CHAPTER 4

PROSPECTIVITY MAPPING OF THE IRATI FORMATION FOR CO_2 GEOLOGICAL STORAGE IN THE PARANÁ BASIN

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ABSTRACT

The Paraná Basin represents an enormous potential for Brazil concerning implementing carbon dioxide capture, utilization and storage (CCUS), a critical technology to ensure a global clean transition. The relevance of the Paraná Basin relies not only on its stratigraphic sequence with a thickness of over 7 km but also because this basin happens to hold most of the CO_2 stationary sources of the entire country. Thus, CCUS can offer a feasible CO_2 mitigation solution for the south-eastern region of Brazil. Furthermore, the Irati Formation is one of the lithologic units within the Paraná Basin that exhibit a high prospect for CO_2 geological storage. The purpose of this chapter is to conduct a prospectivity mapping looking to identify the most favourable areas. The methodology consists of a geological mapping for site selection using the inverse distance weighting (IDW) interpolation method, using as inputs the ANP's wireline logs information and spatial data generated by our IEE-CCS research group. The resulting map validates the high prospectivity of the black shales of the Irati Formation as reservoirs for CO_2 geological storage that comply with both the technical and environmental

requirements in the central region of the Paraná Basin, specifically in the states of São Paulo, Paraná, and Mato Grosso do Sul.

Keywords: CO_2 geological storage, prospect assessment, Irati Formation, Paraná Basin.

1. INTRODUCTION

The future of the global energy sector relies on complying with the climate agreements of decarbonizing its operations to mitigate the effects of climate change. Decarbonization may come through a global clean transition from fossil energy sources into renewable energy sources. According to the IPCC (2018), decarbonization could be through a combination of electrification, the use of hydrogen, sustainable bio-based feedstocks, product substitution, and carbon dioxide capture, utilization and storage (CCUS). In this context, CCUS has been considered as one of the critical technologies to ensure the global clean transition. Also, an essential part of the lowest-cost path to effectively meet the climate targets (Global CCS Institute, 2019).

The relevance of CCUS relies on its ease and flexibility to be retrofitted to many existing fossil energy facilities, especially into the natural gas operations, and its ability to be integrated during the processes of design and construction of new facilities (Global CCS Institute, 2016). Considering the crucial role of CCUS in achieving climate targets and readiness of Brazil for its wide-scale deployment according to the Global CCS Institute (2015), since 2014, lots of efforts have been made to identify the regions with the best rock formations for CO_2 geological storage. Ketzer et al. (2014), in the 'Brazilian Atlas of CO_2 Capture Geological Storage', classified the Campos, Potiguar, Recôncavo, Santos, and Paraná sedimentary basins with a high prospect for CO_2 geological storage. From these five basins, the Paraná Basin represents an enormous potential due to its 7 km of thickness and its strategic position where most of the CO_2 stationary sources the entire country is located.

Although the Brazilian Atlas is one of the most relevant bibliographical sources on the potential for CO_2 geological storage in Brazil, the classification presented by Ketzer et al. (2014) on this atlas was rather general. It did not offer the most favourable areas within the prospective locations in the basin, as it was previously proposed by Caporale (2007) in a map that Rockett (2010) reported.

Therefore, considering the minimum requirements for implementing CO_2 geological storage, Brazil's two existing CO_2 storage prospect maps should

exhibit significant reductions of the proposed areas with high prospectivity. Additionally, to implement industrial CO_2 geological storage projects in the Paraná Basin, the Brazilian energy sector must face the barrier of the lack of nearby storage sites and connectivity to transport and storage infrastructure (NAPP et al., 2014). Based on these concerns, this chapter evaluates the most prospective areas for CO_2 geological storage via detailed mapping of the Irati Formation. Looking to contribute to mitigating CO_2 emissions within the south-eastern region of Brazil, associated with prospective natural gas production, and may help reduce the overall costs of the CCUS project in the Paraná Basin .

2. CO_2 GEOLOGICAL STORAGE PROSPECTIVITY MAPPING OF THE IRATI FORMATION IN THE PARANÁ BASIN

Many authors agree that the selection process of suitable CO_2 geological storage sites is the most crucial step towards successful deployments of CCUS projects (IPCC, 2005; WRI, 2008; ROSNES et al., 2011; THRONICKER et al., 2016; NETL, 2017; SELOSSE & RICCI, 2017; MIDDLETON & YAW, 2018).

According to the NETL (2017), the site selection process consists of four stages: extensive regional evaluations, subregional assessments, detailed characterization of prospective areas, and selection of suitable storage sites ready for permitting under all regulations. This chapter focused on the first stage by identifying the best subregional locations where the Irati Formation offers suitable geological characteristics optimal for detailed reservoir assessments.

A suitable storage site for CO_2 geological storage must comply with three general requirements – capacity, integrity and injectivity (Table 1). The capacity requirement refers to the availability of sufficient CO_2 geological storage volume, the integrity refers to secure sites that do not present a significant risk of leakages, and the injectivity refers to the suitable reservoir properties for continuous CO_2 injections at industrial supply levels (IPCC, 2005; WRI, 2008; and European Communities, 2011). Also, the suitable storage sites must follow all regulations concerning the environmental and societal impacts, as well as the local HSQE risks and economic constraints (RØSNES et al., 2011; JAKOBSEN et al., 2013; and SENIOR, 2014).

Capacity	High CO_2 sorption
	Porous rock
	Good thickness
	Areal continuity
Integrity	Reservoir depth >800 m
	Effective seal
	Simple structural complexity
	Reservoir pressure >73. 9 bar (CO_2 critical pressure)
Injectivity	Good permeability
	Appropriate salinity levels

Table 1. Parameters for suitable CO_2 geological storage sites

Source: San Martín Cañas, 2020.

2.1. The Irati Formation as a suitable storage site for CO_2 geological storage

The previous studies involving prospectivity of CO_2 geological storage in the Paraná basin by Ketzer et al. (2014) and Caporale (2007) did not consider the organic-rich shales formations as prospective reservoirs. According to San Martín Cañas (2020), the shale formations are considered unique exploratory assets that enable the co-development of the reservoirs for natural gas production and CO_2 geological storage in the Paraná Basin.

The relevance of the shales formations relies on the high potential to store CO_2 on their principal constituents: organic matter and smectites, especially montmorillonite (KROOS et al., 2003; BUSH et al., 2008; CHALMERS & BUSTIN, 2008; ROSS & Bustin, 2009; WENIGER et al., 2010; ESTUBLIER et al., 2014; BACON et al., 2015). Therefore, the Irati Formation represents an essential option for the development of CO_2 geological storage in Brazil considering the characteristics of its black bituminous shales: excellent organic matter content that reaches values

over 20% (MILANI et al., 2007) and predominance of smectites (SOUZA, 2018; SAN MARTÍN CÃNAS, 2020).

Furthermore, considering the cost-effectiveness of co-developing natural gas with CO_2 geological storage, the Irati Formation has been considered a potential source rock for hydrocarbon generation in the Paraná Basin (MILANI et al., 2007; ANP, 2013; ANP, 2017; LÓPEZ et al. 2019).

The high prospectivity of co-development of the reservoirs of the Irati Formation for natural gas production and CO_2 geological storage has been presented by San Martín Cañas (2020) through an investigation based on the data mining of the organic geochemical data. The organic geochemical data consist of 484 rock samples retrieved from literature and 19 rock samples produced by our IEE-CCS research group. Considering the potential reservoir requirements for CO_2 storage, the black shales of the Irati Formation have a high CO_2 sorption capacity. The shales have a high content of smectites, high TOC values (mainly of type I and II kerogens), high secondary porosity volume from thermal maturation and magmatic influence of the Serra Geral Formation and good areal continuity. On the potential reservoirs integrity and security requirements, the Irati Formation appears to be safe due to the simple structural complexity within the central region of the Paraná Basin. At these regions, the potential reservoir's unit reaches higher depths (>800 m), confined by effective seals such as the organic-lean shales of the Serra Alta formation and the intrusions of the Serra Geral Formation.

Although San Martín Cañas (2020) verified the capacity and integrity requirements, the author did not validate the injectivity requirement since investigations involving reservoir pressure, permeability and salinity levels are absent because the Irati Formation is not associated with hydrocarbon production.

2.2. Methodology

To identify areas with high prospectivity for CO_2 geological storage within the Irati Formation of the Paraná Basin, a dataset with the information of 125 wells reported in the BDEP well technical data provided by the ANP for the RCGI project 36 were engaged. It involves a collection of shapefiles from San Martín Cañas (2020) corresponding to the minimum CO_2 injection depth, the Guaraní aquifer maximum depth, and the safe distance between the aquifer and the CO_2 injection. Other shapefiles engaged include those from the GASBOL pipeline (GISMAPS, 2016) with the Brazilian administrative boundaries, Paraná Basin's geological settings with the outcrops of the Irati Formation, and regional geological structures (Serviço Geológico do Brasil - CPRM, 2020). The methodology for

the CO_2 geological storage prospectivity mapping of the Irati Formation in the Paraná Basin involves a numerical encoding of the well information regarding hydrocarbon shows and interpolation using the inverse distance weighting (IDW) tool software QGIS 3.12.1.

Understanding that there is a relationship between the hydrocarbon potential and the CO_2 geological storage potential due to the characteristics of the black shales of the Irati Formation discussed in the previous section, from the well information records it was encoded into two numerical values the hydrocarbon show attribute. Such numerical encoding designated values of 0 (zero) in the case of no presence of hydrocarbon shows, and values of 1 (one) for the presence of hydrocarbon shows within the Irati Formation.

Using the values from the numerical encoding and the IDW tool, a map of interpolations of the hydrocarbon occurrences was generated. The yellow colour indicates areas with the best chance for hydrocarbon occurrences. The IDW interpolation map was contrasted against the minimum depth limits for technical and environmental compliance based on CO_2 geological storage. The areas that resulted from the intersection between the IDW interpolation within the safe distance between the aquifer and the CO_2 injection have a high prospectivity for storage and then converted into a separated polygon in red colour. The areas that resulted from the intersection between the IWD interpolation and the Guaraní Aquifer maximum depth, the safe distance between the aquifer and the CO_2 injection, are considered portions with intermediate prospectivity for CO_2 geological storage and separated into an orange-coloured area polygon. The areas that resulted in no chance for hydrocarbon occurrences and outside the minimum CO_2 injection depth were not split into individual polygons and maintained a grey colour as an indicator of no likelihood of hydrocarbon; therefore, indicated as poor prospectivity areas for CO_2 geological storage.

2.3. Results and discussions

As a result, the CO_2 geological storage prospect map of the Irati Formation is presented in Figure 1. The map shows that the areas with high prospects are in the southwestern region of São Paulo, the northwestern region of Paraná, and the central part of the eastern region of Mato Grosso do Sul. Furthermore, the central part of the southern region of São Paulo, the central region of Paraná, and the southern region of Mato Grosso do Sul are considered areas with intermediate prospectivity for CO_2 geological storage.

The areas with high prospects for CO_2 storage comply with the technical constrain of a depth below -800m. The environmental constraints involving the distance between the CO_2 injection and the maximum aquifer depth of approximately -1000 m are consider safe. Based on capacity and integrity requirements, the Guaraní Aquifer is secure from any possible contamination related to the future CO_2 injection in reservoirs of the Irati Formation. In these high prospect areas, the CO_2 geological storage reservoirs are expected to reach depths between -1600 m and -3000 m. The intermediate prospects areas for CO_2 storage comply only with the technical constraints. Still, considering the uncertainties and variabilities related to the actual maximum depth of the Guaraní Aquifer, it is expected that many of these areas are suitable for CO_2 injections if further research validates accurate depths for these limits. In this regard, the proposed reservoirs may reach depths between -1000 m and -1600 m. Such reservoir units can offer a better cost-benefit option than those in the high prospects area, considering the less drilling depth, reservoir pressures, and temperatures that impact the storage infrastructure costs. However, the IDW interpolation of the hydrocarbon occurrences shows a high potential towards the southern part of the Paraná Basin in Santa Catarina and the Rio Grande do Sul. It is essential to address that this region has fewer control points; therefore, the performance of the IDW tool is not accurate. Contrasting with IDW interpolation results presented in Figure 1, San Martín Cañas (2020) proposed a prospectivity map using an interpolation generated by a Support Vector Machine algorithm where the Irati Formation has poor-to-no potential for CO_2 geological storage in this part of the Paraná Basin. This last fact reinforces the poor performance of the IDW tool in this southern region.

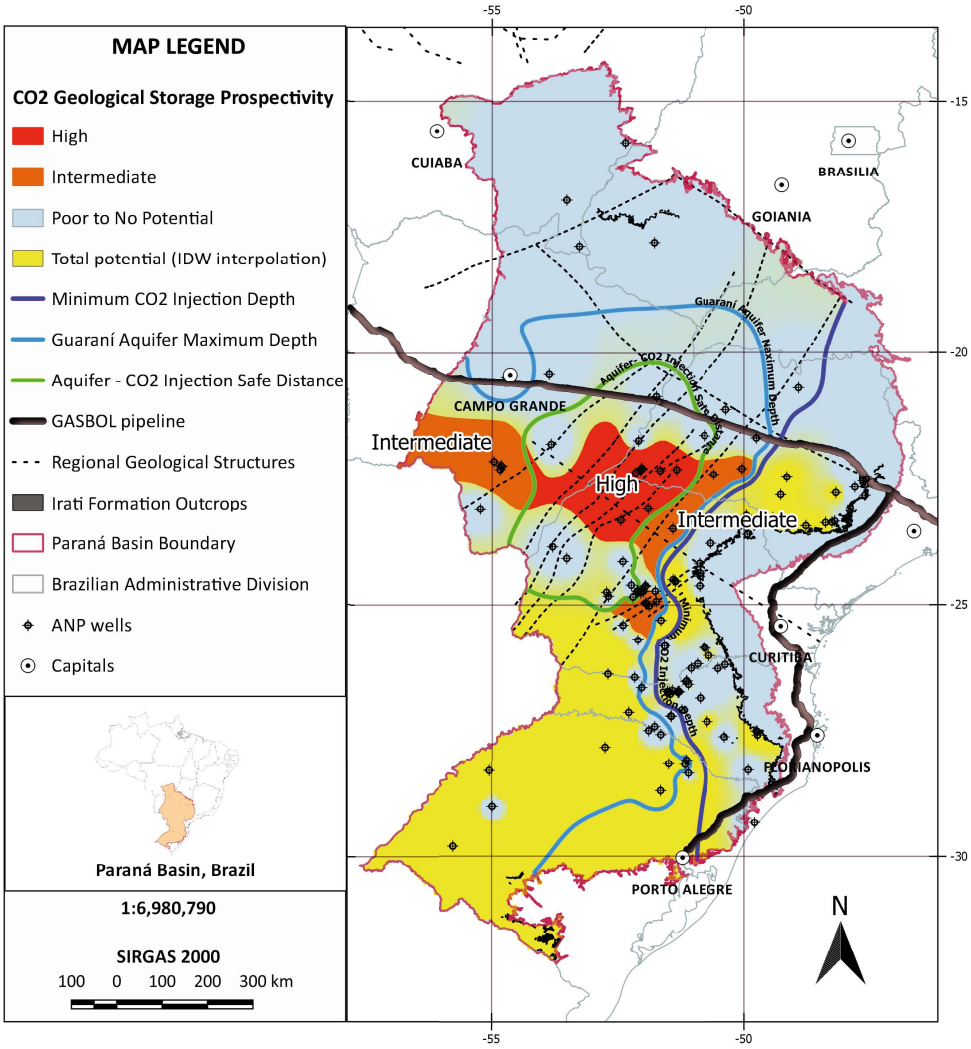

Figure 1. CO_2 geological storage prospectivity map of the Irati Formation in the Paraná Basin.

3. FINAL REMARKS

From mapping the prospective CO_2 storage sites, we can conclude that the most suitable areas of the Irati Formation for CO_2 geological storage within the Paraná Basin are in the states of São Paulo, Paraná and Mato Grosso. Areas with high to intermediate prospectivity for CO_2 storage only comply with the technical and environmental constraints. But also contain most of the CO_2 stationary sources of the whole country.

Addressing the need for connectivity between the storage and transport infrastructure, the proximity of the GASBOL pipeline to the proposed high to intermediate prospectivity areas offers an optimal scenario for the development of CCUS industrial projects in the south-eastern region of Brazil, the most carbon-intensive of the country. Furthermore, the proposed CO_2 geological storage prospectivity map of the Irati Formation offers a more detailed overview of suitable areas than the maps previously presented by Ketzer et al. (2014) and Caporale (2007).

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