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Atlas AR-CO_2. An Argentinian atlas for underground CO_2 storage potential

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Abstract

The recent interest of Argentina in hydrogen production as a clean energy vector using natural gas has brought up the question of how to manage the high CO_2 associated emissions; and if there is in the main sedimentary basins of the country the possibility to store CO_2 underground. Following the successful initiatives of many other countries, we decided to produce an Atlas of the potential for CO_2 underground storage in Argentina.

In this work, we present the first results of this assessment for three basins: Neuquén, Golfo San Jorge, and Claromecó, which are well connected to the expected hydrogen generation sites. Neuquén and Golfo San Jorge Basins are the most important hydrocarbon producers in the country. They have the advantage of being extensively studied and developed. In these basins, we considered several stratigraphic units in the location of oil and gas fields as candidate sites for CO_2 storage. Claromecó Basin is not productive and not as well characterized. Here we analyzed the coal beds present in two geological formations as potential storage sites.

The effective capacity for CO_2 storage of the different candidate sites was calculated using the volumetric method introduced by the USDOE. These values together with a chosen complementary set of criteria allowed us to rank the candidates through multi-criteria decision analysis. We expect that our results provide a starting point for new and more detailed assessments of the potential for underground CO_2 storage in Argentina.

Keywords: Argentina; carbon dioxide; carbon capture and storage; geological storage; storage potential; atlas

1. Introduction

It is widely recognized that, in addition to the reduction of emissions, to meet the global goals of climate change mitigation, it is essential to develop the capacity to safely dispose of CO_2 at large scales being underground geological

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units an optimal alternative for this purpose. The Argentinian state has signed and ratified the Paris Agreement and set its own emission reduction goals for 2030 [1]. There is, in addition, a growing interest in hydrogen production as a clean energy vector using natural gas with carbon capture and storage to avoid associated CO_2 emissions (blue hydrogen).

Argentina is known for its hydrocarbon-rich basins and its oil and gas production. The knowledge of its subsurface is wide; however, its potential for CO_2 underground storage has not been assessed in depth yet. As an initial step in this direction, we decided to review public literature and databases to gather the relevant data, put it together, and apply available methodologies to explore the potential of the country for subsurface CO_2 storage. In this work, we present the first results for three sedimentary basins which are well connected to the envisioned hydrogen production regions: Neuquén, Golfo San Jorge, and Claromecó Basins (Fig. 1).

Neuquén and Golfo San Jorge Basins are the most important hydrocarbon producers in the country. They have the advantage of being extensively studied and developed, with proven seal structures, surface facilities, and transport lines. Given the different sources and the variable quality of the available information, these two basins were analyzed mostly on a local scale except for the data associated with the permeability and containment which were assessed on a regional scale. Claromecó Basin is not productive and not as well characterized, the information available being scarce. It was therefore assessed only at a regional level, and, when local information was not available, we adopted data from analogs elsewhere.

In Neuquén and Golfo San Jorge Basins, favorable areas belonging to a selected group of stratigraphic units were determined according to defined criteria. Oil and gas fields within the limits of these areas were analyzed, in turn considering each stratigraphic unit in the location of each field as an independent candidate. Therefore, the prospects to be evaluated as potential CO_2 storage sites are pairs composed of a stratigraphic unit and an associated hydrocarbon field. The evaluation criteria and ranking methodology applied to follow that from different atlases in other regions of the world adapted to the particularities of the Argentinian basins. In particular, for the estimation of the storage capacity, the stratigraphic units in Neuquén and Golfo San Jorge Basins were considered saline formations, and the USDOE public tool CO2SCREEN was applied. Candidate sites were ranked using the TOPSIS multi-criteria decision analysis, which idealizes an optimum and the worst site and ranks the other alternatives according to their distance to them in the criteria space. Finally, Claromecó Basin was analyzed considering the global capacity for CO_2 storage of the coal beds in Tunas and Bonete Formations.

2. Methodology

In the literature several methods exist, depending on the chosen geographical resolution of the study, to assess the potential for geological CO_2 underground storage in basins, regions, areas, or sites [2]. Different authors converge in similar evaluation techniques, with some variations in the type, quantity, and weights of the criteria and the subsequent data analysis [2-13]. These workflows were compared, homogenized, and adapted to the purpose of our study, to generate a selection of criteria (Table 1). These criteria intend to assess the candidate sites in three aspects: storage unit, containment system, and surface factors. They are, nevertheless, mostly focused on the evaluation of the analyzed geological units - conventional clastic and carbonate rocks, in particular.

In the case of quantitative criteria, such as the storage capacity and the porosity, their allowed range of variation was divided into intervals. Each interval was then assigned a numerical value to sort them from most positive to most negative with respect to the suitability of the candidate as a CO_2 storage site. Candidates with higher values of storage capacity or porosity, for example, are considered more suitable. For categorical criteria, such as the type of storage and the caprock lithology, each category was assigned a numerical value in the same way.

Cut-off values were adopted for some of the criteria, directly discarding those candidates that do not satisfy any of them. For example, temperature and pressure cut-off values are required to ensure that the CO_2 is stored in a supercritical state, conditions reached above 7.38 MPa and 31.1 °C. The list in Table 1 is not exhaustive, and other criteria not considered in this work will be necessary for a more detailed analysis of the CO_2 storage potential in geological units. These must be taken into account in the subsequent stage of this study.

Fig. 1. Location of Neuquén, Golfo San Jorge and Claromecó Basins.

2.1. Storage capacity estimation

The theoretical CO_2 storage capacity of a geological unit represents the maximum amount of CO_2 that it can retain assuming that its entire porous and permeable volume will be in contact with CO_2. This capacity does not consider operational or regulatory restrictions, as it only intends to provide a first quantification of the storage capacity of the units and identify those in which it would be more convenient to advance with detailed studies. In this work, the capacity is not considered as the gross volume of space in the rock available to store CO_2, but it is reduced by efficiency coefficients [5].

The Department of Energy of the United States (USDOE) introduced a calculation methodology that includes efficiency coefficients which, although calculated using information from North America, can be used to estimate the storage potential of CO_2 of prospective storage units around the world [14]. According to this model, capacity is estimated using the volume of a geologic unit from its mapped area and thickness, porosity, and different sets of efficiency coefficients calculated for a selection of geologic settings, as summarized in Eq. (1):

$$G_{CO_2} = A_t h_g \emptyset \rho_{CO_2} E^* \quad (1)$$

Here G_{CO_2} is the storage capacity of the candidate in mass units, A_t is the total area, h_g is the thickness, $\emptyset$ is the porosity, ρ_{CO_2} is the CO_2 density at the depth of interest, and E^* is the efficiency coefficient that converts the gross volume into physically accessible volume for a given geological environment. To perform these calculations, we used the CO2-SCREEN, an open tool provided by the USDOE [15,16], which calculates the P10, P50, and P90 quantiles of the distribution of capacity (in Mt CO_2). In this work we adopted the P50 as an estimate of the CO_2 storage capacity.

As mentioned before, for Claromecó Basin our analysis was limited to the estimation of the CO_2 storage capacity in the coal beds of Tunas and Bonete Formations [17-22]. No data on the adsorption capacity for these coal beds is available in the literature; we applied in the calculations the value published in [23] for the Karoo Basin in South Africa, considered an analog of Claromecó Basin [24]. In [23], the authors reported measured values of the dry and ash-free Langmuir volume (V_L) and the Langmuir pressure (P_L) for several samples from Highveld coal beds (Ecca Group) in the northwest region of Karoo Basin. From these data and knowledge of the pressure (P), moisture percentage (f_W), and ash content (f_A) of the coal beds, we could estimate the maximum volume of CO_2 that can be adsorbed per unit volume under local in situ conditions ($C_{s,max}$), according to Eq. (2):

$$C_{\mathrm{s,max}} = V_{\mathrm{L}} \frac{P}{P+P_{\mathrm{L}}} [1 - (f_{\mathrm{W}} + f_{\mathrm{A}})] \qquad (2)$$

From this result, we calculated the CO_2 storage capacity in Mt using estimates of the volumes of Claromecó coal beds.

Table 1. Criteria and cut-off values adopted

CRITERIUM [unit]	CUT-OFF VALUE
Storage unit	
Type of storage	
Storage capacity [Mt CO_2]	
Porosity [%]	< 10 %
Pressure (MPa)	< 7.38 MPa
Temperature (°C)	< 31.1 ºC
Geological environment	
Permeability [mD]	< 10 mD
Formation water salinity [ppm]	< legal value
Depth [m]	< 800 m and > 2500 m
Containment	
Caprock: Lithology	
Caprock: Lateral homogeneity	
Caprock: Thickness [m]	< 10 m
Efficient entrapment	Unknown
Well density [wells/km^2]	
Surface factors	
Protected areas	Present in the area
Presence of surface infrastructure	

2.2. Multi-criteria decisión analysis: TOPSIS

The next step in the assessment is to rank the candidates according to their potential as CO_2 storage sites applying a multi-criteria decision method. There exist many multi-criteria decision methodologies that vary in complexity, but most of them start with the assignment of numerical weights to the criteria according to the relative importance ascribed to each of them. Then, particular techniques of normalization and ranking are applied, ending with the candidates being sorted from best to worst for the purpose considered and under the chosen criteria and weights.

In this work, we applied the multi-criteria analysis method known as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), previously considered by [12, 13] for the selection of CO_2 storage sites. In this method, each criterium is assigned a weight and each interval/category inside each criterium a value, as discussed before. Then, the best and worst possible (in principle fictitious) candidates are determined, taking for each criterium the most and least favorable scenarios among all analyzed candidates. Finally, a TOPSIS score $T \in [0,1]$ is calculated for each candidate from their mathematical distance to the best (S^+) and the worst (S^-) possible candidates, as follows:

$$T = \frac{S^-}{S^- + S^+} \qquad (3)$$

Here the maximum achievable value $T = 1$ corresponds to a candidate equal to the best possible ($S^+ = 0$ distance to the ideal site) whereas the minimum $T = 0$ corresponds to a candidate equal to the worst possible ($S^- = 0$ distance to the worst candidate).

3. Results

3.1. Neuquén and Golfo San Jorge Basins

Once the working methodology was defined, we proceeded to gather the necessary data. Our sources were mostly published works and public databases, as well as some information provided by the Exploration Group of YPF S.A. We selected several stratigraphic units for this first stage in our study; these are listed in Table 2 for Neuquén and Golfo San Jorge Basins.

Table 2. Stratigraphic units analyzed for Neuquén and Golfo San Jorge Basins.

Basin	Stratigraphic unit
Neuquén	Lower Neuquén Group (undifferentiated)
	Lower Troncoso Member (Huitrín Formation)
	Avilé Member (Agrio Formation)
	Centenario Formation (Upper Member)
	Centenario Formation (Lower Member)
	Mulichinco Formation
	Tordillo Formation
	Upper Cuyo Group (undifferentiated)
Golfo San Jorge	Yacimiento El Trébol Formation – Meseta Espinosa Formation – Lower Bajo Barreal Formation
	Comodoro Rivadavia Formation – Cañadón Seco Formation – Upper Bajo Barreal Formation
	Mina del Carmen Formation – Castillo Formation

For each stratigraphic unit a favorable area was delimited, defined as that satisfying all the cut-off values in Table *1*. The analysis was applied only to those oil and gas fields within this perimeter. Each field was analyzed independently with respect to each stratigraphic unit present in the site, therefore we refer to the individual prospects as pairs field-units.

An important feature of our study is that, when estimating their storage capacity, the geological units were conceptualized as saline aquifers, disregarding all properties related to the hydrocarbon content and/or history production - such as present pressure value and fluid saturation. This allowed us to carry out a quick and systematic first analysis. This limitation, however, must be improved on in subsequent more detailed works.

¡Error! No se encuentra el origen de la referencia. and **¡Error! No se encuentra el origen de la referencia.** show the limits of the favorable areas for each of the stratigraphic units in Table 2 for Neuquén and Golfo San Jorge Basins, respectively. Within these perimeters, a total of 266 field-stratigraphic unit pairs in Neuquén Basin and 176 field-stratigraphic unit pairs in Golfo San Jorge Basin satisfying all the cut-off criteria were analyzed with the TOPSIS methodology. A summary of the results is presented in Table 3.

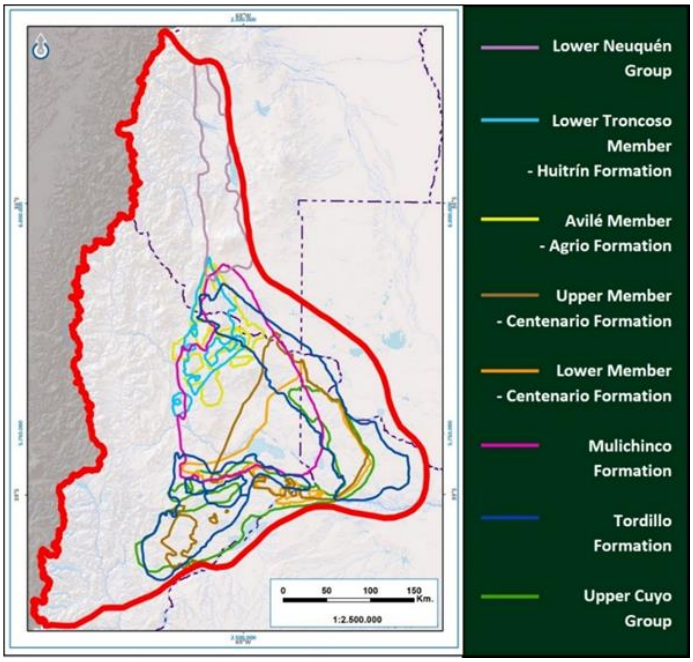

Fig. 3. Favourable areas for CO_2 storage in the selected stratigraphic units of Neuquén Basin.

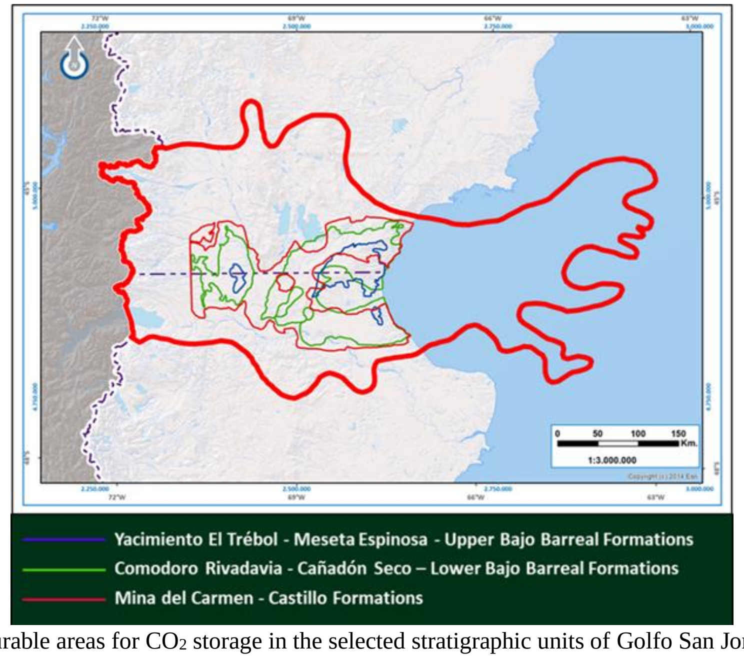

Fig. 2. Favourable areas for CO_2 storage in the selected stratigraphic units of Golfo San Jorge Basin.

The distribution of capacity estimates (P50, in Mt CO_2) is shown in Fig. 4 and Fig. 5 for Neuquén and Golfo San Jorge Basins, respectively. A wide range of values is observed.

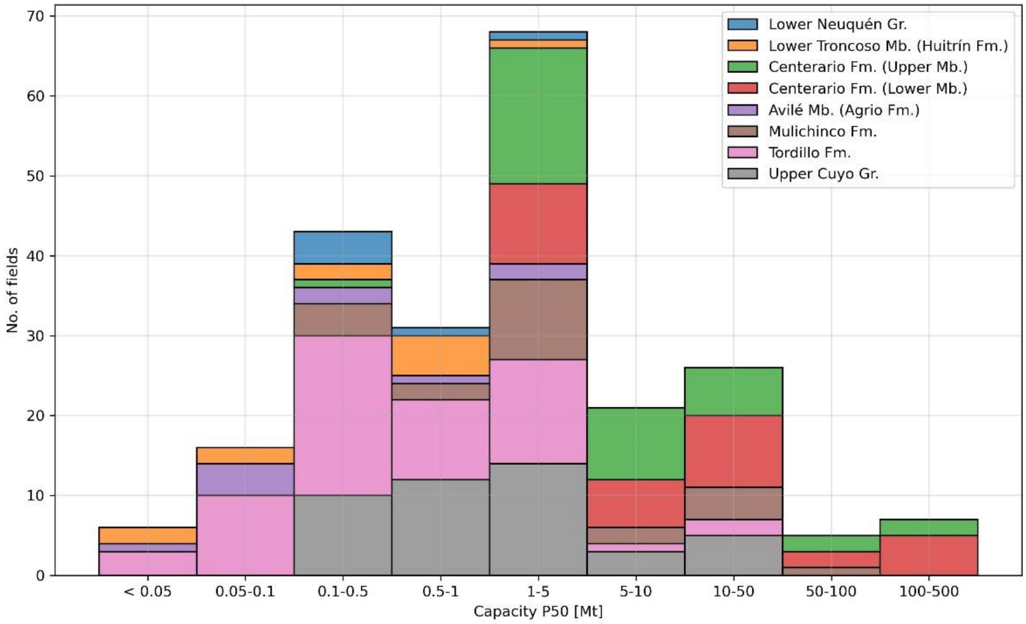

Fig. 5. Distribution of P50 capacity values (in Mt CO_2) per field in Neuquén Basin. The colors show the fraction corresponding to each stratigraphic unit.

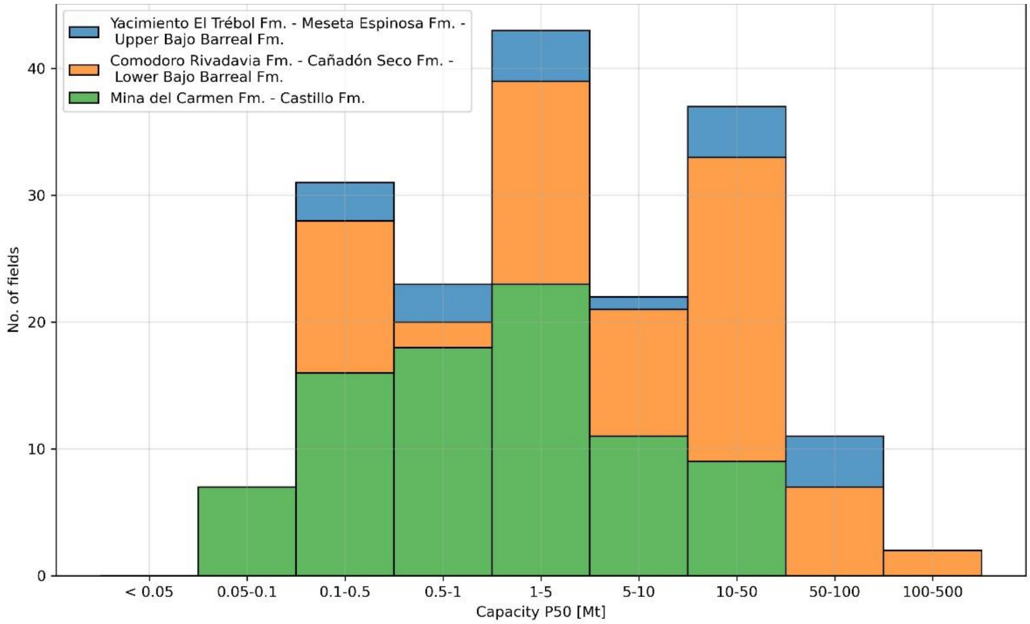

Fig. 4. Distribution of P50 capacity values (in Mt CO_2) per field in Golfo San Jorge Basin. The colors show the fraction corresponding to each stratigraphic unit.

Table 3. Summary of TOPSIS results for the selected stratigraphic units of Neuquén and Golfo San Jorge Basins.

Group	TOPSIS results	Stratigraphic unit	
		Neuquén Basin	**Golfo San Jorge Basin**
1	Maximum TOPSIS scores $T > 0.9$	Centenario Formation (Lower and Upper Members)	Comodoro Rivadavia Formation Cañadón Seco Formation Lower Bajo Barreal Formation
2	Máximum TOPSIS scores $0.7 < T < 0.9$	Mulichinco Formation Upper Cuyo Group	Yacimiento El Trébol Formation Meseta Espinosa Formation Upper Bajo Barreal Formation
3	Máximum TOPSIS scores $0.3 < T < 0.7$		Mina del Carmen Formation Castillo Formation
4	≥10 maximum TOPSIS scores $0.1 < T < 0.3$	Tordillo Formation Avilé member (Agrio Formation)	
5	<10 maximum TOPSIS scores $0.1 < T < 0.3$	Lower Neuquén Group Lower Troncoso Member (Huitrín Formation)	

In Neuquén Basin, Centenario Formation has the highest TOPSIS scores, followed by Upper Cuyo Group and Mulichinco Formation. Lower scores were obtained for Avilé Member of Agrio Formation and Tordillo Formation, with the worst ranked being Huitrín Formation. The added P50 storage capacities for the two best-ranked groups of prospects exceed 2 Gt CO_2, whereas that of the others altogether is below 100 Mt.

In Golfo San Jorge Basin the highest scores were obtained for Comodoro Rivadavia/Cañadón Seco/Lower Bajo Barreal Formations, present mostly in the northern and southern flanks of the basin. Next in order is Yacimiento El Trébol/Meseta Espinosa/Upper Bajo Barreal Formations, with the best candidates located in the northern flank. Finally, the lowest scores correspond to Mina del Carmen/Castillo Formations, within it the best prospects being in the southern flank. In this case, the added P50 storage capacities for the two best-ranked groups of prospects exceed 2 Gt CO_2, whereas that of the others altogether is about 300 Mt.

For both regions, there is a clear correlation between the TOPSIS scores and the storage capacity estimates. This is fundamentally due to the high weight we assigned to this criterium (24%). Furthermore, the largest spread in values among the criteria is that of the storage capacity, mostly determined by the variation in the volumes of the stratigraphic units in the area of the fields. The rest of the criteria showed a much larger uniformity, thus less affecting the ranking. The storage capacity estimates are expected to change, even significantly, as more detailed information and more sophisticated calculation tools are incorporated into the analysis (see, for example, [5]); therefore, our results must be understood as a first screening.

3.2. Claromecó Basin

For Claromecó Basin, we calculated the CO_2 storage capacity of the coal beds in Tuna and Bonete Formations. These coal levels are only present underground and there is no register of outcrops. Their areal extension in the basin is uncertain and inferred according to the presence or absence of the coal beds in the drilled exploratory wells.

The calculated P50 values for the storage capacities are 500 Mt CO_2 and 200 Mt CO_2 for Tunas and Bonete Formations, respectively. These values are very uncertain and must be understood as a first approximation to the storage potential of the coal beds in the basin, which could be improved with further exploration campaigns.

4. Conclusions

The main conclusions of our study can be summarized as follows:

- Both Neuquén and Golfo San Jorge Basins could be analyzed satisfactorily with the chosen methodology and within the defined scope. A total of 226 (Neuquén Basin) and 176 (Golfo San Jorge Basin) candidates were analyzed, given by a group of selected stratigraphic units within the limits of hydrocarbon fields located in favorable areas that satisfy all the imposed cut-offs.
- At the present level of analysis, the Neuquén Basin shows higher potential for CO_2 storage in the center-east region, mainly in the Centenario Formation.
- Under the same analysis, Golfo San Jorge Basin shows the best potential in Cañadón Seco Formation (and equivalents), especially in the southern and northern flanks of the basin. Favorable conditions were also found for Yacimiento El Trébol Formation (and equivalents), but with a smaller extension and restricted mostly to the northern flank.
- Due fundamentally to the characteristics of our analysis and, also, the properties of the studied stratigraphic units, the parameter that most strongly influences the results is the storage capacity. Our capacity estimates are expected to show variations as the resolution of the analysis increases, so the results must be interpreted as a first screening to be used as a guide for further projects.
- In the future, the coal seams of Claromecó Basin could be interesting units to be evaluated with greater precision for their use as CO_2 geological stores in subsurface.

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