SALINE WATER IN CENTRAL FUERTEVENTURA ISLAND, CANARY ISLANDS, SPAIN

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ABSTRACT

Fuerteventura is the second largest (1650 km^2) of the Canary Islands. The relative low relief (maximum altitude of 724 m) respect the other islands and the proximity to the Saharan coast (about 125 km) explains its arid character, with an average rainfall that barely attains 100 mm, and no more than 200 mm in the highlands. Surface runoff is limited to short, flash floods after sporadic, intense downpours. Groundwater recharge is scarce and mostly reduces to an average value of a few mm a^{-1}. This combined with relatively high atmospheric salt accession (closeness to the sea and quite strong winds) produces brackish recharge to the aquifer, as happens in other arid areas of the islands. A few years ago a series of boreholes were drilled to draw water from deep volcanic and intrusive formations. Quite brackish and saline water was found. Studies are being carried out to know the origin of these saline waters. There is an additional component to soil concentration, pointing to a marine origin of salinity, plus gypsum. Preliminary it can be considered the existence of relict marine water in the central part of the area where the old, submarine part of the island basement crops out or is partially covered by Miocene to Recent subaerial volcanics. The paper contributes recent data to a study that is still unfinished.

INTRODUCTION

Fuerteventura is part of the Canarian Archipelago, Spain. It is about 125 km away from the Saharan coast of Africa (fig. 1) It is the second largest island of the Archipelago with a surface area of about 1650 km^2. Its shape is elongated, oriented NE–SW and with a largest dimension of about 100 km.

Groundwater is dominantly brackish, as happens in other arid islands or parts of them. This is due to high evapotranspiration of scarce, rather saline rainwater, affected by the closseness to the windy, rough sea. Average rainfall is only slighly higher than 100 mm a^{-1}, varying between less than 200 mm a^{-1} in the highlands (elevation 700 m) of the central Betancuria massif, to about 80 mm a^{-1} near the SE coastal area. Most rain events are short but intense downpours between october and march. There is a large interannual variability.

To better know the origin of groundwater salinity and solve recently introduced, unsupported and doubtfull feelings that fresher water may be developed by deeper wells, a research study is under way in the central part of the island, around and to the E of the Betancuria massif (fig. 1).

Previous studies on the hydrogeology of Fuerteventura are very scarce. A preliminary survey and interpretation (finished in 1972) was included in the Spanish Government–UNDP programme SPA(69)15, which was followed by the MAC–21 (1982) study. The ITGE has maintained observation networks for some time. A wide survey of wells and sampling programme was carried out the Army Legion, but largely uninterpreted for chemical data up to now. The Las Palmas Water Authority maintains a rainfall gauging network. The Public Works Geological Survey drilled some exploratory boreholes on the 1980's. The Fuerteventura Water Plan and related studies do not add new significant information.

GEOLOGICAL BACKGROUND

Fuerteventura is the oldest of the volcanic Canary Islands. It is the only island in which the deep marine sedimentary basement of the Eastern islands crops out in some reduced areas. On top of it submarine vulnanites pile up, intruded by dominantly basic magmatic bodies and a very dense swarm of mostly basaltic dykes. This submarine complex (the basal complex) has been uplifted and intensively eroded. The age ranges from Upper Cretaceous to Lower Miocene. To the end of the guyot stage some subaerial vulcanites are found. This island, joinly with the Cape Vert archipelago are the only ones with carbonatites outside a pure continental environment (Domény et al., 1999).

On top of the submarine formations a high, large subaerial basaltic shield complex (Gran Tarajal stratovolcano) of Miocene age developped, which was later on deeply eroded and subjected to major landslides (Stillman, 1999).

In the central part of the study area there is a recent and rather extense lava field (malpais), of Pliocene–Holocene age and small thickness, with fingers towards the coast, following the main creeks (barrancos). They rest on older vulcanics or its denudation products, and some poorly sorted alluvium. This is a recharge area.

GROUNDWATER IN FUERTEVENTURA

In Fuerteventura there is no permanent surface water and the barrancos flow only after intense rainfall events and for a very short time. Local inhabitants try to make use of these waters by creating small dams to spead water on the infilling materials (gavias) and to divert it to areas into which they increase soil humidity (nateros). In the old times some large cisterns (maretas) collected runoff from slopes, for town supply. Now most potable water is desalinated ground and sea water. Intense rain events produce some local diffuse and concentrated recharge of shallow aquifers, which is lately abstracted by 1.5 to 3 m diametre dug wells. They were mostly fitted with windmills. Average depth is 25 m, but some may be more than 80 m deep. There are a few brackish water springs (nacientes) which reduce almost to seepages producing no more than a few litres per day.

From the decade of 1980 some relatively deep boreholes (up to 250 m) were drilled looking for greater flows and fresher water. This was unsuccessful but for a few brackish to salty water wells producing a few L s^{-1}. Commonly they are uncased but for the few upper metres. Some of them are now used for reverse osmosis desalination. The residual brine is transported by pipeline to the coast.

Major towns and coastal touristic centres and hotels use desalinated water, but small urban areas and farmers depend on groundwater for human supply, irrigation of small but highly productive orchards and cattle raising. Currently most dug wells around Tuineje are dry. This may indicate interference due to the development of the deep boreholes.

The study area is the central part comprising part of the Betancuria massif and the rolling plains to the East.

STUDY SYSTEMATICS

To try to understand the origin and pattern of groundwater salinity in the study area, experience gained in other arid areas of the islands, mostly the Amurga Massif (SE Gran Canaria) and Lanzarote island, was considered (Custodio, 1992). The study concentrates on chemical and environmental isotope issues since conditions to carry out hydrodynamic studies were poor, boreholes scarce and poorly documented, and actual study economic resources do not allowed drilling and testing.

The objective was the chemical characterization of rainfall as well as many as possible groundwater points, taking into account sample representativity of groundwater conditions. Available, unequiped deep boreholes were logged for temperature and electrical conductivity. Sampling has been repeated to be sure of the representativity and to identify changes. Permanent seepages (nacientes) are the subject of special attention.

Only 27 rainfall samples of bulk precipitation have been recovered, corresponding to six significant events in 1998 and 1999. Sample evaporation was prevented by a floating layer or liquid parafine. Only 4 stations have repeated data, and represent the different altitudes and environments.

A network of 32 groundwater points (seepages, wells and deep boreholes) were sampled twice a year, plus other oriented samplings, with a total a 154 groundwater samples. When possible the samples were taken by means of the well pump. Otherwise a thief sampler was placed at the selected depth, sometimes with some previous bailing, according with electrical conductivity and temperature logs. One sample corresponds to a “perched” level seepage into a deep water level borehole.

In situ measurements of electrical conductivity and pH were often performed, as well as some alkalinity determinations. All chemical analyses have been carried out by the ITGE laboratories in Tres Cantos (Madrid) except for Br determinations, which were carried out by the Barcelona Water Company, and CIEMAT in Madrid. The isotopic concentration of ^{18}O, ^{2}H and ^{13}C were measured at the Cedex, Madrid, and other determinations elsewhere, in a reduced number of samples.

GROUNDWATER CHEMICAL CHARACTERISTICS

Electrical conductivity logs show that groundwater is stratified, with salinity increasing downwards (Herrera and Martínez, 1998). This effect is partly the result of small vertical flows along the boreholes due to small head changes along it (Custodio, 1995). They may show up in the temperature log if they are large enough for equibration with the solid medium temperature not taking place.

Hydrogeologically it can be differenciated an Upper Unit and a Lower Unit. The Upper Unit contains the less saline water: electrical conductivity between 2.5 and 5.5 mS cm^{-1} and temperature between 18 and 25°C, close to the local average temperature. The Lower Unit contains brackish to saline, relatively warm water: electrical conductivity varies between 5.5 and 24 mS cm^{-1} and temperature between 25 and 30°C, which can be explained by normal geothermal gradient.

The Upper Unit contains recharge water with small water–rock interaction. Evaporation of rainfall infiltration prior to recharge is the dominant effect. They are sodium–chloride type waters, as does rainfall, have a moderate alkalinity and relatively low silica content. High nitrate contents in many samples show an anthropic component in water chemistry. They appear dominantly in the highlands and along the creeks, but near the creeks it may also respond to enhanced recharge of episodic surface flows by means of runoff retention and small water spreading works (gavias and nateros).

Below the lava field (malpais) salinity is relatively low due to the high soil permeability and small water retention, but it is still brackish due to incorporation of saline atmospheric solid deposition and some unavoidable evaporation.

The more saline waters of the Lower Unit are of the sodium chloride–sulphate type. Silica content is high and nitrate is almost absent but for some contaminantion from shallow water seeping into the boreholes. Sulphate content is controlled (24 to 59 meq L^{-1}) by gypsum saturation. Sodium chloride increases from Tuineje to Tesejerague.

Figure 2 shows the ratio SO_4/Cl vs. Cl. Chemical path studies show a meteoric origing for all of them but for the Lower Unit, which needs a separate source of sulphate. In general terms, as chloride increases the ratio SO_4/Cl first evolves towards the marine value but for higher values of salinity a gypsum disolution component is needed further to marine water in increasing proportion.

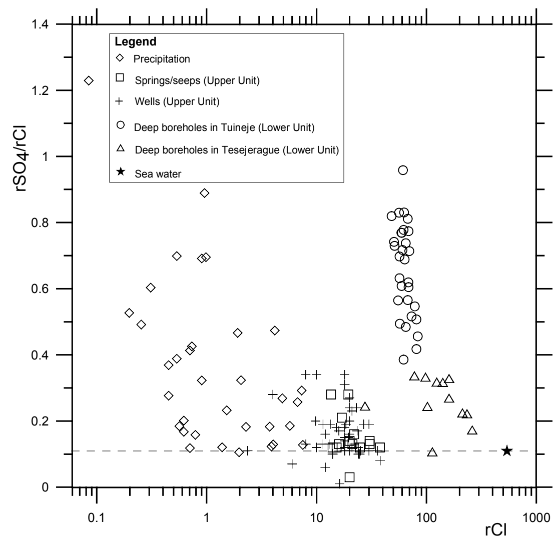

Fig.2.– Plot of rSO_4/rCl vs. rCl. r=meq L^{-1}.

To better understand what chemically happens the ratio Cl/Br has been considered as well (fig. 3). The result is quite surprising since for increasing chlorinity the ratio evolves from high values relative to the marine value to values closer to it. The high ratio for rainfall and the less saline groundwater is contrary to what generally happens. But this has been also observed occasionally in a few samples in other of the Canarian islands (Custodio and Herrera, 2000). Rough sea, windy environment and aridity may enhance the production of airbone salts rich in halite (poor in Br) by partial precipitation of salts from sea spray along the relatively rough coastal strip. The ratio Cl/Br points to a marine component for increasing groundwater salinity but there is other component as well, richer in Cl. This may be due to chloride released by the rock.

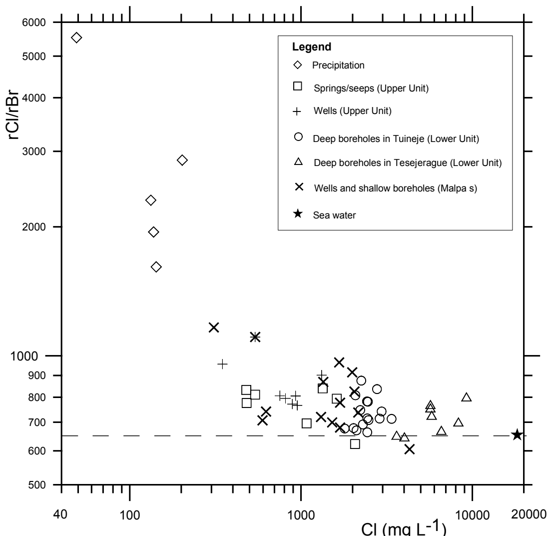

Fig 3.– Plot of rCl/rBr vs. Cl (mg L^{-1}). r=meq L^{-1}.

In a δ^2H vs. δ^{18}O plot (fig. 4), the meteoric line is taken as having slope 8 and deuterium excess between +10‰ (average oceanic value) and +15‰. This may be explained by the largest kinetic evaporation effect in the relativelly dry marine environment in the Saharan belt, which is the same effect to explain the greater deuterium excess observed in rainfall originated in the Mediterranean area.

Water samples from seepages and the Upper Unit in the study area plot along a line of slope 6, characteristic of free water evaporation. This may be linked to natural or artificial ponding on the land surface before infiltration, or to evaporation from bare soil, although in this case a smaller slope can be expected. But the slope 6 may be the result of smaller slope displacements of waters evaporated from the soil at different elevations. Non evaporated groundwater (and projected back evaporated water) cluster around δ^{18}O=–3.2‰ and δ^2H=–18‰, about the same as rainfall average.

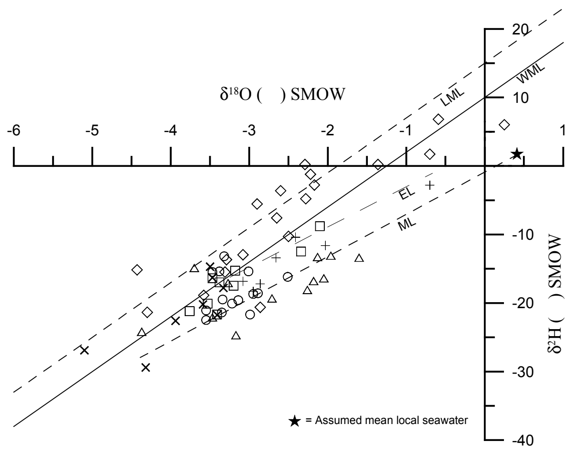

Fig. 4.– Plot of δ^{18}O vs. δ^2H. WML = World Meteorological line (m=8; d=10); LML = Local Meteorological line (m=8; d=15); EL = evaporation line of the Upper Unit (m=6); ML = freshwater – seawater mixing line. m means slope and d excess deuterium (in ‰). See legend in Figure 3.

Most saline groundwaters from the Lower Unit around Tesejerague plot along a line pointing to the sea value, the closer the higher the salinity. Wells from Tuineje do not follow a clear pattern. An evaporated component is possibly included. This precludes at this stage to define the original freshwater composition. Extrapolation to get the isotopic composition of the original freshwater shows that it is possibly lighter than present average rainfall. But rainfall isotopic sampling is currently incomplete and short, and probably does not duly consider the effect of preferential recharge of lighter water in extraordinarily wet periods. In fact wells from the lava field produce groundwater samples which are lighter than the others.

Plotting $\delta^{18}O$ vs. chloride content (fig. 5), most samples are near the rainwater–seawater closed system mixing line, except for samples showing evaporation. Since chlorinity of the rainfall end member conditions the less saline part of the plot, it is not surprising that samples from the lava field and one of the high altitude seepages follow a different mixing line than the others. Lower Unit aquifer water from Tesejerague adapt to one of these lines but not those from Tuineje.

Two seepages and a shallow well from the lava field show $\delta^{34}S$ values of dissolved sulphate from +16 to +18‰, which is close to the present +20‰ of marine water. This shows a dominantly marine origin of airbone salinity. The other samples and especially the most saline and sulphate richer ones have a lower $\delta^{34}S$ of SO_4, with values around +8‰. Then the S is probably linked to vulcanism, which it is now available to water as gypsum. The value of $\delta^{34}S$=+26‰ is probably the effect of sulphate reduction; in fact the water sample was blackened by what is assumed reduced sulphur growths. It is not known if this is natural or the result of organic matter introduced as a drilling component and not removed later on.

The plot of $\delta^{34}S$ (SO_4) vs. SO_4/Cl (fig. 6) shows the two families just commented above, and a few exceptions. The same appears in a plot of $\delta^{34}S$ (SO_4) vs. Cl. One of the seepages seems the discharge of the Lower Unit. The $\delta^{18}O$ value of sulphate is under study.

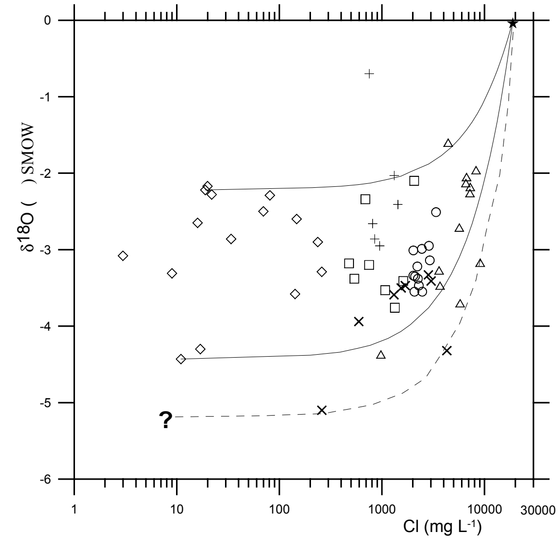

Fig. 5.– $\delta^{18}O$ vs. Cl (mg L^{-1}) for precipitation samples and groundwater of the Betancuria massif. Mixing lines of sea water with hypothetical recharge water. See legend in Figure 3.

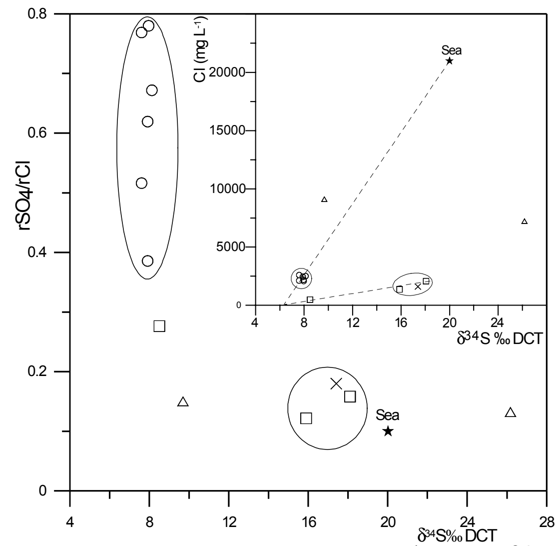

Fig. 6.– rSO_4/rCl (r=meq L^{-1}) vs. $\delta^{34}S$ and insert of Cl vs. $\delta^{34}S$. See legend in Figure 3.

CONCLUSIONS

As preliminary results of the study under way, the relatively high salinity of groundwater in Fuerteventura island is due to intense evaporation of rainfall, which incorporates marine airbone salts in an arid environment. This explains salinity of most springs (seepages) and dug wells. Salinity is even rather high below recent lava fields which present a high surface permeability but in which incipient weathering and air deep circulation allows for evaporation of rainfall infiltration. But deep boreholes show a higher salinity whose explanation needs to consider other sources of dissolved salts. Relict marine water in the submarine vulcanites and intrusives is a possibility but some of the Cl may be released by the rock itself to explain the relatively high Cl/Br ratio. The release of Na from the rock to the water obscures this effect. Also soluble sulphates are present which seem to be of volcanic origin and not seawater related. The low regional permeability of the formations may explain the persistence of this saline water body above sea level, a even a small seepages. Turnover time is under study. Regional low permeability values do not preclude small yields from some deep wells intersecting open fissures. Development of these water should deplete the reserves, combined with large drawdown and replacement with recent groundwater from above. This is known in other areas of the Canaries.

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REFERENCES

CUSTODIO, E. (1992). Coastal aquifer salinization as a consequence of aridity: the case of Amurga phonolitic massif, Gran Canaria Island. Study and Modelling of Salt Water Intrusion (XII SWIM). CIMNE–UPC. Barcelona: 81–98.

CUSTODIO, E. (1995). The impact of vertical water flow in boreholes: influence on monitoring operations. Hydrogéologie, Orléans 3: 3–12.

CUSTODIO, E.; HERRERA, CH. (2000). Utilización de la relación Cl/Br como trazador hidrogeoquímico en hidrología subterránea. Hidrogeología / Boletín Geológico y Minero. ITGE. Madrid (in press).

DEMÉNY, A.; AHIJADO, A.; CASILLAS, R.; BOYCE, A.J.; FALLICK, A.E. (1999). Crustal contamination of carbonatites indicated by $\delta^{34}S$–$\delta^{13}C$ correlations (Fuerteventua, Canary Islands). Rev. Soc. Geol. España. 12(3–4): 453–460.

HERRERA, CH.; MARTÍNEZ, F. (1998). Hidrogeología de la parte central de la Isla de Fuerteventura (Archipiélago de Canarias). Fundación Centro Intern. Hidrología Subterránea. Barcelona (internal).

STILLMAN, C.J. (1999). Giant Miocene landslides and the evolution of Fuerteventura, Canary Islands. J. Volcanology and Geothermal Research, Elsevier. 94: 89–104.