes samples of minerals dissolved after a lengthy chemical treatment. The slow pace of seven analyses per day, however, offsets the high precision of the measurement.



Itaimbezinho Canyon, Rio Grande do Sul, Brazil, a geological scar 130 million years old

CARLOS GOLDGRUB / OPÇÃO BRASIL IMAGENS



Zircon crystals, used to determine the age of rocks

CPGEO/USP

SUPERCONTINENTAL PAST

The researchers at GPGeo study all eras of the Earth's history. In the most recent thematic project, however, their research focused on one critical period in the history of the South American continental crust, when many pieces of the continent were part of two supercontinents.

In the beginning, around 4.5 billion years ago, the surface of the planet was covered by a sea of lava. "The Earth is a thermal pump, and its cooling was what created the rocks," Bley explains. Four billion years ago, the planet cooled sufficiently for the first masses of terra firma to emerge (the oldest known rocks were discovered in 2008 in the province of Quebec, Canada, dating back 4.28 billion years). But it was only 2.5 billion years ago that the continental masses reached considerable size, although they were smaller than the continents of today and separated by enormous oceans.

"At least six times in the Earth's history, these continental masses came together into supercontinents and then broke apart," Bley says. The thematic project focused mainly on a period

approximately 1.3 billion to 500 million years ago, when all the masses on the planet—including land that forms much of Brazil today—joined together into a supercontinent known as Rodinia. Bley, along with Reinhardt Fuck of the University of Brasília (UnB) and Carlos Schobbenhaus of the Geological Survey of Brazil, took part in an international collaboration whose 2008 publication in the journal *Precambrian Research* offered the most detailed reconstruction to date of the formation and breakup of Rodinia.

Around 4.5 billion years ago, the surface of the planet was covered by a sea of lava

Four continents were formed by the fragmentation of Rodinia: Baltica, Laurentia, Siberia and Gondwana. The latter included what today constitutes much of South America, Africa, India, Australia and Antarctica. The four ancestral continents merged once more, forming the famous Pangaea 230 million years ago, which then broke apart and gave rise to the continents of today.

The reconstruction of that remote past is more than an exercise in intellectual curiosity. The discovery of mineral deposits in a certain region of the globe may suggest that other areas that are far away today but were nearby millions of years ago may hold the same riches. The precise determination of the age of the rocks also helps in exploring for those ores. Tassinari cites as an example the dating of rocks in a gold mine in the Iron Quadrangle region of the Brazilian state of Minas Gerais, which were revealed to be two billion years old. Mining companies now must look for rocks of that same age to prospect for potential new deposits.

In another important victory for the project, Bley, Fuck, and Elton Dantas of UnB discovered the oldest rocks in South America, dating back 3.6 billion years, which were found in the city of Petrolina in the Brazilian state of Pernambuco. Considering what still remains to be explored in Brazil, however, Bley suspects that the record is likely to be broken soon. "Since the Earth is so dynamic, these ancient rocks are quite hidden, so a little luck will be needed to find them," he says. "But I believe we'll still get to four billion years old." ■

PROJECTS

1. Tectonic evolution of South America – No. 1992/03467-9 (1993-1995)
2. Crustal evolution of South America – No. 1995/04652-2 (1996-2000)
3. South America in the context of the supercontinents – nº 2005/58688-1 (2006-2011)
4. Geochronology laboratory with high-resolution ion microprobe: support for the development of high-tech oil exploration projects – No. 2003/09695-0 (2005-2008)

GRANT MECHANISMS
1. 2. and 3. Thematic project
4. Partnership for Technological Innovation (PITE)

COORDINATORS
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3. Miguel Ângelo Stipp Basei (IGC/USP)
4. Colombo Celso Gaeta Tassinari (IGC/USP)

INVESTMENT
1. R$200,000.00 (FAPESP)
2. R$800,000.00 (FAPESP)
3. R$3,611,085.27 (FAPESP)
4. US$1,500,000.00 (FAPESP) and US$ 1,500,000.00 (Petrobras)

SCIENTIFIC ARTICLES

1. AMARAL, G. *et al.* Potassium-Argon dates of basaltic rocks from Southern Brazil. **Geochimica et Cosmochimica Acta**. v. 30, p. 159-89, 1966.

2. HURLEY, P. M. *et al.* Test of continental drift by means of radiometric ages. **Science**. v. 144, p. 495-500, 1967.

3. FUCK, R. A. *et al.* Rodinia descendants in South America. **Precambrian Research**. v. 160, p. 108-26, 2008.

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