

Greater India and the New Gondwana Geological Map (IGCP-628)

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Gondwana was the first recognised supercontinent and as such has played a pivotal role in our understanding of supercontinent cycles. It was one of the largest and long-lasting supercontinents in Earth's history, comprising five large continents (Africa, Australia, Antarctica, South America and India) and many other smaller masses scattered today around the globe (e.g. Madagascar, Sri Lanka, New Zealand, and others now embedded in Asia, Europe and North America). Gondwana research involves the understanding of the evolution of our planet, its climatic, thermal and tectonic processes and the evolution of life itself. Since 1872, when the geologist Medicott identified the Gondwana flora in India, through the definition of the Gondwana Land by Suess in 1885 and the first maps by Wegener and Du Toit in the dawn of the twentieth century, this major subject has

been investigated by many scientists worldwide (Medicott and Blanford, 1879, Suess, 1885, Wegener, 1915, Du Toit, 1937). The first geological map of Gondwana was published in 1988 by the American Association of Petroleum Geologists (AAPG), conceived by Prof. Maarten de Wit and his colleagues in South Africa (De Wit et al., 1988). Since then, the geological data for the regions concerned have improved incredibly in the wake of new geochronological laboratories and investigative methodologies. Thorough airborne geophysical reconnaissance has been extended across most parts of the constituent continents. Geophysical advances at continental margins and oceanic floors, the modelling of the restoration with new softwares and the analysis of satellite imagery permits scientifically rigorous reconstruction of Gondwana. The new Gondwana geological

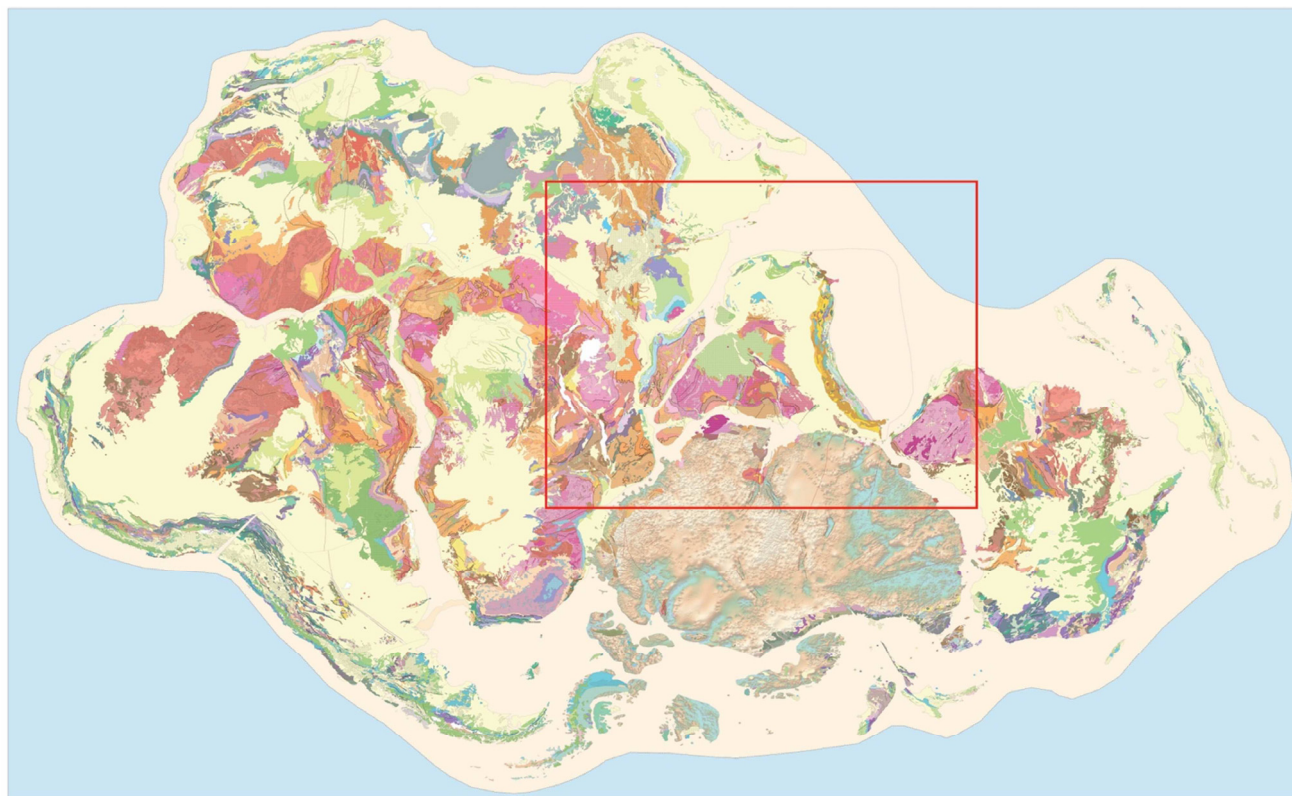


Fig. 1. Sketch of the new geological map of Gondwana, scale 1:5M, reconstructed to 184 Ma, generated at the Gondwana Digital Center of Geoprocessing (GDCG) at Universidade Federal do Rio de Janeiro (UFRJ), in Brazil. Red rectangle indicates area from Fig. 4.

map is an update of the De Wit et al. (1988) map with an approach of the 21st century. A new GIS data-base was built, with a dynamic digital process that allows the construction of not just an improved Gondwana Map, but also a wide variety of maps showing the evolution of this supercontinent.

Amalgamation of Gondwana completed at ca. 500 million years ago, during the Cambrian period, when marine life was flourishing evolving fast to visible organisms (Meert, 2003, Schmitt et al., 2018). For more than 350 million years, this supercontinent as an entity moved between the South Pole and the low latitudes of the southern hemisphere. Large intracontinental basins developed and registered the evolution of life on Earth as plants and vertebrates migrated from

water to terrestrial environments, culminating with the biggest reptiles in the Mesozoic Era (Chatterjee and Scotese, 2017). The continental margins of Gondwana were very heterogeneous. From the present-day location of the Andes to the Papua New Guinea, active tectonics predominated, with subduction zones, collisions and accretion of new terranes along the *Gondwanides*. The northern margin of Gondwana – facing the Tethys ocean – was entirely different, with stable, wide continental shelves and shallow seas from Northern Africa to Papua New Guinea. This extensional tectonic setting allowed small continental blocks to separate from Gondwana, drifting away to be deformed and welded onto Laurasia. Finally, for about 100 million years, starting ca. 200 million years ago (Jurassic period), Gondwana

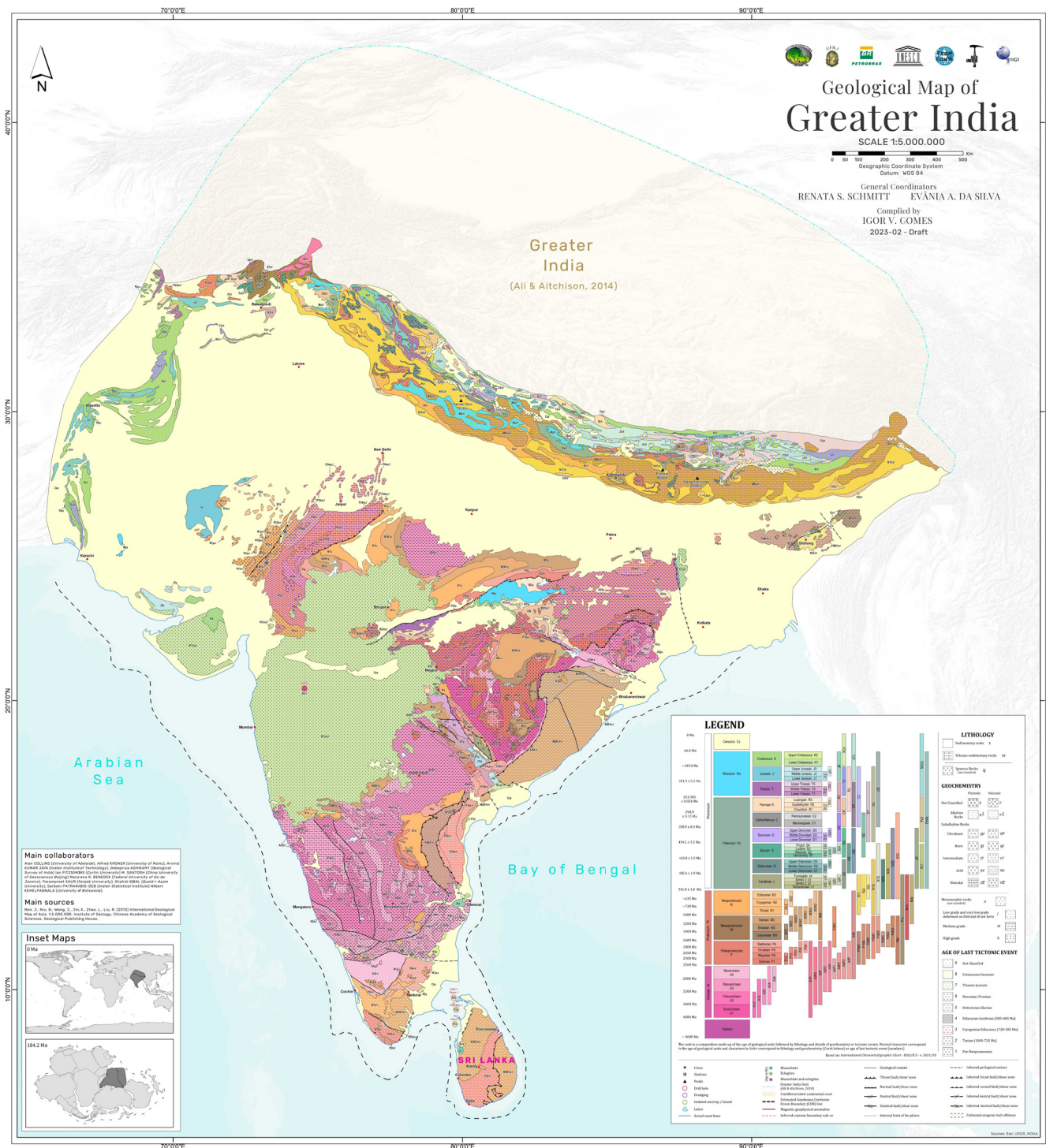


Fig. 2. Layout of the geological map of India 1:5M in the present day with the legend of the new Gondwana geological map in the bottom right. The two inserts in the bottom left show Greater India today and reconstructed to the Gondwana Map for 184 Ma.

started to break up into several land fragments evolving steadily into the present-day picture of the continents and oceans on Earth.

The Geology of Greater India in Gondwana

Amongst the Gondwana-derived lands, the Indian Subcontinent is the only piece of continental crust that moved as an island continent over the course of the past ca.140 million years from the southern hemisphere to its current position in Asia (Chatterjee and Scotese, 2017, Dewey and Bird, 1970). Greater India, the version that existed before 50 million years ago, was even larger previously to the orogenic events that generated the Himalaya (Searle et al., 1987, Meng et al., 2019).

Prior to being combined into the Gondwana reconstruction model, a geological map for each Gondwana-derived continent was the foremost task, as a unique legend was needed in face of a compilation from a diverse database. The resolution of the project was adjusted at 1:5M scale – twice more detailed than the original De Wit's map (1988). A GIS-database of polygons, lines and dots represent geological units, structures and locations. After years of compilation, a legend proposal was defined where the colour of the polygon indicates the rock age, based on the Chronostratigraphic Chart from IUGS/ICS (2016/12). The age refers to: crystallization in igneous rocks, deposition in sedimentary rocks and protolith in metamorphic rocks (Figs. 1,2). The warm colours (shades of pink, red and brown) refer to pre-1.0 Ga units and the orange shades are Neoproterozoic units. The cold colours (blue, green, etc) respond for the Phanerozoic Eon. Textures for igneous (volcanic or plutonic) and metamorphic (high, medium and low grade) units were defined. For the igneous units, the geochemical signature

was also included as a texture. For the metamorphic units, the age of the metamorphic event was added.

The geological map of Indian Subcontinent was initially built based on Ren et al. (2013), with progressive adjustments being made for each region with the support of numerous scientific papers (e.g., Maibam et al., 2016, Saha and Patranabis-Deb, 2014, Santosh et al., 2014, Kumar et al., 2017) and a special report from the Geological Survey of India (Murthy et al., 2017). The comprehensive geological GIS-database allows the generation of a wide set of thematic maps. One example is the actual surface exposures of the Precambrian units of India (Fig. 3). The geological map also presents the actual continent-ocean boundary (COB), compiled from Powell et al. (1988), Bouysse et al. (2009), Gibbons et al. (2013) and Müller et al. (2016). The COB lines were crucial to the reconstruction model for central Gondwana, allied with the combination of continental geological features that work as piercing points (e.g., Meert, 2003, Collins and Pisarevsky, 2005, Torsvik et al., 2001, Reeves et al., 2016). The tightest fit scenario was drawn connecting the Madagascar shear zones with major southern India structures (Praharaj et al., 2021), as well as the Archean Malagasy terranes (Antogil and Masora; Tucker et al., 2011) with the Great Dharwar cratonic block (Fig. 4). The position of Sri Lanka relative to India is reconstructed after Ratheesh-Kumar et al. (2020). The link between the Napier Complex (Antarctica) with the Eastern Ghats belt (India) is demonstrated by Dasgupta et al. (2013). The Naturaliste Plateau within the Australian southwestern coast provided the continental connection with the Indian Subcontinent (Gibbons et al., 2012).

The main challenge was whether or not the ancient northern margin (pre-Himalaya) would be reconstructed, how far it could have rebuilt the Greater India (Fig. 1). As for the whole Gondwana map, a 183 Ma fit was adopted for the interior reconstruction, and the ancient Jurassic Gondwana margins were not restored (Figs. 1 and 4). Furthermore, the geological units post-183 Ma were also maintained within the map. Nevertheless, the deformation and metamorphism that post-dated the Gondwana breakup (Himalayan orogenic features) were kept in the Indian Subcontinent, at least for this first version of the Gondwana map (Fig. 1).

The Gondwana Map Project

This project was born in 2008, during the Gondwana 13 Conference in Dali (Yunnan Province – China), where the International Gondwana Committee pointed out the importance to build a new Gondwana Map updating the original 1:10M De Wit et al. (1988). At that time, the main argument was that this ambitious enterprise was essential for the world scientific community and for the knowledge of the continents and their margins. Upon this challenge, the Brazilians Renata Schmitt (Universidade Federal do Rio de Janeiro - UFRJ) and Edson Milani (PETROBRAS) discussed the possibility to propose this project with the financial support of the Brazilian Petroleum Company. In the end of 2010, the “Revision of the geological map of Gondwana” was approved and parallel to this, the UFRJ group organized the Gondwana 14 Conference at Rio de Janeiro, with scientists from more than 35 countries. During the conference, a workshop about the Gondwana map was held where the challenges to conceive this new map were discussed, such as the legend, the theme, the reconstruction and paleogeography. The proposal was fully supported by the audience, including Maarten De Wit himself, who also participated in this initiative and encouraged the project (Fig. 5). He outlined the crucial points that the new Gondwana geological map ought to include: (a) Detailed geology on the Precambrian units; (b) Propose a better model for the Gondwana margin; (c) Improve the reconstruction model; (d) Eliminate the post Gondwana geological

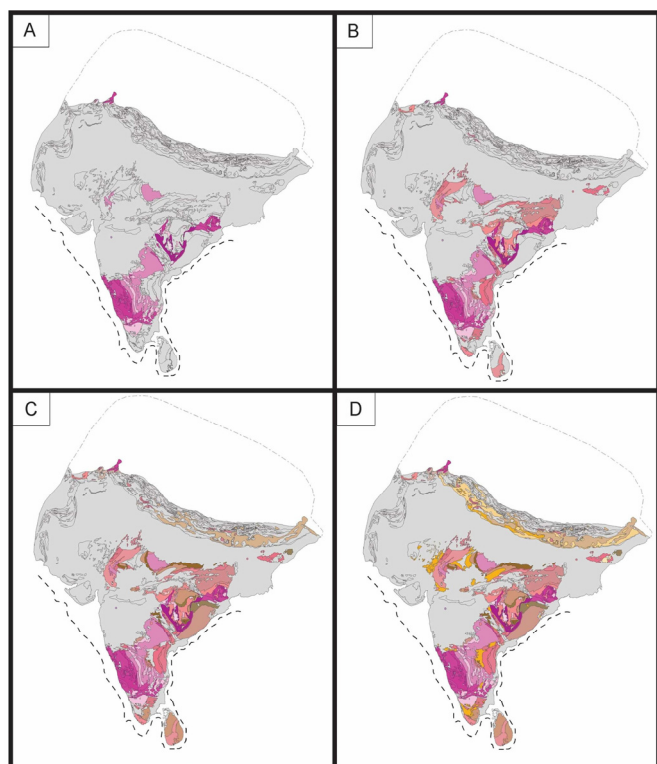


Fig. 3. Surface exposures of Precambrian units of Greater India from the Gondwana geological GIS database. Thick dotted line represents the current continent-ocean boundary of Greater India. (A) Archean geologic units in shades of pink. (B) Archean rocks in shades of pink and Paleoproterozoic units in shades of red. (C) Previously presented geologic units, with the addition of Mesoproterozoic rock exposures in shades of brown. (D) Previously presented geologic units, including Neoproterozoic units in shades of orange.

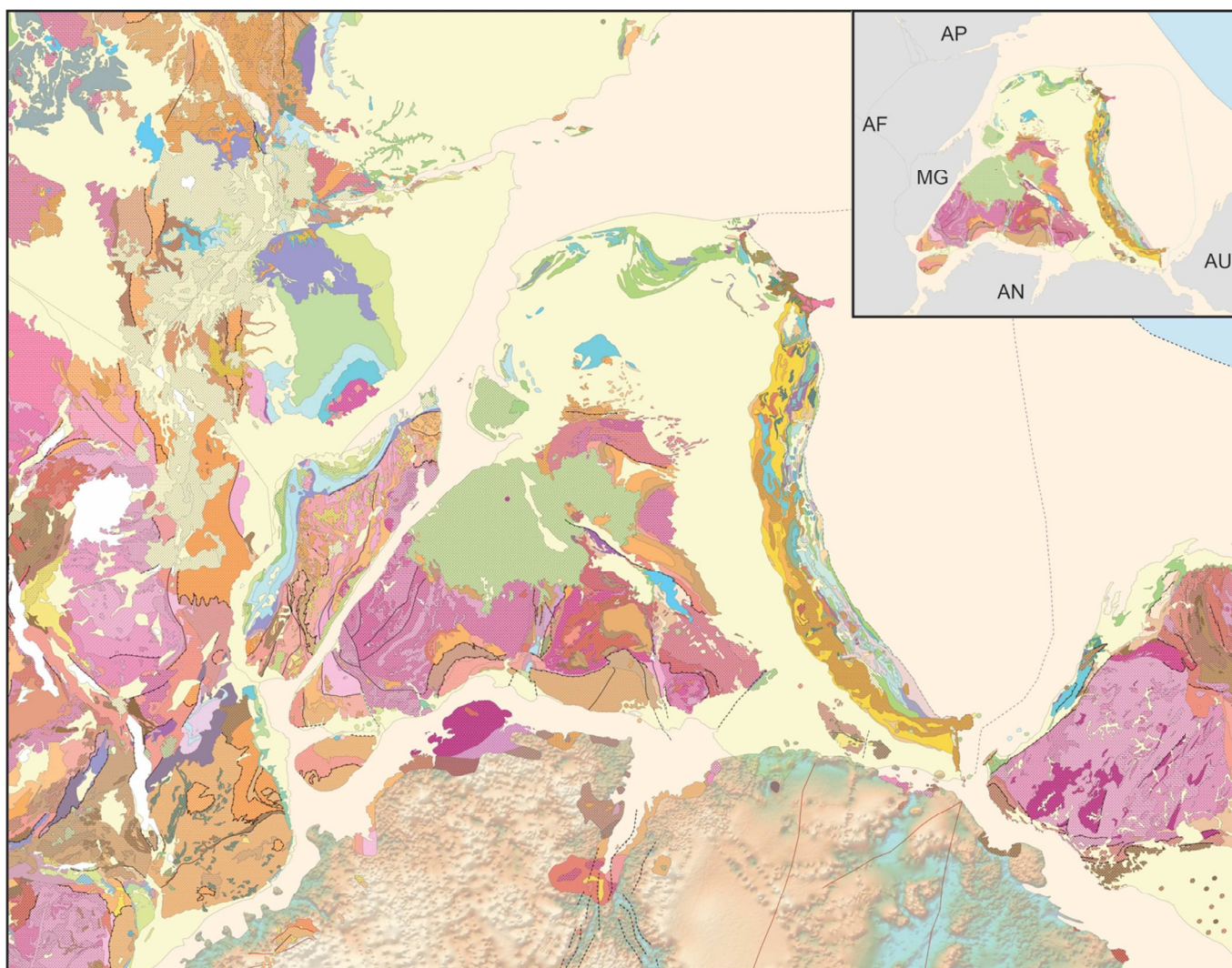


Fig. 4. Geological Map of Indian Subcontinent within the new Gondwana map, reconstructed to 184 Ma (Jurassic period). The insert indicates the counterpart continental blocks, in a clockwise rotation: Australia (AU), Antarctica (AN), Madagascar (MG), East Africa (AF) and Arabian Peninsula (AP). Location within the new Gondwana geological map in Fig.1.

units. He also inaugurated the Gondwana Digital Center of Geoprocessing (GDCG) at UFRJ, where a permanent group of researchers on cartography and geology are working since 2011. This project included vast international collaboration between scientists and students, universities, surveys and global institutions. It became well known as the IGCP 628 “The tectonic evolution and the new geological map of Gondwana” (2013-2019), led by Renata Schmitt (UFRJ) with co-leaders Maarten De Wit (Nelson Mandela University), Umberto Cordani (USP), Alan Collins (University of Adelaide), Colin Reeves (Earthworks), Pierre Rossi (CGMW) and Edison Milani (PETROBRAS).

More than a decade later, the GDCG is a reference center in South America with the database from the Gondwana paleocontinent, represented in the new Gondwana geological map at scale 1:5M, integrating data from the five actual continents reconstructed to the Jurassic period (Fig. 1 - www.gondwana.geologia.ufrj.br). The Gondwana Memory Center (GMC) is another outcome, located at the Geodiversity Museum of UFRJ (www.museu.igeo.ufrj.br). This legacy was only possible after years of workshops, meetings, discussions and collaboration with scientists from all the globe, integrating scientific thinking about Gondwana. In order to promote this integration, it was essential to have undergraduate and graduate students from many fields, making their dissertation and thesis on subjects within the project.

One of the main issues is to get students from developing countries to access developed countries laboratories and universities. This incorporation was fundamental for the achievement of this project. It is important to stress here that Gondwana was formed mostly by the territory of actual developing countries. All these digital tools, allied with the essential basic geological data will help scientists to review and improve the knowledge about this supercontinent that played a major role in the evolution of the Earth. These conclusions allow a better understanding of the global geological processes that today affect our lives. This is one alternative to harmonize a sustainable future on the planet.

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Fig. 5. Some Gondwana project events. Top left: Gondwana 14th International Conference in Buzios, Brazil, 2011. Top right: the inauguration of the GDCG at UFRJ in October, 2011, with Prof. Maarten De Wit. Bottom left: the exhibition of the new Geological map of Gondwana in Thailand during the 17th Gondwana Meeting, 2017. Bottom right: discussion about the geology of India with Prof. Dr. Sarbani Patranabis-Deb (Indian Statistical Institute) in Bangkok.

(University of Adelaide), Wilbert Kehelpannala (University of Botswana), M. Santosh (China University of Geosciences, Beijing) and Debapriya Adhikary (Geological Survey of India). We dedicate this editorial to our late colleagues Sarbani Patranabis-Deb (Indian Statistical Institute) and Alfred Kröner (University of Mainz).

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