MAPPING CO_2 OCCURRENCE AT THE BRAZILIAN SOUTHEST MARGIN

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Abstract

One of the problems faced by the oil and gas industry in exploration and production activities is the presence of corrosive gases in hydrocarbon reservoirs such as CO_2. Both in Brazil and in the rest of the world, many fields have shown a high concentration of CO_2 in their hydrocarbon reserves. With the objective to map the underground CO_2 distribution in three sedimentary basins (Santos, Campos and Espírito Santo), located in southeastern Brazil, this work updates an investigation initiated by EPE in 2018.

Introduction

The CO_2 found in sedimentary basins can be of both organic or inorganic origin. Processes such as diagenesis of organic matter and microbial activities would be some examples of the organic genesis of CO_2. Among the inorganic processes it can be mentioned mantle degassing and contact metamorphisms in carbonates and coals (Santos Neto, 2017).

So far, in Brazil, the areas with major CO_2 concentrations are found in offshore pre-salt reservoirs on the east coast. Current technology allows this gas to be separated and reinjected into reservoirs to improve well productivity. Known as Enhanced Oil Recovery (EOR), this practice has been one of the most effective ways to storage gas and contributes to the development of projects concerned with the adaptation of the fossil fuel industry under the light of the energy transition scenario. Recent studies (Interlenghi et al., 2019) also point out the possibility of Gas-To-Wire offshore generation using natural gas with high CO_2 content (up to 40%).

The present study is part of a CO_2 mapping project in Brazilian sedimentary basins, initially motivated by the high CO_2 content identified in some hydrocarbon accumulations in the pre-salt section (D'Almeida et al., 2018; EPE, 2019).

Gaffney (2010) and Gamboa et al. (2019) described distinct scenarios for CO_2 occurrence in pre salt reservoirs within Santos Basin, even in contiguous geological areas as Libra and Mero fields. As an example, a reservoir has a CO_2-rich gas layer with condensate on top of a heavy oil (18° API) while in a nearby, geologically similar, field CO_2 content is much lower and associated with lighter oils (29° to 30° API).

Method

In Geoscience, the use of data sampling to make estimates in places where there is no information is common. Together with the application of a theoretical model of the natural phenomenon, it is possible to simulate the behavior of the sampled variables, considering the spatial correlation of these samples and not just normal distribution patterns and data independence.

For this study 1.226 wells with CO_2 measurements drilled in Espírito Santo, Campos and Santos basins were contemplated (Figure 1). CO_2 concentrations measured under surface or reservoir conditions, in fluid and in gas, were considered to compose the data base of this investigation. For that reason, more than one value could be present for a same location (well), and in that case the greatest value was used for the purpose of this study.

Geostatistical analysis of the data was carried out through ArcGis 10.8.2 software to generate a CO_2 content distribution map. Several interpolation tests were performed. All showed the same gas distribution trend. Once discontinuities in the CO_2 distribution pattern are not unusual in the study area, the most suitable function used to interpolate the data in this context was the Inverse Distance Weighting (IDW).

IDW interpolation assumes that points close to each other are more similar than points further away. To estimate the value of an unmeasured point, IDW uses the measurement values of surrounding points. Point values closer to the location will have a greater influence on the calculated value than points farther away. Thus, the IDW assumes that each measured point has local influence and this influence decreases with distance. That is, the weight of the close values is greater than the far ones (ESRI ArcGis Manual, 2021).

To minimize the intrinsic distortion issue generated by the interpolation method, a zero CO_2 mask was used at the coastline once in the onshore area the dioxide carbon contamination content is commonly null or extremally low. A polygon mask also was adopted, limiting the interpolation area to the region between coastline and

outer limit of the pre salt polygon extended to the basin borders.

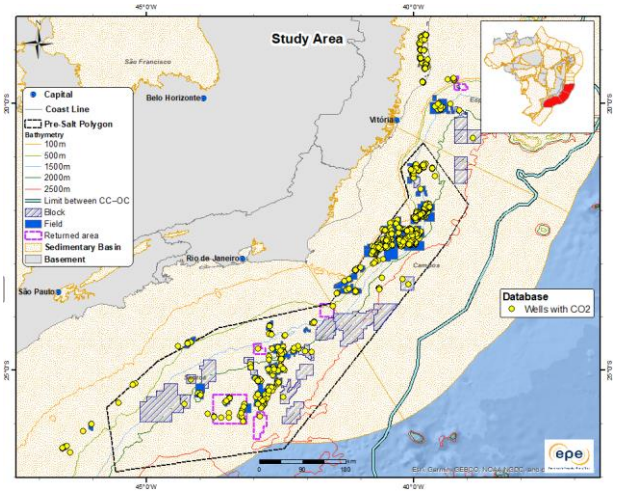

Figure 1 - Database with 1.226 wells used for CO_2 analysis at Santos, Campos and Espírito Santo basins.

Results

Statistical analysis of the data showed a predominance of CO_2 concentrations between 0% to 10% in Campos basin (Figure 2). However, contaminant levels can reach up to 20% in water depth higher than 2.500m in central area of the basin (Figure 3).

In Santos basin, although the majority of the analyzed wells presented low CO_2 rates (Figure 2), it was remarkable the amount of samples with rates above 10% reaching almost 100% CO_2 in some specific areas (Figure 3).

In Espírito Santo basin, low carbon dioxide rates (less than 10%) were recorded both in onshore and offshore wells. Offshore, low concentrations were detected even at higher water depths (Figure 2 and Figure 3).

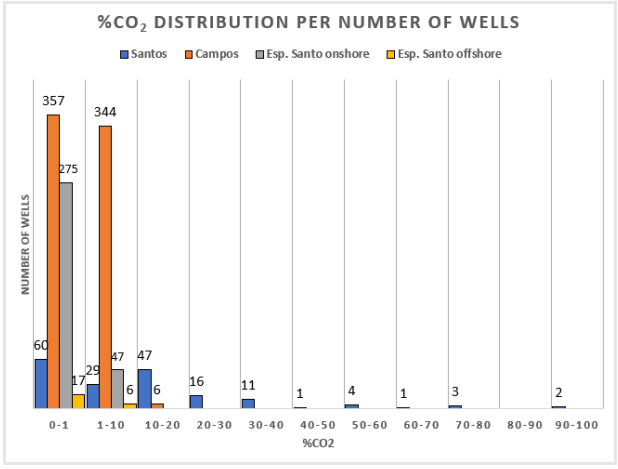

Figure 2 - Histogram: CO_2 content (%) *versus* number of wells, at Santos, Campos and Espírito Santo basins.

Among the greatest CO_2 contents in Santos basin, higher than 55%, some locations stands out aligning in a NE-SW trend in ultra deep water (Figure 3). The values reach 60% and 79% in the region of already returned blocks S-M-172 and BM-S-9, respectively. Block BM-S-24, where Jupiter discovery was made, bear similar concentration of 79%. Libra block and returned Peroba area comprises values of 96% and 99% respectively.

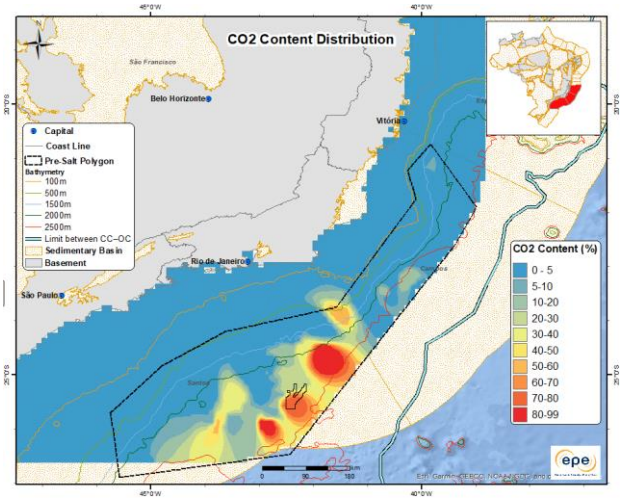

Figure 3 - CO_2 content (%) distribution map by IDW interpolation.

For a more accurate analysis, a group of 157 wells were selected: 85 wells at Santos basin, 65 wells at Campos basin and 7 wells at Espírito Santo offshore basin. These wells were classified as post-salt or pre-salt, according to the reservoir where the highest CO_2 content measurement was taken.

Approximately 50% of the wells in this group have a very low CO_2 content (concentrations lower than 1%), which comprise all Espírito Santo wells, the majority of Campos post-salt wells and some of its pre-salt wells (Figure 4). About one quarter of the wells (38) have CO_2 content between 1% and 10%. In this range there is a balance between Campos post-salt reservoirs and Santos pre-salt reservoirs (Figure 4).

For CO_2 ranges between 10% and 20%, pre-salt reservoirs at Santos basin begin to stand out. But still some areas at Campos appear in this range such as Xerelete pre-salt, Jubarte post-salt and regions in water depths higher than 2.500m.

And for higher CO_2 concentrations (between 20% and 99%) the absolute majority occur in pre-salt reservoirs at Santos basin (Figure 4).

Wells where CO_2 content were measured in a post-salt reservoir are predominantly distributed in the most proximal region of the coast with low rates of carbon dioxide contaminant (Figure 5). But some reservoirs, such as those at Bacalhau field at deep water in the distal region of Santos basin, have also shown a very low carbon dioxide contaminant content both in pre-salt as in post-salt fluids.

CO_2 contents around 20% occur in proximal areas in Campos basin at Parque das Baleias post-salt reservoirs; at Espírito Santo pre-salt reservoirs in water depth around 2.000m and also at the post-salt Campos reservoirs in water depths higher than 2.500m.

Seven wells with the highest CO_2 content (greater than 55% CO_2) are classified as pre-salt reservoirs and are located mostly at distal regions, within the pre-salt polygon, at Santos basin, comprising the former BM-S-9 block and a northeast trend aligning former Peroba block up to former S-M-172 block, passing through BM-S-24 and Libra block.

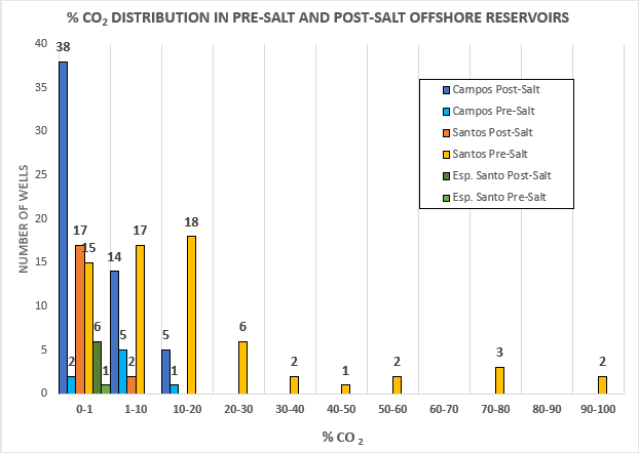

Figure 4 - CO_2 content (%) distribution among pre-salt and post-salt wells at Campos, Santos and Espírito Santo basins.

The grid with the 157 classified wells highlighted in yellow and purple colors is shown at Figure 5. In this map, highest anomalies trend in CO_2 concentrations arranged in the most distal portions of B-domain described by Dehler et. al. (2016) and oriented in the NNE direction follow the pattern of the normal faults related to the opening of the rift in the Santos Basin. These authors associate the Helmut lineament, a geophysical anomaly that limits the extent of this B-domain beyond the continent, to an important crustal boundary along which the Moho rises and the crust becomes progressively thinner.

In Figure 6 , the CO_2 distribution is plotted over the crustal domain described by Zalan et al. (2019) and the highest concentration trend falls closely to the Outer High over stretched/thinned crust. This tectonic context of deep faults cutting a stretched/thinned crust, and probably associated with an increase in late volcanic activity in the rift, represents a propitious framework for CO_2 migration from mantle (Gamboa et al., 2019; Freitas et al., 2016, Dehler et al., 2016).

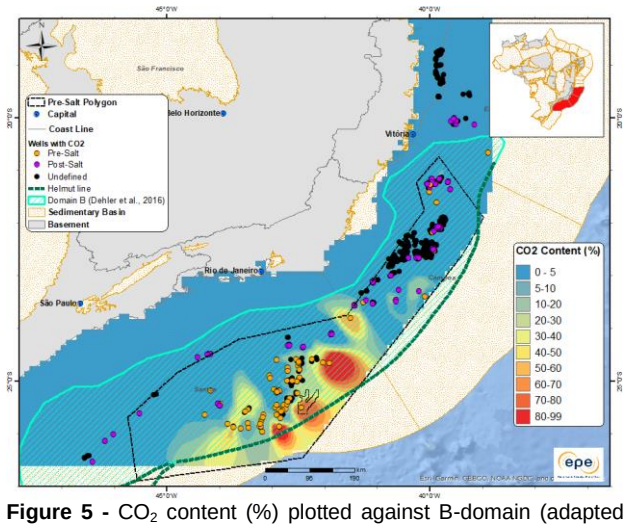

Figure 5 - CO_2 content (%) plotted against B-domain (adapted from Dehler et al, 2016).

Differences in CO_2 rates between the pre-salt and post-salt reservoirs may be not only linked to the effectiveness of the sealing potential of the thick layers of salt characteristic of the Santos Basin, as attested by the reinjection in the Tupi field, but also by the effectiveness of other trapping mechanisms, such as solubility, residual and mineral trap, which would take place during CO_2 migration towards the surface (Zhang & Song, 2014).

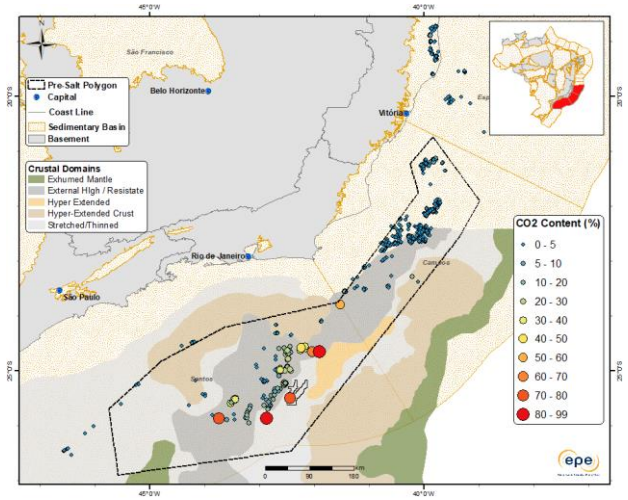

Figure 6 - CO_2 values plotted against crustal domain (adapted from Zalan et al, 2019).

It should be noted that the results presented here do not yet allow us to recognize which fraction of CO_2 comes from reinjection processes. Some operators point out to a concentration that could reach twice the original one after field development with CO_2 injection and all the equipment have been planned to withstand these conditions.

Conclusions

EPE, in its mission, seeks to carry out studies and research that contribute positively to the reduction of information asymmetry and expand the ability to adopt adequate strategies in the planning and development of the national energy sector. The regional mapping of underground CO_2 occurrence in hydrocarbon reservoirs can help oil companies to overview the concentrations of the contaminant in their areas of activities, contributing to planning the infrastructure for production, flow and reinjection of gas. The evaluation showed here has being an ongoing effort undertaken by EPE since 2018.

Many theories about CO_2 origin and concentration at the Brazilian East coast are still under discussion and are being studied to improve comprehension on the subject. Even though the number of wells recently drilled in Santos and Campos basins are much greater when compared to Espírito Santo offshore basin, the CO_2 concentration alluding to the hypothesis of a mantellic origin could be constrained by crustal thickness as stretching and thinning in the three basins increase both southward and basin ward as summarized by Szatmari and Milani (2016). In this context, deep faults could favor the rise of mantle CO_2. This hypothesis is also reinforced by the outlier CO_2 concentration in Campos basin located in its southern part.

Future investigations may help understanding the magnitude of the influence of salt layers in trapping this gas, while isotopic studies are an important tool to distinguish the origins of this gas. Analyzes of the CO_2 content for other Brazilian sedimentary basins, in addition to updating the ones presented here, are on the horizon of EPE studies.

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