Groundwater Resources of Península Valdés

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Abstract In this chapter, the groundwater resources of Península Valdés are analyzed in order to recognize the influence of the late Cenozoic stratigraphic record and the geomorphology on the hydrogeology of the region. The geology of the study area defines a hydrogeological sequence that begins with a non-saturated zone of variable thickness and an essentially aquifer-like behaviour. Under the non-saturated zone there is a phreatic aquifer within the Quaternary deposits or in the sandstones of the Puerto Madryn Formation, and below it, one or more semi-confined or confined aquifers in the same formation or in the underlying Gaiman Formation. The aquifer levels located in the Puerto Madryn Formation are main water supply that supports the farming activities in the region. The groundwater hydrodynamic and the associated hydrochemical and isotopic characteristics are closely related to the climate and to the relationship between the geomorphology and lithology of the region. As climate is quite homogeneous all over the peninsula, the different relationships between the geomorphological and lithological unit allows to define four hydrogeological regions: (1) Aeolian landforms, which represents the main recharge zone with the low salinity waters; (2) Terrace levels, as the circulation area with high salinity waters, (3) Endorheic depressions that are the inland discharge sector where the evaporation is the dominant process and hypersaline playa lakes occurs, and (4) Coastal systems which represents both the regional discharge area as well as the local recharge zone with low salinity groundwater reservoirs.

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1 Introduction

One of the main natural limitations to the social and economic development of arid and semi-arid regions is their limited water availability. In Península Valdés the lack of permanent watercourses has caused groundwater resources to become the basis of all economic activities. In this area the water demand was historically associated to the extensive sheep farming practices (all throughout the peninsula), and to tourism, which is centralized in Puerto Pirámides.

As is known, geomorphology, geology and climate are first-order determinants of hydrogeological phenomena, not just hydrodynamic, but also hydrochemical ones. In the case of Península Valdés, the rains do not show a strong spatial variability (see Chapter "Miocene Marine Transgressions: Paleoenvironments and Paleobiodiversity"). Thus climate could conditioning the groundwater resources at regional level, but do not answer the groundwater spatial variations that exists in the region. The opposite is the case of the geomorphology and lithology—which have important variations in the regions (see Chapters "Geology of Península Valdés" and "Late Cenozoic Landforms and Landscape Evolution of Península Valdés")—that have being correlated with the regional hydrogeology and hydrochemistry (Alvarez et al. 2010). According to that, in this chapter, the late Cenozoic stratigraphic record and the geomorphological units are analyzed in order to recognize their influence over the groundwater resources.

2 Hydrogeological Units

The first step for the groundwater resources evaluation is the analysis of the hydrogeological units. The geological units depending on their capacity to receive, store and transmit water, are classified into *aquifers*, *aquitard*, *aquicludes* and *aquifuges.* In the case of the aquifers, according to the *hydraulic conductivity*, they can also be subclassified as high, low or moderate permeability aquifers.

In the case of Península Valdés, the stratigraphic units described in Chapter "Late Cenozoic Landforms and Landscape Evolution of Península Valdés" are classified in four hydrolithological groups, (1) High permeability aquifers, (2) Moderate to low permeability aquifers, (3) Aquitards and (4) Aquicludes (Fig. 1).

Before starting with the characterization of each hydrogeological unit it should be state out that, only aquifers in porous media have been described in the study area (Windhausen 1921; Stampone and Cambra 1983; Alvarez et al. 2010).

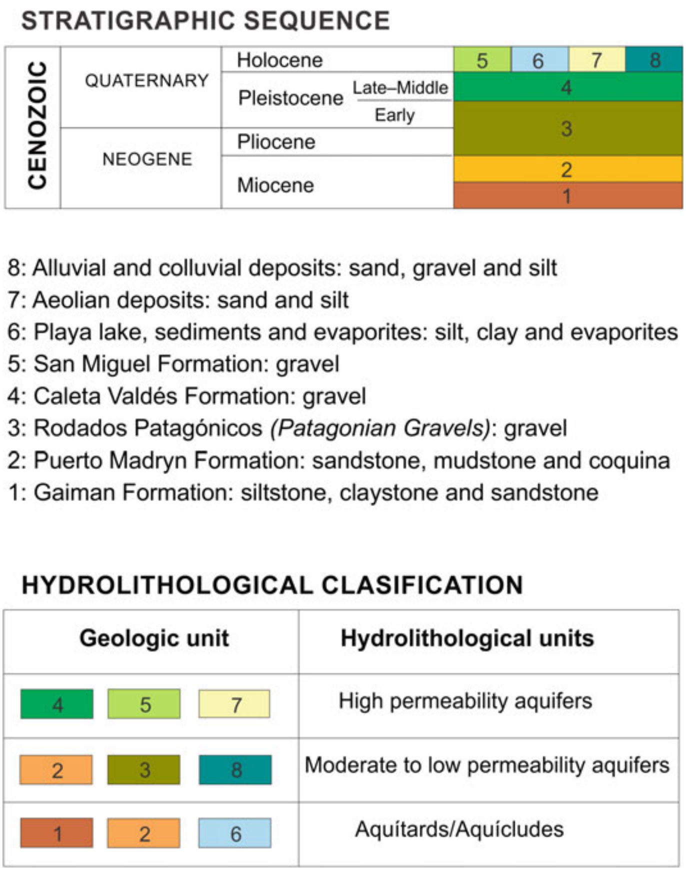

Fig. 1 Stratigrahic units and their hydrolithological classification

2.1 *High Permeability Aquifers*

Within this category are included the Quaternary aeolian deposits and the San Miguel Formation.

Aeolian deposits (Active dunefields and Stabilized aeolian field geomorphologic units; see Chapter "Late Cenozoic Landforms and Landscape Evolution of Península Valdés") cover about 700 km^2, representing 40% of the Península Valdés region. This combined with their lithology (well-selected and nonconsolidated sands with a predominantly medium to fine grain size) makes them the most important hydrological unit regarding the possibilities of effective infiltration. In this unit, indicating the behaviour as a preferential recharge zone, interdune wetlands with permanent vegetation were identified (Fig. 2). Unfortunately, the aeolian deposits occupy only the thin upper layer of the stratigraphic sequence, and their reduced and variable thickness is a limiting factor when considering their potential as productive aquifers.

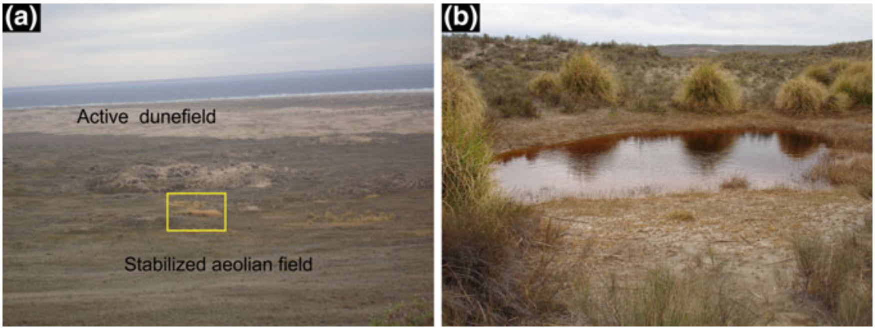

Fig. 2 **a** Regional view of the wetlands in aeolian landforms (stabilized aeolian field and active dunefields) located at the southern sector of Península Valdés; **b** Wetland in the stabilized Aeolian field. The regional location corresponds to the *yellow box* of (**a**). The water body of the photo has an approximately diameter of 5 m

Among the aeolian quaternary sediments, coastal dunes are also found. Although they are scarce and its dimensions are insignificant within the regional frame (see Chapter "Late Cenozoic Landforms and Landscape Evolution of Península Valdés"), they are locally important as reservoirs of shallow water (2–3 m deep) with a relatively good quality in an environment dominated by brackish water.

The San Miguel Formation deposits constitute a small unit (not reaching to cover 1% of the total area of the study region) of local distribution, restricted to the NE coast of the Península Valdés. It is composed by coarse and very coarse gravel with a small sandy matrix and shells. These features certainly allow to classify it as a high permeability aquifer. The water table depth measured in this unit was always less than 6 m.

2.2 *Medium to Low Permeability Aquifers*

Under this classification the undifferentiated alluvium and colluvium deposits, the Rodados Patagónicos and the Puerto Madryn Formation are grouped.

The undifferentiated alluvium and colluvium deposits cover a thin sheet of the *bajadas* (in both the Great Endorehic Basin and the Coastal Zone systems; see Chapter "Late Cenozoic Landforms and Landscape Evolution of Península Valdés") occupying an area that represents approximately 12% of the total surface of the Península Valdés region. This unit has heterogeneous particle size distribution, consisting of gravel, sand and silt. Thus, effective porosity variations are expected to be reflected in the *bajadas* hydrogeological unit. Considering that unsaturated levels that would serve to estimate their permeability were not found, it was decided under a conservative criterion, to include the described deposits in this group.

The Rodados Patagónicos deal a relatively large area, reaching up to 35% of the sector but not exceeding 3 m in thickness. The grain size particle is mainly composed by pebbles (<1.5 cm diameter) with a sandy matrix. The fabric varies from *clast-supported* to *matrix-supported* and this grain size anisotropy (vertical and horizontal) also occurs with the cementation generating some uncertainty about the effective porosity and the potential water-bearing that this formation may have. Since it has not been possible to locate a saturated level that allows attributing a certain permeability value, and because it has been verified in many cases a significant percentage of matrix with a high calcitic cementation degree (calcic soil horizons, see Chapter "Soil–Geomorphology Relationships and Pedogenic Processes in Península Valdés"), it was decided to include this unit into the medium/low permeability aquifers.

Regarding the Puerto Madryn Formation, although the outcropping expression is not relevant because it does not reach 4% of the total area, it has an important development in depth and constitutes the main aquifer unit of the area mostly used for farming activities. It is composed by sandstones, mudstones and coquines, where the variations in the fine fraction percentages are reflected in the *hydraulic conductivity* (K) changes. The K coefficient obtained by pumping tests for the productive aquifer levels were 4.9×10^{-1} and 4.08×10^{-2} m/day for the first level and 2.75 m/day for the deepest ones (Alvarez et al. 2012, 2014).

2.3 Aquitards

Within this category are included both fine sediments of the Puerto Madryn Formation, as well as those of the Gaiman Formation. The first lithoestratigraphic unit includes mudstone layers of variable thicknesses that are interbedded with sandstones strata of more than one meter thick. These sections of the profile are interpreted as aquitards. In the case of the Gaiman Formation, which consists mainly of fine material, it is expected that their physical characteristics are much more homogeneous, and except for the limited sandy levels, the hole unit is consider as an aquitard unit. According to well-drilling reports and stratigraphic sections (see Chapter "Miocene Marine Transgressions: Paleoenvironments and Paleobiodiversity"), the aquitards of the Puerto Madryn and Gaiman formations allowed the existence of more than one aquifer level in each lithoestratigraphic unit (Alvarez et al. 2014).

2.4 Aquicludes

The main aquiclude units are composed by the Quaternary playa lake deposits of the Great Endorrehic Basins system and the more clayey levels of the Gaiman Formation. It is important to note that the hydrological behaviour of the Gaiman Formation in Penísnula Valdés was previously described in groundwater well-drilling reports (Windhausen 1921; Alvarez 2010; Alvarez et al. 2014).

3 Hydrodynamics

The regional hydrodynamic characterization of the Península Valdés region was defined by Alvarez et al. (2010) on the basis of the survey of 89 wells. In this study, the main groundwater watersheds as well as the recharge and discharge areas were identified.

Based on the stratigraphic sequence of the study area (Fig. 1), the local hydrogeological system is formed by: (a) a *non-saturated zone* (NSZ) corresponding to the Quaternary deposits and partly to the Miocene sediments; (b) a *phreatic aquifer* that is contained, depending on its spatial position, within these same deposits or in the sandstones of the Puerto Madryn Formation, and which is mainly exploited in the region; (c) one or more *semi-confined* or *confined aquifers*, limited by clayey or silty-clay strata in the same Puerto Madryn Formation or in the underlying Gaiman Formation. The information available on these deeper aquifers is scarce because they are of no qualitative interest for exploitation.

The description of the hydrodynamic cycle begins with the characterisation of the recharge phenomenon, then it focuses on the circulation, ending with the discharge.

3.1 Groundwater Recharge

Despite the fact that recharge is the most important process in the groundwater cycle, it is the one that causes more difficulties when trying to quantify it, especially in arid regions where the necessary data to assess it is usually insufficient (Scanlon et al. 2010; Timms et al. 2012; de Vries and Simmers 2002).

The geographic location of the Península Valdés area rule out the possibility of infiltration from streams and/or outside recharge for the quaternary and Miocene aquifers. Having discarded the possibility of imported water, the only alternative to explain the presence of groundwater in the study area is water of meteoric origin.

A predominantly groundwater radial divergent morphology, observed at the central–southern sector, coinciding with a groundwater watershed (Fig. 3), indicates a preferential recharge area. This corresponds to the aeolian landform unit (Active dunefields and Stabilized aeolian field geomorphologic units).

Considering the average excesses from the groundwater balance (32 mm/a; Alvarez et al. 2013), the groundwater recharge over the sand dunes area (710 km^2) corresponds to 22.7 hm^3/a. This amount represents near 14.5% of the historic average annual precipitation and it is worth mentioning that for other Patagonian regions similar recharge values have been observed (Paruello and Sala 1995). Nevertheless, the annual recharge could notably vary because the main water excesses occur during storm events (Alvarez et al. 2012, 2013; Simmers 1997; Tweed et al. 2011).

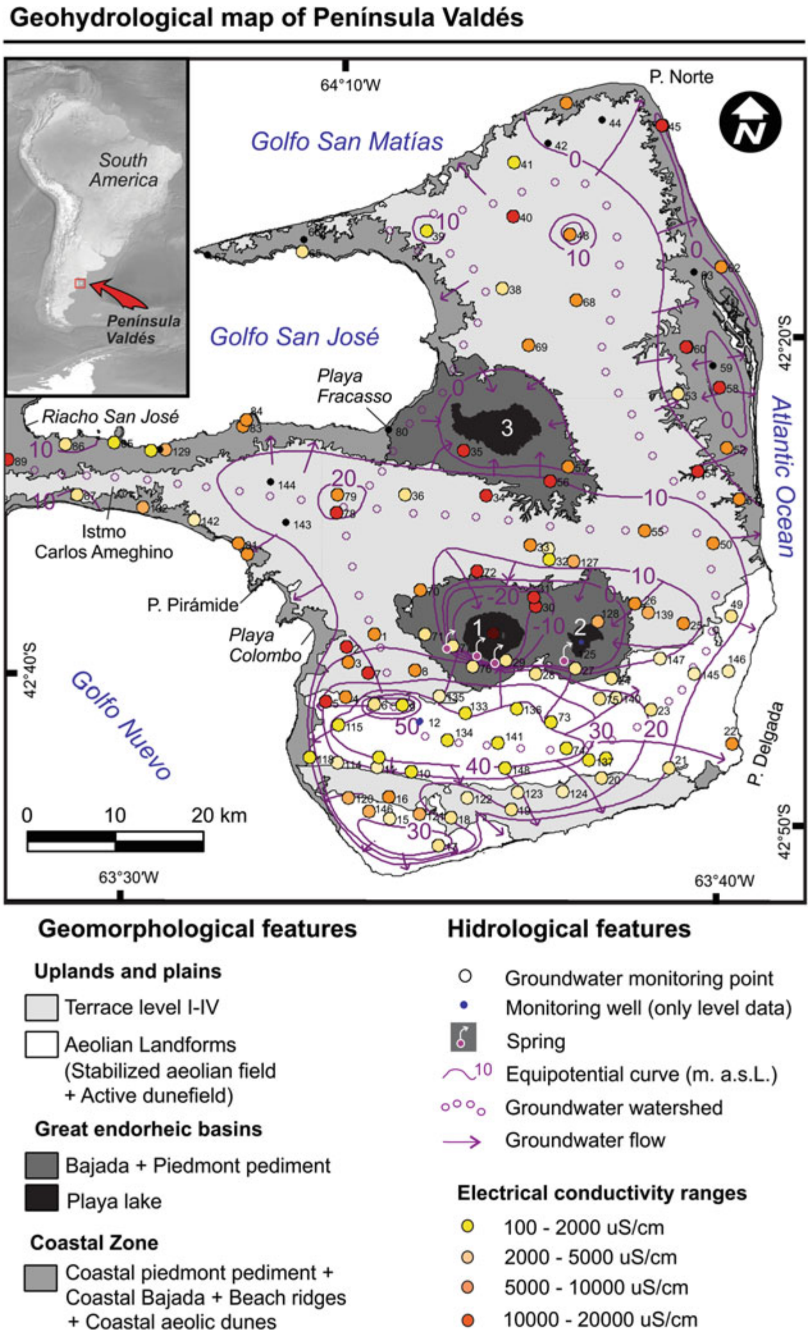

Fig. 3 Groundwater flow map with the associated geomorphological units and the groundwater conductivity values. *1* Salina Grande; *2* Salina Chica; *3* Gran Salitral

3.2 Groundwater Flow

According to Alvarez et al. (2010) two main groundwater watersheds are observed. One runs parallel to the coast of the peninsula and separates the regional discharge towards the sea from the local discharge towards the endorheic depressions (Fig. 3). The other watershed divides the area into a northern and a southern sector, at the latitude of the Istmo Carlos Ameghino (Fig. 3).

In the southern sector water flows from the aeolian landform towards the Golfo Nuevo and the Atlantic Ocean, and towards the Salina Grande and Salina Chica. In the northern sector of the Península Valdés water flows from the terrace levels towards the Gran Salitral, the Golfo San José and the Atlantic Ocean. It is important to highlight that terrace levels (i.e. geomorphic units that includes the Rodados Patagónicos) are one of the geomorphological units that better represents circulation in the hydrodynamic cycle.

3.3 Groundwater Discharge

The regional discharge, interpreted from the equipotential map and evidenced by wet spots and vegetation changes founded over the coastal cliffs, runs towards the Golfo San José, Golfo Nuevo, and the Atlantic Ocean (Fig. 4). At the coastal zone some marshes are found like Playa Colombo, Caleta Valdes, Riacho San José and Playa Fracasso (Fig. 3). In these marshes the groundwater flow have a marine component, but also a continental component. The last is represented by the regional discharge from the peninsula and/or the local discharge from the coastal dunes and ridges (Alvarez et al. 2014; Fig. 3). The discharges have also a significant local components represented by the internal drainage system of the Salina Grande, Salina Chica and Gran Salitral great enhoreic basins (Fig. 3). The wetlands and springs, such as the one originally used to supply the town of Puerto Pirámides, evidence this local discharge and are mainly located at the southern margin of Salina Grande and Salina Chica (Stampone and Cambra 1983; Alvarez et al. 2008, 2013; Fig. 3). The equipotential line that encloses both playa lakes is very noticeable on the map, and its central sector reaches −40 m a.s.l. (Fig. 3).

4 Hydrgeochemistry

4.1 Groundwater Salinity and Major Ionic Composition

As regards, the hydrochemistry of groundwater, the electric conductivity (EC) values—directly related to salt contents—reflects two clearly identifiable zones: a freshwater zone (low salinity) and another one with brackish to saline characteristics.

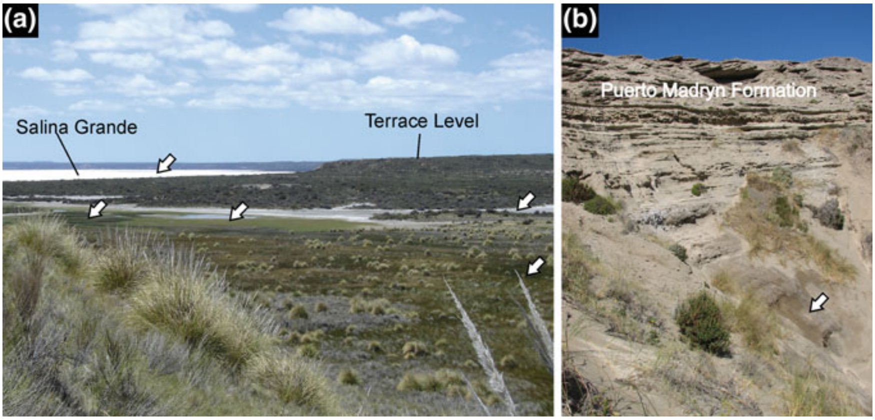

Fig. 4 **a** Wetlands at the southern margin of the Salina Grande; **b** Wet sectors in the coastal cliffs of the Golfo Nuevo near to Puerto Piramides locality. *White arrows* mark groundwater discharge areas

The low salinity zone—develops in the southern sector—matches with aeolian landform units and the radial divergent morphology of the water table, defined as the main recharge area. The electric conductivity values between 100 and 2000 μS/cm are located in the area with equipotential curves between 50 and 40 m a.s.l. and towards the limit of the aeolian landform units the values reaches 5000 μS/cm (Fig. 3). The high salinity zone, with electric conductivity values above 5000 μS/cm, occurs in the northern and western sectors, coinciding with the circulation and discharge areas (Alvarez et al. 2008; Fig. 3). At the Terrace levels most of the values are in the range 5000–10,000 μS/cm, and surface and subsurface waters in playa lakes have values above 30,000 μS/cm (Fig. 3).

Regarding the ionic composition of the water, the predominant major ion water type is sodium chloride, with sodium bicarbonate type water occurring only in the low salinity zone (Alvarez et al. 2010). In order to clarify the illustration of the different geomorphological units in the *Piper plot*, a selection of representative water samples were done. The ionic classification of the springs samples were included as well (Fig. 5).

The aeolian landform units presents sodium chloride–bicarbonate and sodium bicarbonate–chloride water types, with only one sample showing the presence of the calcium/sodium chloride–bicarbonate facies.

In the case of the Great Endorheic Basin system, the groundwater chemistry is mainly a sodium chloride water type, with localized occurrences of sodium chloride–sulphate water facies. The prevalence of chlorides marks the evolution of water and corroborates the discharge properties of the unit.

Despite the fact that geomorphologically the spring samples belong to the Great Endorheic basin system in the piper plot they are classified as sodium chloride–sulphate water type, with a larger proportion of bicarbonate and a smaller proportion of total salts than the water from the geomorphological unit containing them.

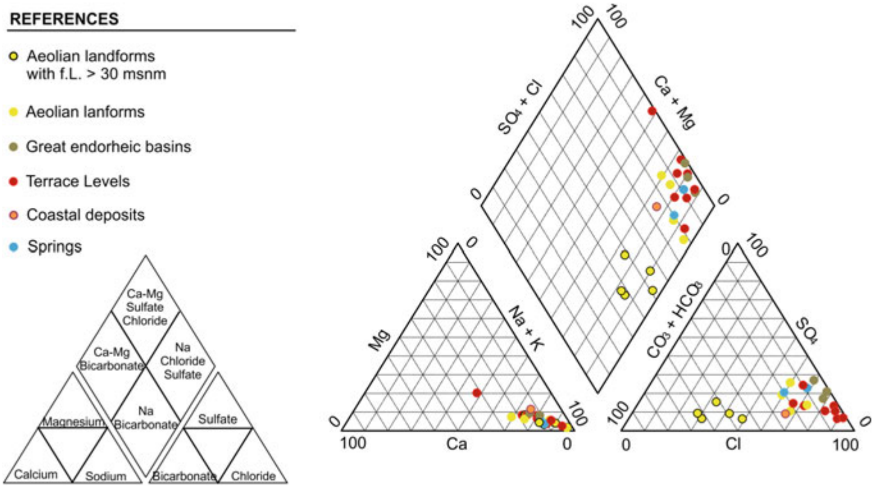

Fig. 5 Piper plot showing the major ionic composition of water samples on each geomorphological unit

The ionic composition of the groundwater from the Puerto Madryn Formation below the Terrace Levels unit does not seem to correspond to the circulation phenomenon essentially. In a normal evolution of the groundwater composition, the water type varies from bicarbonate at the recharge zone to sulphate in the circulation area and finally to chloride type at the discharge zone. In the case of Península Valdés, the circulation zone is characterized by sodium chloride–sulphate water type, quite similar to those waters observed in endorheic depressions. This is possibly due to the fact that there are smaller basins within the plain, as well as the low flow velocity of the groundwater.

In the Coastal Zone system the deposits of the geomorphic units composed of sandy material (i.e. coastal dunes) varies from sodium chloride–bicarbonate water type to sodium chloride–sulphate water type. On the other hand the geomorphic units constituted by gravel material (i.e. beach ridges) have sodium chloride–sulphate water type (Fig. 5).

4.2 Groundwater Isotopic Composition

The isotope hydrology was used as a complementary tool to analyze the source of the groundwater contained in the different landforms. Selected points of the different geomorphological units as well as the subsurface water samples of the Salina Grande and Salina Chica were analyzed (Fig. 6). In this analysis, seawater, individual rains, and the 1999–2000 weighted average precipitation of the Puerto Madryn collected station were included (Fig. 6).

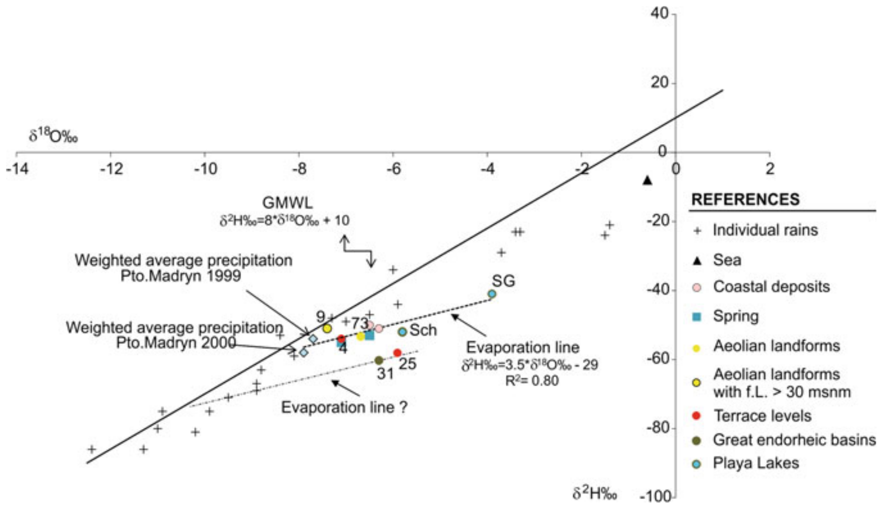

Fig. 6 δ^2H versus δ^{18}O diagram with representative water samples of the region. Samples include geomorphological units, springs, seawater and rainwater from Puerto Madryn station (belonging to the National Network of Argentina and Global Network for Isotope in Precipitation; IAEA/WMO 2002; Dapeña and Panarello 2008). Salina Grande: SG and Salina Chica: Sch

The isotopic composition of all, most all the analyzed groundwater samples shows an alignment from a near-average rainwater origin towards the Salina Grande (SG) composition (Fig. 6). This alignment would indicate evaporation processes occurred during infiltration through the unsaturated zone, or in surface previously to its infiltration. The extreme evaporation takes place in the playa lakes as it is evidenced by the isotopic composition of the Salina Grande (Fig. 6).

Regarding the aeolian landforms (with phreatic levels at 30 m a.s.l.), their position on the δ^2H versus δ^{18}O diagram, near to the global meteoric water line, indicates an origin of direct recharge from rainwater without evaporation or mix with other waters.

Another situation that could occur is the evaporation process from rainwater of different composition as could be interpreted for the samples number 25 and 31 (Fig. 6). The possibility of water mixing with deepest groundwater levels with different isotopic composition is not ruled out but cannot be verified.

5 Geohidrological Regions

The integration of geomorphological, lithological and hydrogeological studies of the Península Valdés allows to define four geohydrological regions (Fig. 7): Two in the Uplands and plains system (aeolian landforms and terrace levels) one in the Great endorheic basin system and one in the Coastal zone system (Fig. 7;

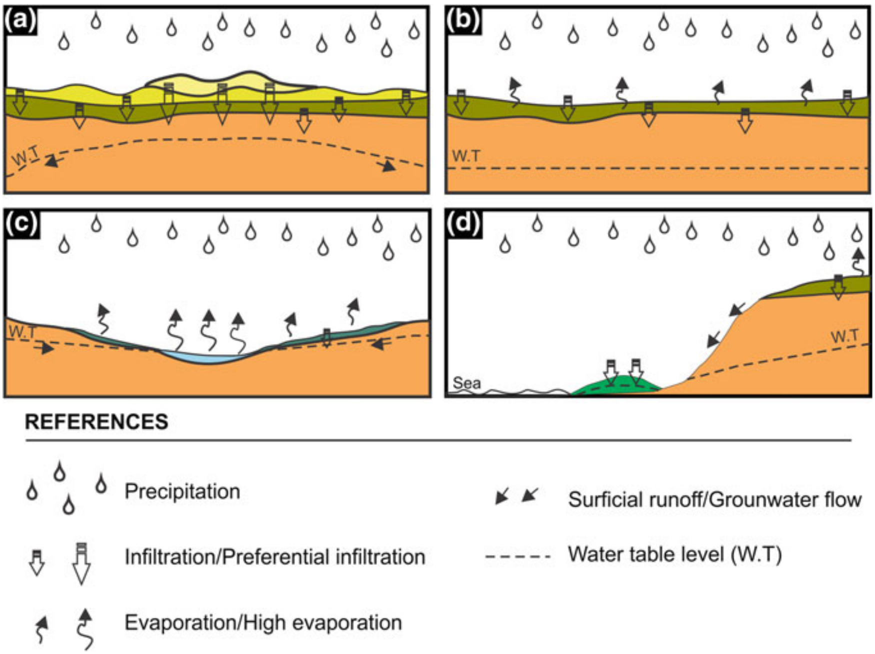

Fig. 7 Geohydrological regions. **a** Aeolian landforms; **b** Terrace Levels; **c** Great Endorheic Basin; **d** Coastal Zone. The references of the geological units are according to that showed in Fig. 1

see Chapter "Late Cenozoic Landforms and Landscape Evolution of Península Valdés"). Based on the groundwater hydrodynamics (recharge, flow and discharge), the hydrochemical composition and the isotopic characteristics of the groundwater of each geomorphologic system, a conceptual model is defined in order to explain the functioning of the hydrogeological system.

5.1 *Aeolian Landforms*

As it was said before, aeolian landforms (i.e. stabilized aeolian field + Active dunefield of the Uplands and plains system) constitutes the main recharge area (Figs. 3 and 7a). A hypothetical cross section of this region starts with a high primary permeability unit, constituted by a stabilized aeolian field and active dunefileds deposits that overlies the Rodados Patagónicos and/or the Puerto Madryn Formation. The recharge takes place in this area due to the already mentioned soil moisture excess, but it is favoured by the fast infiltration process. A special mechanism that is a determining factor of the recharge process in arid regions (Hernández et al. 2002; Hernández 2005).

The fast infiltration is an effective recharge mechanism for arid environments as the evapotranspiration is minimized. It is favoured by the superficial grain size sediments (as the present aeolian sands) and the low retention capacity of the soils like the one present in this unit (Alvarez et al. 2013). The lack of vegetation over the active aeolian landforms gives an extra chance to the fast infiltration mechanism. Likewise the vegetation adaptation to arid climate leads to the plant to survive with less water favouring the soil moisture excesses, and thus the leaching.

According to the groundwater hydrochemistry, the aeolian landforms region is typified by low salinity waters where the bicarbonate anion is more abundant. This ionic type, added to the hydrodynamic characteristics of the area, indicates that the infiltration of rainwater is the hydrological process that prevails over this region (Fig. 5).

5.2 Terrace Levels

Terrace Levels—all of them in the Uplands and plains system and composed by the deposits of the Rodados Patagonicos unit—represents the most extensive circulation areas, including local recharge–discharge zones. The condition of low recharge and poor groundwater circulation (as could be interpreted from the hydrodynamic map, Fig. 3) gives to this unit a general poor groundwater quality. Groundwater of this unit is mainly salty with local freshwater sites (1200–9500 μS/cm) and mainly a sodium chloride–sulphate water type. Additionally, an increase of the saline content could be due to an evaporation effect (interpreted from the enrichment in the isotopic composition; Fig. 6). The rainwater that occasionally infiltrate over this unit could suffer an evaporation process previously to reach the aquifer (Fig. 7b). This is a common process in arid climate regions, where the superficial sediments have low permeability (Ahmed et al. 2013). Another mechanism that increases the groundwater saline content is the evaporite precipitation by complete evaporation of rainwater over less permeable sediments and then dissolution by rainwater and leaching towards the aquifer (Fitzpatrick et al. 2000; Tweed et al. 2011). As the soils that characterized the terrace levels are the Natrargids (soils with alluvial clay accumulation and high exchangeable sodium percentage; see Chapter "Soil–Geomorphology Relationships and Pedogenic Processes in Península Valdés"), the presence of salt precipitation in the unsaturated zone is very common and the described processes is highly probable. The flat topography with little to medium endorheic basins, combined with the hydrolithological configuration (low permeability sediments overlaying the Miocene sediments), favours the mentioned processes as it makes the rainwater remains on the surface and evaporate before its infiltration (Fig. 7b).

5.3 Great Endorheic Basin System

The great endorheic basin system (Fig. 7c) represents the most relevant inland discharge areas (i.e. Salina Grande, Salina Chica and Gran Salitral salt pans) showing a typical radial phreatic morphology with a tendency towards a convergent cylindrical pattern and high hydric gradients. Discharge is also evidenced by the presence of stratigraphic springs at the hillslope of the great endorheic basins (Fig. 4a), where groundwater emerges and runs towards the playa lakes (Alvarez et al. 2008). Playa lakes are areas where all the groundwater from the discharge evaporates creating salt deposits (Brodtkorb 1999) and saline to hypersaline water. This evaporation process that takes place over the playa lakes is corroborated by the enrichment in the isotopic composition of both δ^2H and δ^{18}O (Fig. 6).

Furthermore, on the hillslopes of the endorehic depressions, salt dissolution–precipitation occurs, since the presence of Natrargids (see Chapter "Soil–Geomorphology Relationships and Pedogenic Processes in Península Valdés") facilitates this process, as in terrace levels.

In the case of the springs that flow on the southern margin of the endorheic depressions (Salina Grande and Salina Chica) they are less evolved and their conductivities are of the order of 3000–4000 μS/cm, due to their proximity to the main recharge located in the sand dune area.

5.4 *Coastal Zone Region*

The sand and gravel deposits at the Coastal zone conforms a local recharge area, whose morphology is that of a divergent radial flow and it is independent from the regional hydrogeomorphological behaviour (Fig. 7d). Its waters are chloride–bicarbonate to chloride types having the sand dunes lower salinity content than the coastal ridges. The recharge mechanism that operates is the same described for the aeolian landforms, but the extra saline content could be due to the proximity to the sea and the marine aerosols that increase the saline content of the rain water (Appelo and Postma 2005; Salama et al. 1999). The presence of these local recharge areas are due to the hidrolithological configuration, characterized by superficial high permeable deposits overlaying less permeable sediments. This allows to the fast infiltration of rainwater and then accumulation over the less permeable unit conforming a shallow aquifer. This unit, in which the groundwater has a relatively good quality and where the water table is at a shallow position, it is of particular interest to understand the hunter-gatherer populations that occupied the Península Valdés more than 5000 years ago (see Chapter "Archaeology of the Península Valdés: Spatial and Temporal Variability in the Human Use of the Landscape and Geological Resources").

6 Perspective and Future Works

The groundwater resources of Península Valdés are closely related to the climate and to the relationship between the geomorphology and lithology of the region. As climate is quite homogeneous all over the peninsula, this control mainly conditioned the recharge phenomena at a regional scale. The spatial geohidrological variations are more closely related with the variations in the geomorphology and in the relationships between the lithological units.

Ongoing research over the hydrogeology of the Peninsula Valdes is needed to understand with more detail hydrodynamics and hydrochemistry in the region. Mathematical modelling of the recharge phenomena and of the hydrochemistry processes that modifies groundwater quality would probably tackle this topics. It would be also interesting to orient future works into the study of the aquifer porosity variations, and the delimitation and study of deeper aquifer levels in order to find new water reservoirs for this waterless region.

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Glossary

Aquicludes	Rocks or unconsolidated material of low hydraulic conductivity which yield inappreciable quantities of water to drains, wells, springs and seep
Aquifer	Permeable water-bearing rocks or unconsolidated material capable of yielding exploitable quantities of water
Aquifuges	Rocks or unconsolidated material that cannot absorb or transmit water
Aquitard	Rocks or unconsolidated material that transmits water at a very slow rate compared with an aquifer
Clast-supported	Conglomerate or sand in which most individual clasts are in contact with each other. The matrix (finer material between the gravel clasts, such as sand, silt or mud) fills the spaces between the clasts
Confined aquifers	Aquifer overlain and underlain by an aquifuge, aquiclude or acuiclude
Hydraulic conductivity	Is a measure of the soil ock or unconsolidated material’s ability to transmit water when submitted to a hydraulic gradient.

Matrix-supported	Conglomerate or sand where the individual clasts are held together by the matrix (i.e. they are not necessarily in contact with each other). The rock may appear disorganized without any clear internal structure
Non-saturated zone or unsaturated zone	Portion of the lithosphere in which the interstices are filled partly with air and partly with water
Phreatic aquifer	An aquifer that is physically in contact with the atmosphere through the groundwater surface
Piper plot	Ternary diagram useful to visualize the chemistry of a rock, soil, or water sample. The apex of the diagram include major cations and anions founded in nature
Saturated zone	Zone of the water-bearing material in which all voids, large and small, are filled with water
Semi-confined	Aquifer overlain and/or underlain by a relatively thin semi-pervious layer, through which flow into or out of the aquifer can take place

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