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A synthesis of the national-scale geochemical survey in the last 50 years in Brazil

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Abstract

At the end of the 19th century, classical geochemistry arrived in Brazil through Henri Gorceix, arrived primarily used in his studies of mineralogy and petrology. Meanwhile, exploration geochemical arrives later, in the mid-20th century. But it was only in the late 1960s that systematic geochemical survey at the national level began, starting with the creation of CPRM - Geological Service of Brazil, culminating in over 50 years of uninterrupted activities, providing coverage of the entire country at various scales: global (7.3%), national (6.2%), regional (22.7%), and local (2.3%). Throughout this period, 681 projects were carried out and a variety of sample matrices were collected, such as stream sediment (226,792), soil (122,202), heavy-mineral pan concentrate (107,959), rock (56,807), among others (8,258), totaling 522,018 samples so far. All this collection has been progressively recovered, compiled, and organized into a robust public database (open access), developed by CPRM - Geological Survey of Brazil. More recently, high-density geochemical surveys were conducted in partnership with the China Geological Survey with the aim of comparing analytical and sampling methodologies. For the future (until 2050), two main actions are planned: 1) an expectation of an increase in the coverage of high-density prospecting surveys, ranging from 951,386 km² (restrictive scenario: 11.2% of Brazilian territory) to 2,204,778 km² (favorable scenario: 25.9% of Brazilian territory); 2) a forecast of Brazil's participation in the Global Geochemical Baselines Program, where sampling will be subdivided by regions – North (736), Central-West (225), Northeast (305), and South-Southeast (343) – totaling 1,609 sampling cells.

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1. Introduction

The term “geochemistry” was first used by the Swiss chemist Schönbein in 1838 (White 2005) and refers to the branch of earth science that studies the processes controlling the abundance, composition, and distribution of chemical elements, compounds, and isotopes in natural environments (Demetriades et al. 2020). Initially, the discipline garnered limited attention until its significant development in the 20th century through the works of scholars like Frank Wigglesworth Clarke and Viktor M. Goldschmidt, the latter often referred to as the “father of modern geochemistry”, for his groundbreaking work on the distribution of elements in the Earth’s crust in 1935.

Between 1847 and 1871, the German chemist Karl Bischof introduced analytical methods into geology to establish relationships between the abundance of chemical elements and geological features. The mid-1930s marked the beginning of geochemical exploration applied to mineral exploration, starting in the USSR, further driven mainly by post-World War II industrial reconstruction needs (Hawkes and Webb 1962; Batista et al. 2022). Professor John Stuart Webb (1920–2007) was a pioneer in applying geochemistry to identify geochemical provinces and potential mineral deposits (Howarth 2010). He also recognized the broader applications of geochemical mapping, including agricultural, marine, and environmental uses.

Geochemical mapping involves determining the spatial distribution of chemical elements and other physicochemical parameters, conducted at various scales, depending on research objectives. The final product derives from the geospatialization and interpretation of chemical element distributions and the processes influencing them. Regionally,

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geochemical mapping supports mineral exploration, geological mapping, metallogenetic studies, agriculture, land use, and environmental management.

This paper provides a brief overview of Brazil's geochemistry history and highlights the advancements in the National Geochemical Survey, which has been conducted by the CPRM-Geological Survey of Brazil over the past 50 years. It also discusses the future planning of the exploration geochemistry and global geochemical baselines program.

2. Evolution of Geochemistry in Brazil

Geochemistry in Brazil dates back to the late 19th century, with Minas Gerais as a pioneer. Henri Gorceix's analysis of rocks and rare earths complemented his studies in mineralogy and petrology at the Escola de Minas in Ouro Preto. Inspired by Goldschmidt, Djalma Guimarães conducted research on rare minerals and elements using optical emission spectrography in the laboratory of the State Service for Mineral Production of Minas Gerais (Dutra 2002).

The first geochemical survey in Brazil occurred in 1952 in Araxá (MG), collecting thousands of samples to measure natural radioactivity. These samples revealed anomalies in elements like barium, strontium, niobium, rare earths, thorium, phosphorus, and uranium (Dutra 1958). In the 1960s, Brazilian geochemistry advanced technologically with the creation of the University of Bahia's geochemistry laboratory and support from the National Department of Mineral Production (DNPM), now the National Mining Agency (ANM), in collaboration with the USGS. The first systematic geochemical study by Brazilian researchers focused on the Cupriferous Province of the Curaçá river basin (1961-1965), demonstrating geochemistry's effectiveness in mineral prospecting.

DNPM's Ten-Year Master Plan in 1965 significantly boosted Brazil's mineral sector development. Throughout the 1960s, international geochemical discoveries reinforced geochemistry's role in mineral research, particularly in areas covered by thick soil layers typical of some Brazilian regions.

Advancements in Brazilian geochemistry raised questions about geochemical processes in tropical climates and the most appropriate methodologies. Research at Brazilian universities led to specific methodologies adopted by prospectors and geoscientists. The 1970s marked a golden period for national geochemistry, highlighted by the first master's course in geochemistry at the University of Bahia and the creation of the Companhia de Pesquisa de Recursos Minerais (CPRM) in 1969 (Rocha 1972). At that time, the CPRM (currently Geological Survey of Brazil) sought experienced professionals in applied geochemistry as the Professor J.S. Webb (Machado 1971). Additionally, the establishment of national laboratories, including LAMIN (Laboratório de Análises Minerais), catered to analytical demands.

Exploration geochemistry became systematic among public and state-owned companies, with significant contributions from institutions like SGB-CPRM (e.g. Heineck et al. 1975), Nuclebrás (e.g. Pereira 1982), DOCEGEO (e.g. Motta et al. 1975), PETROMISA (e.g. Frota et al. 1983), Instituto Tecnológico Vale (since 2010; e.g. Sahoo et al. 2019, 2020; Salomão et al. 2020) and MINEROPAR (e.g. Licht and Tarvainen 1996), along with state, private and multinational companies. From these efforts came several discoveries of mineral deposits, some of them in the Carajás Mineral Province, especially in the Copper Belt (Salobo, Igarapé Bahia, Furnas, Sequeirinho, Paulo Afonso Sul, Azul, etc.).

The growing volume of geochemical data has created a need for advanced storage and processing systems, with CPRM leading the way. The Geochemical Sampling Statistics System - SEAG standardized data collection, archiving, and processing, serving as a model for national prospecting companies (Bruni 1982). Advances also extended to exploratory research in the oil and gas sector, with Petrobras/CENPES contributing significantly to new field discoveries and reservoir evaluations.

3. Systematic Geochemical Surveys in the Geological Survey of Brazil

Geochemical surveys constitute one of the main actions of the Geological Survey of Brazil since the late 1960s and reaching their peak in the 1970s and 1980s. These surveys range from small-scale to detailed projects, with a focus on prospecting. During this period, a significant portion of the Brazilian territory was covered geochemically, resulting in the selection of targets for intense mineral research and leading to the discovery of numerous mineral deposits, some of them world-class. Notable discoveries include Pitinga/AM (Sn-Ta-Nb-ETR-U-Th), Seis Lagos/AM (Nb-ETR-Sc-Fe-Mn), Rio Capim/PA (Kaolin), Morro do Engenho-Santa Fé/GO (Ni-Co), Palmeirópolis (polymetallic), among others such as Miriri/PE-PB (phosphate rock), Redenção/BA (Pb-Zn), Repartimento/RR (P-ETR), Bom Jardim/GO (Cu), Natividade/TO (Au), and so on. More recently, research in Middle Jequitinhonha (Li), West of Pernambuco (Au), and North of Mato Grosso (Au, Cu) has been noteworthy.

During the historical period of 1968-2000 (Figure 1), approximately 378,000 samples of stream sediments, heavy mineral concentrates, soil, and rock were collected at different scales. In the subsequent period, between 2001 and 2024 (Figure 2), about 144,137 samples were collected and analyzed. Specifically, during this last period, approximately R$ 52 million (US$ 9.3 million) were invested in sample collection and R$ 24 million (US$ 4.3 million) in chemical and mineralogical analyses, totaling around R$ 76 million (US$ 13.6 million) over 24 years, or an average of R$3.2 million (US$ 0.6 million) per year.

It is noteworthy that in the last period, the geochemical surveys conducted by the SGB adopted a more systematic approach (Caritat 2018), utilizing ICP OES-MS analyses of stream sediments and digestion by aqua regia. This allowed for better data integration in contiguous areas, leading to continuous coverage of the Brazilian territory using consistent sampling and analytical methodologies. The accumulated total of geochemical surveys covers approximately 25% of the national territory, equating to around 2 million km² (Figure 3). The northeastern region has the highest sample coverage at around 45%, while other regions have coverage of less than 24%. The SGB-CPRM geochemical database includes 681 projects responsible for collecting 107,959 samples of heavy mineral concentrate, 56,807 rock samples, 122,202 soil samples, 226,792 active stream sediment samples, and 8,258 among other matrices, totaling 522,018 samples.

Most of the projects developed by SGB/CPRM are regional in nature, on scales of 1:100,000 and 1:250,000, with the former predominating. Most smaller-scale projects

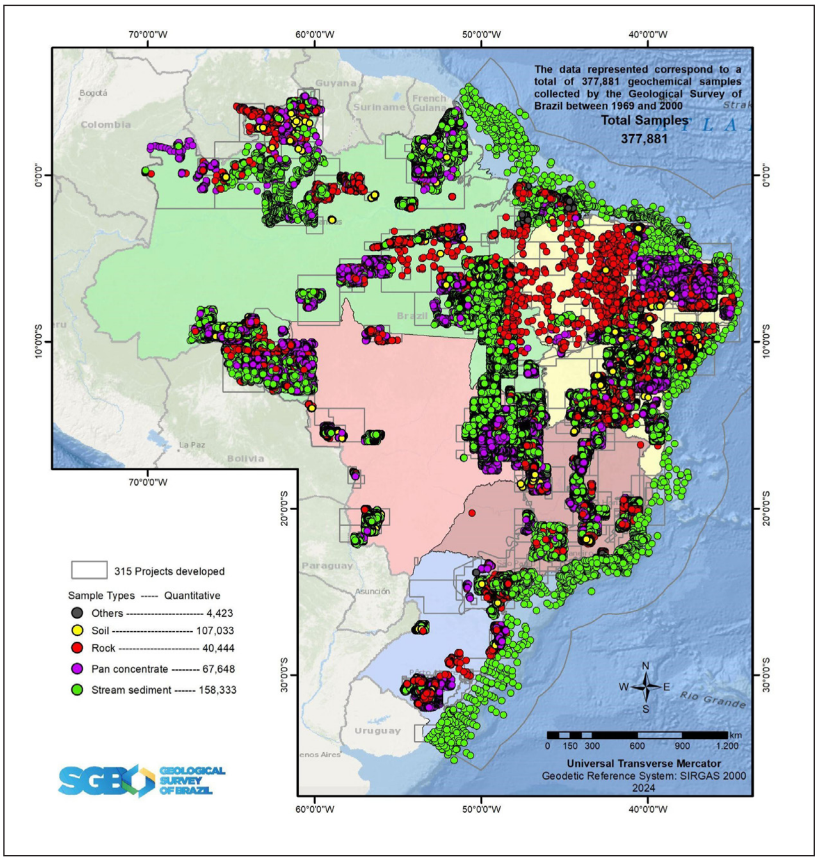

FIGURE 1. General distribution, by region, of geochemical survey projects carried out by SGB-CPRM between 1969 and 2000 (historical period).

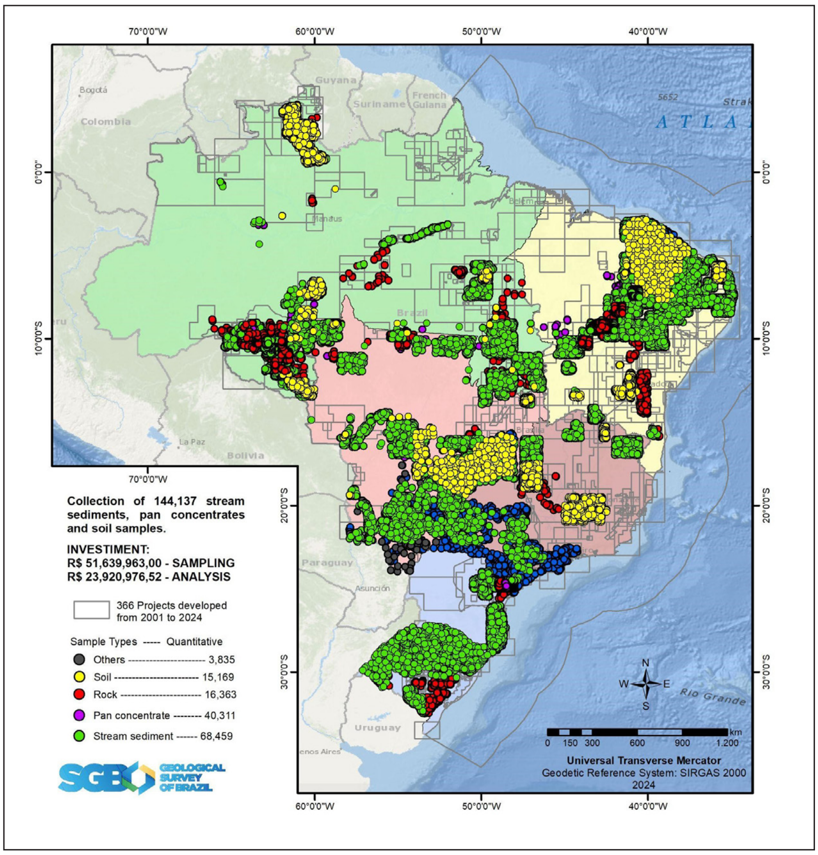

FIGURE 2. General distribution, by region, of geochemical survey projects carried out by SGB-CPRM between 2001 and 2024, including related costs.

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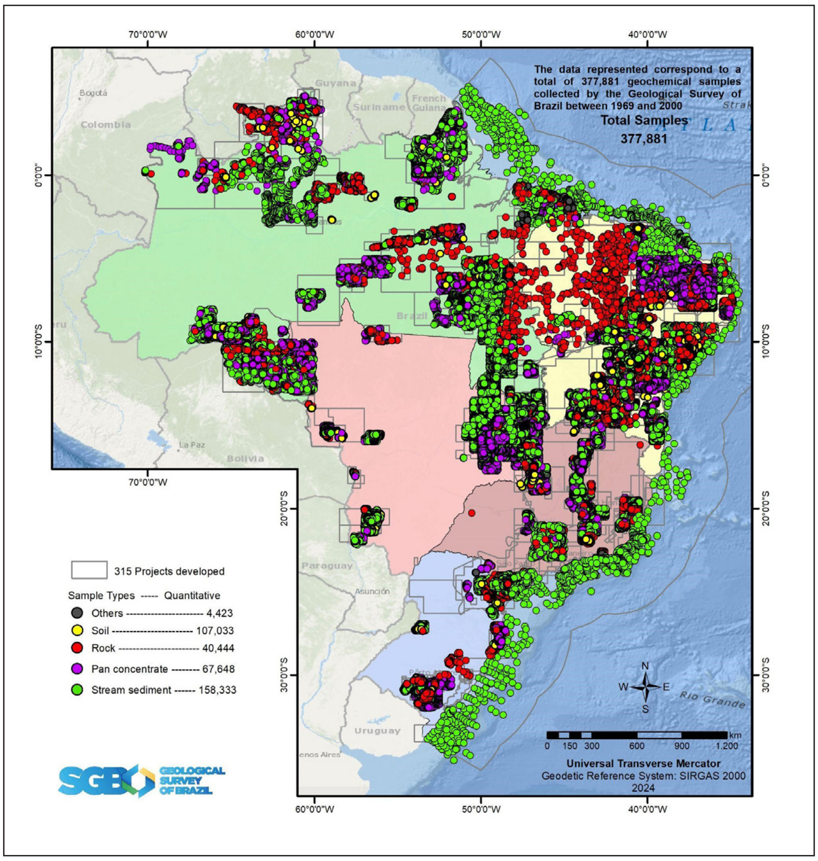

FIGURE 3. General distribution of the different sample matrices collected and analyzed by SGB-CPRM between 1969 and 2022. This collection is available for consultation and download in the institution's corporate database (GeoSGB).

were developed in the northern region (Amazonia), where geological knowledge is still limited and access is more difficult. Regional-scale projects (1:100,000) are distributed across all regions, their dissemination marked by the Basic Geological Surveys of Brazil Program (PLGB), initiated in the 1980s. Despite the extensive volume of samples and large surveyed areas, additional geochemical surveys using the same matrix and analytical methods are still needed, particularly at the 1:100,000 and 1:250,000 scales. In regions like the Amazon, environmental conditions and logistical challenges (access and cost) prevent surveys at larger scales. Considering only stream sediment samples, the geochemical coverage by SGB until 2019 was around 40% at different scales (Table 1).

The objective of SGB is to achieve full coverage of the Brazilian territory, prioritizing areas with greater mineral potential and insufficient geological-metalogenetic knowledge, including those represented by onshore sedimentary basins, which are responsible for important mineralization (phosphate, uranium, limestone, etc.) and areas with significant geochemical coverage gaps (Figure 3).

Currently, exploratory geochemical surveys focus on regional mapping using stream sediment and heavy mineral concentrate samples (Figures 4 to 6), with sampling densities tailored to the scales of work (Lins 2003). This sampling generates important information that not only identifies areas favorable to mineralization but also aids in geological cartography, especially in less known regions, and supports environmental management actions.

Additionally, it is crucial to plan new surveys in specific and strategic areas, such as provinces and mineral districts, including some areas covered by previous surveys conducted during the historical period (1969-2000). Samples from this period are not always reanalyzable, moreover, the geochemical results are based on different analytical methodologies compared to current ones, including different sample preparation and analysis methods, and fewer analyzed elements. In this context, the National Decennial Plan (Brasil 2024) includes long-term planning to map areas with little or no knowledge, continue systematic coverage of areas (mainly in 1:100.000 scale) and research specific substances (Li, Co, Cu, Ni, Au, U, graphite, phosphate, etc.).

TABLE 1. Status of Geochemical Cartography Performed by SGB.

Scale	Global> 1000 km^2	National 100 to 1000 km^2	Regional 10 to 100 km^2	Local 1 to 10 km^2
% covered	7.312	6.2	22.7	2.3
Sampling density	1/2600 km^2	1/140 km^2	1/15 - 45 km^2	1/2 - 6 km^2

FIGURE 4. Materials used to collect geochemical samples (a) and examples of samples (b) collected from active stream sediment and heavy mineral concentrate (GeoSGB). Subsequently, the samples are weighed and identified with barcodes (c).

FIGURE 5. Examples of collecting sediment samples from streams in different environments: Amazonian (a) and semi-arid (b) regions.

FIGURE 6. Steps of gravel collection in the semi-arid environment and preparation of heavy mineral concentrate samples: (a) sampling at dry drainage; (b) transport; and (c) concentration.

To expand the geochemical sampling capacity, a large sample survey program was implemented in various regions of Brazil during the second decade of this millennium (Figure 7), with the support of a private company (Brazil Explore) contracted for this purpose. This data supported several projects, including ARIM/Remanso-Sobradinho, Novas Fronteiras/Southeast of Rondônia, Novas Fronteiras Centro-SE of Roraima, ARIM/Southeast of Amazonas, ARIM/Seridó, Fosfato Brasil, among others.

In addition to the National Geochemical Sampling Program, some scientific partnerships were signed in the second decade of the 2000s, such as a cooperation agreement between the geological surveys of Brazil and China. This agreement facilitated the Geochemical Mapping of the Piatã Sheet (Santos and Oliveira Neto 2023), enabling the exchange of knowledge in sampling and analytical techniques, and comparison of results obtained from different sampling densities, granulometric fractions, and analytical procedures (Figure 8).

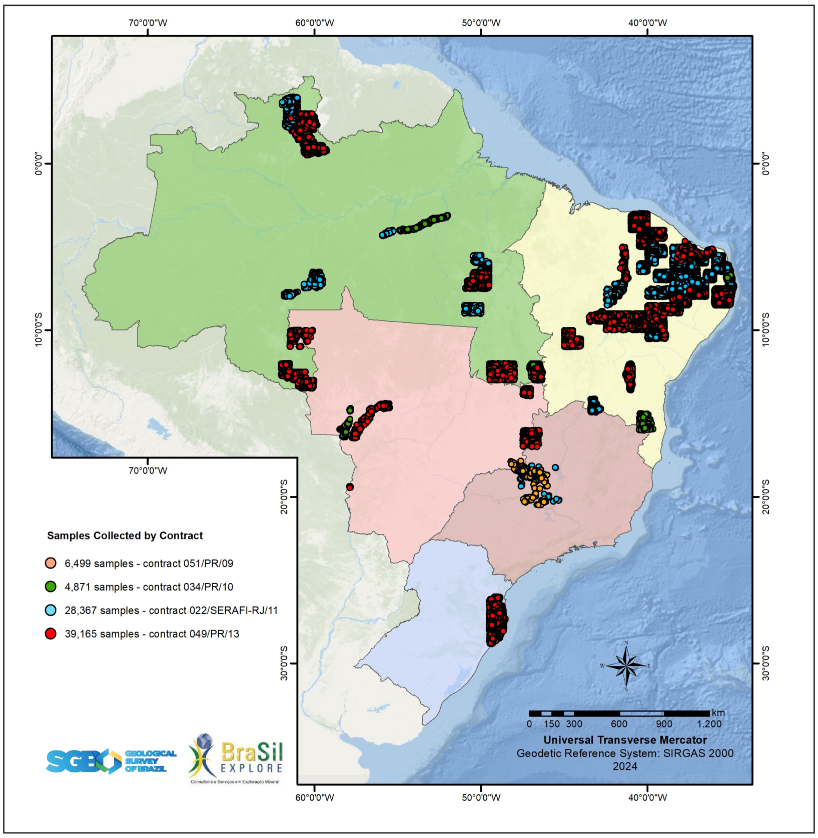

FIGURE 7. National Geochemical Sampling Program conducted by SGB/CPRM and operationalized by Brasil Explore (2011-2014).

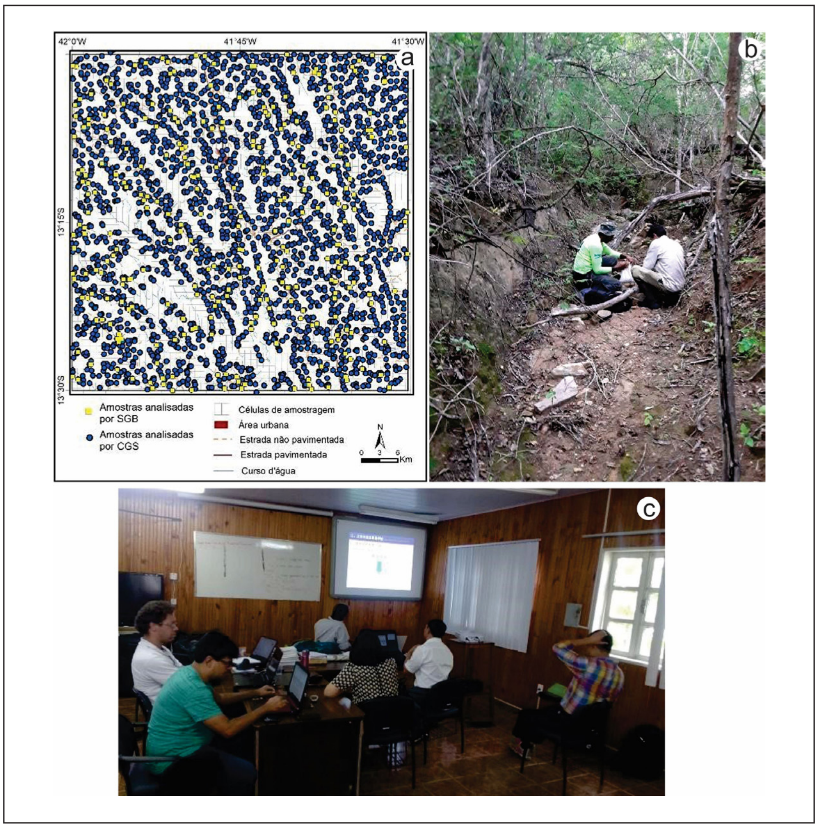

FIGURE 8. Geochemical Mapping of the Piatã Sheet/BA (2016-2023), on a 1:100,000 scale with high sampling density, carried out in the interior of Bahia, São Francisco Craton: a) sampling map; b) geochemical site sampling; and c) office work of the geochemistry teams from Brazil and China.

The generation of a large volume of data from these surveys made it imperative to define strategies for the retrieval, organization, consistency and storage of geochemical data into the institutional database of the SGB (GeoSGB Bases). From 2018 onwards, surveys conducted in Bahia, Pará, Rondônia, Goiás, and Rio Grande do Sul stand out, totaling more than 80,000 km² of geochemical coverage on a 1:100,000 scale. These surveys supported projects of Geological Mapping and Geological-Geophysical Integration in the Contendas-Macajuba Region (BA), Geology, Mineral Resources, and Crustal Evolution of Carajás (PA), and Geological and Mineral Resources Integration of the Northwestern Portion of Rondônia State. In the same year, the geochemical data entry application (FCampo) was structured to be filled out via the Survey123 app from the ESRI platform, allowing real-time data acquisition through tablets during field stages and synchronization to the database at the end of each day (Figure 9). This format has proven very effective in reducing inconsistencies in database entry, facilitating monitoring of sampling progress at each stage, and quickly identifying possible inconsistencies.

From this robust geochemical database several geochemical technical reports were published, mainly in the last decade, such as of Quadrilatero Ferrífero (Larizzatti et al. 2014), Rio Grande do Sul Shield (Andriotti et al. 2018), Araripe Basin (Lins 2018), Quixadá-Itapiúna (Calado 2020b), João Câmara-São José Campestre (Calado 2020a), Granjeiro-Cococi (Abreu 2023) and the Geochemical Atlas of Stream Sediments in the Eastern Carajás Region (Neves and Pitarello 2023). These data are extensively used in the elaboration of models of mineral potential, represented by prospectivity maps of selected areas from Brazil (Tavares et al. 2020).

The last geochemical surveys were carried out in Bahia, Mato Grosso, Amazonas, Pará, and Rondônia. In Bahia State for example, ten 1:100,000 sheets sampled in 2021-2022 correspond to Lagoa Real Uraniniferous Province and Central Gavião Block. Highlights also include actions in the Carajás region (PA), Sucunduri (AM), northern Mato Grosso, and eastern Rondônia (Figure 10).

4. Origin ans Evolution of Analytical Techniques in Brazil

The development of analytical methodologies and geochemical extraction techniques in Brazil is closely tied to the growth of mineral research and the need for precise analyses in geosciences and environmental sciences. This advancement gained momentum in the 1960s and 1970s with the launch of geological mapping projects and support from institutions like the National Department of Mineral Production (DNPM) and the Geological Service of Brazil (CPRM).

During that period, classical chemical analysis methods, such as gravimetry, volumetry, and spectroscopic techniques, were widely used for determining chemical substances in various matrices, including water, soil, and food. For instance, gravimetry relied on measuring precipitate mass to determine analyte concentrations, while volumetry involved titration for reagent quantification. Spectroscopic methods, like atomic absorption and fluorescence spectroscopy, enabled faster and more sensitive analyses, driving progress in analytical chemistry.

The introduction of Atomic Absorption Spectrometry (AAS) and, later, X-ray Fluorescence Spectrometry (XRF) marked a significant advancement, particularly for geoscience studies and mineral quality control. These methods offered notable improvements over traditional approaches like gravimetry and volumetry, providing greater sensitivity and accuracy. AAS enabled trace-level analysis of elements, essential for soil and ore samples containing low metal concentrations. XRF also excelled in analyzing major elements and detecting heavy metals and other constituents, making it indispensable in geochemical research.

4.1 Use of ICP-OES and ICP-MS

In the 1980s and 1990s, Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) became established in Brazil, bringing significant advances to geochemical analyses. These technologies allow for much more detailed and accurate

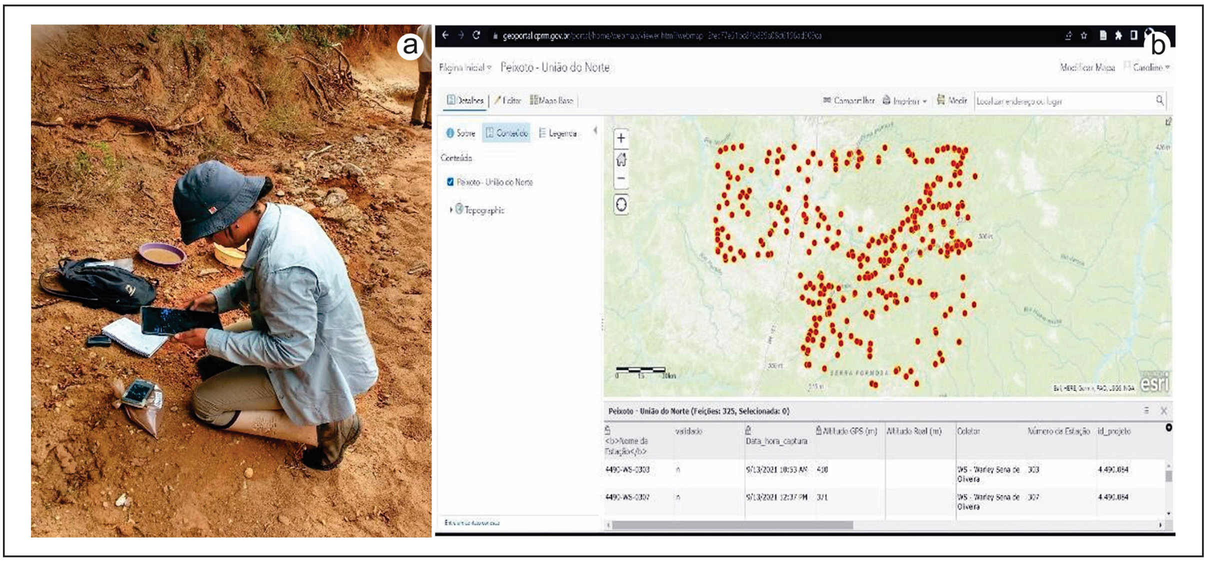

FIGURE 9. Example of geochemical data collection using the Survey123 app from the ESRI platform: a) Acquisition of geochemical data in the field; b) Application screen showing the spatialized data.

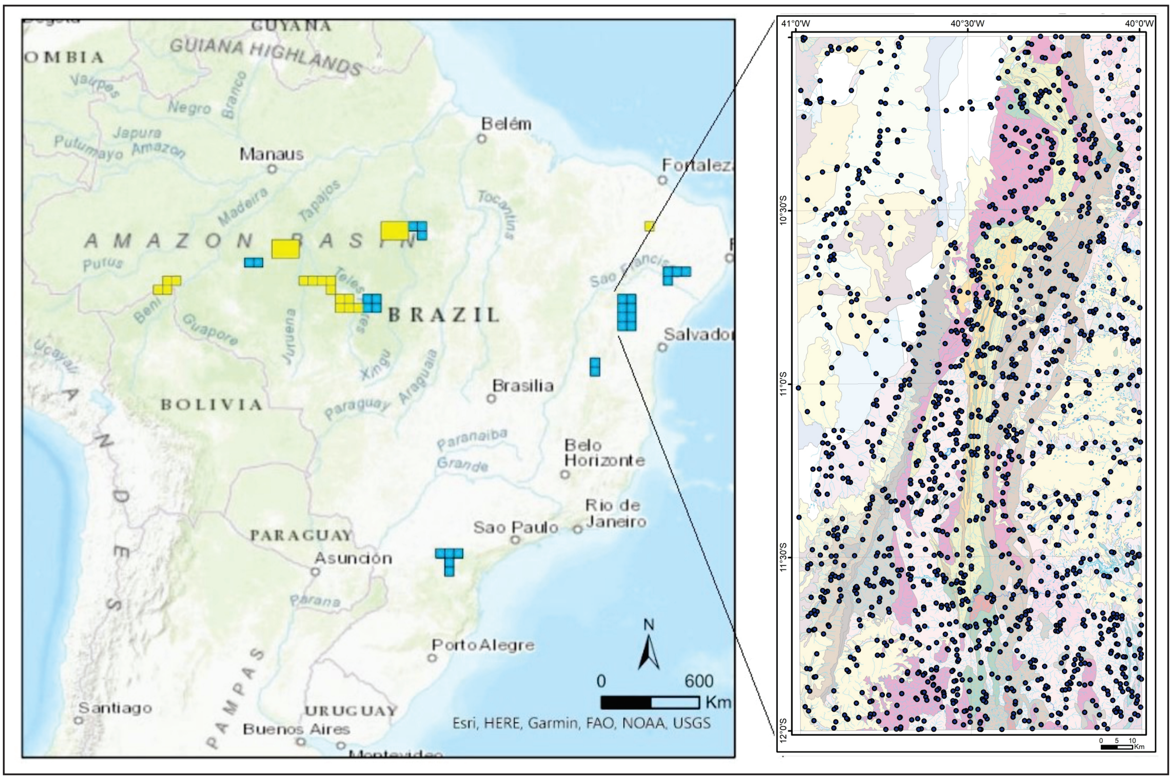

FIGURE 10. Regional geochemical coverage executed (blue) and in progress (yellow) from 2021 onwards and an example of sample distribution according to geological substrate and surface water resources availability, (central portion of the Gavião Block, Bahia - executed in 2022).

data to be obtained, especially in studies aimed at quantifying elements at very low concentrations, the so-called specific elements (Gross 2017).

Both ICP-OES and ICP-MS have multi-element capability, enabling the analysis of multiple elements simultaneously, which increased the efficiency of analyses (Linge 2024). This made it possible to perform complete geochemical characterization studies with a single reading, saving time and resources. These technologies have been implemented by universities and research laboratories in Brazil and have enabled faster and more accurate multi-elemental analyses, helping to characterize mineral deposits and ore bodies in much detail and reliability. Using ICP-OES and ICP-MS, researchers have been able to accurately identify the presence and concentrations of a wide range of elements in soil, rock and water samples, which has helped to map valuable mineral resources and better understand the geochemical characteristics of deposits.

4.2 Advances in Geochemical Extractions

Geochemical extraction techniques are essential for dissolving components of rock, mineral or soil samples and preparing them for analysis. Traditionally was used in Brazil, and in many other places, the alkaline fusion or acid digestion method. These methods were essential to ensure efficient dissolution of resistant minerals and to release the elements of interest for analysis, such as alkaline fusion. This method uses alkaline reagents, such as sodium hydroxide (NaOH) or sodium carbonate (Na_2CO_3), mixed with the sample and heated to high temperatures (usually above 1,000ºC). Alkaline fusion is especially useful for samples containing refractory minerals (difficult to dissolve with acids), such as silicates.

In recent years, the use of microwave digestion for geochemical discovery has become increasingly common and efficient in Brazilian laboratories. This method has brought important improvements compared to traditional methods, especially in the analysis of samples rich in minerals such as silicates, which are more difficult to dissolve. Some advantages of microwave digestion is a greater efficiency and speed. Microwave digestion heats the sample and reagent in a uniform and controlled manner, accelerating the dissolution process compared to digestion in traditional heating blocks. This reduces the time required to prepare each sample.

4.3 Development of Analytical Norms and Standards

As analytical techniques advanced, international standards, such as those from the ISO (International Organization for Standardization) and ASTM (American Society for Testing and Materials), were adopted and adapted in Brazil to enhance quality control in analyses. The implementation of these standards improved the reliability of results and facilitated comparability with global data (Linge and Potts 2024).

Brazilian institutions, including the Brazilian Association of Technical Standards (ABNT) and the National Institute of Metrology, Quality, and Technology (INMETRO), worked to align Brazilian geochemical analysis practices with international standards. These organizations developed and adapted standards specifically for the analysis of minerals, soil, and water, ensuring consistency with global norms.

This alignment with international standards has enabled Brazil's research institutions, such as the University of São Paulo (USP) and the Institute of Technological Research

(IPT), to invest in new technologies and advance analytical techniques (Hergt et al. 2009). These advancements have not only improved the precision of mineral deposit identification but also facilitated environmental studies and assessments of soil and water contamination.

5. Low Density Geochemical Mapping: Future Perspectives of the Geochemical Baselines Mapping Program in Brazil

5.1 Geochemical Baselines Mapping Program

Since the late 1980s, a “Global Geochemical Baselines” project has been discussed worldwide **(**Figure 11a**)**, aiming to standardize the collection and analysis of geochemical data on a global scale and define natural distribution standards (background) for future comparisons. The first proposal for continental-scale geochemical mapping came from Europe in 1986, following the Chernobyl nuclear accident (April 26, 1986) and resulted in IGCP Project 259 ‘International Geochemical Mapping’ - 1988/1992 and IGCP Project 360 ‘Global Geochemical Baselines’ - 1993/1997 and Darnley et al. (1995). At that time, geochemists realized for the first time that there was no standardized background geochemical data to assess the impact of such continent-wide accidents. The Working Group on Global Geochemical Baselines organized the project in:

- Phase 1 - included a review of geochemical mapping activities worldwide, an assessment of requirements and methods for global geochemical mapping and recommendations published in “A Global Geochemical Database for Environmental and Resource Management (Darnley et al. 1995).
- Phase 2 - establishment of a worldwide network of geochemists, develop sampling methods, initiate sampling in Europe (FOREGS) and publish the FOREGS Geochemical Mapping Field Manual (Salminen et al. 1998).
- Phase 3 - facilitate collection of samples through training, consultation, workshops, etc. Promote standardization of all geochemical survey methods worldwide.
- Phase 4 - Mapping the Chemical Earth (2016 - present). China Geological Survey and UNESCO International Centre on Global-Scale Geochemistry, Langfang, China. Present global concentrations and distribution of elements on the earth and their cycles and interaction in lithosphere, pedosphere, hydrosphere and atmosphere. Provide insights into natural resources, environments, and global changes.

According to Chemical Abstracts Service Registry Number and Substance Count, in mid-2024, more than 200 million chemical substances were registered. A large number of these chemicals were few tested and this is a point in the risk assessment process. According to WHO, chemicals can be related to cancer, cardiovascular diseases, allergies and hypersensitivities, reproduction and developmental problems, nervous system. Potentially sensitive groups are elderly, children, asthmatics, fetuses, reproductive age. Examples of associate chemicals are asbestiform minerals, benzene, phthalates, organo-chlorines, organo-phosphates, dioxins, As, Pb, Cd, Hg, Ni. For the potentially toxic chemical that occur naturally in the environment (e.g., As, Hg, Cd, Pb, Cr) it is critical to map their abundance and spatial distribution considering all geochemical compartments and landscapes (soils, sediments, waters).

Natural and anthropogenic processes generate considerable variations in the chemical element content and distribution of natural materials, and these variations require adequate documentation to support the planning of a wide spectrum of governmental actions (Frizzo et al. 2005). According to Danrley et al. (1995), research conducted since 1988 as part of the International Geochemical Mapping Project (IGM) has confirmed that available data regarding the surface geochemical composition of the Earth are incomplete or inconsistent. This highlights the importance of a high-quality international geochemical database as an essential resource for scientific research and addressing environmental and economic issues related to human health, soil fertility, agriculture, water supply and irrigation, waste disposal, mineral exploration and mining, industrial pollution, and general land use.

This database will allow legislators to establish thresholds for chemical element contents in the environment, recognizing locations with naturally elevated concentrations and enabling the temporal monitoring of variations in these concentrations resulting from anthropogenic or natural actions. Moreover, in geoscientific terms, continental-scale mapping allows for the recognition of large geochemical provinces and the identification of geochemically interesting areas. It will also help calibrate and validate data from airborne geophysical surveys (radiometric – K, Th, and U) in Brazil.

As mentioned earlier, the Geological Survey of Brazil has already conducted hundreds of geochemical surveys using over time different matrices, collection techniques, analytical methods, detection limits, and sampling spatial distribution. This heterogeneity hampers any attempt to fully integrate these data, especially when considering international data, aiming to determine global geochemical background levels. Therefore, a project of this nature could also help to level and integrate these existing data.

In the 1990s, there was an initiative to contribute to the efforts of the Global Geochemical Baselines – IUGS-IAGC, in the standardization and harmonization of geochemical mapping procedures and data management on an international scale. This action marked the inclusion of CPRM in the group of countries committed to the idea (Frizzo et al. 2005). Since 2008, SGB has been carrying out low-density geochemical surveys nationwide through drainage (water and stream sediment) and regolith (soil) sampling, with sampling densities between 1 sample per 100 km² and 200 km² and 700 km², respectively (Mapa 2023).

For the Geochemical Baselines Project, the collected samples will serve as reference material and must be obtained following strictly established procedures (Darnley et al. 1995; Darnley 1997), including adequate quantities for analytical processing and storage. It must also respect standardization and systematization requirements, such as sampling means and standardized sample density. The methodology provides for the analysis of chemical elements of economic and environmental importance with the lowest possible detection limits, in addition to a rigorous quality control at each stage. Since 2016, the project has been coordinated by the International Centre on Global-scale Geochemistry (ICGG) in Langfang, China, which initiated an international scientific cooperation project called “Mapping the Chemical Earth,” responsible for bilateral collaboration with participating countries.

Given the characteristics of low density and global scope for the purpose of the "Global Geochemical Baselines," the IGCP-259 report (Darnley et al. 1995) recommends dividing the terrain into approximately 160 km x 160 km cells of the Global Reference Network (GRN), corresponding to 410 cells in Brazil (Figure 11b).

Among the main objectives of the project, we highlight:

1. the establishment, at an international level, of baselines for 76 parameters that will help quantify environmental changes and search for new natural resources.
2. adoption of standardized methods and reference materials. Lowest possible detection limits on all elements and tight quality control at every step of the process.
3. long term observation of changes and cycles in the lithosphere, pedosphere, hydrosphere biosphere and atmosphere.
4. build up a bridge between the scientific community, decision makers and the public.
5. Make available on the internet, through the Chemical Earth platform, maps and geochemical data from all countries.

For South America and the Caribbean, the Geological Services of Latin-speaking countries met through ASGMI - Association of Geological Services of Latin Countries and, through monthly meetings that have taken place since 2020, established guidelines and standardized methodologies for

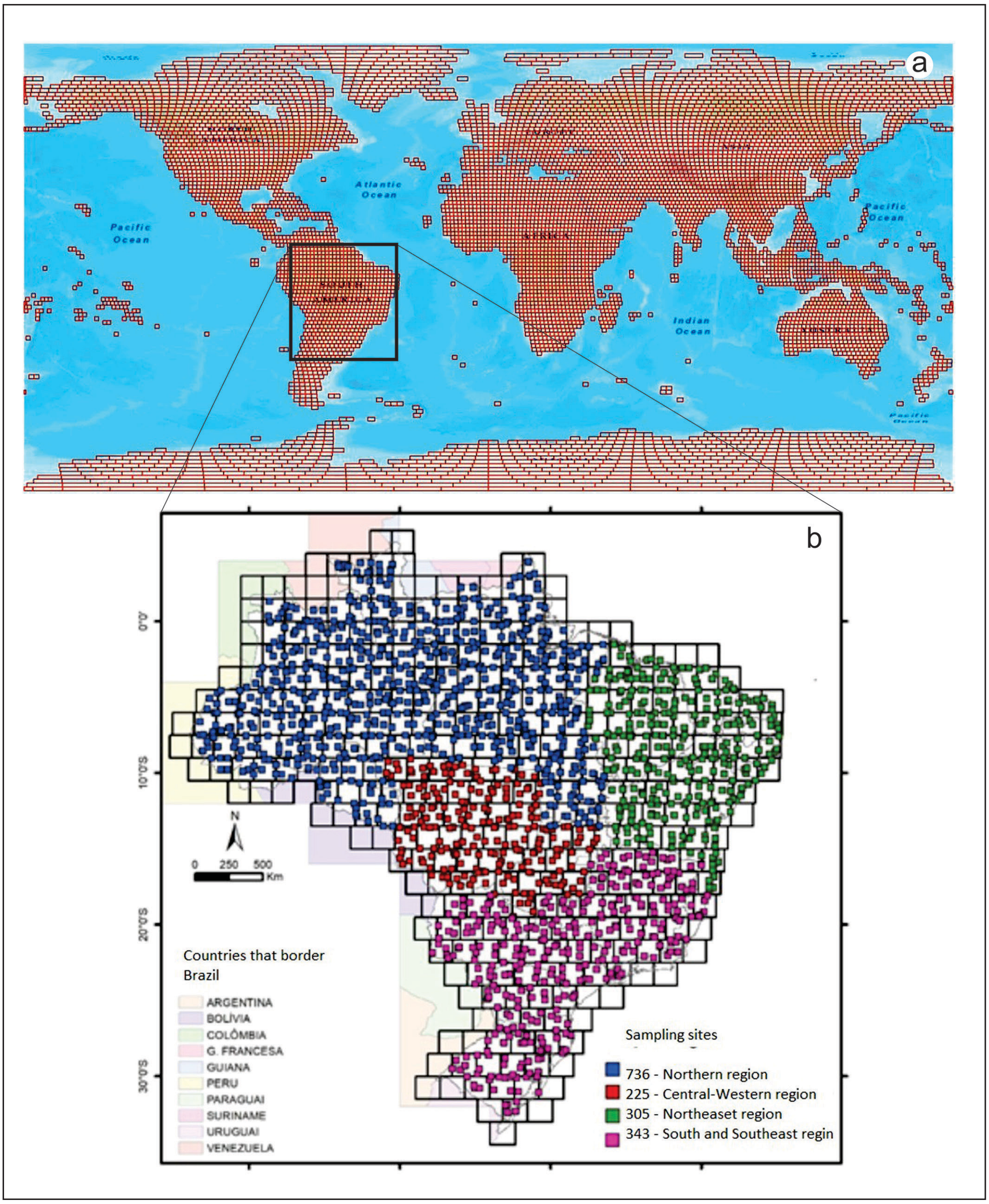

FIGURE 11. a) Reference Cells for the Global-Scale Geochemical Mapping Project (Global Geochemical Reference Network- GRN); b) Global Geochemical Baselines Program in Brazil, containing the 410 sampling cells and the spatial distribution of the 1,627 collection stations.

development of the Geochemical Baselines South America and Caribbean project.

A personal meeting between researchers from the Geochemistry Specialist Group took place in Bogotá, Colombia, in June 2018. A second meeting took place in Medellin, Colombia in September 2022. These meetings included presentations of the activities carried out by each country in the area of Geochemistry and field practices: collection of floodplain, soil and river water samples.

The group produced the Manual for the Geochemistry of the ASGMI countries to show the present use of the geochemistry of each Geological Survey of South America and Caribe. Collaborated with the elaboration of the Manual of Geochemical Methodologies of IUGS.

6. Final Remarks: Challenges for the Geochemical Surveys in Brazil

In the context of exploratory geochemical surveys, the main objectives of SGB for the coming decades are to increase the coverage of the Brazilian territory at scales of 1:100,000 and 1:250,000, and to integrate Brazil into the Global Geochemical Mapping initiative (Global Geochemical Baselines Mapping). To address the planning needs for area coverage, the National Mining Plan considered three main scenarios, conditioned by available human and financial resources and the possibility of their progressive increase. The projected mapped area by 2050 increases from 951,386 km² (first scenario: 11.2%) to 2,204,778 km² (third scenario: 25.9%), with a significant increase in areas in the Amazon region in the latter scenario (Figure 12), which demands higher human and financial resources than other regions (Figure 13).

The purposes of the Global Geochemical Mapping at SGB include: (1) provide documentation on composition of a variety of surficial materials at locations evenly spaced all over the country; (2) provide a supply of locally relevant standards reference material for use in the region of origin and (3) provide reference points for normalizing and linking national geochemical and geophysical databases; (4) provide baseline data for preparation of Brazil Geochemical Atlas; (5) provide samples for future research (e.g. isotopic analysis, speciation studies etc.); and (6) provide sites for recurrent monitoring in the future. Recommended sample media are: floodplain sediment (basin of 1,000 km^2 to 6,000 km^2) - top (0 to 25 cm) and bottom (deepest accessible depth); humus surface/organic matter (if available); and stream water (untreated, for anions; acidified, for total cations; and filtered (45 μm) and acidified (dissolved cations).

To fulfill any of these scenarios, SGB-CPRM foresees the continuous improvement of its researchers, whether through short- to medium-duration training (courses, scientific events, technical meetings) or through master's, doctoral, and postdoctoral courses. Studies aimed at improving employed techniques and utilizing other sampling methods are planned, such as hydrogeochemistry and pedogeochemistry.

Since SEAG, SGB has demonstrated a continuous concern with the preservation and safeguarding of this

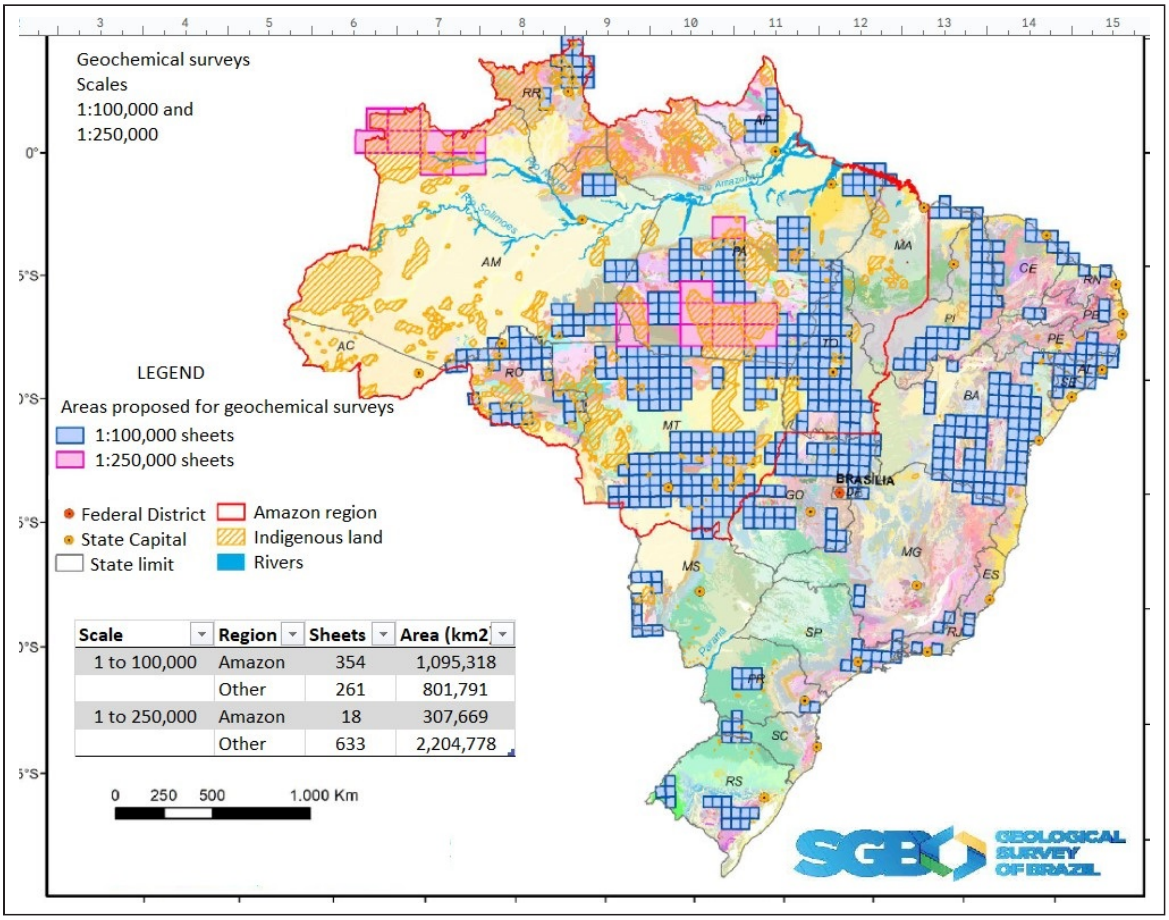

FIGURE 12. Geochemical mapping planning on the 1:100,000 and 1:250,000 scales by SGB-CPRM in the Amazon and non-Amazon regions for the next 30 years.

FIGURE 13. Sampling routine in the Amazon region: a) long displacements in small boats; and b) an example of sample collection in this scenario.

important collection, prioritizing a significant institutional effort aimed at data recovery and consistency in recent years, making the geochemical database increasingly robust and reliable. Additionally, SGB-CPRM's corporate database has been undergoing a profound overhaul, aiming to make it a standardized and integrated repository that is more user-friendly, agile, and timely in data delivery and consultation.

The projects validated by the SGB-CPRM Data Consistency Team can be accessed directly on the Geology GIS platform or in the download folders on the geosgb.cprm.gov.br portal (Figure 3). Furthermore, all published products linked to these data are available on the above portal and in the institutional repository (rigeo.sgb.gov.br).

SGB's concern with the sample and aliquot bank is also noteworthy, which is of great importance in any research institution where stored materials are available for reanalysis or analysis by other analytical methods, thus reducing costs associated with resampling.

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SCM			■	■	■	
APCM			■	■	■	

A - Study design/ Conceptualization **B** - Investigation/ Data acquisition
C - Data Interpretation/ Validation **D** - Writing
E - Review/Editing **F** - Supervision/Project administration

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