UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
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PROGRAMA DE PÓS-GRADUAÇÃO EM GEOCIÊNCIAS

GÊNESE E ESTRATIGRAFIA DO AQUÍFERO "SAL GROSSO", LITORAL NORTE DA PLANÍCIE COSTEIRA DO RIO GRANDE DO SUL

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ORIENTADORA – Profa. Dra. Maria Luiza Correa da Camara Rosa

BANCA EXAMINADORA
Profa. Dra. Carolina Danielski Aquino – Departamento de Geologia, Universidade Federal do Paraná
Profa. Dra. Manoela Bettarel Bállico – Departamento de Geociências, Universidade Federal de Santa Catarina
Prof. Dr. Pedro Antonio Roehe Reginato – Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul

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RESUMO

No litoral norte da planície costeira do Rio Grande do Sul, um aquífero granular próximo dos 70 metros de profundidade formado por sedimentos predominantemente grossos e angulosos chamou a atenção de sondadores, que lhe deram o sugestivo apelido de “Sal Grosso”. Apesar de pouco conhecido em termos geológico-estratigráficos, o aquífero tem sido cada vez mais utilizado para abastecer a crescente população litorânea, a partir da captação por poços tubulares. Considerando que o conhecimento estratigráfico é imprescindível para a gestão dos recursos hídricos, buscou-se compreender a configuração deste aquífero e investigar a sua gênese a partir de dados oriundos de amostras de calha de perfuração de 29 poços e do levantamento de 19 sondagens elétricas verticais. O registro sedimentar investigado, com espessura aproximada de 100 metros, foi analisado pela ótica da estratigrafia de sequências. Foi verificada a existência de uma sucessão vertical formada por três unidades, interpretadas como de origem: aluvial (onde se encontra o aquífero), marinha e de barreiras costeiras. A análise dos sedimentos que compõem o aquífero “Sal Grosso” levou à interpretação de que a região investigada representa a porção distal (fluvial) de um sistema aluvial. Espacialmente, o aquífero constitui uma feição alongada na direção NO-SE, praticamente perpendicular à linha de costa atual. A geometria apresentada, somada às características sedimentológicas da unidade aquífera, levaram à interpretação da presença de um paleocanal, responsável pelo transporte de sedimentos oriundos de rochas granitoides do Escudo Sul-Riograndense, associado ao sistema de paleodrenagem do rio Jacuí. A análise estratigráfica resultou na elaboração de um modelo evolutivo associado a uma sequência deposicional completa, indicando que o aquífero Sal Grosso se formou em contexto de trato de sistemas de nível baixo. Posteriormente, houve uma transgressão marinha que possibilitou a deposição de um espesso pacote de sedimentos finos, que constitui importante proteção ao aquífero. Após, a linha de costa passou a progradar, com o desenvolvimento dos sistemas laguna-barreira em contexto de trato de sistemas de nível alto/estágio de queda.

Palavras-Chave: Bacia de Pelotas, sistema aluvial, sondagem elétrica vertical, paleocanal, geologia costeira.

ABSTRACT

In the coastal plain of the Pelotas Basin, southernmost Brazil, a granular aquifer close to 70 m deep, formed by coarse and angular sediments, caught the attention of drillers, who gave it the suggestive nickname of “Sal Grosso”. Despite being little known in geological and stratigraphic terms, the aquifer has been increasingly used to supply the growing coastal population, using tube wells. Considering that stratigraphic knowledge is essential for the management of groundwater resources, we sought to understand the configuration of this aquifer and investigate its genesis based on drilling samples data from 29 groundwater wells and through the survey of 19 vertical electrical soundings. The sedimentary record investigated, with an approximate thickness of 100 m, was analyzed through the perspective of sequence stratigraphy. It was verified the existence of a vertical succession formed by three units, interpreted as: alluvial (where the aquifer is located), marine and coastal barriers. The analysis of the sediments that make up the “Sal Grosso” aquifer led to the interpretation that the investigated region represents the distal (fluvial) portion of an alluvial system. Spatially, the aquifer constitutes an elongated feature in the NW-SE direction, perpendicular to the current coastline. The geometry and sedimentology led to the interpretation of a paleochannel, responsible for the transport of sediments from the granitoid rocks of the Sul-Riograndense Shield, associated with the paleodrainage system of the Jacuí River. The stratigraphic analysis resulted in the elaboration of paleogeographic model associated with a complete depositional sequence, indicating that the Sal Grosso aquifer was formed during a lowstand. Later, there was a marine transgression that allowed the deposition of a thick bundle of muddy sediments, which constitutes an important protection to the aquifer. Afterwards, the coastline started to prograde, with the development of the barrier-lagoon systems in a highstand/falling stage systems tracts context. The advance in the understanding of stratigraphy generates subsidies for decision-making that enable better management of the groundwater resources.

Keywords: Pelotas Basin, alluvial system, vertical electrical sounding, paleochannel, coastal geology.

LISTA DE FIGURAS

SUMÁRIO

ESTRUTURA DA DISSERTAÇÃO

Esta dissertação de mestrado está estruturada em um artigo submetido na revista *Sedimentary Geology*. A sua organização compreende as seguintes partes principais:

TEXTO INTEGRADOR:

Texto Integrador composto pelos seguintes capítulos: a) introdução com a formulação do problema de investigação e a hipótese; b) objetivos da pesquisa; c) o estado da arte do tema da pesquisa; d) os materiais e métodos utilizados; e) resumo dos principais resultados obtidos; f) conclusões; g) referências bibliográficas.

ARTIGO:

Manuscrito do artigo intitulado "***Evolution and genesis of a coastal aquifer confined in the coastal plain of the Pelotas Basin, southern Brazil: implications for stratigraphic knowledge***".

COMPLEMENTOS:

Anexos referidos no texto integrador, contendo figuras e tabelas.

1 INTRODUÇÃO

Na planície costeira da Bacia de Pelotas, a mais meridional do Brasil, perfis litológicos e construtivos de poços tubulares do litoral norte do Rio Grande do Sul evidenciam a existência de um aquífero granular próximo dos 70 metros de profundidade. Formado predominantemente por sedimentos mais grossos e angulosos em relação aos demais depósitos em subsuperfície, chamou a atenção de sondadores, que lhe deram o sugestivo apelido de “Sal Grosso”. Além das suas características sedimentológicas, diferencia-se também por fornecer altas vazões e água de boa qualidade, captada por inúmeros poços tubulares profundos existentes na região, especialmente nos municípios de Tramandaí e Osório. Porém, apesar de servir como importante fonte de abastecimento hídrico para a crescente população do litoral norte, o seu contexto geológico é ainda pouco conhecido.

A depleção da água subterrânea e a intrusão da água do mar tornaram-se uma grande preocupação nos sistemas de aquíferos costeiros em regiões tropicais e subtropicais do mundo (CHANDRAJITH *et al.*, 2014). Como são minoria os poços que captam água do Sal Grosso que apresentam problemas de escassez, salinização ou outros tipos de contaminação, o empirismo segue prevalecendo na sua gestão. Na prática, a locação de novos poços é feita com base em resultados positivos anteriores, sem que haja uma motivação imediata para desvendar com maior detalhamento o que acontece em subsuperfície. Assim, fica evidente a necessidade de estudos que possibilitem um melhor planejamento, e para isto é imprescindível compreender a geologia local. Na planície costeira do Rio Grande do Sul (PCRS), estudos sistemáticos da geologia costeira são realizados através de observações geomorfológicas, de afloramentos, testemunhos de sondagens e, mais recentemente, a partir de dados geofísicos utilizando o georradar. Como consequência, a evolução costeira é bastante conhecida para os últimos 325 ka. No entanto, como o aquífero Sal Grosso é mais antigo e ocorre a uma profundidade maior, carece de estudos que proporcionem um melhor entendimento do seu contexto e evolução geológica.

Assim, este trabalho buscou compreender a configuração do aquífero Sal Grosso na área de estudo (Figura 1) e investigar a sua gênese, considerando o seu contexto estratigráfico.

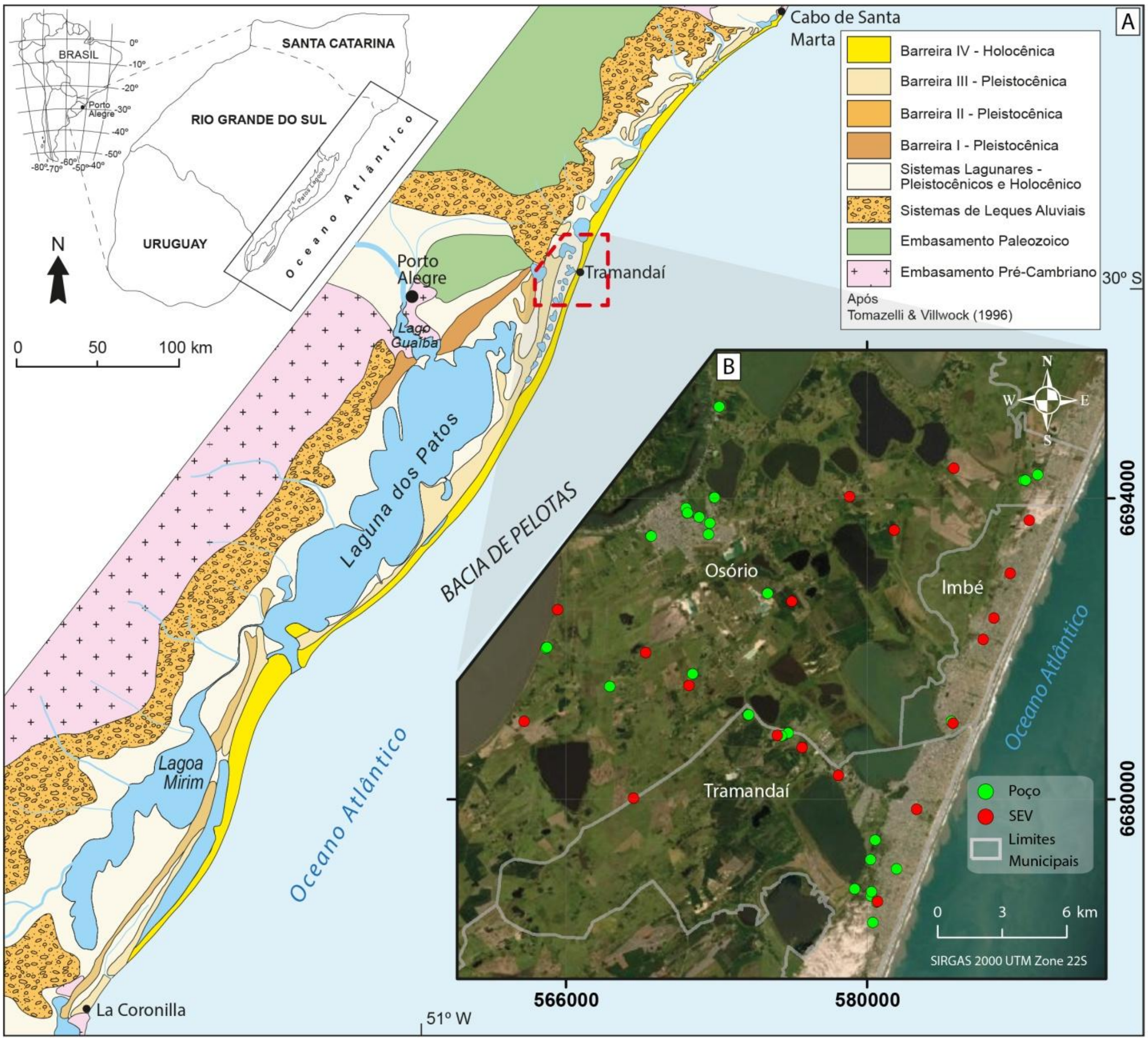

Figura 1. (A) Mapa geológico/geomorfológico da porção emersa da Planície Costeira da Bacia de Pelotas, sudeste do Brasil (adaptado de DILLENBURG; BARBOZA, 2014). O polígono vermelho tracejado marca a área de estudo, detalhada no mapa base da ESRI© (B), com a localização dos poços (em verde) e das SEVs (em vermelho), distribuídos nos municípios de Tramandaí, Osório e Imbé.

A hipótese testada foi que a gênese do aquífero Sal Grosso teria relação com um sistema aluvial. Esta hipótese apoia-se no fato dos sedimentos que formam o aquífero apresentarem características diferenciadas em relação aos demais depósitos encontrados em subsuperfície: seus grãos são maiores e exibem aspecto textural imaturo em comparação, por exemplo, aos depósitos de barreiras costeiras, presentes em posição mais rasa. Além disso, a maior profundidade de ocorrência leva a pensar que o material sedimentar que forma o aquífero Sal Grosso teria sido depositado anteriormente aos sistemas laguna-barreira, a partir do conhecido sistema de leques aluviais, cuja implementação na região costeira deu-se provavelmente a partir do final do Terciário (VILLWOCK; TOMAZELLI, 2000).

2 OBJETIVOS

O objetivo geral do trabalho foi investigar a gênese e compreender a configuração do aquífero Sal Grosso, considerando o seu contexto estratigráfico.

Os objetivos específicos foram:

- Identificar os limites de topo e base do aquífero.
- Caracterizar a geometria do aquífero.
- Determinar as características sedimentológicas das amostras de perfuração dos poços.
- Caracterizar a variação estratigráfica na espessura investigada.

3 ESTADO DA ARTE

3.1 Planície Costeira da Bacia de Pelotas

A Bacia de Pelotas é uma bacia sedimentar da margem sudeste do Brasil, limitada ao norte pelo Alto de Florianópolis (GAMBOA; RABINOWITZ, 1981) e ao sul pelo Cabo Polônio, no Uruguai (URIEN; MARTINS; LORENZETTI, 1978). Teve sua origem nos eventos geotectônicos que, a partir do Cretáceo inferior, fragmentando o continente do Gonduana, conduziram à abertura do Atlântico Sul (ASMUS; PORTO, 1972; TOMAZELLI; VILLWOCK, 2000). Seu embasamento é formado por rochas pertencentes ao Escudo Uruguaio-Sul-Riograndense, ao Escudo Catarinense e à Bacia do Paraná. Na sua porção superior emersa encontra-se sua planície costeira, a qual ocupa uma área de aproximadamente 40.000 km² e possui o mais completo registro do quaternário costeiro do Brasil. Sob o ponto de vista tectônico, esta planície caracteriza-se por apresentar uma grande estabilidade, sendo submetida somente a uma lenta subsidência, própria de uma bacia marginal aberta ainda em processo ativo de sedimentação (TOMAZELLI; VILLWOCK, 2000).

Os principais sistemas deposicionais da planície costeira (Figuras 1 e 2) são: um sistema de leques aluviais e quatro sistemas laguna-barreira, primeiramente descritos por Villwock *et al*. (1986). Sistemas laguna-barreira são comuns em costas dominadas por ondas, onde as amplitudes de maré são baixas. Como a costa está sujeita a um regime de micromarés, que no estado do Rio Grande do Sul apresenta amplitude média de 0,5 metros (DILLENBURG *et al.*, 2009), o transporte e a deposição de sedimentos é francamente dominado pela ação das ondas e das correntes a elas associadas (TOMAZELLI; VILLWOCK, 2000).

Ainda parcialmente ativo, o sistema de leques tem idade terciária e aflora na porção oeste, próximo às áreas-fontes. Os quatro sistemas laguna-barreira foram formados por ciclos transgressivos-regressivos da ordem de 100 ka, controlados pela glacioeustasia (VILLWOCK; TOMAZELLI, 1995). Cada um desses sistemas está associado às elevações alcançadas em suas transgressões, as quais podem ser correlacionadas aos estágios dos isótopos de oxigênio das curvas de Shackleton e Opdyke (1973) e Cline *et al*. (1984), ou seja, a períodos interglaciais – quando o nível do mar estava mais alto. Portanto, conforme suas idades, os sistemas laguna-barreira são denominados: I (325 ka), II (200 ka), III (125 ka) e IV (6 ka – atualmente ativo). Desde os últimos 6 ka, as curvas de variação para a costa brasileira indicam um declínio progressivo do nível relativo do mar (ANGULO; LESSA; DE SOUZA, 2006), porém a taxas muito pequenas (ANGULO; LESSA, 1997) na região da área de estudo.

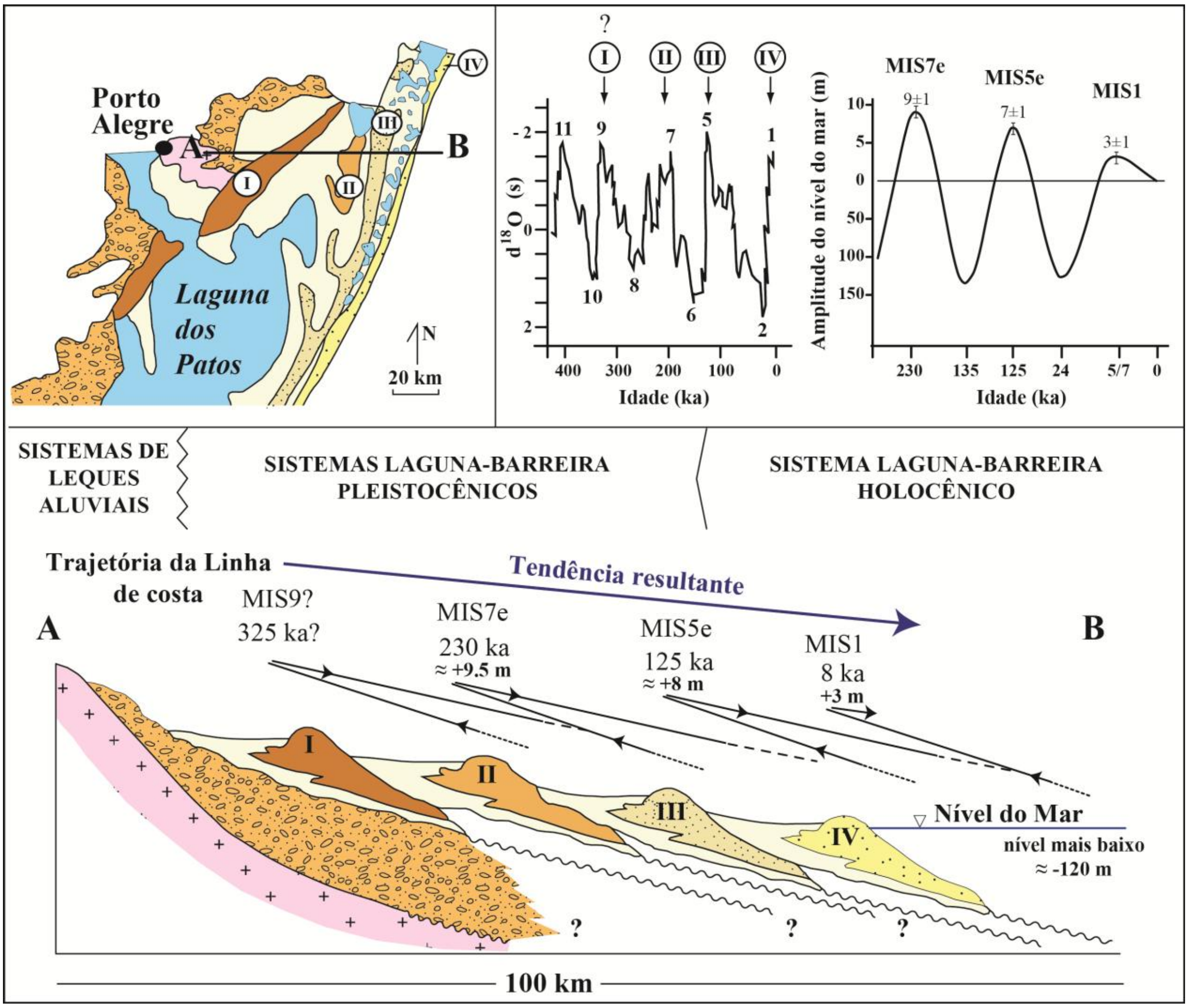

Figura 2. Perfil esquemático da seção transversal A – B, mostrando a justaposição lateral dos sistemas laguna-barreira I a IV, sendo cada um correspondente a um pico de oxigênio, em períodos interglaciais da ordem de 100 ka (Modificado por ROSA *et al*., 2017 de TOMAZELLI; VILLWOCK, 2000).

Recentemente, Rosa *et al*. (2017) propuseram uma hierarquização do arcabouço estratigráfico da Bacia de Pelotas, organizando os diversos estudos existentes na bacia, nas mais variadas escalas – desde as mais baixas até as mais altas frequências. Neste trabalho, os depósitos relacionados aos sistemas laguna-barreira I a IV foram interpretados como sequências de alta frequência que mostram em conjunto um padrão progradacional, com altitudes progressivamente mais baixas no sentido do oceano, correspondendo a um trato de sistemas regressivo/nível em queda de uma sequência de maior ordem.

3.2 Sistema Aquífero Costeiro

De acordo com o Mapa Hidrogeológico do Rio Grande do Sul (MACHADO; FREITAS, 2005), os poços considerados neste trabalho fazem parte de dois sistemas aquíferos: o Quaternário Costeiro I e o Quaternário Costeiro II. O Sistema Aquífero Quaternário Costeiro I, na porção leste, apresenta capacidades específicas mais altas, que ultrapassam os 4m³/h/m, e concentrações de salinidade inferiores a 400 mg/L. Na porção mais a oeste, o Sistema Aquífero Quaternário Costeiro II apresenta capacidades específicas que variam de baixas a médias, entre 0,5 e 1,5 m³/h/m, e concentrações de sólidos dissolvidos que variam entre 600 e 2000 mg/L (MACHADO; FREITAS, 2005). Apesar de contemplarem os aquíferos mais recentes, estas definições são pouco representativas em profundidade, pois não abrangem as unidades mais antigas, contexto onde o aquífero Sal Grosso se encaixa.

Recentemente, Troian *et al*. (2020) definiram as principais unidades hidroestratigráficas do Sistema Aquífero Costeiro (SAC), a partir da construção de um modelo conceitual (Figura 2), no qual as diferentes variações existentes em subsuperfície são mais bem detalhadas. Utilizando informações de perfis compostos de perfilagens geofísicas, tais como resistividade elétrica, porosidade total e efetiva e sais totais, os autores avaliaram qualitativamente as unidades hidroestratigráficas identificadas, que apresentaram características distintas. As unidades hidroestratigráficas 1 e 3 (Figura 2) apresentaram valores altos de porosidade efetiva e baixa salinidade, representando os aquíferos regionais com características produtivas e de qualidade mais favoráveis, enquanto as unidades 2 e 4 exibiram valores visivelmente menores de porosidade efetiva e salinidade mais elevada.

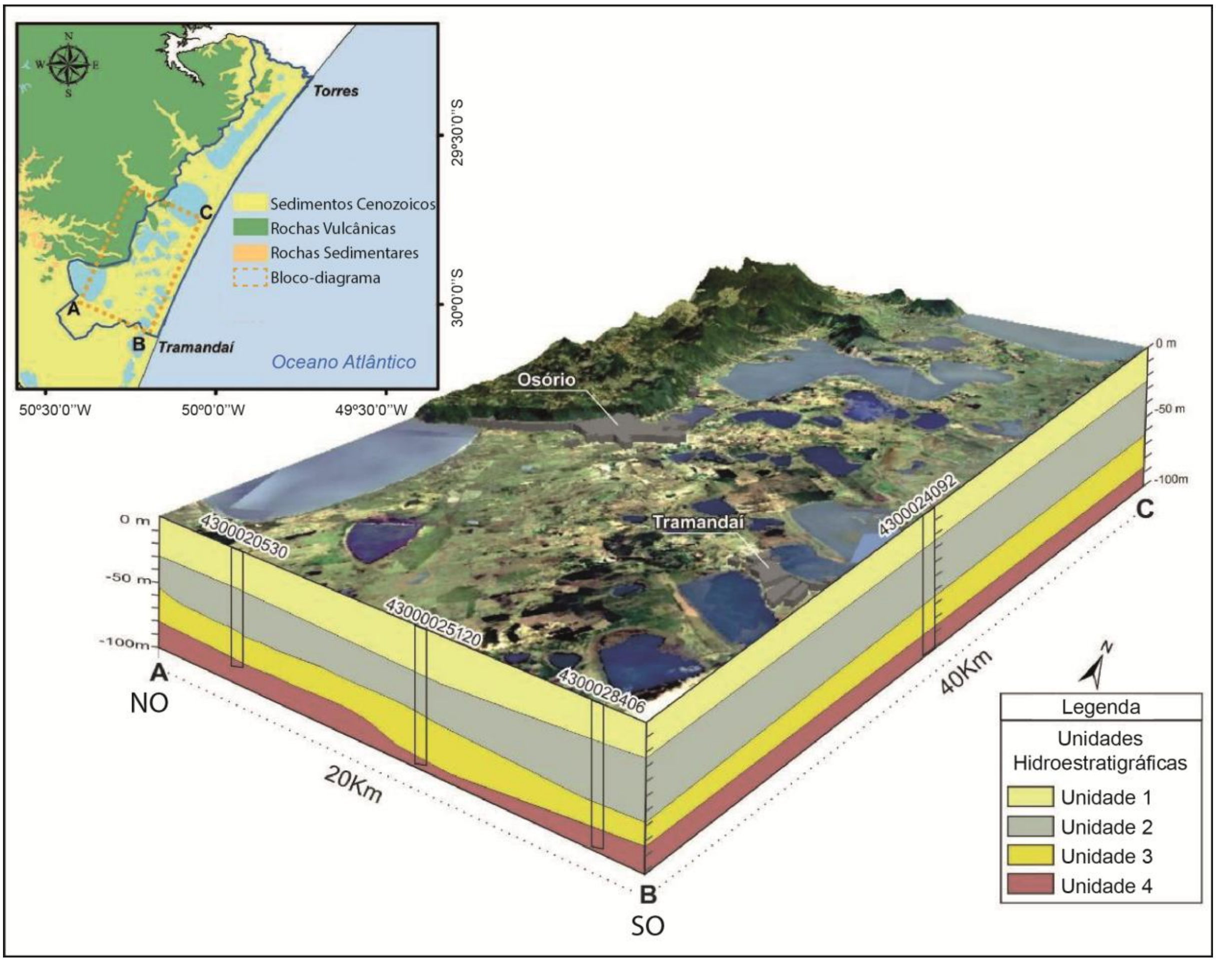

Figura 3. Bloco-diagrama esquemático do modelo conceitual (adaptado de TROIAN *et al*., 2020) mostrando a distribuição das principais unidades hidroestratigráficas do Sistema Aquífero Costeiro na área de estudo.

4 MATERIAIS E MÉTODOS

4.1 Método Direto

Foi elaborado um banco de dados com os perfis litológicos e construtivos de poços existentes na área de estudo a partir do Sistema de Informações de Águas Subterrâneas do Serviço Geológico do Brasil (SIAGAS-CPRM) e de dados cedidos pela Companhia Riograndense de Saneamento (CORSAN). Destes, foram selecionados 29 poços que continham informações mais confiáveis, e organizados em uma planilha com coordenadas, altimetrias e limites de base e topo do aquífero, quando identificados. As amostras de perfuração dos poços da CORSAN, separadas em pequenos volumes e acondicionadas em caixas apropriadas numeradas com os intervalos de profundidade (Figura 4A), serviram para confirmar e complementar as descrições dos perfis. Durante o manuseio desses dados, diferentes unidades foram observadas em subsuperfície, e seus limites de base e topo também foram tabelados.

4.1.1 Análises sedimentológicas

A perfuração de dois novos poços pela Companhia Riograndense de Saneamento (CORSAN) na área de estudo oportunizou que amostras de calha fossem recuperadas em quantidades suficientes para a realização de análises sedimentológicas, que incluíram ensaios granulométricos por peneiramento e pipetagem e observações sobre os aspectos morfoscópicos e composicionais de cada intervalo em profundidade (Figuras 4B, 4C e 4D). Cada poço apresentou 15 intervalos, resultando em um total de 30 amostras analisadas. Esses intervalos são determinados pelo próprio sondador, que realiza a amostragem ao perceber mudanças no material que vai sendo perfurado, tais como: como granulometria, cor, composição, presença de conchas, etc.

Amostras de calha dos poços são deformadas e não preservam as estruturas sedimentares, portanto não possibilitam a realização de uma análise faciológica completa, como normalmente é feita a partir de testemunhos de sondagem. Mesmo nessa condição o material sedimentar foi analisado, obtendo-se descrições dos diferentes depósitos encontrados na espessura investigada.

Foi adotada a metodologia do Laboratório do Centro de Estudos de Geologia Costeira e Oceânica (CECO) do Instituto de Geociências da Universidade Federal do Rio Grande do Sul (IGEO/UFRGS). Inicialmente as amostras foram secadas em estufa e quarteadas. Após, foi feita a separação da fração lamosa a partir do peneiramento a úmido, utilizando peneira de malha 0,062 mm. O material retido (areias) foi secado, pesado em balança de precisão, e peneirado em uma sequência de peneiras com malhas em intervalos regulares de 1 phi. O material lamoso foi submetido ao processo de pipetagem, a partir do qual foi possível separar as porções de silte e de argila, segundo a velocidade de decantação das partículas (Lei de Stokes).

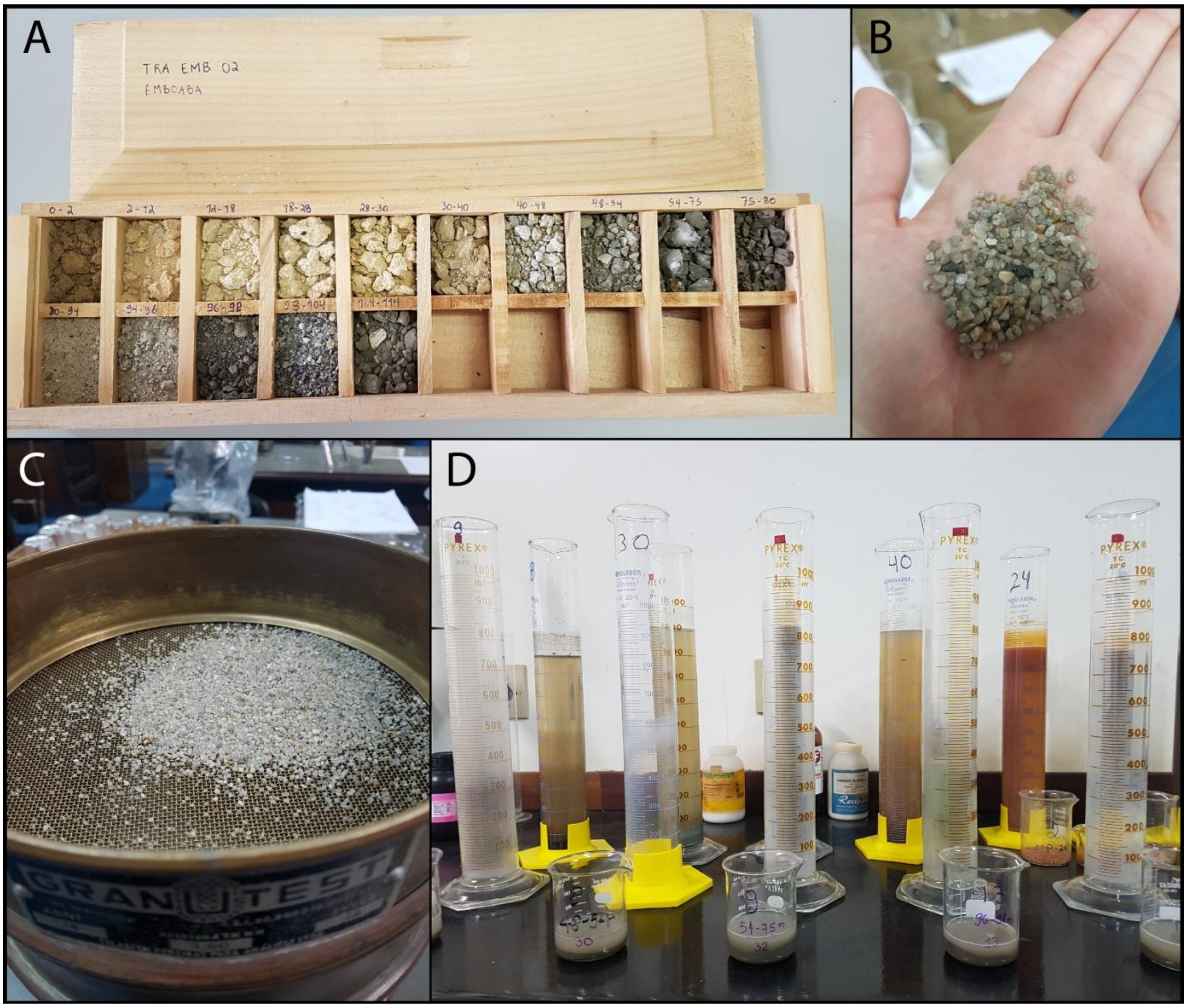

Figura 4. (A) Caixa de amostras de perfuração de poço e seus intervalos de ocorrência. (B) Aspecto visual da fração granulosa (> 2 mm) do aquífero Sal Grosso. (C) A análise granulométrica dos sedimentos maiores que 0,062 mm foi realizada a partir de peneiramento. (D) Pipetagem na fração de finos, separando as frações de silte e argila.

Os resultados das análises granulométricas foram inseridos no *software* SysGran 3.0, seguindo as instruções de Camargo (2016). O tratamento dos resultados da distribuição granulométrica dos sedimentos proporcionou análises estatísticas pelo método de Folk e Ward (1957) e as classificações texturais segundo Shepard (1954). A partir desses resultados foram construídos os perfis colunares dos dois poços no *software* Adobe Illustrator®.

Segundo Carver (1971), a análise do tamanho do grão é aplicada para correlacionar amostras provenientes de diferentes unidades estratigráficas, determinar o agente de transporte e deposição (vento, rio, corrente de turbidez, etc.)

e determinar processos de deposição final para caracterizar o ambiente de sedimentação. Assim, a análise granulométrica, em conjunto com os aspectos morfoscópicos e composicionais observados em cada intervalo, possibilitou a separação, descrição e interpretação das diferentes unidades identificadas em subsuperfície.

4.2 Método Indireto

Os diferentes tipos de materiais existentes no ambiente geológico apresentam como uma de suas propriedades fundamentais o parâmetro físico resistividade elétrica, o qual reflete algumas de suas características, servindo para caracterizar seus estados, em termos de alteração, fraturamento, saturação, etc., e até identificá-los litologicamente, sem necessidade de escavações físicas (BRAGA, 2016). Em função disso, o método geoelétrico da eletrorresistividade tem sido muito utilizado em investigações de subsuperfície, especialmente em prospecção hidrogeológica.

Uma das técnicas possíveis neste método é a da sondagem elétrica vertical (SEV), um levantamento unidimensional que consiste em uma sucessão de medidas do parâmetro geoelétrico resistividade, efetuadas a partir da superfície do terreno (BRAGA, 2006). Desta forma é possível estimar as espessuras e as profundidades das unidades geológicas presentes em subsuperfície (CUTRIM *et al.*, 2007; CUTRIM; REBOUÇAS, 2005).

Neste estudo, foram levantadas 18 sondagens elétricas verticais com um eletrorresistivímetro modelo *Supersting R1 IP*, além do aproveitamento de uma SEV previamente existente na área. A técnica aplicada na aquisição dos dados consiste em injetar corrente elétrica (I) no solo através de dois eletrodos (A e B), e medir a diferença de potencial (ΔV) entre outros dois eletrodos, denominados M e N (Figura 5).

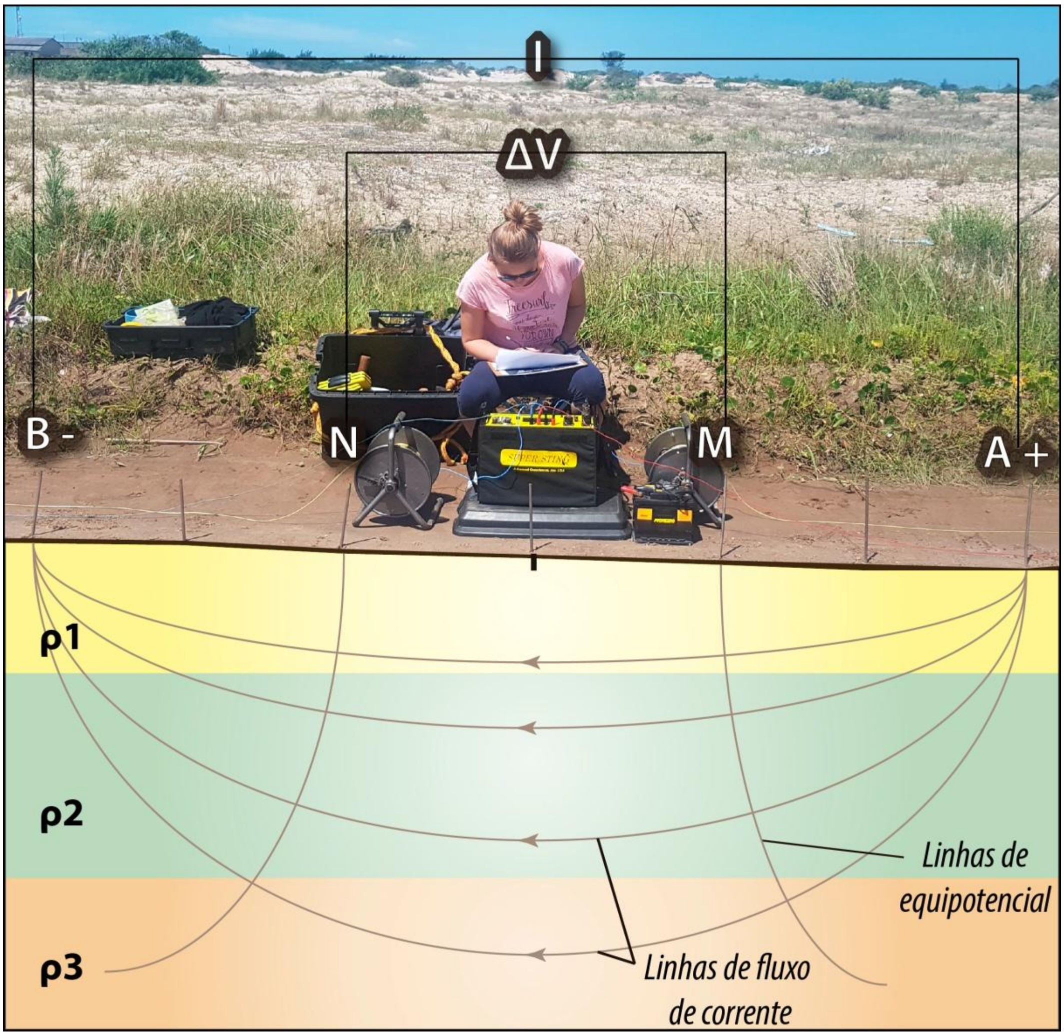

Figura 5. Esquema ilustrativo da configuração de campo adotada na investigação de subsuperfície através da sondagens elétricas verticais (arranjo *Schlumberger*) realizadas com eletrorresistivímetro. A corrente elétrica é injetada no solo através dos eletrodos A e B, e a diferença de potencial entre os eletrodos M e N é medida.

O arranjo *Schlumberger*, adotado no campo, caracteriza-se pelo pequeno espaçamento entre os eletrodos de potencial M e N (praticamente mantidos fixos), enquanto os eletrodos A e B vão sendo afastados (GIAMPÁ; GONÇALES, 2013).

A cada medida realizada a posição dos eletrodos é alterada, e a resistividade aparente (ρα) é obtida usando a equação baseada na lei de Ohm (Ω), em que K é um coeficiente geométrico relacionado às posições dos eletrodos a cada medida realizada:

$$\rho a = K \cdot \frac{\Delta V}{I} \quad (1)$$

Sendo:

ρ_a = resistividade aparente (Ω·m);

K = coeficiente de geometria (metros);

ΔV = diferença de potencial (Volts);

I = corrente elétrica (Ampére).

O coeficiente geométrico K, cuja fórmula é apresentada a seguir, depende da posição dos eletrodos, que varia de acordo com as distâncias entre eles e a cada medida realizada.

$$K = \pi \cdot \frac{(AM \cdot AN)}{MN} \tag{2}$$

Sendo:

K = coeficiente de geometria (metros);

AM = distância entre eletrodos A e M (metros);

AN = distância entre eletrodos A e N (metros);

MN = distância entre eletrodos M e N (metros).

Assim, com o aumento da distância entre os eletrodos de corrente, o volume total da subsuperfície incluída na medida também aumenta, permitindo alcançar camadas cada vez mais profundas, sendo que profundidade teórica de investigação pode ser tomada como AB/4 (BRAGA, 2016). Para alcançar a espessura de interesse neste estudo, os levantamentos foram feitos até as distâncias máximas entre os eletrodos de corrente de 400 e de 600 metros, teoricamente assegurando um alcance de 100 e 150 metros em profundidade.

O processamento dos dados adquiridos no campo foi realizado no IPI2win, um *software* para análise de dados geoelétricos, disponibilizado pelo Departamento de Geofísica da *Moscow State University Geological Faculty*. Os dados são inseridos no programa através de planilhas contendo as distâncias entre os eletrodos A e B e M e N, além da resistividade aparente encontrada para cada medição realizada nas sondagens (KURNIAWAN, 2009).

Assim, foram gerados os modelos geoelétricos para cada uma das SEVs. Algumas delas foram propositalmente realizadas próximas a poços com perfis litológicos confiáveis, a fim de balizar as interpretações dos diferentes estratos geoelétricos com a geologia de subsuperfície.

4.3 Geoprocessamento

Os dados deste estudo foram integrados em um projeto em sistema de informações geográficas, através do *software* ArcGIS® 10.5, possibilitando a realização de análises espaciais e a geração de mapas. Interpolações de variáveis, como das profundidades de topo ou de tamanho de grão, foram feitas para investigar a distribuição espacial das características do aquífero Sal Grosso e das demais unidades identificadas. A análise por meio do geoprocessamento permitiu a visualização da distribuição espacial do aquífero, que compõe um dos elementos essenciais considerados na interpretação da sua gênese.

4.4 Estratigrafia de Sequências

Os poços deste trabalho foram analisados com base na estratigrafia de sequências, que é uma forma de correlacionar o registro sedimentar com base no tempo, a partir de uma abordagem cronoestratigráfica. Através deste método o preenchimento de uma bacia sedimentar é subdividido em pacotes de rochas (sequências) geneticamente relacionadas, limitadas por discordâncias ou concordâncias correlatas (MITCHUM, 1977).

As sequências são compostas por tratos de sistemas, os quais são delimitados por superfícies-chave e identificados de acordo com o padrão de empilhamento sedimentar apresentado. Na análise estratigráfica, busca-se identificar mudanças nos padrões de empilhamento, os quais refletem a interação entre o espaço disponível para ser preenchido e o influxo sedimentar (CATUNEANU, 2006).

Assim, a análise 1D dos poços iniciou com a identificação dos padrões de empilhamento existentes nos seus perfis colunares. A partir de mudanças nos padrões, foram traçadas as superfícies-chave, separando os tratos de sistemas.

Dentre os diferentes tipos de sequências estratigráficas, os dados deste trabalho foram tratados de acordo com o modelo de sequência deposicional, utilizando a discordância subaérea como limite de sequência. O critério adotado para definir a posição da discordância subaérea em cada um dos poços foi a base dos depósitos relacionados ao aquífero Sal Grosso.

A análise 2D envolveu a confecção de seções de correlação utilizando o *software* Strater 5®, que permitiram o rastreio das superfícies-chave e unidades encontradas na análise 1D. Para uma correta comparação entre os dados, as seções foram construídas em uma mesma escala vertical e as altitudes foram referenciadas ao nível do mar atual.

5 RESULTADOS

As análises sedimentológicas, os perfis de poços e as SEVs permitiram a identificação de três unidades estratigráficas (Figura 6), formadas por depósitos interpretados como aluviais (onde se encontra o aquífero), marinhos e de barreiras costeiras. Com base nisto, foram construídos os perfis colunares e as seções estratigráficas.

Foi verificado que os poços mais próximos do continente mostraram uma maior variabilidade no registro sedimentar, com intercalação de depósitos continentais e marinhos, não identificada nos poços mais distais.

Em relação à investigação geofísica, as SEVs mostraram geralmente intervalos mais resistivos na base (aquífero), fazendo contraste com as camadas condutivas logo acima (correspondentes aos sedimentos finos marinhos). No topo, apresentaram valores intermediários de resistividade. Os modelos geoelétricos e suas interpretações podem ser conferidos na seção de anexos (ANEXOS A a T).

Além disso, foi feita a análise da distribuição espacial da unidade aquífera, gerando um mapa de profundidade de topo. A localização dos poços e das SEVs é apresentada na seção de anexos (ANEXOS U e V).

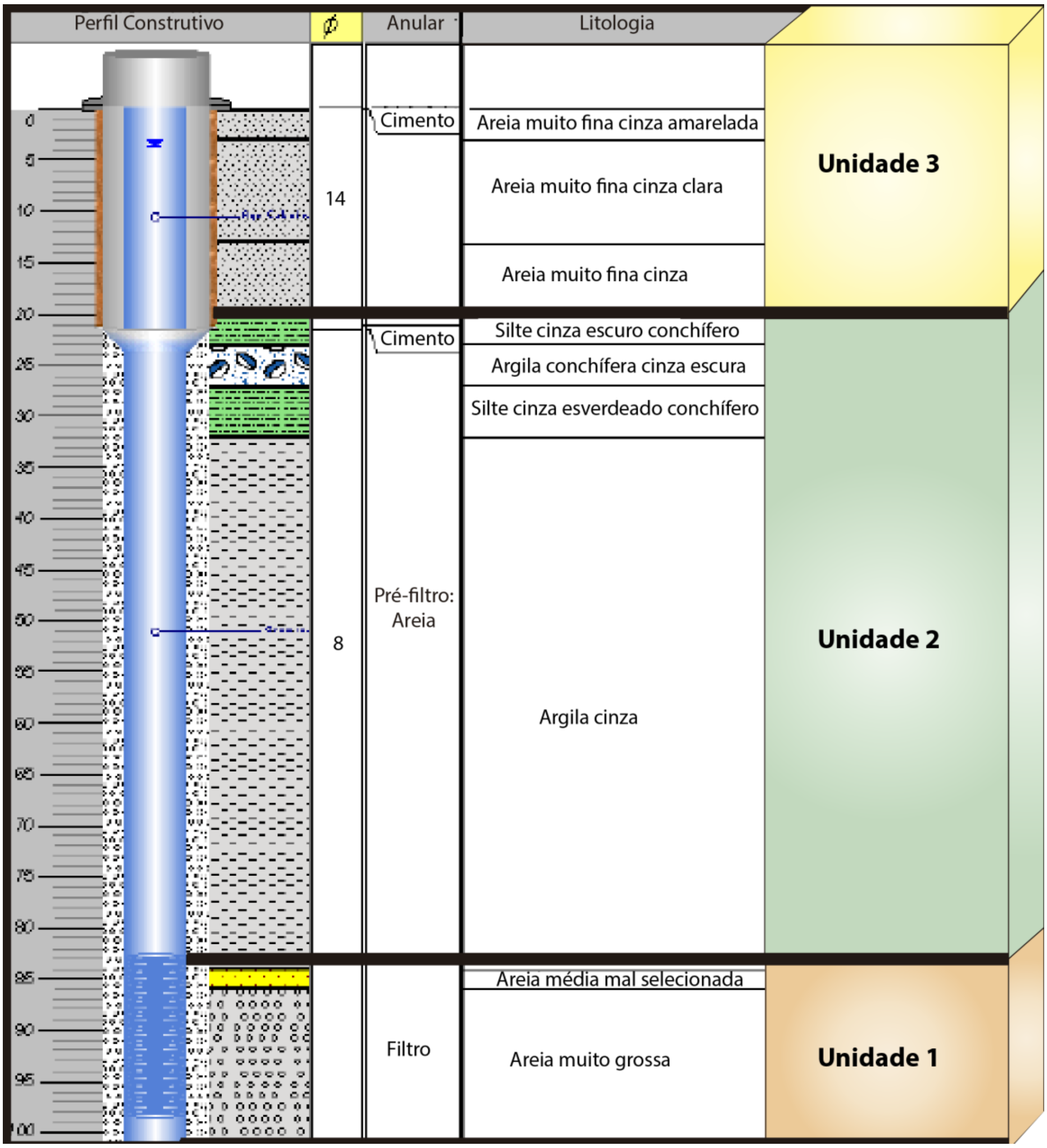

Figura 6. As três unidades identificadas exemplificadas em um perfil litológico e construtivo de poço representativo da área de estudo. Reparar que o filtro está posicionado na unidade 1 (aquífera). A unidade 2 (marinha) é formada por sedimentos finos (silte, argila). No topo, a unidade 3 mostra predomínio de areia muito fina.

6 CONCLUSÕES

A análise espacial do aquífero Sal Grosso na área de estudo mostrou que ele constitui uma feição restrita e alongada na orientação NO-SE, entre os municípios de Osório e Tramandaí. A geometria apresentada, somada às características sedimentológicas da unidade aquífera, levaram à comprovação da hipótese, com a interpretação de um paleocanal, que teria sido formado a partir de um sistema aluvial, correspondendo a sua porção mais distal (fluvial).

A área-fonte mais provável dos sedimentos que formam o aquífero Sal Grosso são as rochas granitoides do escudo Sul-Riograndense, trazidos a partir de um sistema de paleodrenagem do rio Jacuí.

Ampliando a área de estudo, foi possível verificar a presença de outros possíveis paleocanais, localizados alguns quilômetros ao norte e ao sul da área investigada, o que leva a pensar em um contexto de vale inciso nessa região da planície costeira, onde existiram múltiplos canais no passado, os quais foram preenchidos e hoje formam o aquífero granular profundo.

A análise estratigráfica permitiu a identificação de uma sequência deposicional, na qual o aquífero Sal Grosso compõe o seu trato de sistemas de nível baixo (TSNB). Posteriormente, houve uma transgressão marinha que possibilitou a deposição de um espesso pacote de sedimentos finos (silte e argila) em trato de sistemas transgressivo (TST). Após atingir o máximo transgressivo, a linha de costa passou a progradar, com o desenvolvimento dos sistemas laguna-barreira, em contexto de trato de sistemas de nível alto/estágio de queda (TSNA/TSEQ).

Assim, foi possível interpretar que houve um período de mar mais baixo, seguido por um grande “afogamento” e um novo período de queda. Este grande ciclo representa uma escala intermediária dentro do arcabouço estratigráfico da Bacia de Pelotas, com as sequências de alta frequência relacionadas aos sistemas laguna-barreira I a IV inseridas como parte do trato de sistemas de nível alto/estágio de queda desta sequência de maior período.

Esta sucessão é interessante também do ponto de vista hidrogeológico: por conta da sua espessura e constituição litológica, o pacote de sedimentos finos da unidade marinha atua como um “selante", protegendo a unidade aquífera Sal Grosso. Além disso, espera-se encontrar outros aquíferos também formados neste mesmo contexto (TSNB) em outros setores da planície costeira da Bacia de Pelotas.

A intercalação de depósitos continentais e marinhos, evidenciada nos poços proximais, levou ao questionamento de qual teria sido o controle para estas variabilidades no registro: alogênico ou autogênico? Foi levantada a possibilidade de estas variações estarem associadas a uma paleolinha de costa naquela posição, porém esta interpretação demanda mais dados para ser investigada mais profundamente e análises mais detalhadas poderão ser realizadas futuramente para elucidar esta questão.

Durante as análises sedimentológicas dos poços de Tramandaí e Osório foi possível reconhecer minerais de zircões nas amostras de perfuração da unidade Sal Grosso, o que motiva a tentativa de recuperação desses minerais em quantidade suficiente para realizar datações deste tipo em futuros trabalhos.

Por fim, as amostras de calha de perfuração de poços forneceram informações suficientes para a realização de análises estratigráficas, ainda que de forma limitada – pois são amostras deformadas. O aproveitamento desses dados, complementados por sondagens elétricas verticais, permitiu estudar o registro sedimentar correspondente a aproximadamente 100 metros de profundidade, o que além de caracterizar a gênese do aquífero também resultou no aprofundamento do conhecimento acerca da evolução de depósitos costeiros da Bacia de Pelotas que se encontram sob a planície costeira.

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8 ARTIGO

Esta seção contempla o artigo relacionado a este trabalho e submetido à revista *Sedimentary Geology*.

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8.2 Manuscrito do Artigo

Evolution and genesis of a coastal aquifer confined in the coastal plain of the Pelotas Basin, southern Brazil: implications for stratigraphic knowledge

Luísa Collischonn [a] luisa.collischonn@ufrgs.br (corresponding author)

Maria Luiza Correa da Camara Rosa [a, b] luiza.camara@ufrgs.br

[a] Universidade Federal do Rio Grande do Sul, Instituto de Geociências, Programa de Pós-Graduação em Geociências, Av. Bento Gonçalves 9500, Porto Alegre, RS 91509-900, Brazil

[b] Universidade Federal do Rio Grande do Sul, Instituto de Geociências, Centro de Estudos de Geologia Costeira e Oceânica, Av. Bento Gonçalves 9500, Porto Alegre, RS 91509-900, Brazil

HIGHLIGHTS

- Interpretation of a depositional sequence composed of high-frequency depositional sequences controlled by allogenic and autogenic factors.
- Determination of the fluvial genesis of the aquifer system and its evolution mainly related to a lowstand context.
- Identification of a paleochannel related to the Jacuí River, one of the main sediment transport axes from the basement to the Pelotas Basin.
- Presentation of a paleogeographic model expanding the knowledge of the evolution of the coastal plain of the Pelotas Basin.
- Determination of the distribution of the aquifer, impacting the management of water resources.

ABSTRACT

In the coastal plain of the Pelotas Basin, southernmost Brazil, a granular aquifer close to 70 m deep, formed by coarse and angular sediments, caught the attention of drillers, who gave it the suggestive nickname of “Coarse Salt” (“*Sal Grosso*”). Despite being little known in geological and stratigraphic terms, the aquifer has been increasingly used to supply the growing coastal population, using tube wells. Considering that stratigraphic knowledge is essential for the management of groundwater resources, we sought to understand the configuration of this aquifer and investigate its genesis based on drilling samples data from 29 groundwater wells and through the survey of 19 vertical electrical soundings. The sedimentary record investigated, with an approximate thickness of 100 m, was analyzed through the perspective of sequence stratigraphy. It was verified the existence of a vertical succession formed by three units, interpreted as: alluvial (where the aquifer is located), marine and coastal barriers. The analysis of the sediments that make up the Coarse Salt (*Sal Grosso*) aquifer led to the interpretation that the investigated region represents the distal (fluvial) portion of an alluvial system. Spatially, the aquifer constitutes an elongated feature in the NW-SE direction, perpendicular to the current coastline. The geometry and sedimentology led to the interpretation of a paleochannel, responsible for the transport of sediments from the granitoid rocks of the Sul-Riograndense Shield, associated with the paleodrainage system of the Jacuí River. A greater stratigraphic variability present in wells closer to the continent, with intercalation of continental and marine deposits, indicated the position of a coastline, prior to the formation of the coastal barrier unit, which represents the predominant depositional system in the actual coastal plain. The stratigraphic analysis resulted in the elaboration of paleogeographic model associated with a complete depositional sequence, indicating that the Coarse Salt (*Sal Grosso*) aquifer was formed during a lowstand. Later, there was a marine transgression that allowed the deposition of a thick bundle of muddy sediments, which constitutes an important protection to the aquifer. Afterwards, the coastline started to prograde, with the development of the barrier-lagoon systems in a highstand/falling stage systems tracts context. The advance in the understanding of stratigraphy generates subsidies for decision-making that enable better management of the groundwater resources.

KEYWORDS

Pelotas Basin, alluvial system, vertical electrical sounding, paleochannel, coastal aquifer.

1. INTRODUCTION

In the coastal plain of Pelotas Basin, the southernmost in Brazil, lithological and constructive profiles of tube wells on the northern coast of Rio Grande do Sul show the existence of a granular aquifer about 70 meters deep. Formed predominantly by thicker and angular sediments in relation to the other subsurface deposits, it attracted the attention of sounders, who gave it the suggestive nickname of “Coarse Salt” (“*Sal Grosso*”). In addition to its sedimentological characteristics, it also differs by providing high flows and good quality water, captured by numerous deep tube wells that already exist in the region, especially in the municipalities of Tramandaí and Osório. However, despite being an important source of water supply for the growing population of the northern coast, its geological context is still not widely known.

Groundwater depletion and seawater intrusion have become a major concern in coastal aquifer systems in tropical and subtropical regions of the world (Chandrajith et al., 2014). As the wells that capture water from Coarse Salt (*Sal Grosso*) do not present serious problems of scarcity, salinization or any other type of contamination, empiricism continues to prevail in their management. In practice, new wells are leased based on previous positive results, without an immediate motivation to unravel in greater detail what happens in the subsurface. Thus, the need for studies that enable better planning is evident, and in order to do that it is essential to understand the local geology. In the Rio Grande do Sul coastal plain, systematic studies of coastal geology are carried out through geomorphological observations, outcrops, drill cores and, more recently, from geophysical data generated by a ground-penetrating radar. As a result, coastal evolution is well known until the last 325 ka. However, as the Coarse Salt (*Sal Grosso*) aquifer is older and occurs at a greater depth, it lacks studies that provide a better understanding of its context and geological evolution.

Thus, this work sought to understand the configuration of the Coarse Salt (*Sal Grosso*) aquifer in the study area (Figure 1) and investigate its genesis, considering its stratigraphic context.

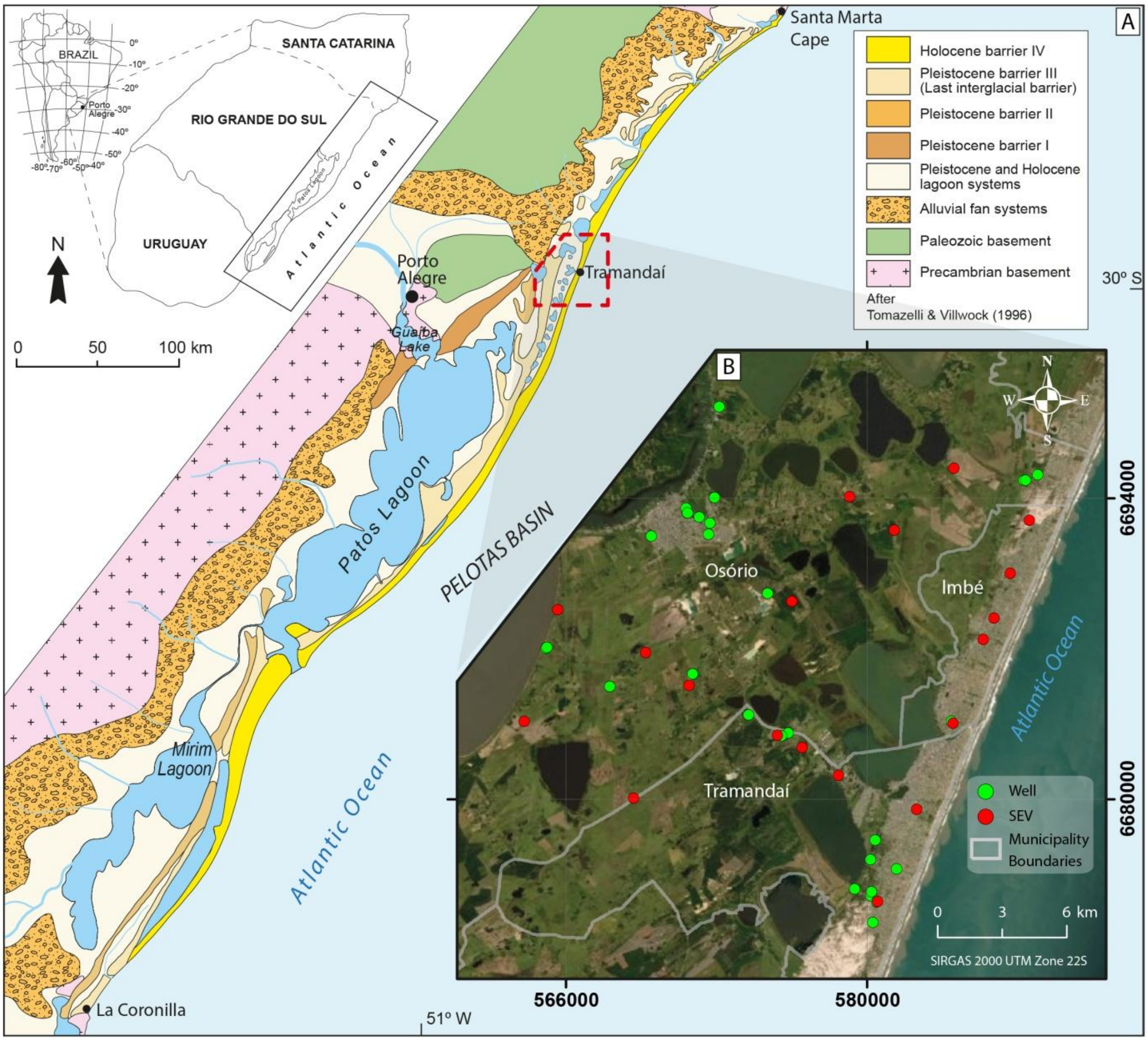

Figure 1. (A) Geological/geomorphological map of the emerging portion of the coastal plain of the Pelotas Basin, southeastern Brazil (after Tomazelli and Villwock, 1996). The red dashed polygon marks the study area, detailed in the ESRI® Basemap (B), with the location of the wells (in green) and SEVs (in red), distributed in the municipalities of Tramandaí, Osório and Imbé.

Drilling samples from groundwater wells are abundant and provide information for performing stratigraphic analyses, albeit in a limited way – as they are deformed samples. The use of these data, complemented by vertical electrical soundings, allowed the study of the sedimentary record corresponding to approximately 100 meters in depth, which, in addition to characterizing the genesis of the aquifer, also resulted in a better understanding concerning the evolution of coastal deposits in the Pelotas Basin that lie beneath the coastal plain.

2. GEOLOGICAL AND HYDROGEOLOGICAL CONTEXT

2.1. Pelotas Basin Coastal Plain

The Pelotas Basin is a sedimentary basin on the southeastern margin of Brazil, limited to the north by Alto de Florianópolis (Gamboa and Rabinowitz, 1981) and to the south by Cabo Polônio, in Uruguay (Urien et al., 1978). It was originated in geotectonic events that, since the Lower Cretaceous and the fragmenting of the Gondwana continent, led to the opening of the South Atlantic (Asmus and Porto, 1972; Tomazelli and Villwock, 2000). Its basement is formed by rocks that belong to the Uruguayan-Sul-Rio-Grandense Shield, the Santa Catarina Shield and the Paraná Basin. Its coastal plain is found in its upper emerged portion. It occupies an area of approximately 40,000 km² and has the most complete record of the coastal quaternary of Brazil. From a tectonic point of view, this plain is characterized by its great stability, being submitted only to a slow subsidence, typical of an open marginal basin still in an active process of sedimentation (Tomazelli and Villwock, 2000).

The main coastal plain depositional systems (Figures 1 and 2) are: an alluvial fan system and four barrier-lagoon systems, first described by Villwock et al. (1986). Barrier-lagoon systems are common on wave-dominated coasts where tidal ranges are low. As the coast is subject to a micro tidal regime, which in the state of Rio Grande do Sul has an average amplitude of 0.5 meters (Dillenburg and Hesp, 2009), the transport and deposition of sediment is highly dominated by the action of waves and currents associated with them (Tomazelli and Villwock, 2000).

Still partially active, the fan system is of tertiary age and outcrops in the western portion, close to the source areas. The four barrier-lagoon systems were formed by transgressive-regressive cycles (100 ka), controlled by glacioeustasy (Villwock and Tomazelli, 1995). Each of these systems is associated with the elevations achieved in their transgressions, which can be correlated to the oxygen isotope stages of the Shackleton and Opdyke curves (1973) and Cline et al. (1984), that is, to interglacial periods – when the sea level was higher. Therefore, according to their ages, the barrier-lagoon systems are called: I (325 ka), II (200 ka), III (125 ka) and IV (6 ka – currently active). Since the last 6 ka, the variation curves for the

Brazilian coast indicate a progressive decline in the relative sea level (Angulo et al., 2006), but at very small rates (Angulo and Lessa, 1997) in the region of the study area.

Recently, Rosa et al. (2017) have proposed a hierarchy of the stratigraphic framework of the Pelotas Basin, organizing the various studies existing in the basin, at the most varied scales – from the lowest to the highest frequencies. In this work, the deposits related to the barrier-lagoon systems I to IV were interpreted as high-frequency sequences that together show a progradational pattern, with progressively lower altitudes towards the ocean, corresponding to a regressive/falling stage systems tract from a higher order sequence.

2.2. Coastal Aquifer System

According to the hydrogeological map of Rio Grande do Sul (CPRM, 2005), the wells considered in this work are part of two aquifer systems: Coastal Quaternary I and Coastal Quaternary II. The Coastal Quaternary Aquifer System I, in the eastern portion, has higher specific capacities, exceeding $4m^3/h/m$, and salinity concentrations below 400 mg/L. In the westernmost portion, the Coastal Quaternary Aquifer System II has specific capacities ranging from low to medium, between 0.5 and 1.5 m3/h/m, and dissolved solids concentrations ranging from 600 to 2000 mg/L (CPRM, 2005). Despite considering the most recent aquifers, these definitions are not very representative in depth, as they do not cover the older units, context where the Coarse Salt (*Sal Grosso*) aquifer fits.

Recently, Troian et al. (2020) defined the main hydro-stratigraphic units of the coastal aquifer system, from the construction of a conceptual model (Figure 2), in which the different variations existing in subsurface are more detailed.

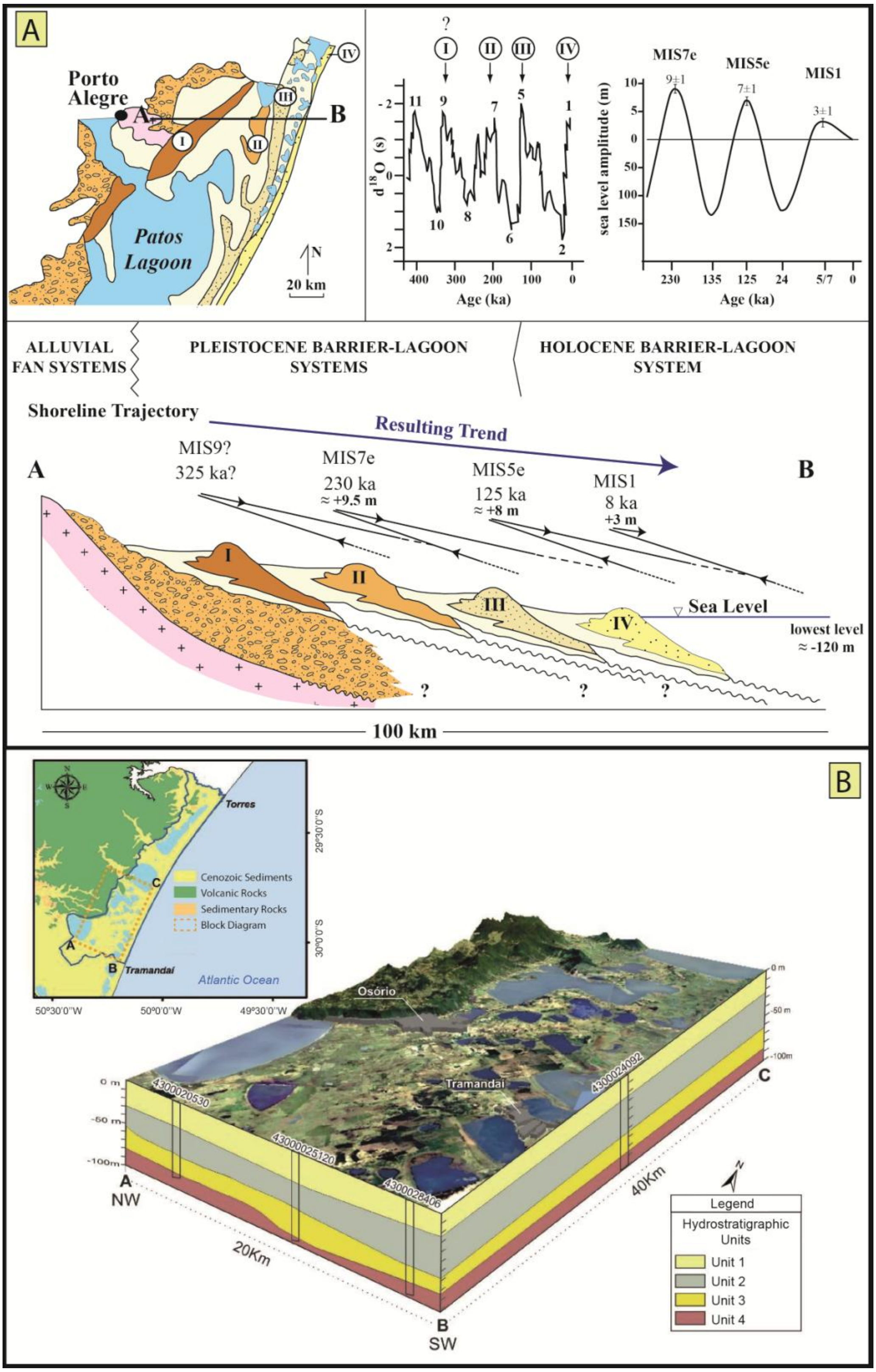

Figure 2. (A) Schematic profile of the cross section A – B, showing the lateral juxtaposition of the lagoon-barrier systems I to IV (Tomazelli and Villwock, 2000). (B) Conceptual model by Troian et al. (2020) showing the main hydrostratigraphic units of the Coastal Aquifer System in the study area.

3. METHODS

3.1. Direct Method

A database was developed with the lithological and constructive profiles of existing wells in the study area from the Groundwater Information System (SIAGAS) of the Geological Survey of Brazil (CPRM) and data provided by the Riograndense Sanitation Company (CORSAN). Among these, 29 wells that contained more reliable information were selected and organized in a spreadsheet with coordinates, altimetry and base and top limits of the aquifer, when the identification was possible. The drilling samples from CORSAN wells, separated into small volumes and packed in appropriate boxes numbered with the depth ranges, served to confirm and complement the profile descriptions. In the study of these data different units were observed in subsurface, and their base and top limits were also tabulated. Based on the observed boundaries and descriptions, columnar sections were constructed for the wells.

3.1.1. Sedimentological Analyses

The drilling of two new wells by the Riograndense Sanitation Company (CORSAN) in the study area provided the opportunity for trough samples to be recovered in sufficient quantities to perform sedimentological analyses, which included sieving and pipetting grain size tests and observations on the morphoscopic and compositional aspects of each depth interval. The intervals are determined by the driller himself, who performs the sampling when he perceives changes in the material that is being drilled: such as grain size, color, composition, presence of shells, etc.

Gutter samples from the wells are deformed and do not preserve the sedimentary structures, so they do not make it possible to perform a complete faciological analysis, usually done from drill cores. Even in this condition, the sedimentary material was analyzed and generated descriptions of the different deposits that were found in it.

The methodology of the sedimentological laboratory from Center for Studies in Marine and Coastal Geology (CECO) of the Institute of Geosciences (IGEO) of the Federal University of Rio Grande do Sul (UFRGS) was adopted. Initially the samples were dried in an oven and quartered. After, the sludge fraction was separated by wet screening, using 0.062 mm mesh sieve. The retained material (sands) was dried, weighed on a precision scale, and sieved in a sequence of sieves with meshes at regular intervals of 1 phi. The muddy material was submitted to the pipetting process, through which it was possible to separate the silt and clay portions, according to the particles settling velocity (Stokes' law).

The data of the granulometric analysis was processed in the software SysGran, following the instructions of Camargo (2016). The granulometric distribution of the sediments data processing provided statistical analysis by the Folk and Ward (1957) method and the textural classifications according to Shepard (1954).

From these results the columnar sections of the two wells, both with depths close to 100 meters, were constructed. According to Carver (1971), grain size analysis is applied to correlate samples coming from different stratigraphic units to determine the transport and deposition agent (wind, river, turbidity current, etc.) and to determine final deposition processes to characterize the sedimentation environment. Thus, the granulometric analysis, together with the morphoscopic and compositional aspects observed in each interval, enabled the separation, description and interpretation of the different units identified in subsurface.

3.2. Indirect Method

The different types of materials existing in the geological environment present, as a fundamental property, the electrical resistivity physical parameter, which reflects some of their characteristics, which serves to characterize their states, in terms of alteration, fracture, saturation, etc., and even to identify them lithologically, with no need for physical excavations (Braga, 2016). Due to this, the geoelectric method of electroresistivity has been widely used in subsurface investigations, especially in hydrogeological prospecting. One of the possible techniques in this method is the vertical electric sounding (VES), a one-dimensional survey that consists of a succession of measurements of the geoelectric parameter resistivity, made from the surface of the terrain (Braga, 2006). So, it is possible to estimate the thickness and depth of the geological units present in subsurface (Cutrim et al., 2007; Cutrim and Rebouças, 2005).

In this study, 18 vertical electrical soundings were collected with a SuperSting R1 IP electrical resistivity meter in addition to the use of a previously existing VES in the area. The technique applied in the data acquisition consists in injecting electric current (I) into the soil through two electrodes (A and B), and measuring the potential difference (ΔV) between two other electrodes, called M and N. The Schlumberger array, adopted in the field, is characterized by the small spacing between the potential electrodes M and N (practically kept fixed), while the electrodes A and B are separated (Giampá and Gonçales, 2013).

With each measurement performed in the survey the position of the electrodes is changed, and the apparent resistivity (ρα) is obtained using the equation based on Ohm's law (Ω), in which K is a geometric coefficient related to the positions of the electrodes in each measurement performed:

$$\rho a = K \cdot \frac{\Delta V}{I}$$

With the increase in the distance between the current electrodes, the total volume of the subsurface included in the measurement also increases and that makes it possible to reach deeper and deeper layers (Braga, 2016). To reach the theoretical minimum depth of 100 meters, and to reach the thickness that is relevant to this study, the surveys were made with maximum distances between the current electrodes of 400 and 600 meters.

The processing was carried out in IPI2win, a computer program for geoelectric data analysis, made available by the Department of Geophysics of Moscow State University Geological Faculty. The field data is inserted into the program through spreadsheets containing the distances of AB/2 and the apparent resistivity for each measurement performed in the survey (Kurniawan, 2009).

So, geoelectric models were generated for each of the VES. Some of them were purposely carried out near wells with reliable lithological profiles, in order to mark the interpretations of the different geoelectric strata with subsurface geology.

3.3. Geoprocessing

The data of this study were integrated into a geographic information system project, through the ArcGIS® software, enabling spatial analysis and the elaboration of maps. Interpolations of variables, such as top depths or grain size, were made to investigate the spatial distribution of the characteristics of the Coarse Salt (*Sal Grosso*) aquifer and the other identified units. The geoprocessing analysis allowed the visualization of the spatial distribution of the aquifer, which is one of the essential elements considered in the interpretation of its genesis.

3.4. Sequence Stratigraphy

The wells of this work were analyzed based on sequence stratigraphy, which is a way to correlate the sedimentary record based on time, from a chronostratigraphic approach. Through this method the filling of a sedimentary basin is subdivided into bundles of genetically related rocks (sequences), limited by unconformities or they correlative conformities (Mitchum, 1977).

The sequences are composed of systems tracts, which are delimited by key surfaces and identified according to the presented sedimentary stacking pattern. In the stratigraphic analysis, we seek to identify changes in stacking patterns, which reflect the interaction between the space available to be filled and the sedimentary influx (Catuneanu, 2006).

Thus, the 1D analysis of the wells began with the identification of the stacking patterns existing in their columnar sections. From changes in patterns, the key surfaces were traced, separating the tracts from systems. Among the different types of stratigraphic sequences, the data of this work were treated according to the depositional sequence model, using the subaerial unconformity as the sequence limit. The criterion adopted to define the position of the subaerial unconformity in each of the wells was the basis of the deposits related to the Coarse Salt (*Sal Grosso*) aquifer.

The 2D analysis involved the creation of correlation sections in the Golden software Strater 5® program, which allowed the screening of the key surfaces and units found in the 1D analysis. For the correct comparison between the data, the sections were built on the same vertical scale and the altitudes were referenced to the current sea level.

4. RESULTS

4.1. Columnar sections of wells

The construction of the columnar sections of the wells showed the existence of a vertical succession, formed by three sedimentary units with very distinct characteristics (Figure 3), which have been generally described and interpreted, from the bottom to the top, as:

- Unit 1 (aquifer): Formed by quartz-feldspar grains, predominantly coarse grain size. The grains are matte to polished, angular, and have an immature aspect. Granules often occur. It may have small contribution of fines, which occur as deposits of little thickness (rarely greater than 5 meters) interspersed with the deposits of thicker sand. In the larger fractions (granule and pebble) there are commonly lithic fragments indicative of felsic rocks. This sedimentary unit corresponds to the Coarse Salt (*Sal Grosso*) aquifer. It was interpreted as of fluvial origin.

- Unit 2: It is characterized as a thick bundle with a predominance of fine sediments (silt, clay). Some intervals with greater sandy contribution, of fine or very fine grain size (generally up to three intervals of maximum 6 meters thick) are observed. This unit commonly has greenish coloration and presence of shells (gastropods and bivalves). Many of them are fragmented, possibly due to the drilling process. However, some are well preserved, especially those of the class of gastropods, which have approximately five millimeters in the major axis. More rarely, corals and bryozoans have been identified. This unit was interpreted as of marine origin.

- Unit 3: It has a predominance of spherical, translucent or slightly opaque quartz grains, of fine or very fine grain size, better selected and rounded (high textural maturity) in relation to the deposits of the other units. The interpretation is that this unit, which emerges on the coastal plain, is formed by deposits of coastal barriers.

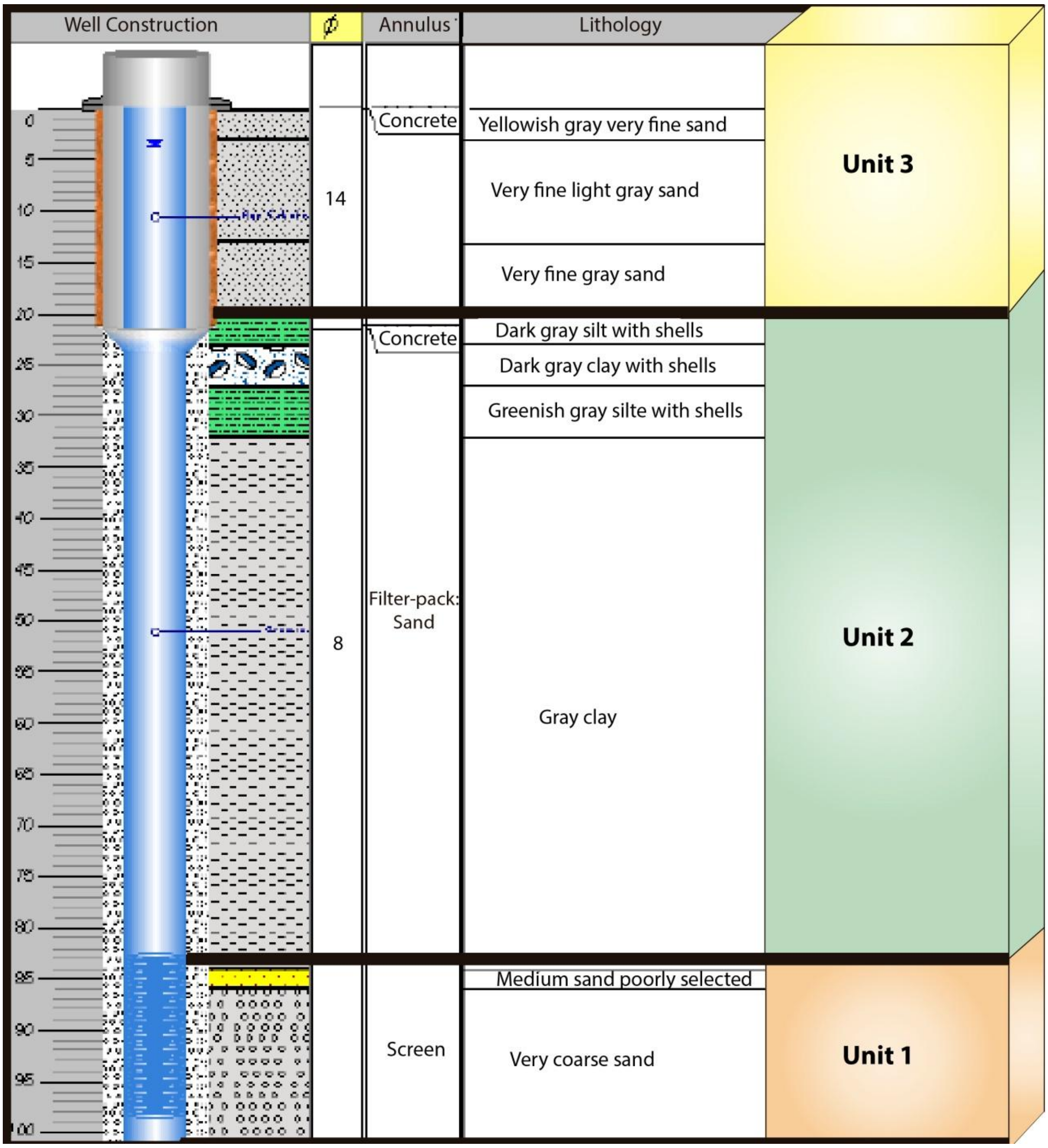

Figure 3. Example of a lithological and constructive well profile in the study area. The vertical succession identified is formed by three sedimentary units with very distinct characteristics: Unit 1 (aquifer) presents quartz-feldspathic grains of greater granulometry; Unit 2 is characterized by a thick package of fine sediments, with a greenish color and presence of shells; at the top, Unit 3 is predominantly formed by spherical quartz grains, of fine or very fine grain, corresponding to coastal barrier deposits.

The units were described mainly on the basis of sedimentological analyses of the wells of Osório (COR OSO 01A) and Tramandaí (COR TRA EMB 02), which had samples in sufficient volume to do so. It was also possible to describe the samples from the other wells, although they were less detailed and accurate. However, because they exist in greater numbers, they were important for the construction of columnar sections and the extrapolation of interpretations to a larger area, validating the results previously found for the Osório and Tramandaí wells.

Based on the record of the wells, the average top depth found for unit 1, alluvial, was 67 meters. Unit 2 showed an average thickness of 47 meters and top depth equal to 20 meters. The thickness of this unit, interpreted as marine, was 45 meters in the Osório well and 50 meters in the Tramandaí well.

The average thickness values for unit 1 were not calculated as they would be underestimated due to the limitation in the depth of the wells, as not all wells reached the base depth of the deposits. However, it can be said that unit 1 had thicknesses around 20 meters, with values varying more in relation to the average than the other units.

4.1.1. Grain Size Analysis

In the COR OSO 01A well, almost all intervals were classified as sand in Shepard's diagram (Figure 4). Only three ranges were classified as sandy silt or silica sand: range 5 (from 21 to 36 meters), range 7 (from 42 to 48 Meters) and range 9 (from 54 to 60 meters). The results obtained by the Folk and Ward method (1957) provided the classifications according to the average grain sizes found for each interval – the basis for the construction of columnar sections. These results showed that between the depths of 21 and 66 meters, sediments classified as silt and fine sand are intercalated. From the surface to the depth of 21 meters, the intervals are classified as fine sand. Closer to the base, between 66 and 78 meters there are sediments of coarse sand grain size.

The results of the last three intervals (between 78 and 98 meters) were not used because the drilling of the well reached the base and ended up contaminating the sediments positioned just above. After visual inspection, this portion of the columnar section was reclassified, considering the intervals 13, 14 and 15 as being formed by fines.

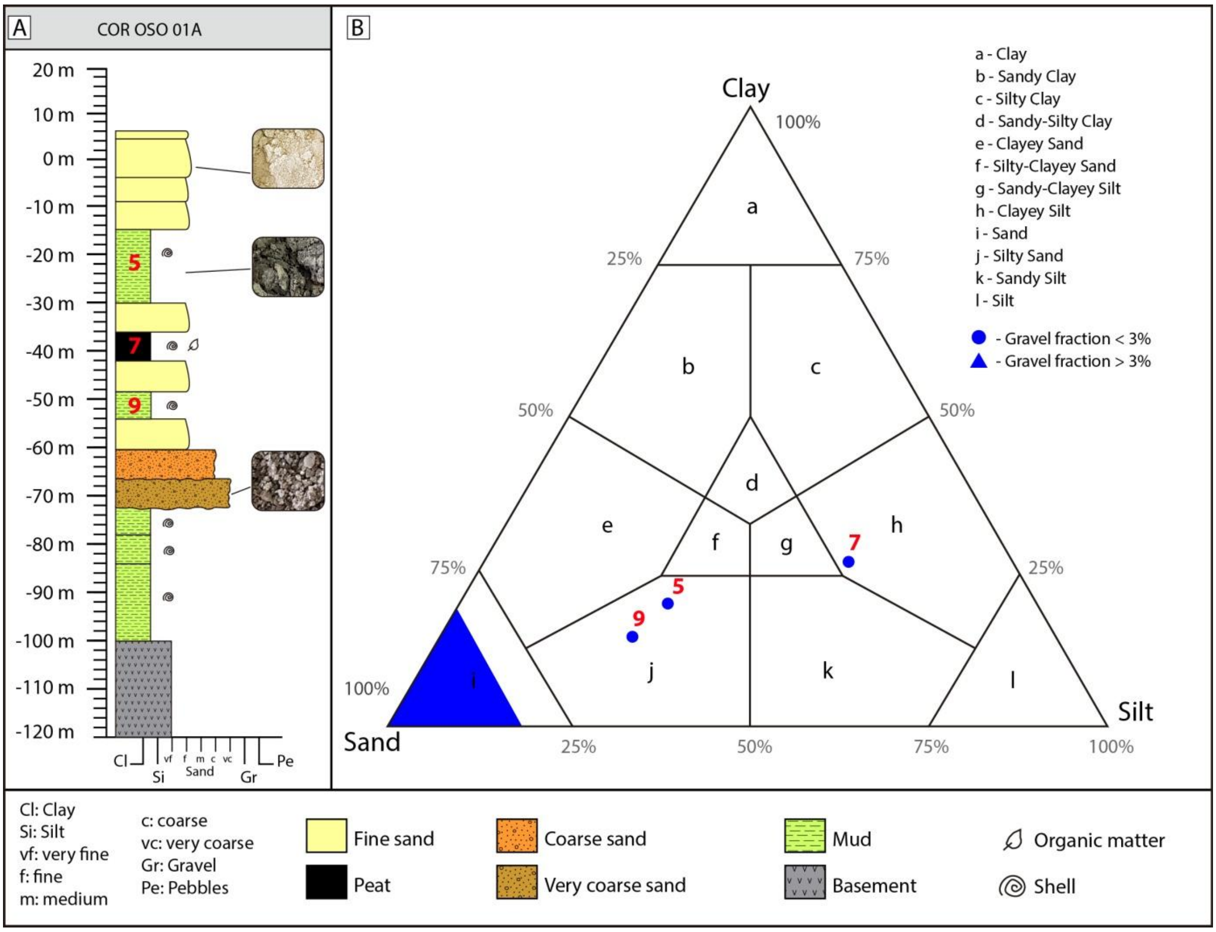

Figure 4. (A) Column profile constructed from sedimentological analysis of samples from the COR OSO 01A well, with photos representing intervals of each unit (altitude values are in meters and referenced to sea level). (B) The results for each interval were plotted on the Shepard diagram. All intervals of the COR OSO 01A wells were classified as sand (with a granular fraction greater than 3%), with the exception of intervals 5, 7 and 9.

The COR TRA EMB 02 well, more distal in relation to the Osório well (COR OSO 01A), did not show the same intercalations of silt and fine sand, but rather a thick bundle of silty sediments from 30 to 80 meters deep. The intervals closest to the top, from the surface to 30 meters, were classified as fine sand. In the basal portion, between 80 and 104 meters, there is a predominance of medium and coarse grained sand. Shepard's diagram (Figure 5) shows that the intervals (6 to 10) that form the 50 meter continuous bundle of fine sediment are classified as silty sand, clayey silt and silty clay.

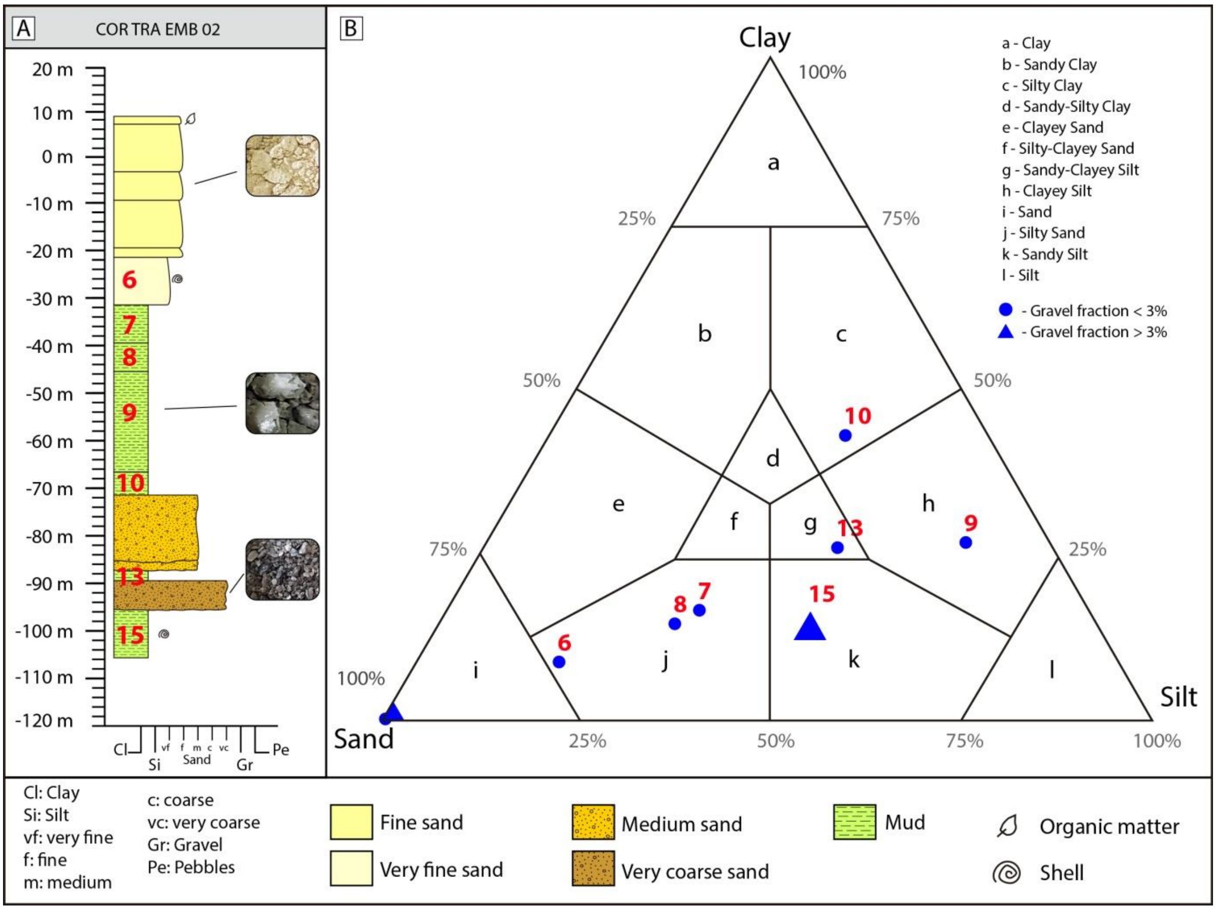

Figure 5. (A) Column profile constructed from sedimentological analysis of samples from the COR TRA EMB 02 well, with representative photos of intervals for each unit (altitude values are in meters and are referenced to sea level). (B) The results for each interval were plotted on the Shepard diagram. The COR TRA EMB 02 well shows a continuous and thick package of muddy sediments between 30 and 80 meters deep, corresponding to intervals 6, 7, 8, 9 and 10.

4.2. Geoelectric profiles

Geoelectric stratigraphy of the VES showed, in general, more resistive layers at the base, in contrast to conductive layers above, and closing with layers of intermediate resistivity at the top.

From the calibration of the VES with nearby wells, it was possible to observe the good correspondence of the resistivities values of the geoelectric layers with the subsurface lithologies, which encouraged the interpretation of VES also in more isolated locals, where there were no wells. This was possible because the subsurface geology, in the scale of this work, did not show significant changes in relation to the general order of the observed units, probably due to the great stability from the tectonic perspective in the basin.

When the aquifer unit is identified it appears as high resistive due to its grain size characteristics (coarser sediments). The bundle of fines (silt and clay) of the central portion corresponds to a range of low resistivity. At the top, intermediate resistivity values can be correlated to fine sand deposits from coastal barriers. However, the most resistive layers of the base are not always identified, which indicates probable absence of the Coarse Salt (*Sal Grosso*) aquifer in certain places.

A characteristic case of indirect identification of the Coarse Salt (*Sal Grosso*) aquifer can be seen in VES 13 (Figure 6), in which the aquifer unit was identified at 73 m depth, with electrical resistivity of 597 Ω·m. This high value contrasts with the unit positioned stratigraphically above, with layers of values ranging from 12 to 82 Ohm·m. This VES is 187 meters from the COR TRA EMB 02 well, and it is possible to observe in the correlation section that there is good correspondence between the lithologies and the electrical resistivity values.

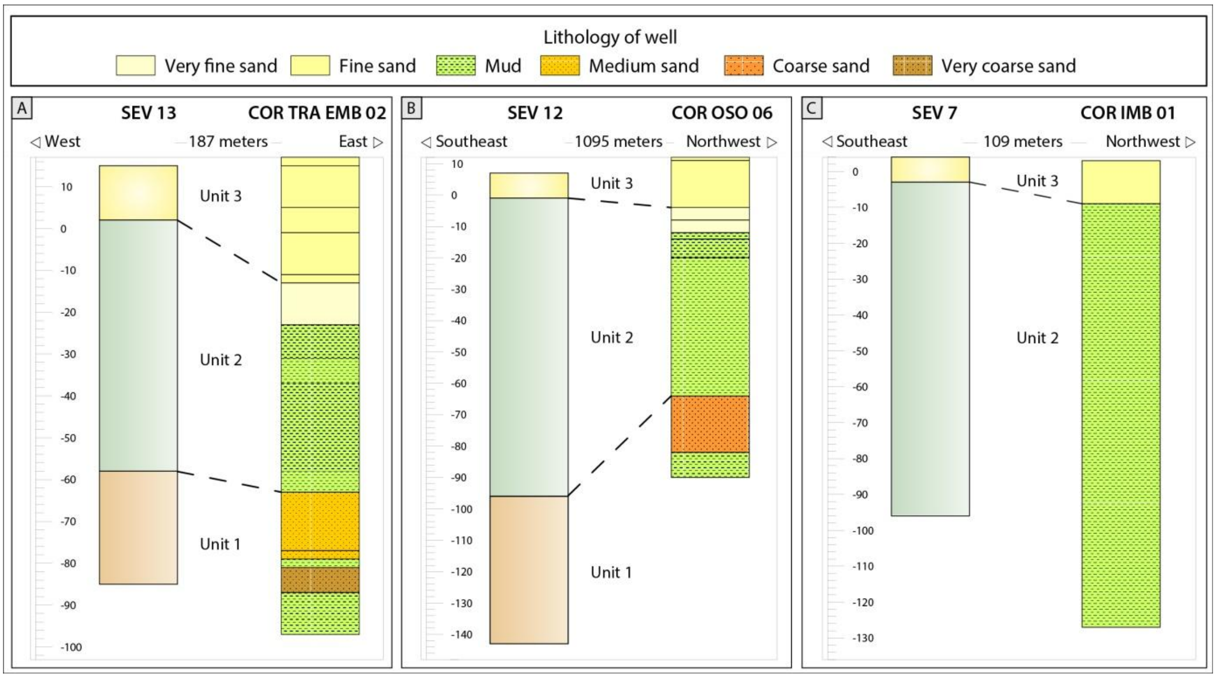

Figure 6. Correspondence between the units interpreted from the SEVs and the lithological profiles of the wells (altitude values are in meters and are referenced to sea level). (A) SEV 13 is 187 meters from well COR TRA EMB 02 and shows good correlation, especially at the top of unit 1. (B) Despite the large distance between SEV 12 and COR OSO 06 well, there is still good correlation between the units interpreted in the geoelectric profile and the subsurface lithologies. (C) SEV 7 and the COR IMB 01 well, both located in the municipality of Imbé, are only 109 meters apart and did not identify unit 1 (aquifer).

Another case of good correlation (Figure 6) can be checked between the VES 12 and the COR OSO 06 well, despite the large distance between them - more than 1000 meters. This VES was performed with a maximum opening between the electrodes of current equal to 600 meters, and identified the top of the aquifer unit at 103 m depth.

In places where the aquifer is not present, geoelectric profiles show only unit 2 (conductive) and unit 3 at the top, without the identification of high resistivity values at the base of the profiles related to the thick sediments of the aquifer. Thus, the low resistivity values of unit 2 persist until the theoretical depth reached, of 100 or 150 meters (depending on the maximum opening of the current electrodes in the lifting).

This is what can be observed in VES 7 (Figure 6), located in the municipality of Imbé, which presents at its top resistivity values corresponding to the coastal barrier deposits of unit 3. From the depth of 7 meters to the theoretical maximum of 100 meters, no geoelectric layers were reached with resistivity values that could indicate the presence of the aquifer. This VES was correlated to the COR IMB 01 well, with depth greater than 100 meters, whose drilling samples also did not accuse the presence of lithologies corresponding to the aquifer. It is important to highlight, at this point, the low resistivity value presented in VES 7 - less than 1 Ω·m - which indicates probable salinity below 7 m of depth.

Other surveys carried out near the coast line in the municipality of Imbé also did not identify the aquifer, as is the case of VES 8, which reached the theoretical depth of 100 meters, and identified only values of electrical resistivity corresponding to units 2 and 3. The geoelectric model of this VES indicated, at 85 m, an electrical resistivity value related to the probable salt wedge. With even greater spacing between the current electrodes, the VES 17, 18 and 19 investigated a theoretical maximum depth of 150 meters, but also did not identify the Coarse Salt (*Sal Grosso*) aquifer.

Eight of the 19 vertical electrical soundings identified the aquifer. The average top depth of the aquifer found through the VES was 65 meters. The marine unit (conductive) presented average top depth equal to 15 meters and average thickness of 50 meters. In most cases it was not possible to define the base of the aquifer, because it was below the theoretical depth reached by the VES or there was not enough contrast of resistivity to limit its occurrence with another unit at depth.

4.3. Spatial analysis

Interpolation of the top depths of the aquifer unit showed that it occurs as a NW-SE orientation feature (Figure 7), between Osório and Tramandaí.

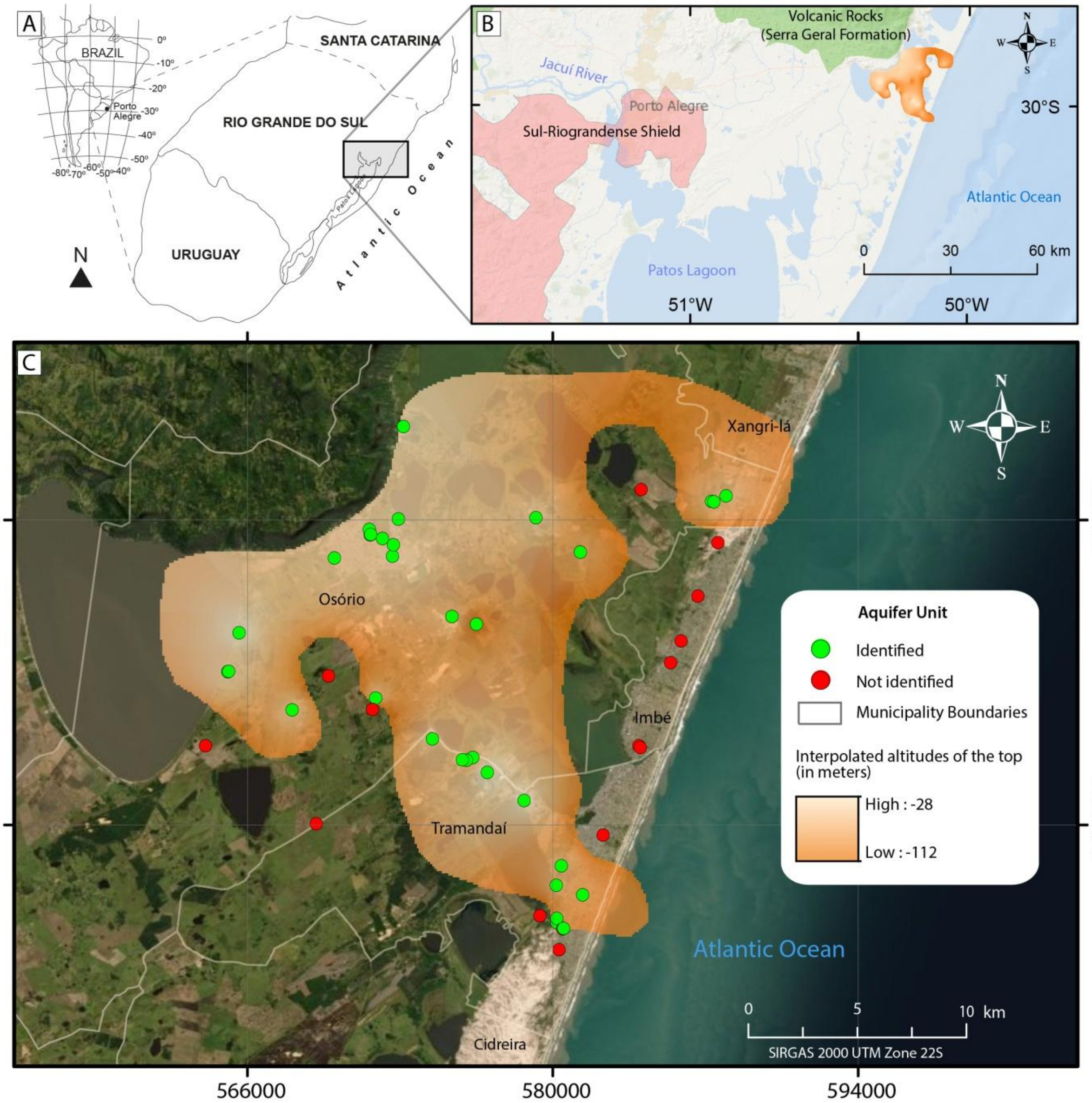

Figure 7. Location of the study area (A), with the feature found near the volcanic rocks of the Serra Geral Formation of the Paraná Basin and approximately 70 km northeast of the Pre-Cambrian basement (B). (C) Spatialization of the Coarse Salt (*Sal Grosso*) aquifer in the study area, based on its identification in wells and SEVs. The generated feature is restricted and has a NO-SE orientation, between the municipalities of Osório and Tramandaí. The top depths of the aquifer were referenced to sea level and their altitudes were interpolated (in orange).

In this map it is possible to visualize the points that have identified and those that have not identified the aquifer unit, which can be from wells or VES

To verify that this feature would persist regardless of the type of interpolated data, topographic maps of the unit were generated using only VES data, or only well data. Both continued to show this same restricted and oriented feature practically perpendicular to the coast line. Thus, it was interpreted as belonging to an alluvial system, with the occurrence of alluvial fans in the most proximal portions and a river system in the most distal portions. Depending on the context of relative sea level, paleo-estuaries may be associated with the mouth of this system.

4.4. Stratigraphic analysis

The vertical succession of facies observed in the columnar sections showed, from the base to the top, the patterns of sedimentary stacking: progradational, retrogradational and progradational. The boundary surfaces were defined from the changes in the patterns: subaerial unconformity (sequence boundary), maximum regression surface and maximum flood surface. Thereby, the sedimentary record was subdivided into:

- A lowstand systems tract (LST), related to alluvial deposits related to the aquifer unit (at the base);
- A transgressive systems tract (TST), formed by marine deposits and;
- A highstand/falling stage (HST/FSST) systems tract, formed by the deposits of coastal barriers (at the top).

The Osório well (COR OSO 01A), located near the mainland, presents an intercalation of marine and continental deposits (including peat) in the context of Unit 2 (Figure 8).

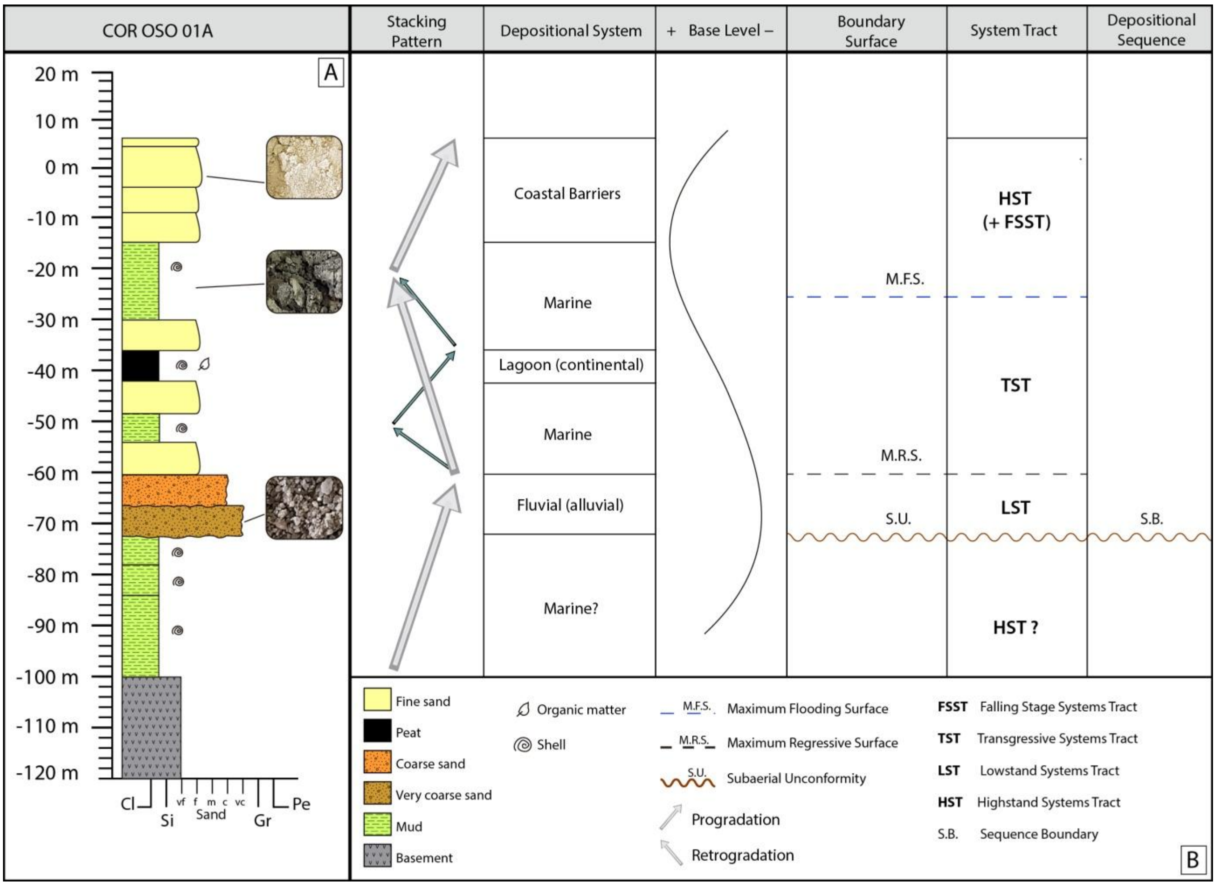

Figure 8. (A) Lithological profile of the COR OSO 01A well, located in the municipality of Osório (the altitude values are in meters and are referenced at sea level) and its stratigraphic analysis (B).

This variability is not identified in more distal wells (close to the ocean), such as COR OSO 06 (Figure 9) and the COR TRA EMB 02 (Figure 10), in which unit 2 is formed basically by a thick bundle of muddy sediments.

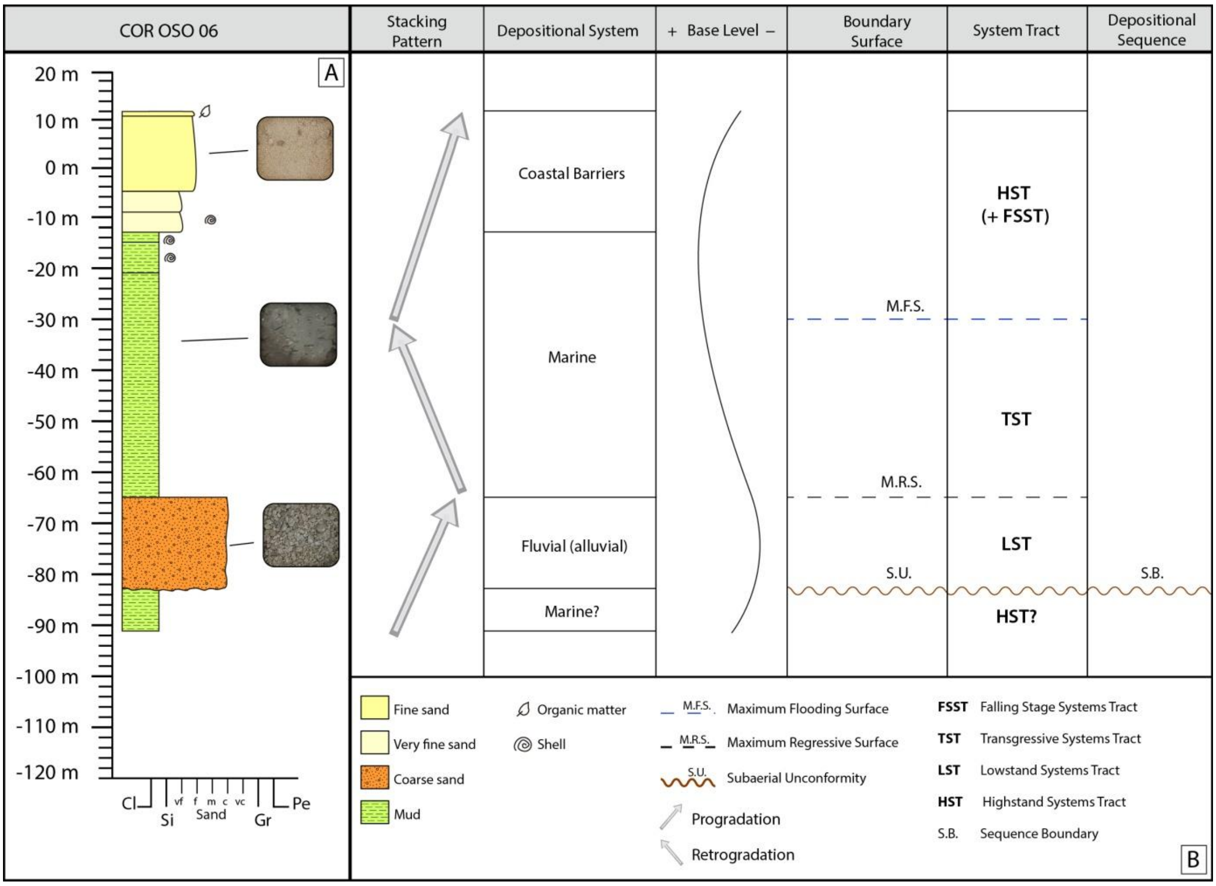

Figure 9. (A) Lithological profile of the COR OSO 06 well, located in the municipality of Osório (altitude values are in meters and are referenced to sea level) and its stratigraphic analysis (B).

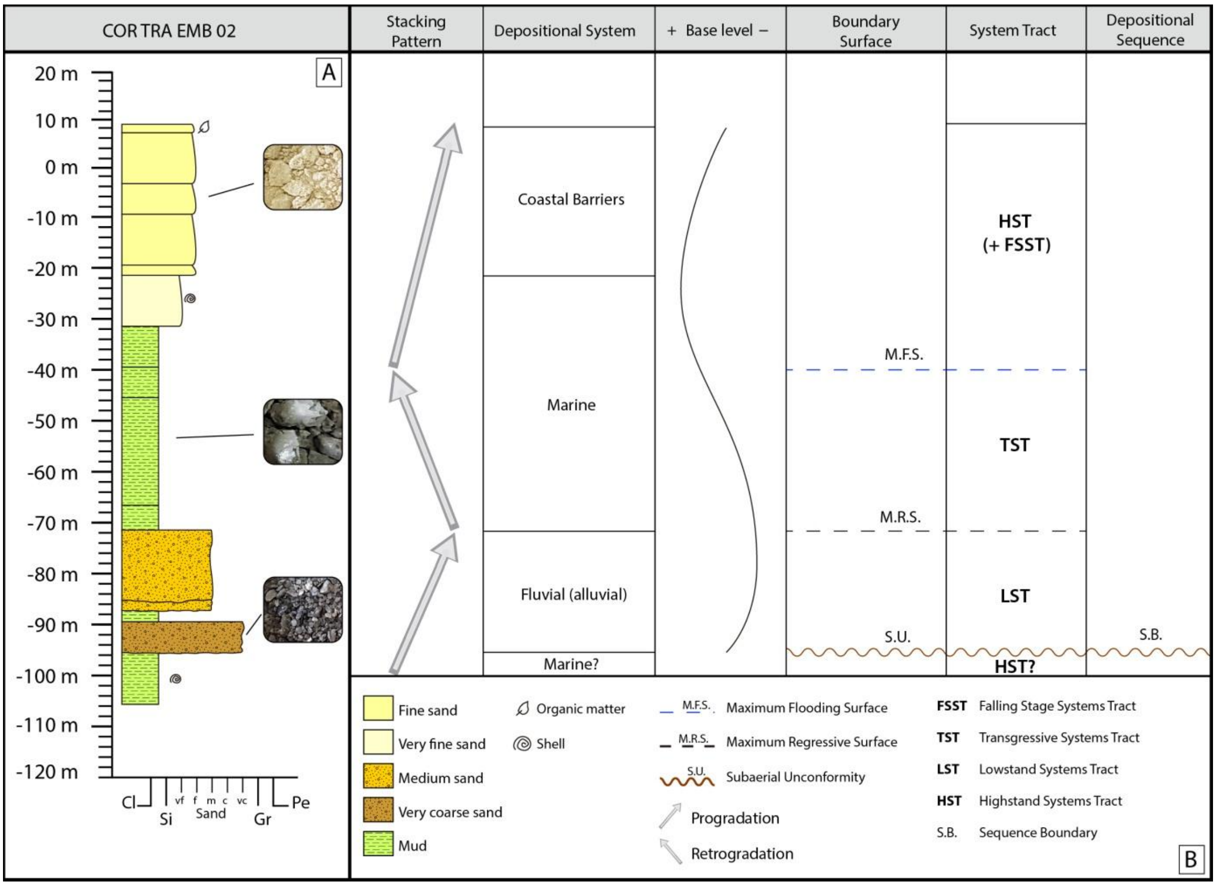

Figure 10. (A) Lithological profile of the COR TRA EMB 02 well, located in the municipality of Tramandaí (altitude values are in meters and are referenced to sea level) and its stratigraphic analysis (B).

A dip section was built (Figure 11) based on these wells, where these observations can be better visualized.

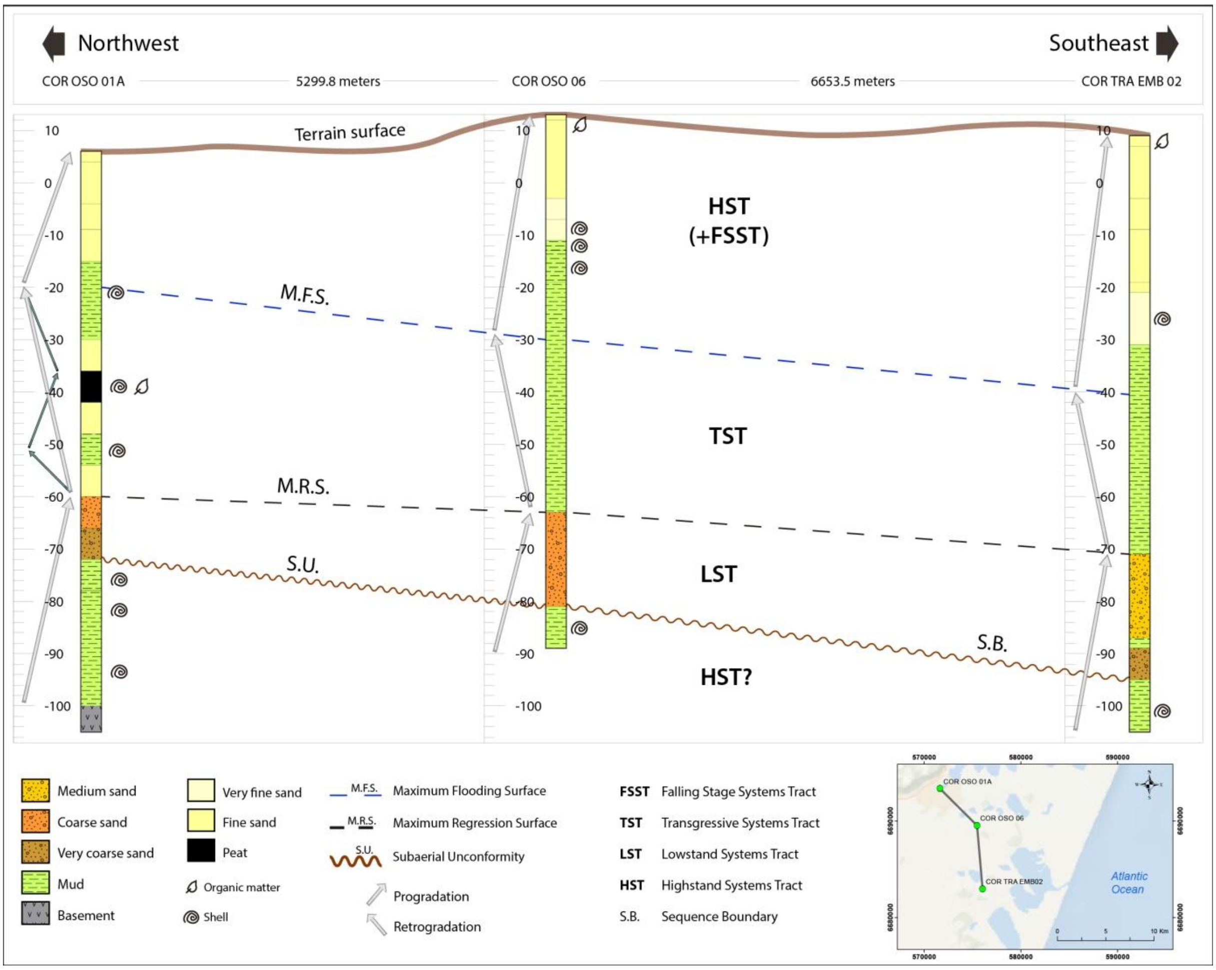

Figure 11. Stratigraphic analysis of the dip section constructed from the COR OSO 01A, COR OSO 06 and COR TRA EMB 02 wells showed that the verified units compose a depositional sequence, whose basal limit is the subaerial unconformity. In this sequence, the set of high-frequency sequences formed by the lagoon-barrier systems I to IV are part of its top, in a highstand/falling stage systems tract context.

The construction of a strike section showed that, laterally to the Osório well, other wells also have intercalations in sedimentary deposits. Consequently, this greater variability which was verified results in a greater number of changes in stacking patterns within unit 2 of the most continental wells.

The stratigraphic analysis allowed to interpret that the units verified in the wells compose a depositional sequence, whose boundary is the subaerial unconformity, defined as the base of the deposits of the alluvial system that form the Coarse Salt (*Sal Grosso*) unit. In this longer period sequence, the set of high-frequency sequences, formed by the lagoon-barrier systems I to IV, constitutes its top, in a highstand/falling stage systems tract context.

5. DISCUSSIONS

The analysis of the sediments that make up the Coarse Salt (*Sal Grosso*) aquifer unit led to the interpretation that it originated from an alluvial system, with restricted spatial distribution and elongated in the NW-SE orientation, practically perpendicular to the current coastline. The unit extends from the boundary with the volcanic rocks of the Serra Geral formation to near the beach, between Osório and Tramandaí, with a larger axis of approximately 22 kilometers. The width is variable and there is a narrowing towards the ocean in this main axis, which presents higher values in the most proximal portion, flowing 8 km in the limit between Osório and Tramandaí, and 3 km near the coastline. Thus, analysed together, the geometry presented and the sedimentological characteristics of the Coarse Salt (*Sal Grosso*) unit lead to the interpretation that it constitutes a paleochannel in the studied portion.

Several other paleochannels have already been identified in the Pelotas Basin, as in the works of Calliari (2005), Biancini et al. (2014), Zouain et al. (2003), Baitelli (2012), Barboza et al. (2005), Leal et al. (2016), Lima and Parise (2018), Weschenfelder (2005), Weschenfelder et al. (2010, 2008) e Weschenfelder and Correa (2019), but usually located in shallower and latest portions (from the Late Pleistocene or Holocene) than those related to the Coarse Salt (*Sal Grosso*) unit.

Regarding the source area, the compositional and textural characteristics immediately rule out the possibility that it might have been originated from the volcanic rocks of the Serra Geral formation, despite the geographical proximity. Coarse Salt (*Sal Grosso*), as its nickname suggests, is formed by coarse, angular grains, and composed predominantly of quartz-feldspar grains. Therefore, it is most likely that this material originated from rocks coming from the Sul-Riograndense Shield, which emerge 70 km southwest of there (Figure 12).

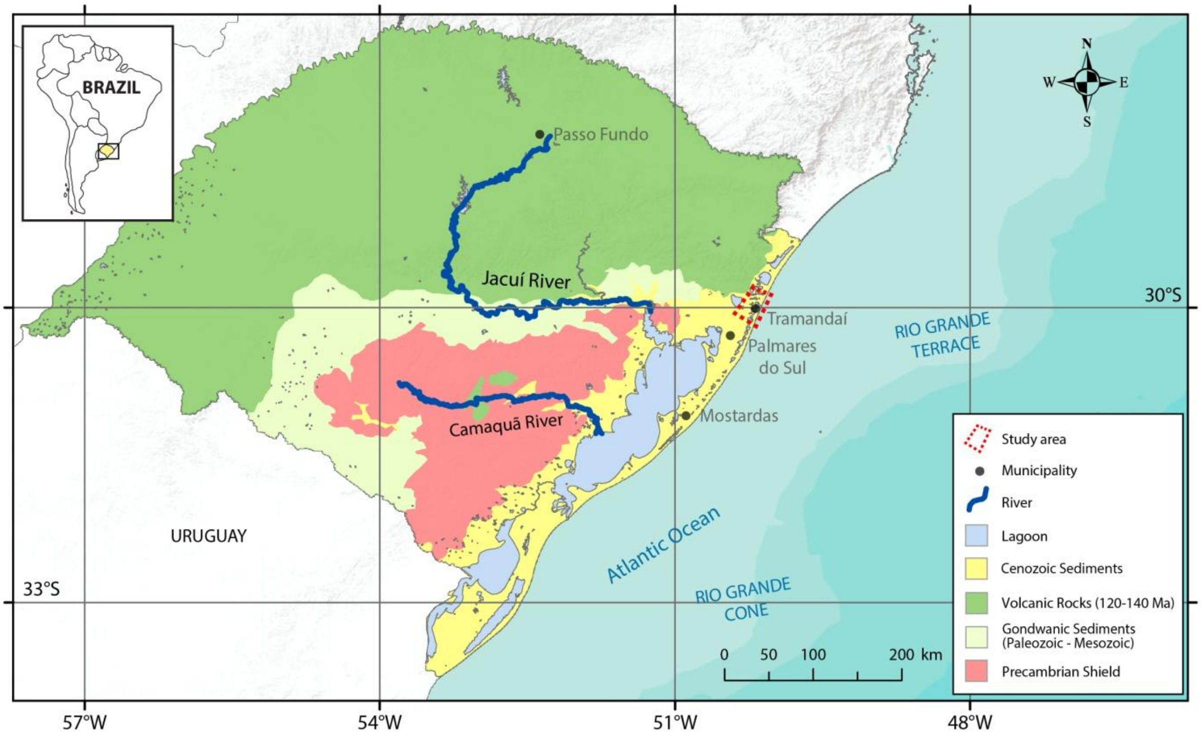

Figure 12. Current courses of the Jacuí and Camaquã rivers. The most likely area of origin of the sedimentary material that forms the Coarse Salt (*Sal Grosso*) aquifer is rocks from the Pre-Cambrian basement (Sul-Riograndense Shield), 70 km away from the study area. Note that the Rio Grande Terrace and the Rio Grande Cone occur as projections onto the continental shelf, and the Rio Grande Terrace is lined up in front of a possible ancient exit from the Jacuí River.

The Jacuí River (Figure 12) it is the largest river in the state of Rio Grande do Sul and it is part of the Jacuí River Basin (area of 71,600 km2). With its sources in the Middle Plateau region, near the municipality of Passo Fundo, it travels an approximate total length of 710 km to its mouth, with the formation of the Delta do Jacuí, where the Gravataí, Sinos and Caí rivers also flow (“FEPAM,” 2021; “Pró-Guaíba,” n.d.). In the work of Machado and Remus (2011) a study of the heavy mineral assemblage is made to determine the provenance of unconsolidated sand deposits, sampled at various points along the main course of the Jacuí River and its main tributaries. The result indicated that the main source area of the sediments is the Sul-Riograndense Shield, which comes from tributaries on the right bank of the Jacuí River. The authors also suggest that the results found can be used to assess the contribution of these sediments in the filling of the younger portion of the Pelotas Basin.

According to studies conducted by Baitelli (2012), the past drainage of the Jacuí River (paleojacuí) would have flowed into the sea in different places, as the morphology of the coastal plain was being shaped by the successive eustatic variations that controlled the sea level in the Quaternary. Initially, it would have flowed into Palmares do Sul, a municipality located approximately 40 km south of the boundary between Tramandaí and Imbé. However, this exit to the sea would have been obstructed by the sediments of the barrier-lagoon system III, developed, according to the author, 133 ka ago. The second exit would have been further south, in the region of Mostardas. This one was closed by the sediments of the barrier-lagoon system IV, in formation 6 ka ago.

Meanwhile, interpretations by Baitelli (2012) for the paleodrainage of the Jacuí River are related to a more recent period than the deposition of the Coarse Salt (*Sal Grosso*) unit - probably within the range corresponding to the unit here interpreted as coastal barriers (Unit 3). The paleogeography prior to the barrier-lagoon systems I to IV is less known, due to less accessibility to the data, since obtaining it through drill cores or geophysical methods of good resolution is hampered by the greater depth of the deposits.

Still, Silva (2009) identified a seismic feature of Pliocene paleodrainage, interpreted by him as a probable exit from the Jacuí River to the platform, near the latitude of the municipality of Mostardas (Figure 12) and few more than 50 km east of the current coastline, in a position consistent with that of the paleochannel identified by Weschenfelder (2005) and Weschenfelder et al. (2008). This older drainage feature dates back to the evolutionary scenario proposed by Villwock and Tomazelli (1995), whose paleogeographic context in the Pliocene to Lower Pleistocene range would be formed by a large coastal plain built by a system of coalescing alluvial fans along the eastern edge of the topographically higher terrains, and the most distal portions of these systems would be reworked by fluvial carvings and lagoon and marine terracing (Villwock and Tomazelli, 2007).

Still regarding features present on the continental shelf, it is worth noting the evidence of two projections with similar morphologies: the Rio Grande Cone and the Rio Grande Terrace (Figure 12). These projections are related to the drainage systems active at the time of deposition, and one of them - the Rio Grande Terrace - occurs aligned in front of a possible ancient exit from the Jacuí River, in a position compatible with the study area of this work.

The development of the drainage of Rio Grande do Sul is covered by Silva (2009), mainly based on the works of Ab'Saber (1969), Potter (1997) and Lisboa et al. (2001), which claim that its development would have occurred in association with the evolution of a passive continental margin from the Cretaceous Period in the fragments of the Gondwana continent, where the state of Rio Grande do Sul is today. The starting point would have been the uplift of Uruguay - Southwest Africa (Potter, 1997), which would have generated the Uruguay River drainage system, the largest and most important in the state.

According to Ab'Saber (1969), in a regional context, a primordial drainage with irregular pattern would have developed from the modern deformation of the Caçapava planing surface, directed to all the marginal quadrants of the Sul-Riograndense Shield. Also according to the author, in the fragility range between the intersection of the Shield and the basaltic plateau - two independent modern deformation nuclei - important drainage lines would have been formed since the Paleogene Period, and in this context the Jacuí is the most remarkable and complex heritage. Therefore, considering that since the Paleogene Period there have been no other major tectonic events with the potential to significantly reflect in the direction of the paleodrainage of the area, and considering the sedimentological characteristics of the filling material and the location of the paleochannel identified in this work, it is reasonable to consider that this same Jacuí River, in a remote period, may was responsible for the arrival and deposition of sediments from the rocks of the Sul-Riograndense Shield, coming to the ocean near the municipality of Tramandaí, in a period of lower relative sea level than the current one.

Lisboa et al. (2001) also mention the fact that the Camaquã and Jacuí rivers escape the semi-ring pattern imposed by the uplift of Uruguay and have their current courses aligned in the east-west direction, presenting a predominantly straight geometry, which could be explained by past modifications, such as by capture processes (Ab'Sáber, 1969; Lisboa and Castro, 1998) and by recent drowning of the low course of these systems in the coastal lagoon system (Villwock and Tomazelli, 1995). According to Silva (2009), because the fact of Jacuí-Guaíba system is transversal to the structures of the Shield in the northwest-southeast direction and because there are no known ancient deposits in the current east-west orientation, Lisboa et al. (2001) proposed the hypothesis of the existence of an ancient low semi-ring course of the Jacuí, whose exit to the Atlantic would have been close to the Rio

Grande channel, with part of the deposits related to this system deposited in the Rio Grande Cone (Martins et al., 1972). In this context, it can be understood that the paleochannel identified in this work might have developed after the change in the drainage pattern, already with the current east-west alignment, that is, after this possible more southerly exit mentioned by Lisboa et al. (2001).

During the sedimentological analysis of the Tramandaí and Osório wells, it was possible to recognize zircon minerals in samples from the Coarse Salt (*Sal Grosso*) unit, which motivates the attempt to recover these minerals in sufficient quantity to carry out this kind of dating in future works. Detrital zircons present in the Coarse Salt (*Sal Grosso*) unit samples could provide information as to the material's provenance through the determination of ages using U-Pb dating, as in the work of Dickinson and Gehrels (2008), where the method was applied to determine the ages of present zircons in fluvial deposits in Mexico, showing the flow direction of paleodrainages. Likewise, this technique could be used to better understand the paleodrainage configuration responsible for the arrival of the sedimentary material that forms the Coarse Salt (*Sal Grosso*) unit, which would also provide insights into the tectonic configuration and relief of that period. As the characteristic material of the Coarse Salt (*Sal Grosso*) unit, due to its granulometric and compositional characteristics, excludes the possibility that it originated from the basaltic volcanic flows that cover a large part of the surrounding region, the application of this method could confirm the hypothesis raised here: that the material would have been transported from drainage from the rocks of the Sul-Riograndense Shield.

Regarding the identification, the aquifer unit is more easily observed in wells than in VES. This distinction is related to the fact that wells are usually drilled close to previous positive results, increasing the probability of success. In other words, while the wells are concentrated in the same region with the best record in terms of aquifer productivity, the VES were collected mainly in places with a lack of information, therefore, with greater risks regarding the identification of the aquifer unit. In addition, there is a limitation in the identification of the unit depending on the technique that is used. According to Giampá and Gonçales (2013), the dimension relations of the structures (width of a fractured band, thickness of a sedimentary layer) must be compatible with the depth. So, it is much more difficult to detect the presence and establish the thickness of thin layers located at great depth. That is, in cases where the VES do not identify the Coarse Salt (*Sal Grosso*) aquifer - it might be too thin in these portions, or there is even the possibility that there is a predominance of floodplain deposits there, that would present a much smaller or practically unimpressive resistive contrast with the fines unit just above.

These possibilities meet the hypothesis of alluvial deposit, in which heterogeneities are expected in relation to thickness, grain size and top depth. In this case, the restricted feature should be part of an incised valley, probably a river channel, filled predominantly by thicker sediments that, today, form the aquifer. According to Posamentier and Walker (2006), extensive accumulations of river deposits in sedimentary basins formed over millions of years typically show distinct spatial variations in average grain size, geometry, proportion, and spatial distribution of channel and floodplain deposits. Thus, it can be concluded that the channel would be just one of the possible subenvironments in the complex sedimentary record of a fluvial depositional system, but the most easily identifiable in the wells and indirectly in the VES - largely due to its grain size, which is also expressed as an aquifer in that portion.

Sinha et al. (2013) used the technique of vertical electrical sounding to map a large complex of paleochannels in northwest India, providing an understanding of its geometry. Although shallower, the fluvial deposit identified in India showed similarities with the Coarse Salt (*Sal Grosso*) deposit: both are distributed over a wide area, have variable thicknesses, and were easily identified in the VES due to the contrasts in resistivities of the saturated sand body in relation to the adjacent deposits. As in the present study, the VES technique allowed a greater understanding of the dimensions of the paleochannel complex, but issues related to time (age) still need to be resolved.

In Rusydy et al. (2020) the presence of groundwater at greater depths was investigated through vertical electrical soundings, using the same maximum horizontal opening between the current electrodes as applied in this work - up to 600 meters - which allowed the identification of a deep aquifer in the basin of Krueng Aceh. The authors drew attention to the increase in the local population in the basin, which started to demand not only the shallow aquifer, but also deeper aquifers such as the one mapped, generating the need for protection plans for this water source. The same phenomenon of population growth happens on the northern coast of Rio Grande do Sul (2016; 2020; 2019), generating pressure for the drilling of new wells that capture water from aquifers deeper than the unconfined ones - already quite exploited by numerous wells, many of them built improperly and serving as vectors of contamination (Reginato et al., 2008). Therefore, the Coarse Salt (*Sal Grosso*) aquifer has enormous potential as it generally offers good flow rates and good quality water (Collischonn, 2018; Troian et al., 2020), leading to the need for its recognition and strategic planning in order to ensure its long-term sustainability.

Expanding the research area, it is possible to verify that there are other wells that also capture water from the Coarse Salt (*Sal Grosso*) aquifer unit, which present even thicker sediments than those found in the Tramandaí and Osório Wells. This is the case of wells near the municipalities of Palmares do Sul and Balneário Pinhal, approximately 20 km south of the area detailed in this work ("CPRM - Serviço Geológico do Brasil," 2021). Similarly, but approximately 10 km north of the identified paleochannel, the wells of Balneário de Atlântida Sul also show the presence of the aquifer unit. With the interpolation of the most representative grain sizes found in the Coarse Salt (*Sal Grosso*) unit, 21 more wells were included in the work, resulting in a total of 50 wells analyzed. Although the distribution of wells is quite irregular, generating information gaps about the continuity of the aquifer unit (mainly in the area north of Balneário Pinhal), there are also regions where wells exist but do not identify thicker sediments, which reinforces the lateral variability of the presence of the Coarse Salt (*Sal Grosso*) unit. This is the case in the municipality of Imbé, where neither the VES nor a well of 138 meters have identified the aquifer, despite the fact that they are located between two regions in which the aquifer is present.

This spatial variability suggests that there was a period in which there were multiple channels that varied laterally, and the areas with the largest grain sizes are associated with the more constant presence of channels in the past. This implies that, even though the unit occurs in the position indicated in the conceptual model of compartmentalization of the coastal aquifer system of Troian et al. (2020), where it was called a hydrostratigraphic unit 3 (Figure 2), this does not mean that it has potential as an aquifer in all locations, precisely because of the heterogeneities - typical of an alluvial system.

The very definition of systems tract as a set of contemporary depositional systems (Jr and Fisher, 1977) leads to the understanding that not necessarily only the same depositional system will be active and will occupy a wide geographical space in the same time interval, an idea based on the principle of superposition of strata, by Nicolaus Steno – a simple and attractive model, but one that does not account for the existing complexities in a sedimentary basin. The coarse sediments that form Coarse Salt (*Sal Grosso*) are conditioned to the existence of the fluvial depositional system, which, compared to the marine system, is spatially more restricted. Besides, a fluvial system is formed by several subenvironments – channel, point bar, levees, floodplain – which contributes to the facies variability found in this type of depositional system. All of this reflect in the hydrogeological potential, since heterogeneity is highly dependent on hydrodynamic parameters, such as porosity and permeability (Hornung and Aigner, 1999; Miall, 2014), what reinforces the importance of detailed subsurface investigations - which on the scale of this work include the variations observed in columnar sections of wells interpreted from geoelectric profiles.

The coastal barrier deposits that make up the highstand/falling stage systems tracts of the sequence identified in this work have extensive lateral continuity parallel to the coastline and, together, result in a progradation perpendicular to the coastline (Dillenburg and Hesp, 2009; Rosa et al., 2017). Hence, their lateral variation is smaller when compared to fluvial deposits, so that they are always identified at the top of the sections of the study area, regardless of the orientation. As for the marine deposits that form the bundle of fine sediments, they are also widely distributed in the investigated area, according to what is expected for this type of system. This homogeneity of marine deposits is only disturbed in wells that are closer to the continent, which show greater variability in the sedimentary record, characterized by the occurrence of continental deposits intercalated with marine deposits. These variations indicate that these wells must be located in an ancient context of interface between continent and ocean, that is, in a paleocoastline, which must have remained close to this position for some time. Although the deposits have not been dated, the expressive thickness of the fine deposits indicates that the dominance of the marine system must have lasted for a long period in the region.

The stratigraphic units that were identified were represented in a dip section (Figure 13) and explain about the evolution of the sedimentary filling of the Pelotas Basin in the studied interval, which is summarized as follows:

Initially, there was a relative sea level fall, when the activity of the fan system expanded with dominance of the alluvial-fluvial systems. After that, these systems were “drowned” due to an increase in the relative level, which enabled the deposition of a thick bundle of fine sediments (silt and clay) with shells in an inferior shoreface or offshore environment. After it reached the transgressive maximum, the shoreline started to prograde into a highstand systems tract/falling stage systems tract, forming the sandy sediment deposits of the barrier-lagoon systems I to IV at the top of the sequence.

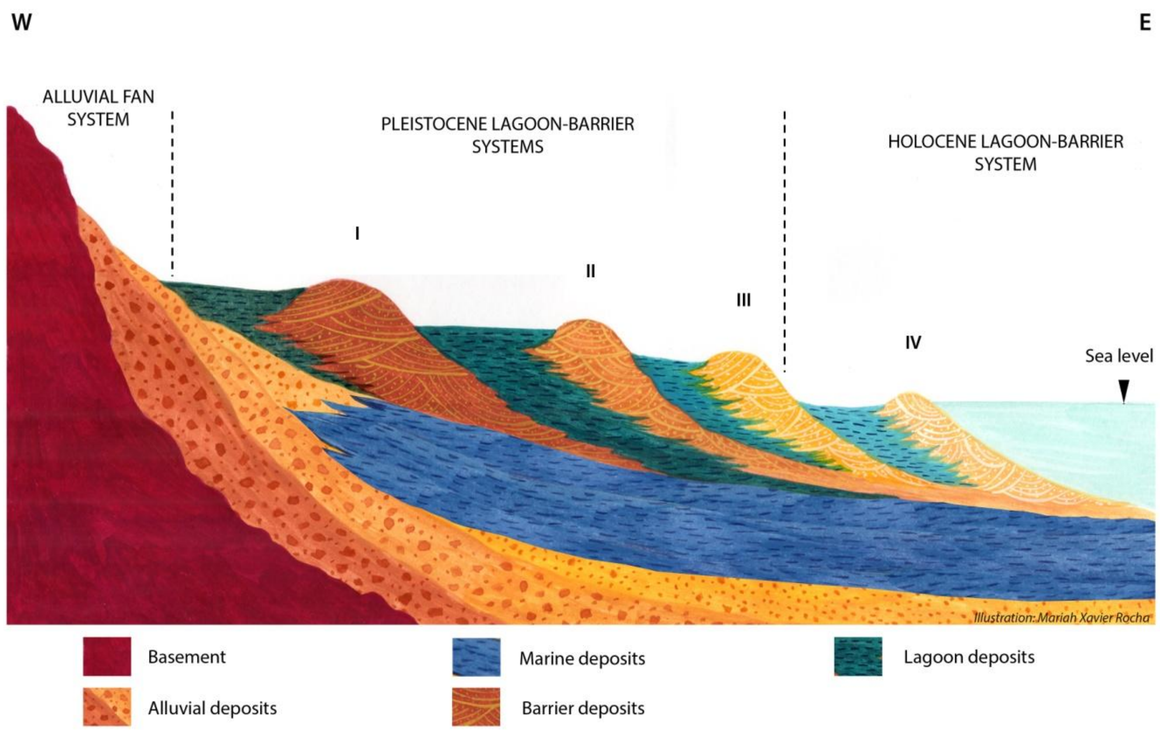

Figure 13. Illustrative dip section that integrates the knowledge of the stratigraphy investigated in this work with the model proposed by Tomazelli and Villwock (2000), with the insertion of deposits interpreted as marine (Unit 2) between alluvial (Unit 1) and coastal barrier deposits (Unit 3).

This major transgression that “drowned” fluvial systems and deposited fine marine sediments is not illustrated in the classic schematic profile of the coastal plain (Figure 2). The marine unit has a considerable thickness of 47 meters on average. That was observed in all wells and identified in the VES. The occurrence of marine deposits in this stratigraphic position means that the sea was higher before the beginning of the deposits of the barrier-lagoon systems, able to accumulate the thick bundle of fines. Deposits with such accumulation were no longer observed in the most recent record, even with the subsequent changes in sea level (Collischonn, 2018). From a hydrogeological perspective, the bundle of fines acts as an important "sealant", protecting the Coarse Salt (*Sal Grosso*) aquifer unit. Due to the evidences that were presented, it would be important that the marine unit be considered in relation to the stratigraphy of the coastal plain, as it provides greater detail and advances in understanding its evolution.

The logic of sequence stratigraphy was used by Rosa (2012) e Rosa et al. (2017) to analyze the record of the barrier-lagoon systems in the coastal plain of the Pelotas Basin, where each system was considered as corresponding to a high-frequency sequence, related to glacioeustatic cycles of approximately 100 ka. Using the same logic in another scale, it was possible to place the set of these high-frequency sequences in a larger sequence which is identified in this work. Thus, this longer period sequence can be inserted into the stratigraphic framework of the Pelotas Basin, where the barrier-lagoon system sequences composes its highstand/falling stage systems tract. The lowstand and transgressive systems tracts are related, respectively, to alluvial (aquifer unit) and marine deposits.

The intercalation of continental and marine deposits, evidenced in the proximal wells, led to the questioning of which would have been the control for these variations in the record: allogenic or autogenic? It was pointed out as a possibility that these variations might be associated with a paleoshoreline at that position - if so, the base level could be varying at a higher frequency. Another possibility is that the variations would be related to autogenic processes (internal to the system itself); therefore, the variations would be more localized. In order to verify this possibility a strike section was constructed in an attempt to visualize whether the same stacking patterns would be occurring laterally in the more proximal wells. The section showed that some of the wells had a greater number of oscillations than others, and some of them had the same stacking patterns, which could mean allogenic control. More detailed analyzes of these wells and others to confirm this hypothesis still need to be carried out.

Finally, the integrated analysis of the data of this work led to an elaboration of a paleogeographic model (Figure 14) that synthesizes, in a simplified way, the geological evolution in the investigated portion:

a) The model starts with the development of alluvial systems in the coastal plain, with alluvial fans in the most proximal portions, going distally to fluvial systems, flowing into the ocean.
b) Then, the rise in sea level begins, but at a slow rate, smaller than the sediment influx, what results in a normal regression of the shoreline, in a

lowstand systems tract (LST) context. At this stage, the incised valleys were filled with fluvial deposits, forming the Coarse Salt (*Sal Grosso*) aquifer unit.

c) With the progressive increase in the rate of sea level rise, the sediment influx is overcome, generating a “drowning” of the systems, characterized by the transgression of the coastline in a transgressive systems tract (TST) context. These conditions allowed the deposition of the fine sediments (silt and clay) that form the thick package of the marine unit.

d) The relative sea level must have oscillated for some time at the position of the shoreline near the Osório well (COR OSO 01A). These higher frequency oscillations might have generated the intercalations of continental and marine deposits that existed in the wells closest to the continent (this is just a hypothesis, which should be further investigated).

e) As the relative sea level rise rate progressively decreases, it is again outweighed by the sediment influx rate, generating a general progradational pattern in a highstand systems tract/falling stage systems tract (HST/FSST). In this context the barrier-lagoon systems I to IV developed.

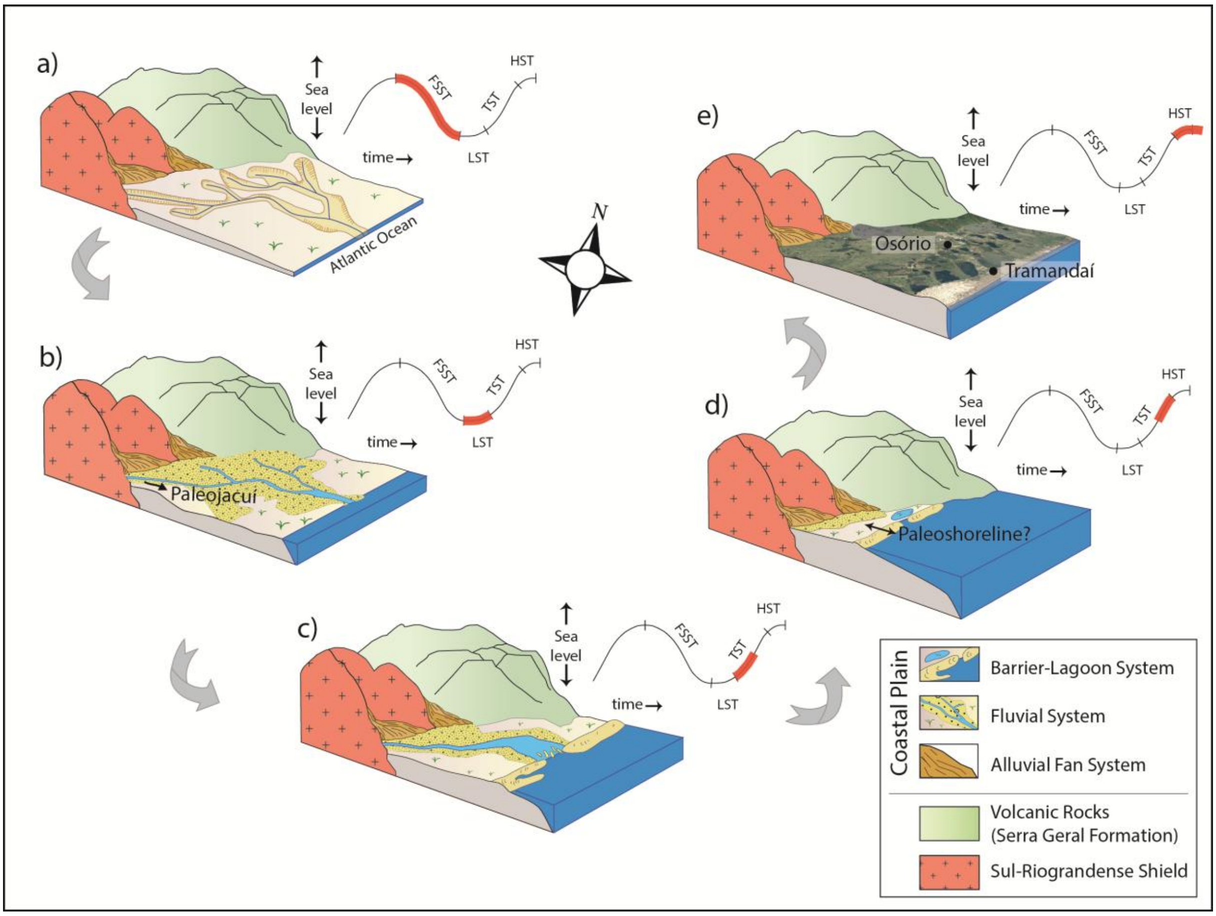

Figure 14. Simplified illustrative model that synthesizes the geological evolution proposed for the investigated portion. The Sul-Riograndense Shield (in red) constitutes the source area of the Coarse Salt (*Sal Grosso*) aquifer, whose sedimentary material was probably transported to the study area from a paleodrainage of the Jacuí River (paleojacuí). Each letter (from a to e) represents a progressive step in time and corresponds to a segment of the sea level variation curve.

6. CONCLUSIONS

The spatial analysis of the Coarse Salt (*Sal Grosso*) aquifer in the study area showed that it constitutes a restricted and elongated feature in the NW-SE orientation, between the municipalities of Osório and Tramandaí. The geometry and the sedimentological characteristics of the aquifer unit led to the identification of a paleochannel, which would have been formed from an alluvial system, which corresponds to its most distal portion (fluvial). The most likely source area of the sediments that form the Coarse Salt (*Sal Grosso*) aquifer are the granitic rocks from the Sul-Riograndense Shield, which outcrop 70 km southwest of there, possibly brought in through a paleodrainage system from the Jacuí River. A broader analysis allowed the verification the presence of other possible paleochannels, located a few kilometers to the north and south of the area of investigation, which leads to the conclusion of an incised valley context in this coastal plain region, where there were multiple channels in the past, which were filled and now form the deep aquifer.

The columnar sections of the wells and the geoelectric profiles of the VES showed the existence of different units, which present a vertical succession formed by deposits interpreted as: fluvial (at the base), followed by marine deposits, and ending with coastal barrier deposits (at the top). Wells closer to the continent showed greater variability in the sedimentary record with intercalation of continental and marine deposits, which were not identified in the more distal wells. This greater variability may be related to an ancient context of interface between continent and ocean, an indication that the most proximal wells would be located close to an paleocoastline, which remained for some time in that position. However, there is not enough data to analyze this interpretation any further.

The stratigraphic analysis of the approximate thickness of 100 meters that was investigated in this work allowed the identification of a depositional sequence. The Coarse Salt (*Sal Grosso*) aquifer was formed in a LST context. Later, there was a marine transgression that enabled the deposition of a thick package of fine sediments (silt and clay). These sediments constitute an important protection to the Coarse Salt (*Sal Grosso*) aquifer. After the transgression reached its maximum, the coastline started to prograde again, with the development of the barrier-lagoon systems, in a HST/FSST context. Thus, it is likely that there was a period of lower sea, followed by a great “drowning” and a new falling stage. This large cycle represents an intermediate scale within the stratigraphic framework of the Pelotas Basin, with the high-frequency sequences related to barrier-lagoon systems I to IV inserted as part of the HST/FSST of this longer period sequence.

Based on the interpretations made in this work, a simplified paleogeographical model that synthesizes the geological evolution in the analyzed portion was elaborated (Figure 14). According to the results exposed in study, the understanding of stratigraphy generates subsidies for decision-making that enable a better management of the groundwater resources.

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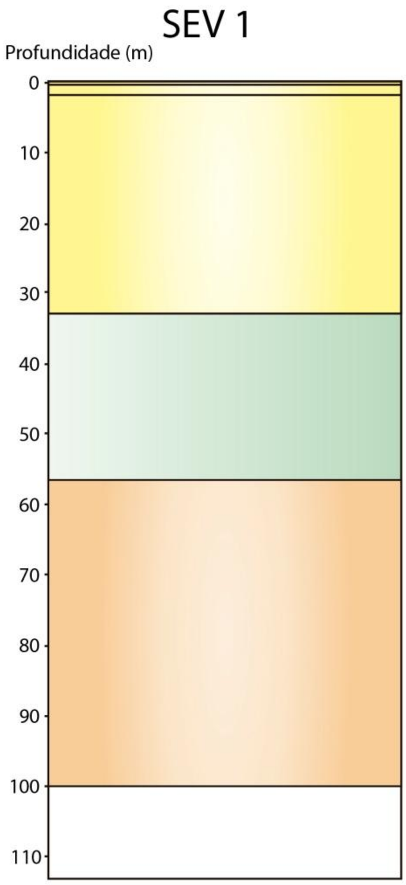
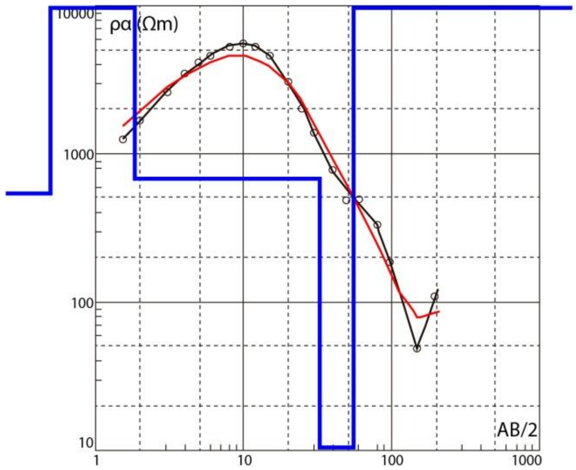
ANEXOS

ANEXO A - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 1



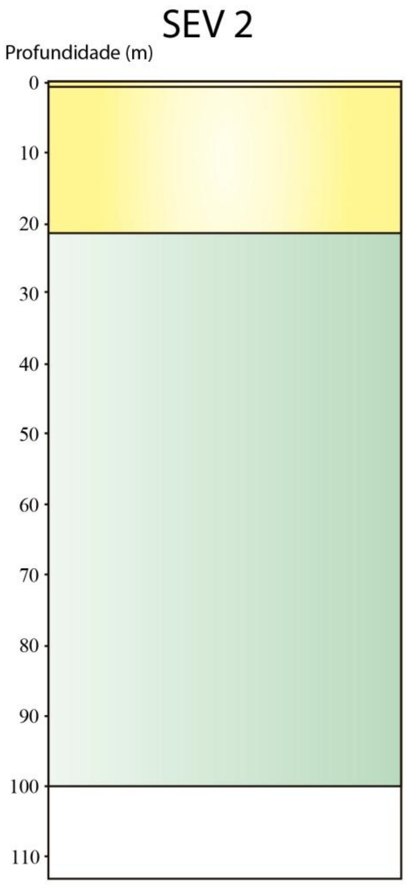


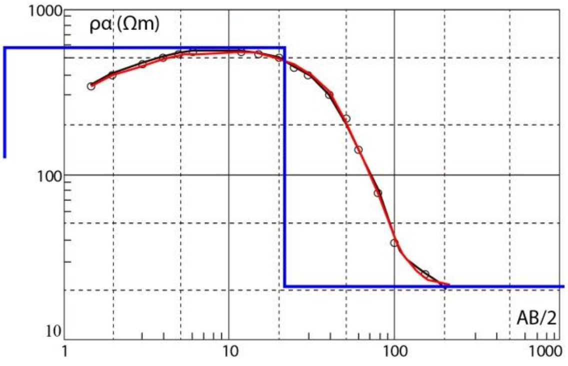
Camada	ρ	h (m)	d (m)	Unidade
1	54.9	0.494	0.494	3
2	3424	1.31	1.8	
3	68.8	31	32.8	
4	1.01	23.6	56.4	2
5	1228			1

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 20.6%

ANEXO B - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 2



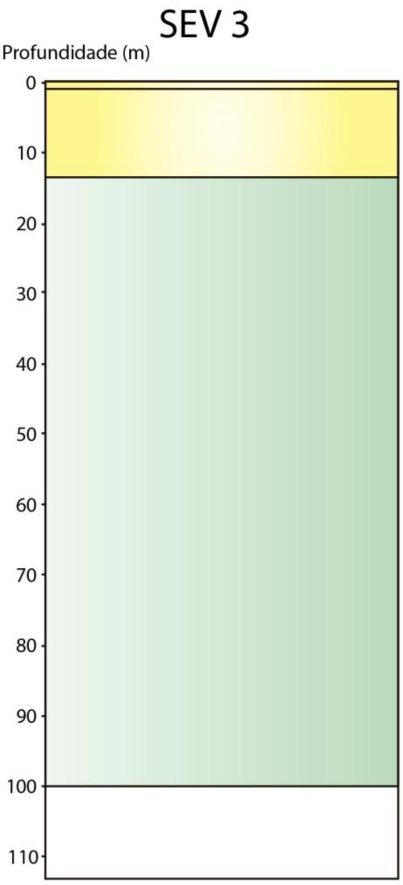


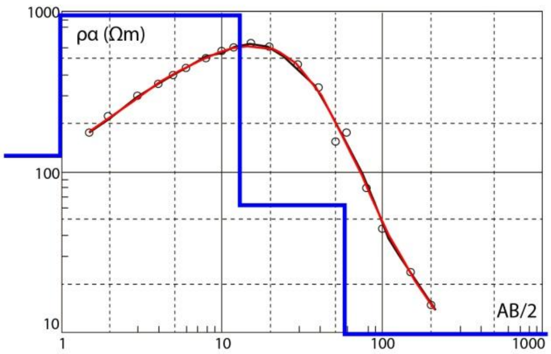
Camada	ρ	h (m)	d (m)	Unidade
1	125	0.277	0.277	3
2	588	20.8	21.1	
3	20.7			2

ρ = resistividade   h = espessura   d = profundidade da camada

—o— curva de campo   —— curva ajustada   RMS 3.59%

ANEXO C - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 3



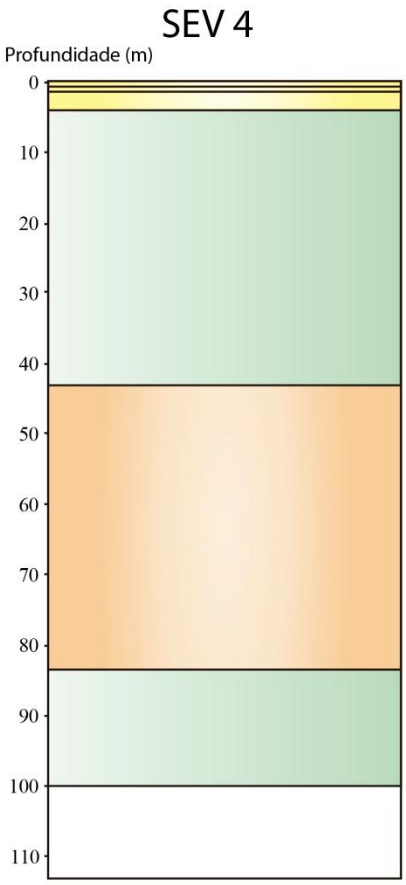


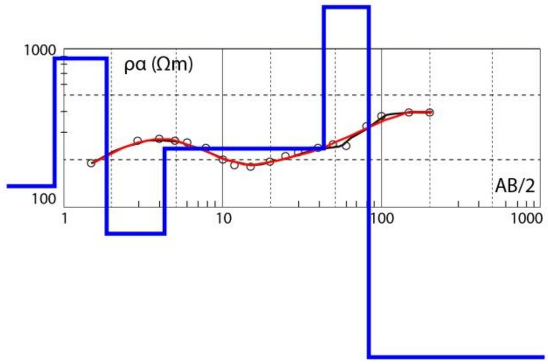
Camada	ρ	h (m)	d (m)	Unidade
1	127	0.982	0.982	3
2	946	11.8	12.8	
3	61.6	44.9	57.7	2
4	9.76			

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 3.94%

ANEXO D - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 4



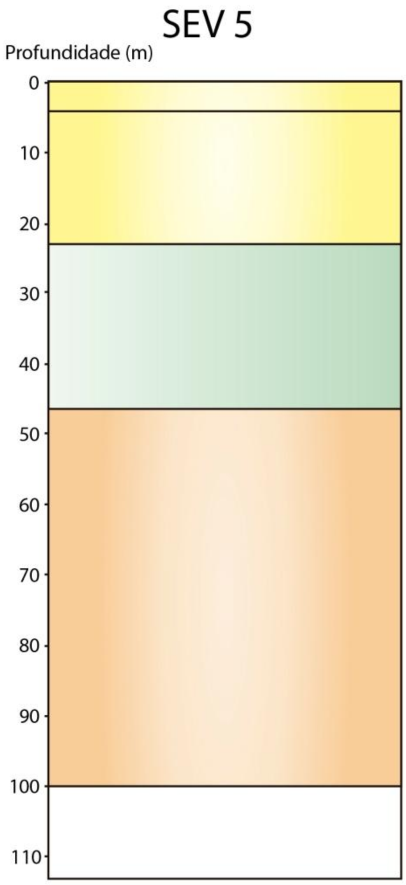


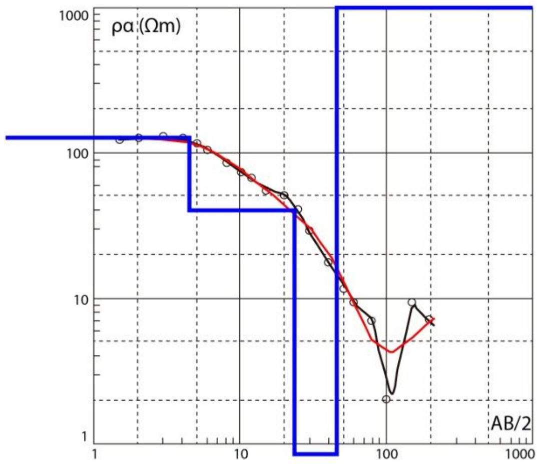
Camada	ρ	h (m)	d (m)	Unidade
1	137	0.873	0.873	3
2	874	1.02	1.89	
3	68.2	2.39	4.28	
4	236	38.4	42.7	2
5	1854	41.2	83.9	1
6	10.9			?

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo ——— curva ajustada RMS 3.94%

ANEXO E - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 5



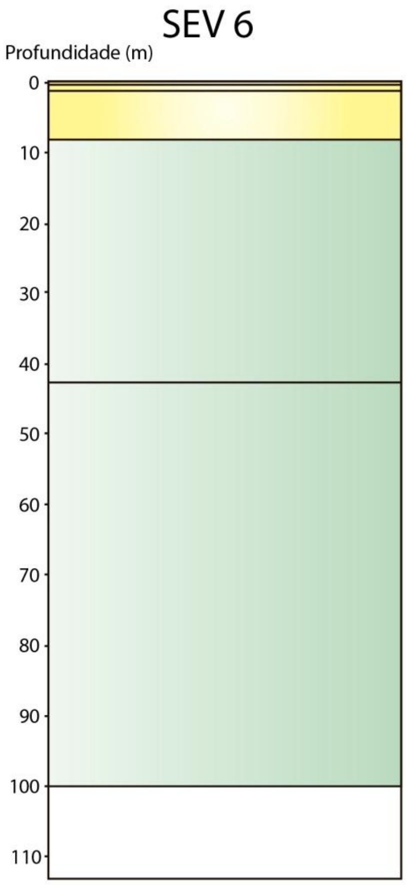


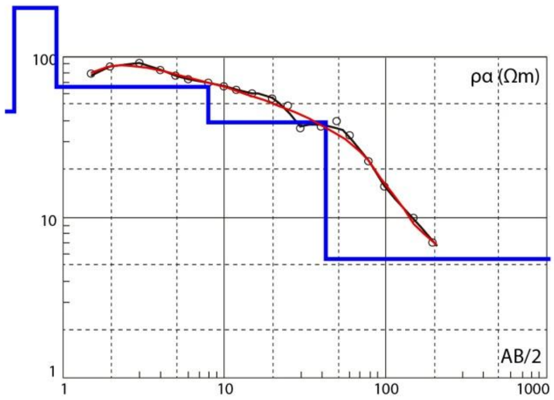
Camada	ρ	h (m)	d (m)	Unidade
1	127	4.39	4.39	3
2	40.6	18.5	22.9	
3	0.841	23.8	46.7	2
4	960			1

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo ——— curva ajustada RMS 23.8%

ANEXO F - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 6



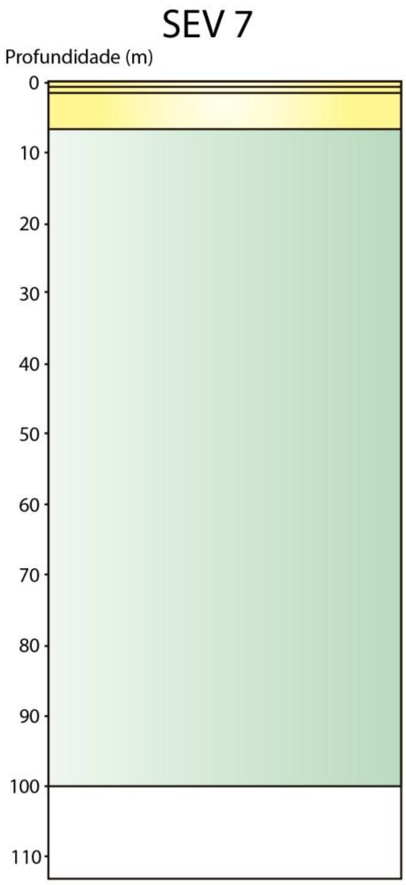


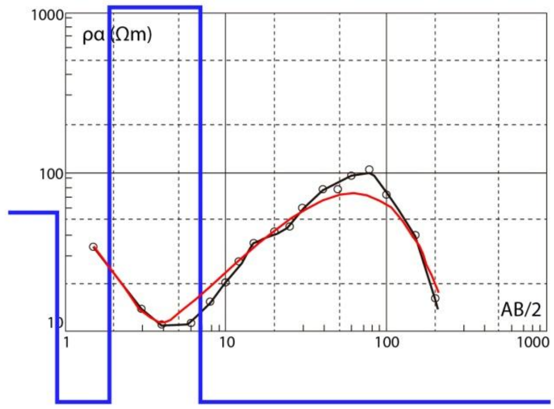
Camada	ρ	h (m)	d (m)	Unidade
1	46.6	0.49	0.49	3
2	242	0.416	0.906	
3	65.9	7.22	8.13	
4	39.6	34.7	42.8	2
5	5.52			

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 5.8%

ANEXO G - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 7





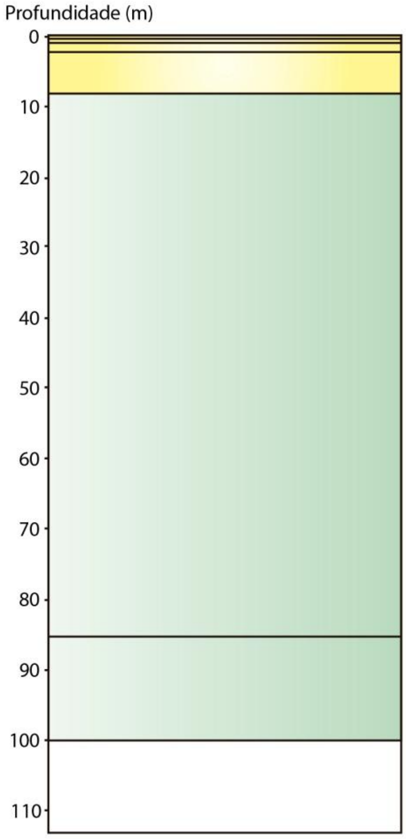
Camada	ρ	h (m)	d (m)	Unidade
1	56	0.899	0.899	3
2	2.6	0.998	1.9	
3	1065	5.14	7.04	
4	0.379			2

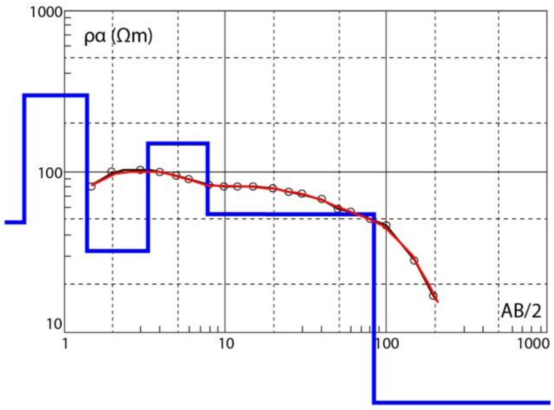
ρ = resistividade h = espessura d = profundidade da camada

—○— curva de campo —— curva ajustada RMS 15.6%

ANEXO H - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 8

SEV 8



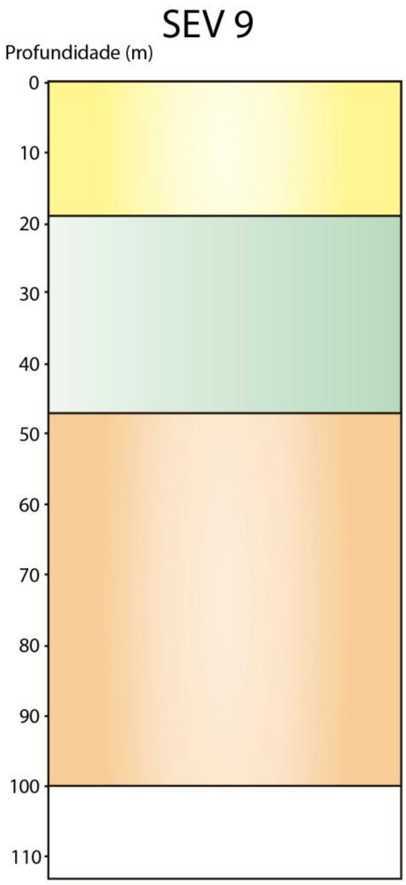


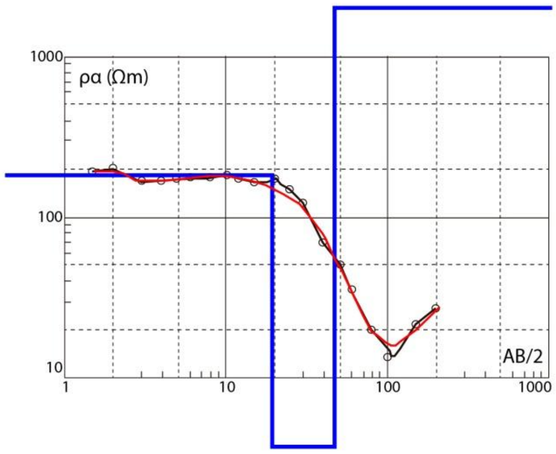
Camada	ρ	h (m)	d (m)	Unidade
1	47.6	0.575	0.575	3
2	297	0.801	1.38	
3	31.8	1.97	3.35	2
4	150	4.46	7.81	
5	55	77.4	85.2	
6	0.257			

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 2.51%

ANEXO I - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 9



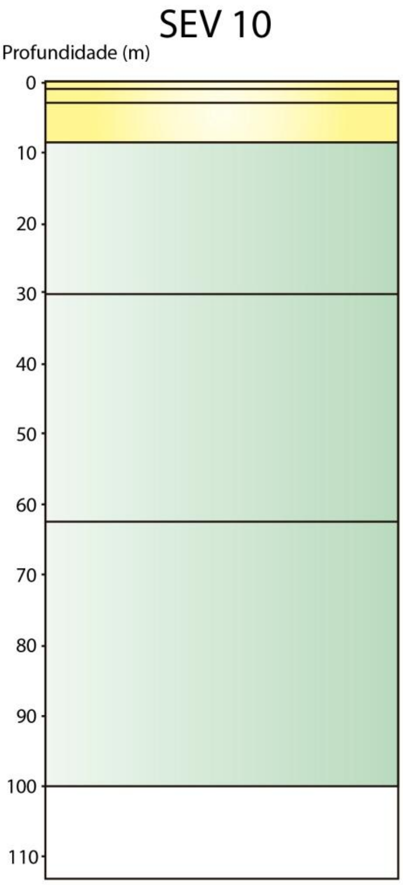


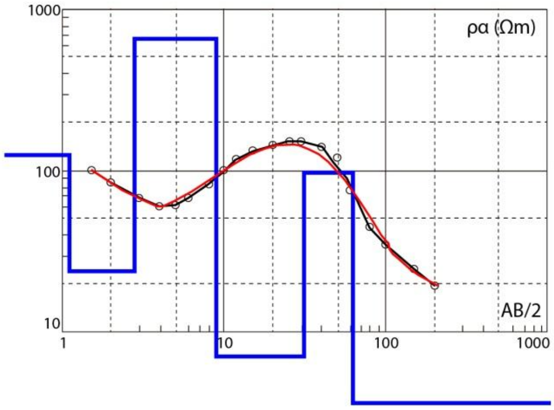
Camada	ρ	h (m)	d (m)	Unidade
1	183	19.5	19.5	3
2	3.73	27.6	47.1	2
3	2030			1

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo ——— curva ajustada RMS 7.32%

ANEXO J - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 10



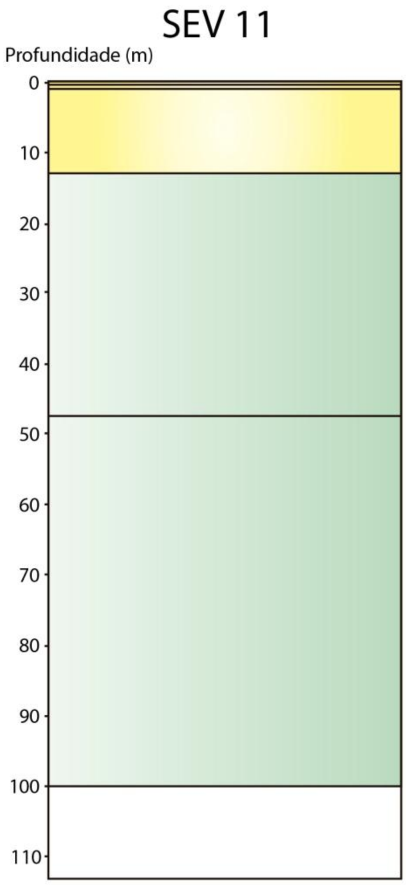


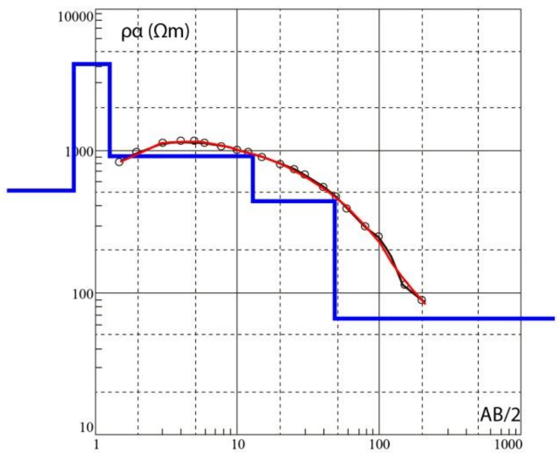
Camada	ρ	h (m)	d (m)	Unidade
1	125	1.12	1.12	
2	24.6	1.63	2.75	3
3	663	6.16	8.91	
4	7.13	21.3	30.2	
5	98.9	32.3	62.5	2
6	0.677			

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 5.45%

ANEXO L - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 11



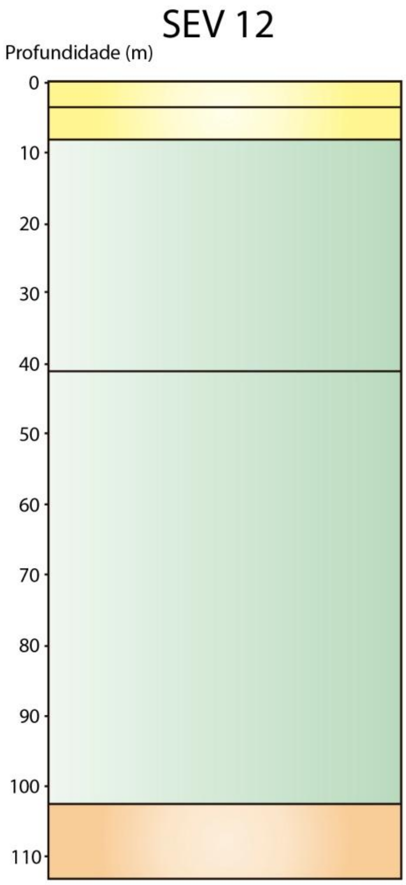


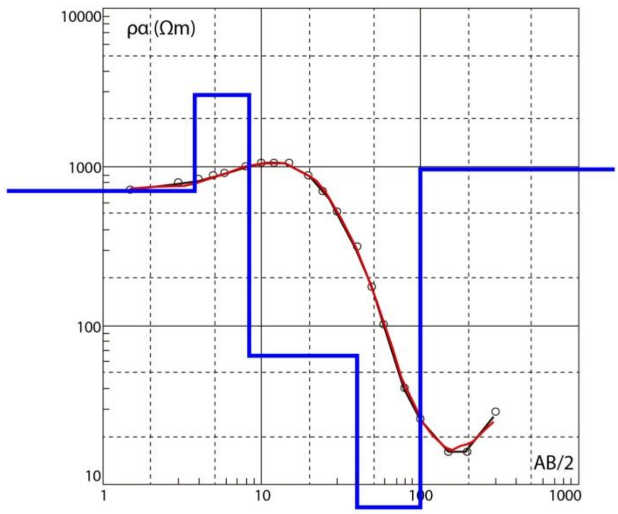
Camada	ρ	h (m)	d (m)	Unidade
1	517	0.709	0.709	3
2	3961	0.531	1.24	
3	898	11.8	13	
4	437	35	48	2
5	65.2			

ρ = resistividade h = espessura d = profundidade da camada

—○— curva de campo ——— curva ajustada RMS 2.91%

ANEXO M - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 12



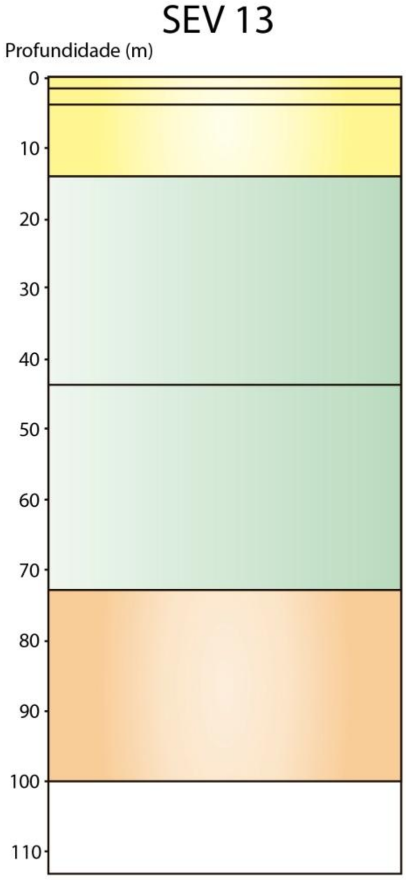


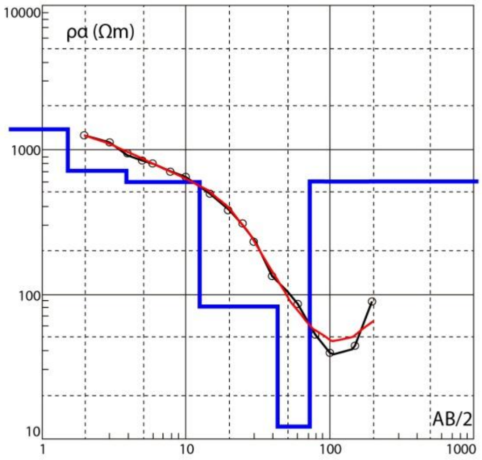
Camada	ρ	h (m)	d (m)	Unidade
1	721	3.67	3.67	3
2	2768	4.75	8.42	
3	63.9	32.7	41.1	2
4	5.67	61.4	103	
5	980			1

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo ——— curva ajustada RMS 3.94%

ANEXO N - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 13





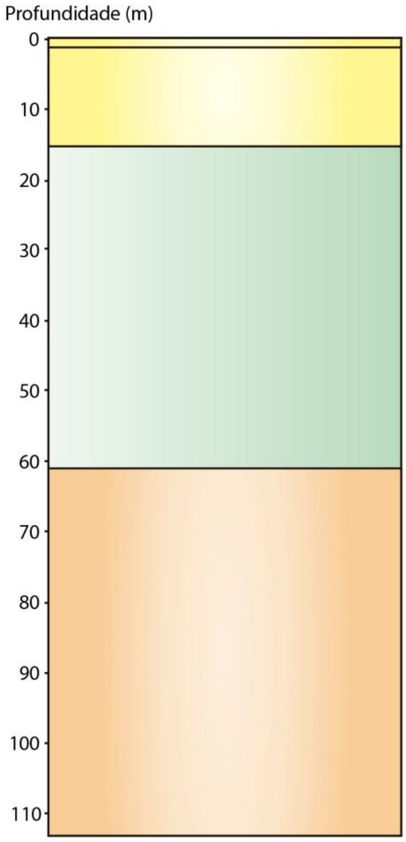
Camada	ρ	h (m)	d (m)	Unidade
1	1383	1.54	1.54	3
2	717	2.35	3.89	
3	600	8.62	12.5	
4	81.8	31	43.5	2
5	12.1	29.4	72.9	
6	597			1

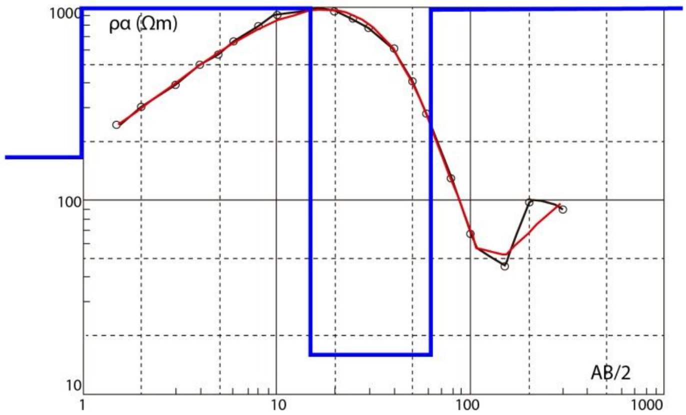
ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo ——— curva ajustada RMS 11.6%

ANEXO O - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 14

SEV 14



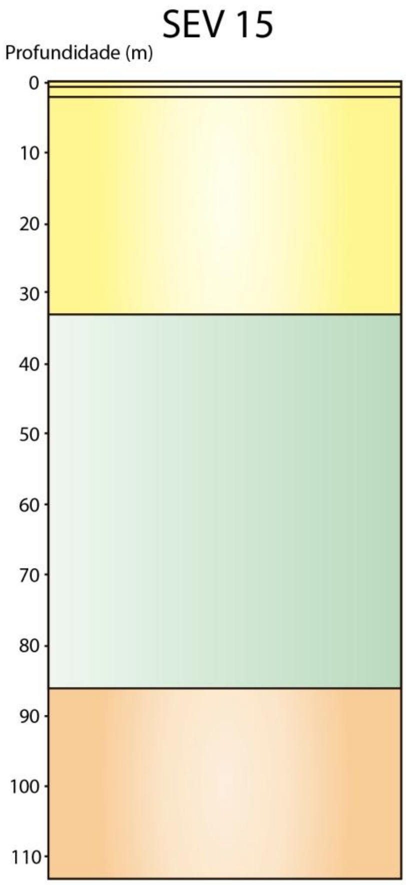


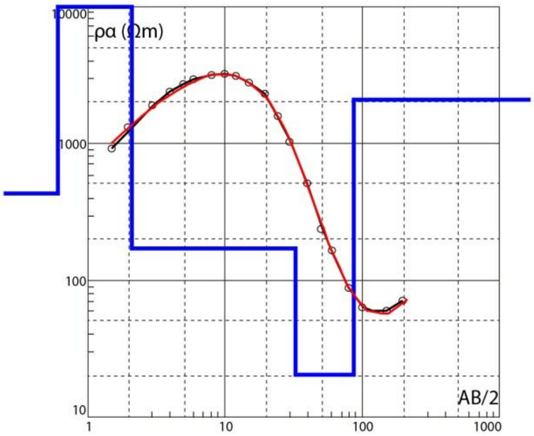
Camada	ρ	h (m)	d (m)	Unidade
1	168	0.964	0.964	3
2	1539	14.2	15.2	
3	16	46.4	61.6	2
4	3684			1

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 10.2%

ANEXO P - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 15



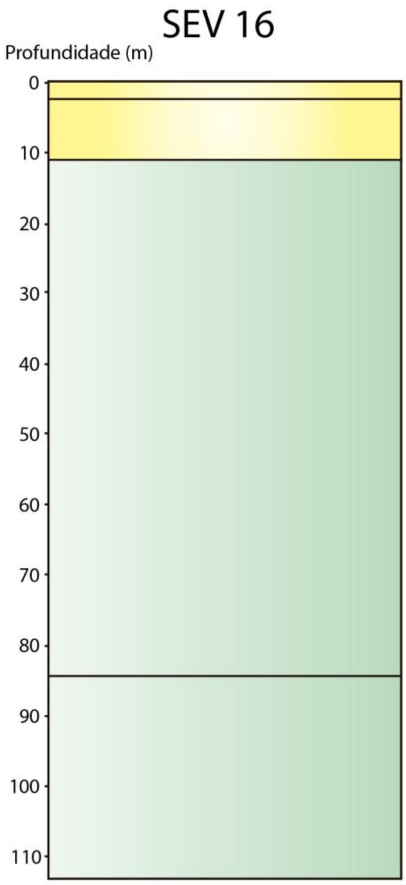


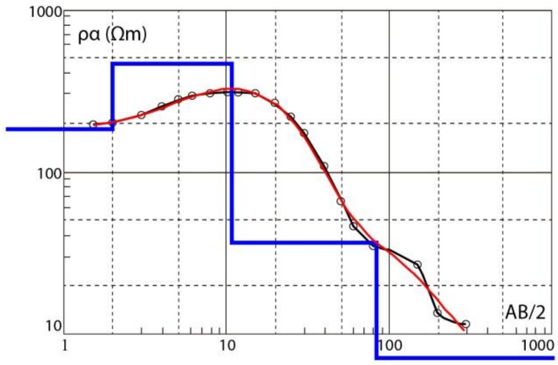
Camada	ρ	h (m)	d (m)	Unidade
1	435	0.614	0.614	3
2	24198	1.46	2.07	
3	172	30.6	32.7	
4	20.6	53.6	86.3	2
5	2085			1

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 3.59%

ANEXO Q - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 16



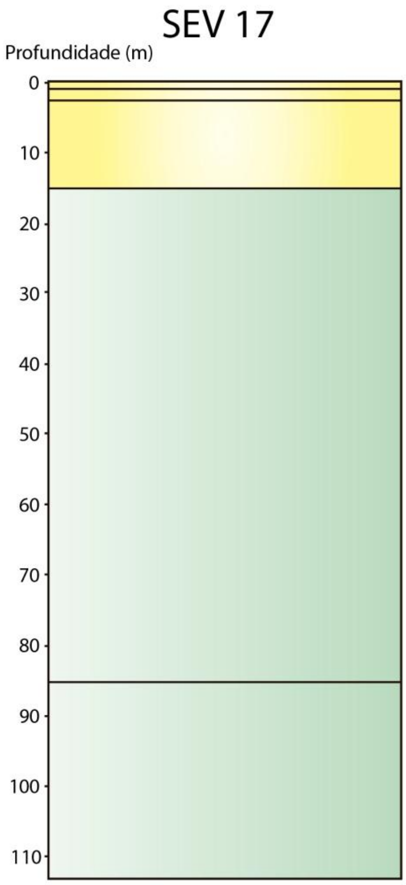


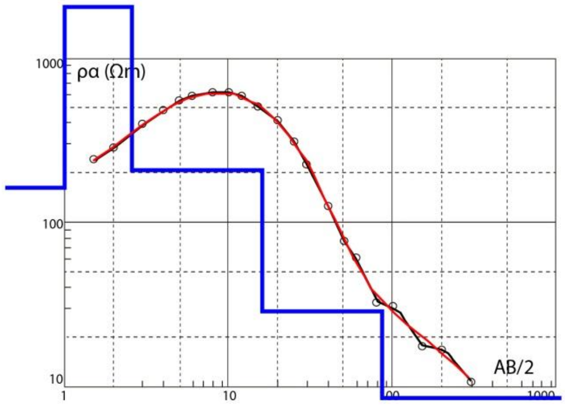
Camada	ρ	h (m)	d (m)	Unidade
1	184	1.98	1.98	3
2	466	8.64	10.6	
3	36.6	73	83.6	
4	7.08			2

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 7.29%

ANEXO R - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 17



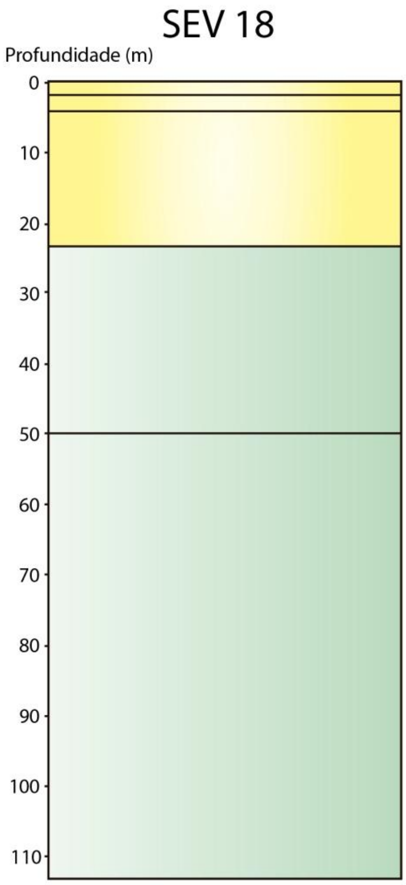


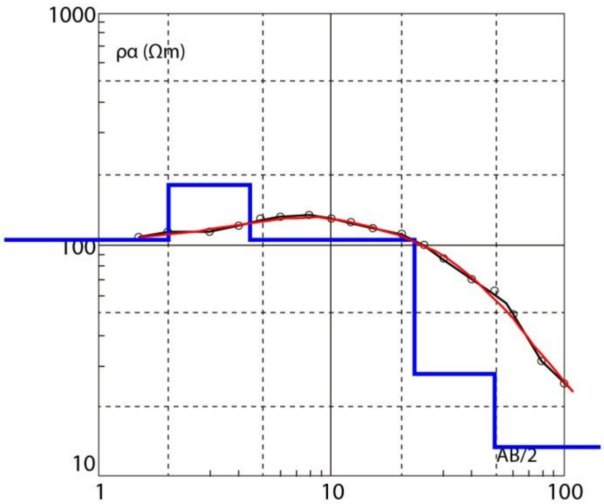
Camada	ρ	h (m)	d (m)	Unidade
1	168	1.01	1.01	3
2	3155	1.54	2.55	
3	206	13.2	15.8	
4	29.1	69.6	85.3	2
5	8.68			

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 4.58%

ANEXO S - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 18



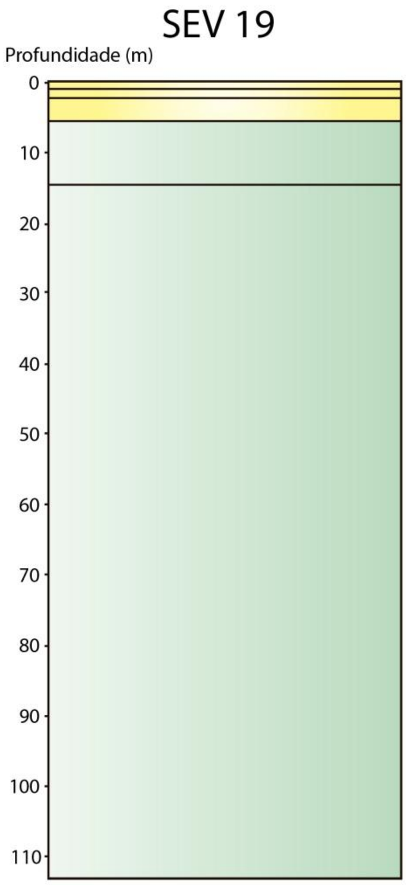


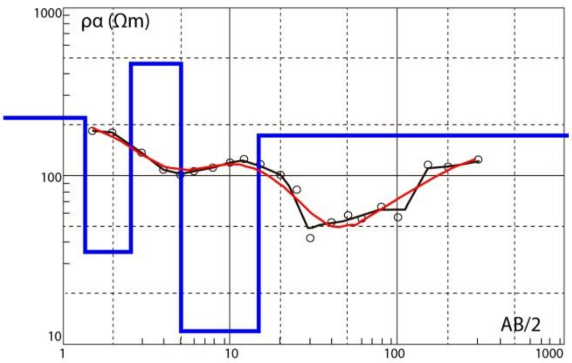
Camada	ρ	h (m)	d (m)	Unidade
1	104	2.01	2.01	3
2	180	2.48	4.49	
3	104	17.9	22.4	
4	27.7	27.6	50	2
5	13.5			

ρ = resistividade   h = espessura   d = profundidade da camada

—o— curva de campo   —— curva ajustada   RMS 2.51%

ANEXO T - MODELO GEOELÉTRICO E INTERPRETAÇÃO DA SEV 19





Camada	ρ	h (m)	d (m)	Unidade
1	221	1.36	1.36	3
2	34.9	1.16	2.52	
3	464	2.6	5.12	
4	11.8	9.78	14.9	2
5	174			

ρ = resistividade h = espessura d = profundidade da camada

—o— curva de campo —— curva ajustada RMS 10.7%

ANEXO U – LOCALIZAÇÃO DAS SONDAGENS ELÉTRICAS VERTICAIS

	Tipo	Município	Nome	Longitude	Latitude
1	SEV Campo I	Osório	SEV1	565597	6688811
2	SEV Campo I	Osório	SEV2	569703	6686834
3	SEV Campo I	Osório	SEV3	571724	6685298
4	SEV Campo I	Tramandaí	SEV4	576980	6682417
5	SEV Campo I	Tramandaí	SEV5	578677	6681114
6	SEV Campo I	Tramandaí	SEV6	582313	6679527
7	SEV Campo I	Imbé	SEV7	583996	6683545
8	SEV Campo I	Imbé	SEV8	585399	6687435
9	SEV Campo I	Tramandaí	SEV9	580480	6675250
10	SEV Campo I	Osório	SEV10	569147	6680059
11	SEV Campo I	Osório	SEV11	564051	6683636
12	SEV Campo II	Osório	SEV12	576502	6689206
13	SEV Campo II	Osório	SEV14	579203	6694100
14	SEV Campo II	Osório	SEV15	581267	6692527
15	SEV Campo II	Osório	SEV16	584036	6695394
16	SEV Campo II	Imbé	SEV17	587556	6692975
17	SEV Campo II	Imbé	SEV18	586647	6690511
18	SEV Campo II	Imbé	SEV19	585889	6688452
19	SEV CORSAN	Tramandaí	SEV13	575846	6682987

ANEXO V – LOCALIZAÇÃO DOS POÇOS

	Tipo	Município	Nome	Longitude	Latitude
1	Poço CORSAN	Tramandaí	COR NTR 01	581370	6676778
2	Poço CORSAN	Tramandaí	COR TRA NTR 02	580370	6678111
3	Poço CORSAN	Tramandaí	COR TRA NTR 03	580160	6677209
4	Poço CORSAN	Tramandaí	COR TRA ETA 01	576323	6683093
5	Poço CORSAN	Tramandaí	COR NTR 04	580181	6675497
6	Poço CORSAN	Tramandaí	COR NTR 05	580192	6675686
7	Poço CORSAN	Tramandaí	COR TRA OAS 01	580441	6675221
8	Poço CORSAN	Tramandaí	COR TRA NTR 06	579410	6675827
9	Poço CORSAN	Osório	COR OSO ATL 02	587941	6695107
10	Poço CORSAN	Osório	COR ATL 03	587283	6694846
11	Poço CORSAN	Osório	COR OSO ATL 03A	587375	6694839
12	Poço CORSAN	Osório	COR OSO 01	571618	6693335
13	Poço CORSAN	Osório	COR OSO 03	565067	6687022
14	Poço CORSAN	Osório	COR OSO ATL 04	572181	6693148
15	Poço CORSAN	Imbé	COR IMB 01	583930	6683632
16	Poço CORSAN	Osório	COR OSO 05	572631	6692325
17	Poço CORSAN	Tramandaí	COR TRA EMB 01	574470	6683939
18	Poço CORSAN	Osório	COR OSO 06	575374	6689580
19	Poço CORSAN	Osório	COR OSO 07	571577	6693560
20	Poço CORSAN	Tramandaí	COR TRA OAS 02	580269	6674273
21	Poço CORSAN	Tramandaí	COR TRA EMB02	576031	6682959
22	Poço CORSAN	Osório	COR OSO 01A	571635	6693336
23	Poço SIAGAS	Osório	4300021746	572687	6692868
24	Poço SIAGAS	Osório	4300021899	571887	6685830
25	Poço SIAGAS	Osório	4300021898	573122	6698275
26	Poço SIAGAS	Osório	4300024094	569962	6692251
27	Poço SIAGAS	Osório	4300021749	568051	6685265
28	Poço SIAGAS	Osório	4300021750	572907	6694036
29	Poço SIAGAS	Osório	4300020530	565115	6687060

ANEXO I

Título da Dissertação/Tese:

GÊNESE E ESTRATIGRAFIA DO AQUÍFERO "SAL GROSSO", LITORAL NORTE DA PLANÍCIE COSTEIRA DO RIO GRANDE DO SUL

Área de Concentração: Geologia Marinha

Autor: **LUÍSA COLLISCHONN**

Orientador: Profa. Dra. Maria Luiza Correa da Camara Rosa

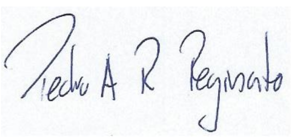
Examinador: Prof. Dr. **Pedro Antonio Roehe Reginato**

Data: 23/07/2021

Conceito: A

PARECER:

O trabalho desenvolvido enfocou o estudo da gênese e estratigrafia de uma camada de sedimentos, que ocorre no litoral norte do estado do Rio Grande do Sul. Para o desenvolvimento desse estudo foram aplicadas diferentes técnicas que permitiram obter resultados importantes e significativos, que atingiram os objetivos propostos, bem como a hipótese levantada pelos autores. Os resultados apresentados tem uma grande relevância científica e também social, pois além de permitirem o aumento do conhecimento sobre a geologia e evolução da planície costeira, trazem contribuições importantes para a hidrogeologia da região, que poderão ser utilizados na perfuração de novos poços, que venham a atender a demanda crescente por recursos hídricos. O trabalho e o artigo estão bem redigidos e estruturados. A metodologia está descrita e explicada, mas alguns pontos poderiam ser mais explorados e aprofundados. A apresentação dos resultados está muito boa e as discussões foram bem desenvolvidas. No entanto, alguns pontos que foram discutidos no artigo poderiam se também mais aprofundados ou detalhados. O modelo evolutivo é interessante, embasado nos resultados obtidos e explica a evolução e formação da camada de sedimentos que está sendo estudada. Assim, considero a dissertação apresentada como excelente.

Assinatura:  Data: 23/07/2021

Ciente do Orientador:

Ciente do Aluno:

ANEXO I

Título da Dissertação/Tese:

GÊNESE E ESTRATIGRAFIA DO AQUÍFERO "SAL GROSSO", LITORAL NORTE DA PLANÍCIE COSTEIRA DO RIO GRANDE DO SUL

Área de Concentração: Geologia Marinha

Autor: **LUÍSA COLLISCHONN**

Orientador: Profa. Dra. Maria Luiza Correa da Camara Rosa

Examinador: Profa. Dra. **Carolina Danielski Aquino**

Data: 17/07/2021

Conceito: BOM

PARECER:

A dissertação da Luísa está muito boa, no entanto tem alguns pontos que poderiam ser detalhados e discutidos melhor, principalmente na parte dos resultados e discussões.
A minha contribuição para a dissertação está indicada no documento encaminhado via e-mail.

Assinatura: Data: 17/07/2021

Ciente do Orientador:

Ciente do Aluno:

ANEXO I
Título da Dissertação/Tese:
“GÊNESE E ESTRATIGRAFIA DO AQUÍFERO "SAL GROSSO", LITORAL NORTE DA PLANÍCIE COSTEIRA DO RIO GRANDE DO SUL”
Área de Concentração: Geologia Costeira
Autor: **LUÍSA COLLISCHONN**
Orientador: Profa. Dra. Maria Luiza Correa da Camara Rosa
Examinador: Profa. Dra. Manoela Bettarel Bállico
Data: 08/08/2021
Conceito: A
PARECER:
A dissertação da aluna Luíza versa sobre aquíferos costeiros, um assunto extremamente importante e pouco explorado. Aquíferos costeiros são muito sensíveis, principalmente com relação à contaminação dos mesmos, dessa forma estudos que detalham esses sistemas são relevantes e muito necessários. O presente trabalho adota os conceitos da estratigrafia de sequências para a caracterização de aquíferos costeiros, aliado com outras duas técnicas. A dissertação está bem estruturada; com objetivos claros e bem definidos. Os resultados foram bem apresentados, o que não gerou dúvidas com relação à estratigrafia proposta. A discussão está bem estruturada, o modelo deposicional simplificado ficou excelente, e fica claro a evolução dos sistemas deposicionais. O presente trabalho foi submetido em uma revista internacional (A2), o que é excelente, e pela qualidade dos dados apresentados tem grande chance de ser publicado. Parabenizo a autora e sua orientadora pela proposta de estudo, pois o trabalho é extremamente relevante para a sociedade. Obs. As observações e dúvidas foram grifadas no PDF. Esse documento será encaminhado para a aluna.
Assinatura: Data: 08/08/2021
Ciente do Orientador: Ciente do Aluno: