HYDROGEOLOGICAL AND HYDROCHEMICAL STUDY OF THE COASTAL PLAINS OF SAIDIA AND BOU-AREG (NORTH-EASTERN MOROCCO)

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Introduction

North-eastern Morocco has a mediterranean climate, with low rainfall, which is irregularly distributed both within the year and over succeeding years. The climate is very dry in summer, and moderately to weakly humid in winter. Annual rainfall over a 15 year's period has revealed 1983 to be the dryest year, with 116.3 mm, while 1986 was the most humid one, with 412.6 mm. The average over this period amounts to 278.6 mm/year.

The coastal area shows groundwater salinization, which is due to the presence of connate salt water, to sea water intrusion and also to the infiltration of irrigation water, concentrated by evaporation. Low salinity water resources are scarce, and should be carefully managed.

The present study focuses on two aquifer systems in the Mediterranean coastal area of north-eastern Morocco (fig. 1). One is situated in the most easterly coastal plain, up to the Algerian border: the eastern part of Saidia plain. The other one is situated more towards the west, in Bou-Areg plain, behind the lagoon of Bou-Areg Sebkha, which is separated from Mediterranean Sea by a 25 km long, narrow strip of land. A 3-4 km wide gully cutting through it, assures contact between the lagoon and the sea. Saidia plain is mostly dispersely populated, with some agricultural activity, while the city of Saidia is a summer resort. In the western part, outside the studied area, a large sea fish farm is causing extensive groundwater salinization by leakage from sea water filled basins. Bou-Areg plain is largely brought under intensive agriculture and horticulture, thanks to its fertile heavy soils and the implementation of an irrigation system since 1970.

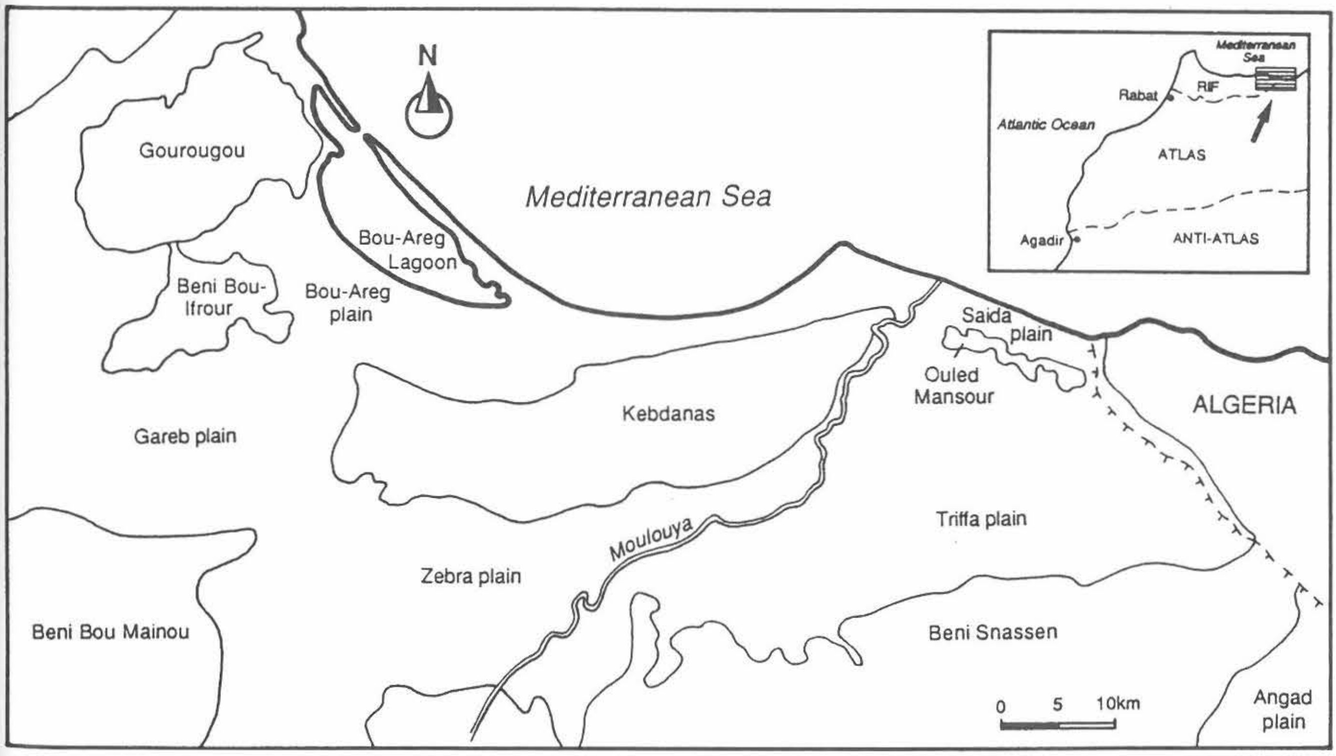


Fig. 1 - Location of study area.

Eastern Saidia plain

Saidia plain (fig. 2) is an elongated area, squeezed in between the Ouled Mansour hills and the sea. To the east, it is bounded by the Algerian border, following the Kiss River. From north to south, several parts, occurring as longitudinal, parallel strips, can be distinguished (e.g. fig. 3): the shore, the northern dunes, the flat of Sareg, the southern dunes, and finally the flat of Merzakan,up to the Ouled Mansour hills.

STRUCTURE OF AQUIFER SYSTEM: The aquifer system has been investigated by means of borings at 13 sites (fig. 2) (El Halimi, in prep.; El Halimi et al., in press). Two transversal SSW-NNE trending cross-sections (AB and CD) have been established (fig. 3 and 4). The aquifer system is composed of Quaternary sediments. Its base is consisting of marls and marly clays, probably of Miocene age. This substratum is overlain by unit X, containing clayey, marly or peaty fine sand with shell fragments. Next follows unit Y, consisting of fine to medium sand with shells. It is overlain by unit Y', consisting of peat and sandy clay to marly sand. The overlying unit Z consists of fine, medium to coarse sand with shell fragments. In most of the area, unit Z reaches the surface. This is the case on the shore and in both dune belts. In the flats of Sareg and Merzakan, a superficial unit Z', composed of silty clay, occurs on top of unit Z.
The units X, Y and Z are considered to be pervious, X showing a lower hydraulic conductivity than Y and Z. Units Y' and Z' are considered to be semi-pervious. Towards the west (profile AB), the pervious character of unit X is still decreasing, with its clay, marl and peat content increasing, as well as its thickness. This causes the hydraulic conductivity of the aquifer system to decrease towards the west.

PIEZOMETRIC MAP: The piezometric map, based on measurements performed in September 1995, is shown in figure 2. The highest heads are recorded in the south-eastern part, where the adjacent Ouled Mansour hills reach the highest altitudes. Groundwater flow occurs towards the north-west. Locally the heads are increased at locations at dune belts. Local lowering of the water table is indicating groundwater abstraction from wells.

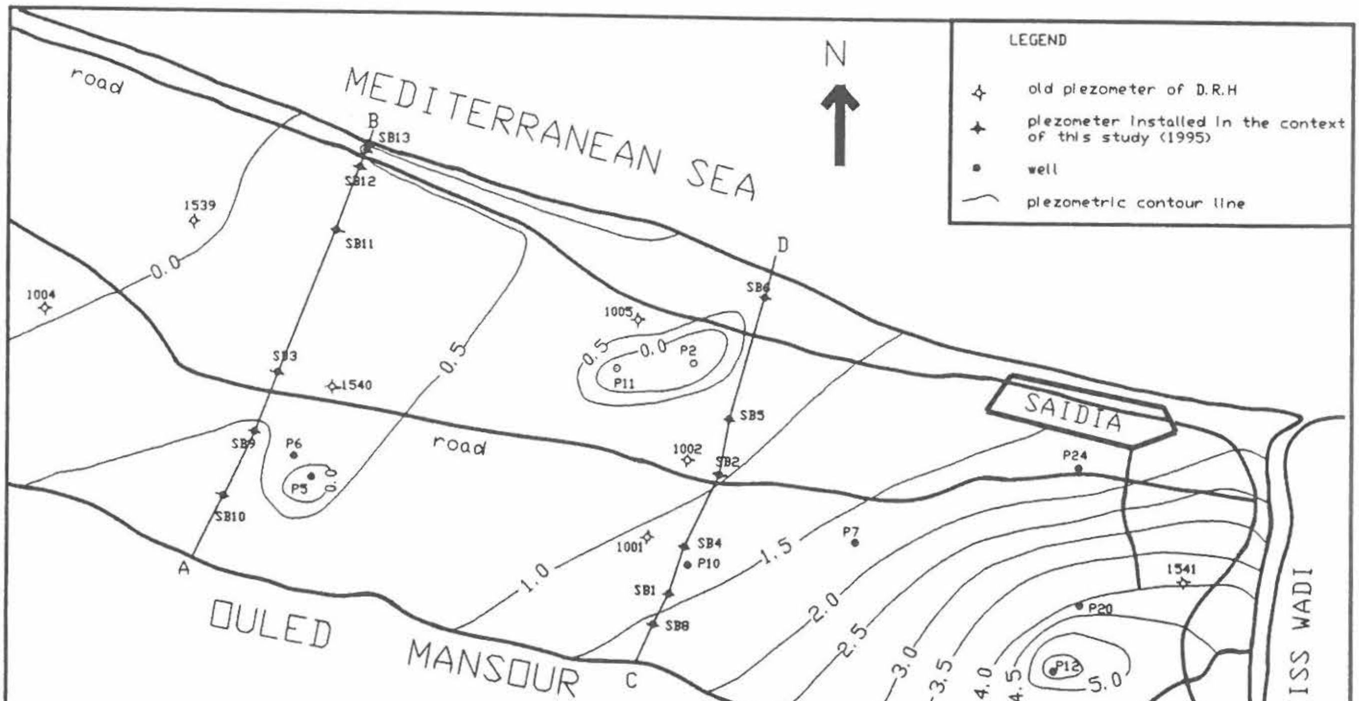


Fig. 2 - Location of observation wells in the coastal plain of Saidia; water table contours (September 1995).

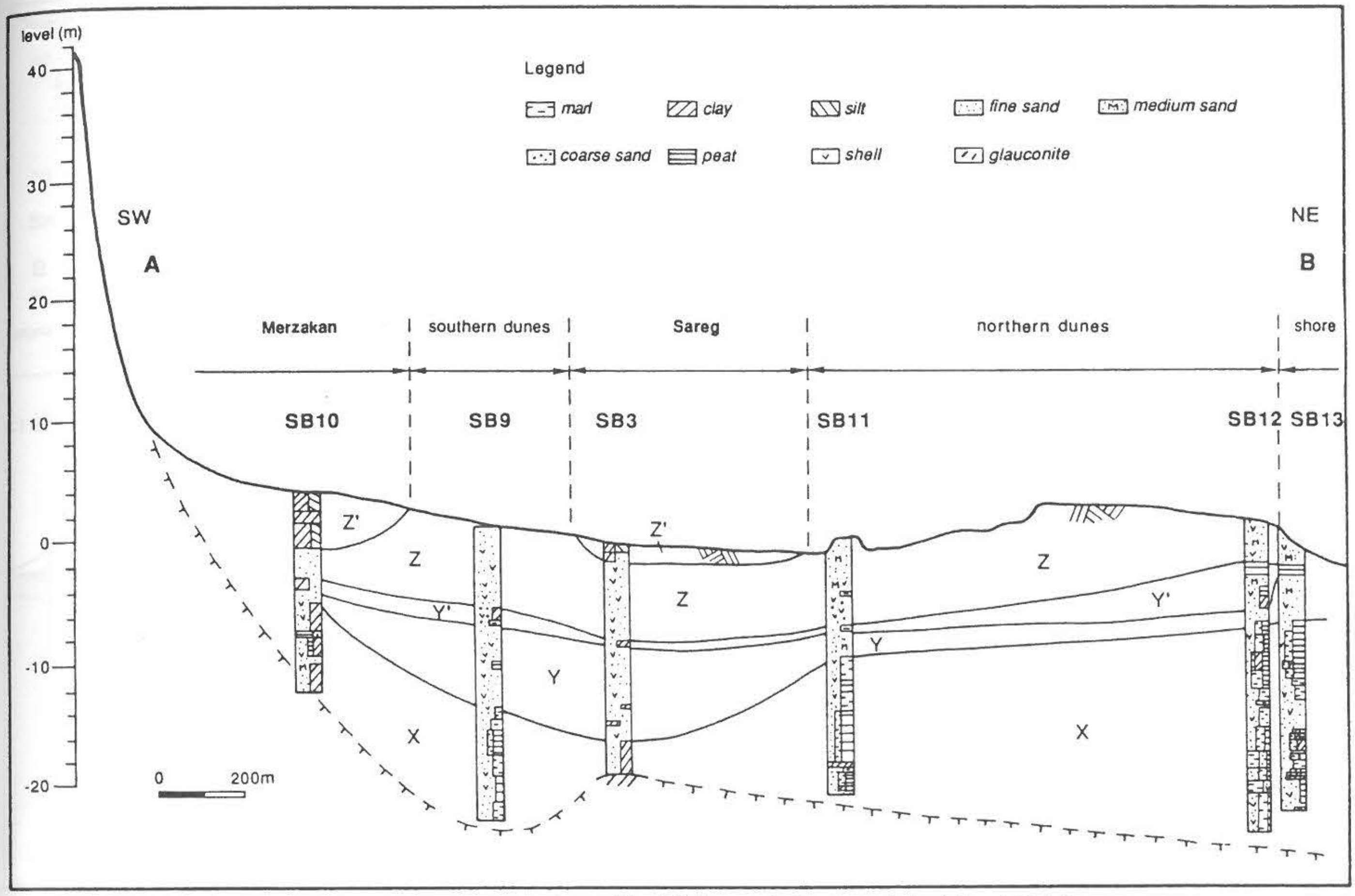


Fig. 3 - Lithology and hydrogeological structure in profile AB through the coastal plain of Saidia.

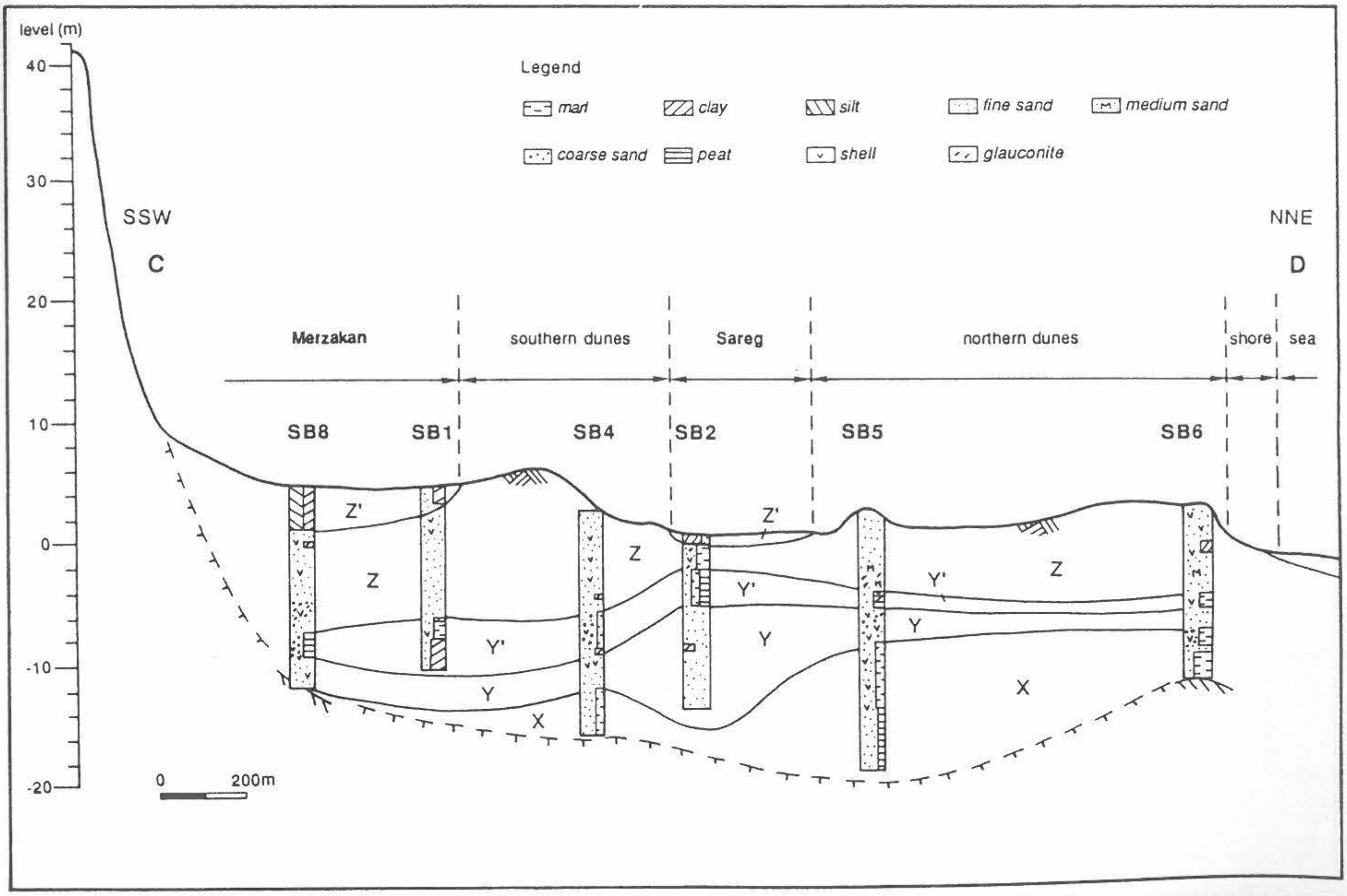


Fig. 4 - Lithology and hydrogeological structure in profile CD through the coastal plain of Saidia.

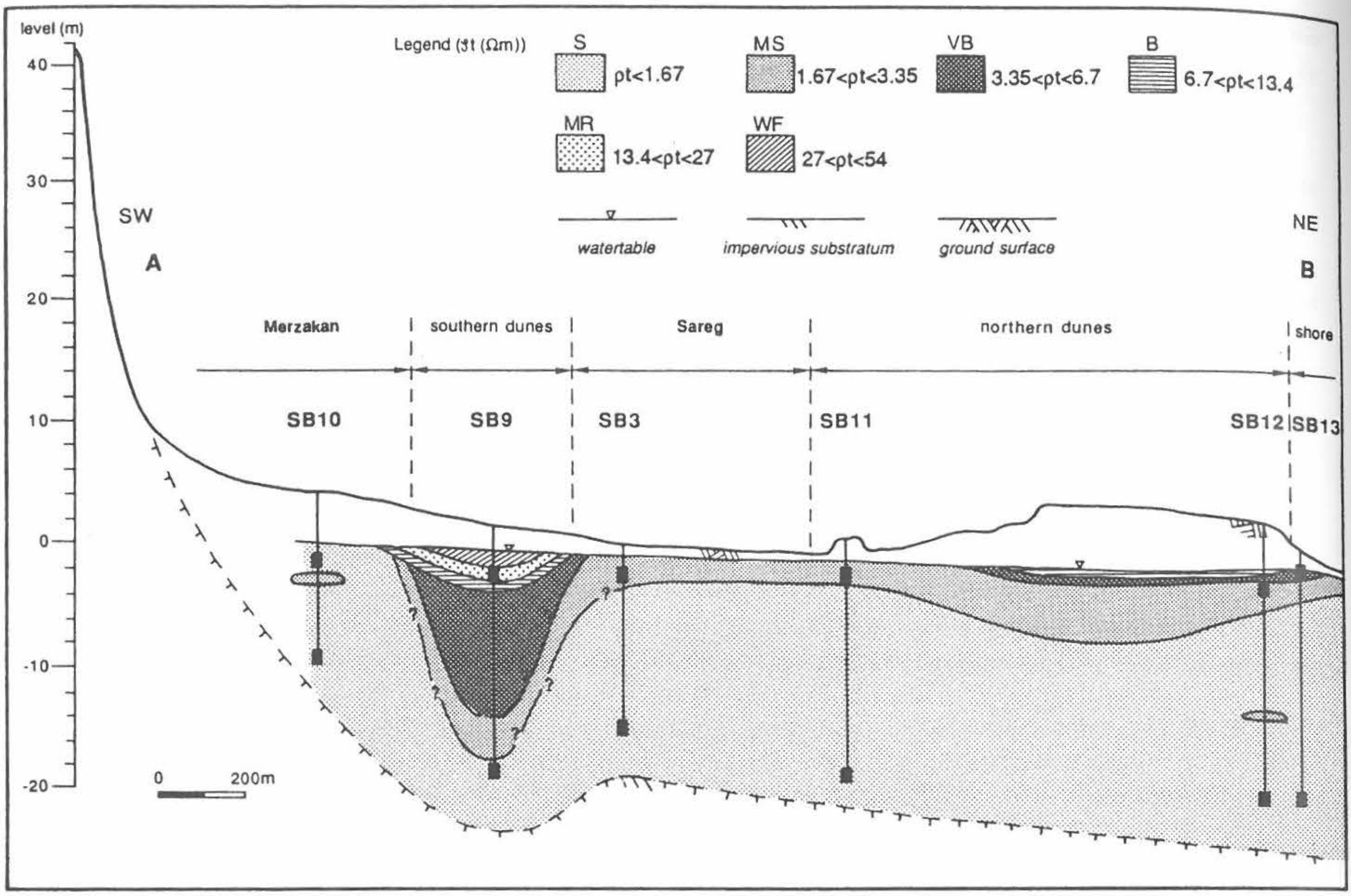


Fig. 5 - Resistivity profile AB through the coastal plain of Saidia.

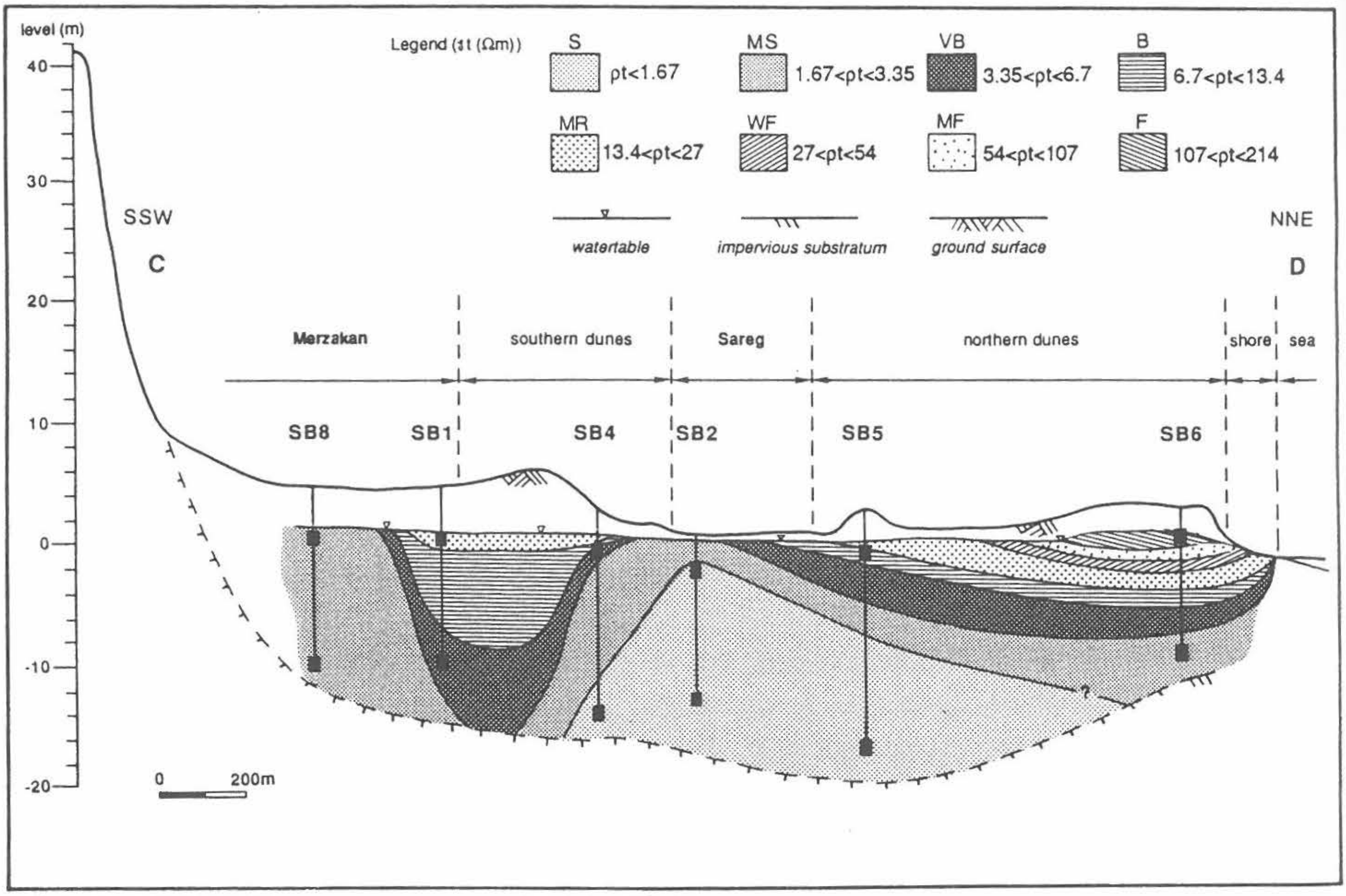


Fig. 6 - Resistivity profile CD through the coastal plain of Saidia.

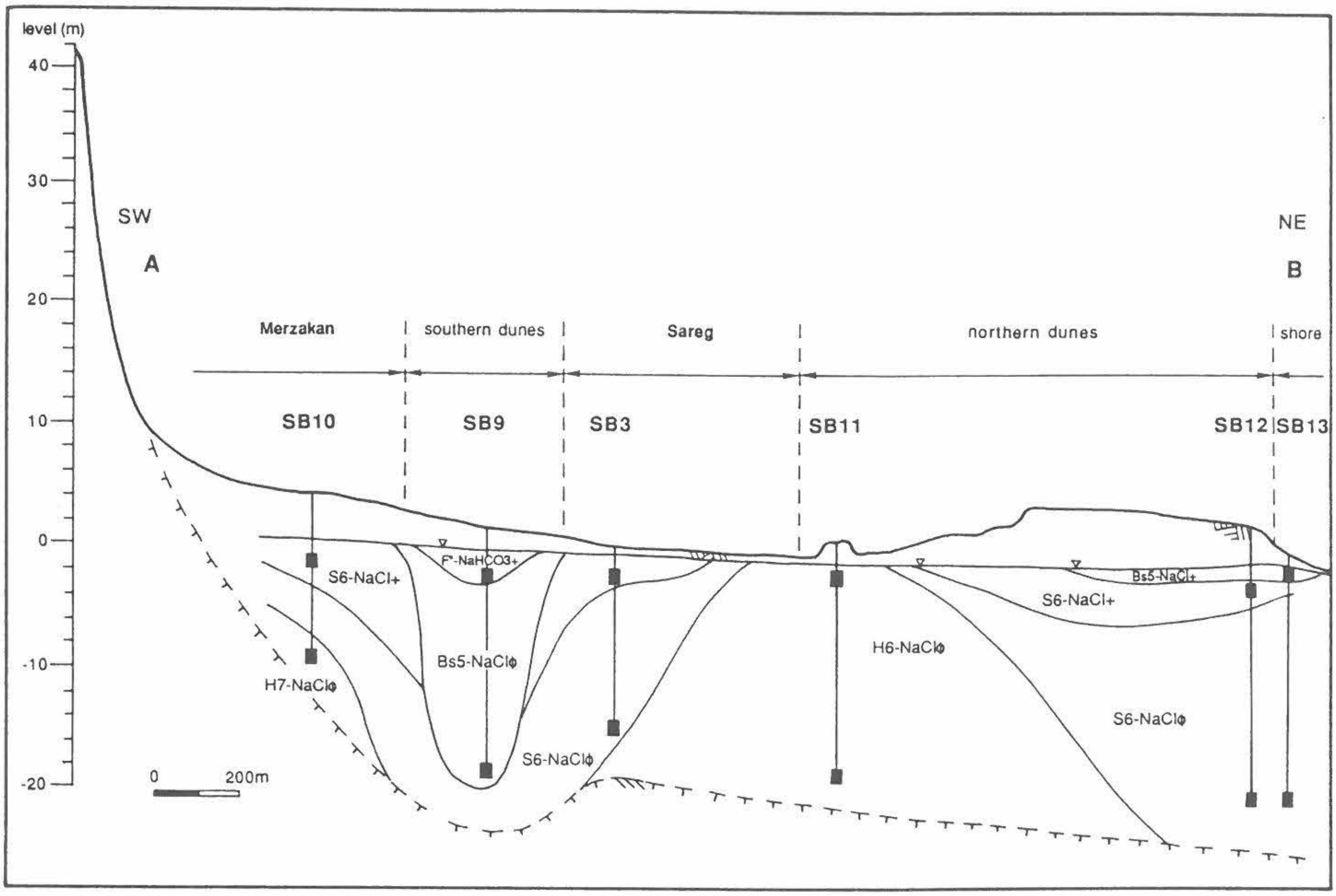


Fig. 7 - Hydrochemical cross-section AB through the coastal plain of Saidia.

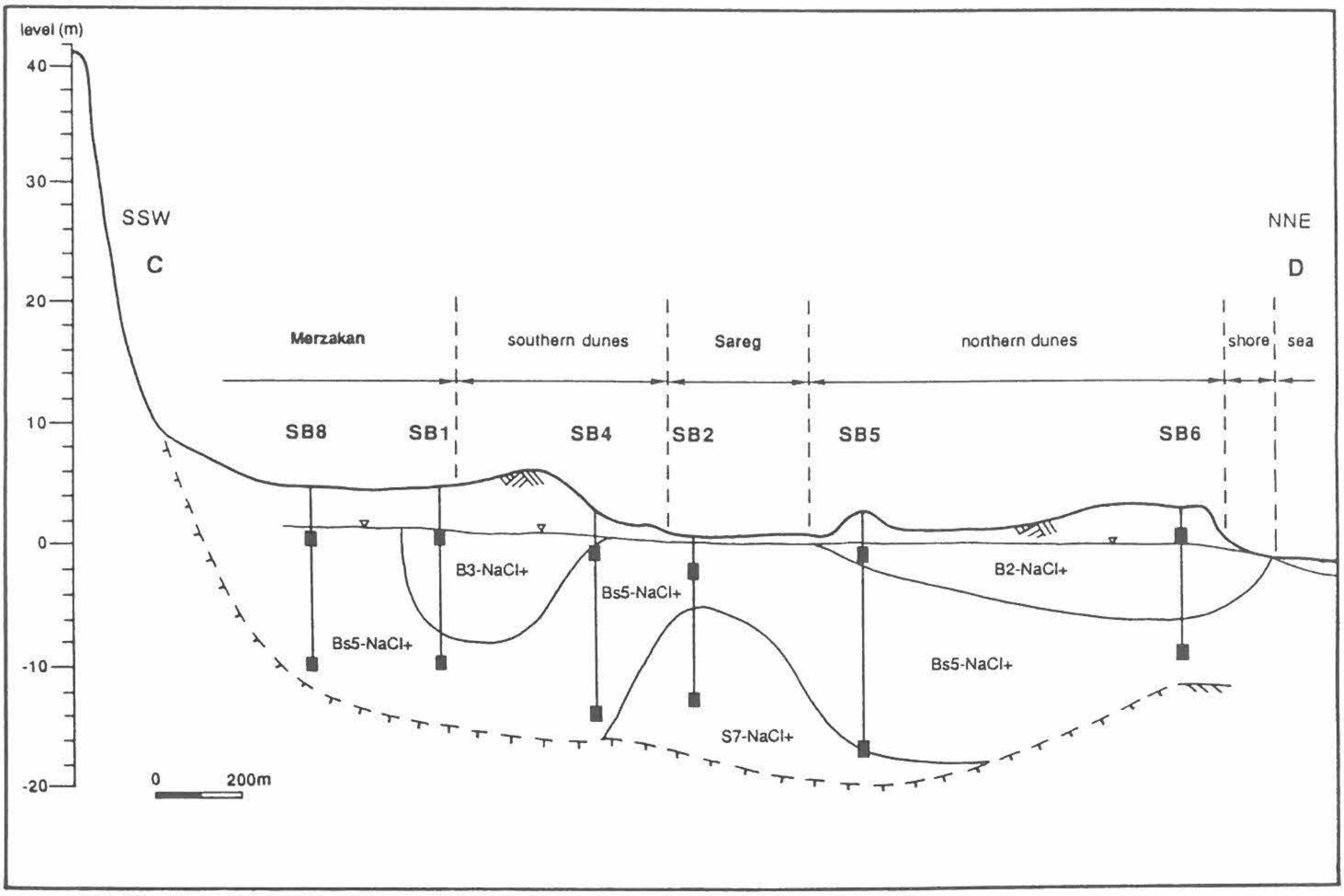


Fig. 8 - Hydrochemical cross-section CD through the coastal plain of Saidia.

RESISTIVITY PROFILES: In the boreholes, LN and SN resistivity logs have been recorded. The LN resistivity has been used to obtain an estimation of the groundwater quality, by assuming an average formation factor of 5.93, obtained from several measurements, and a relation for TDS = $7225/\rho_w$, accounting for the average groundwater temperature of 25 °C. As such, the estimated groundwater quality could be ranked in the salinity classes of De Moor & De Breuck (1969).
Profile CD (fig. 6) shows an appreciable freshening to have developed below both dune belts. In SB8, towards Ouled Mansour hills, the aquifer system contains slightly diluted water when compared to the main deep part of the system, below the flat of Sareg (SB2) and in depth at SB4 and SB5. This could possibly indicate recharge by less saline waters, originating from Ouled Mansour hills.
Profile AB (fig. 5) is showing much less freshening by recharge in the dune area (in SB9, the measuring apparatus was broken, causing the log to be interrupted). Almost the whole aquifer system is still containing salt water.

GROUNDWATER TYPE PROFILES: Every borehole was equipped with a piezometer with 1 meter of filter screen at the bottom. At most sites, two boreholes were executed, allowing to sample both deeper and shallower parts of the aquifer system. After chemical analyses, the groundwaters were classified according to Stuyfzand (1986). The results have been represented in groundwater type profiles (fig. 7 and 8). The conclusions drawn from the resistivity profiles could be confirmed.

Bou-Areg plain

SITUATION: Bou-Areg plain is formed by a Neogene synclinal depression, bordered to the west, the south and the south-east by the mountains of Gourougou and Beni Bou-Ifrour, the hills of Selouane in between Bou-Areg and Gareb plains, and the mountain chain of Kebdanas (fig. 1). In the depression, continental sedimentation during the Quaternary has built deposits of considerable thickness. These deposits consist mainly of loam and loamy clay, often containing coarser elements (boulders and gravels) (Chaouni Alia, in prep.; Chaouni Alia et al., in press).

REGIONAL SURVEY: Piezometric measurements taken from piezometers and wells have allowed to map the piezometric surface (fig. 9). This map clearly shows groundwater to flow towards Bou-Areg lagoon.

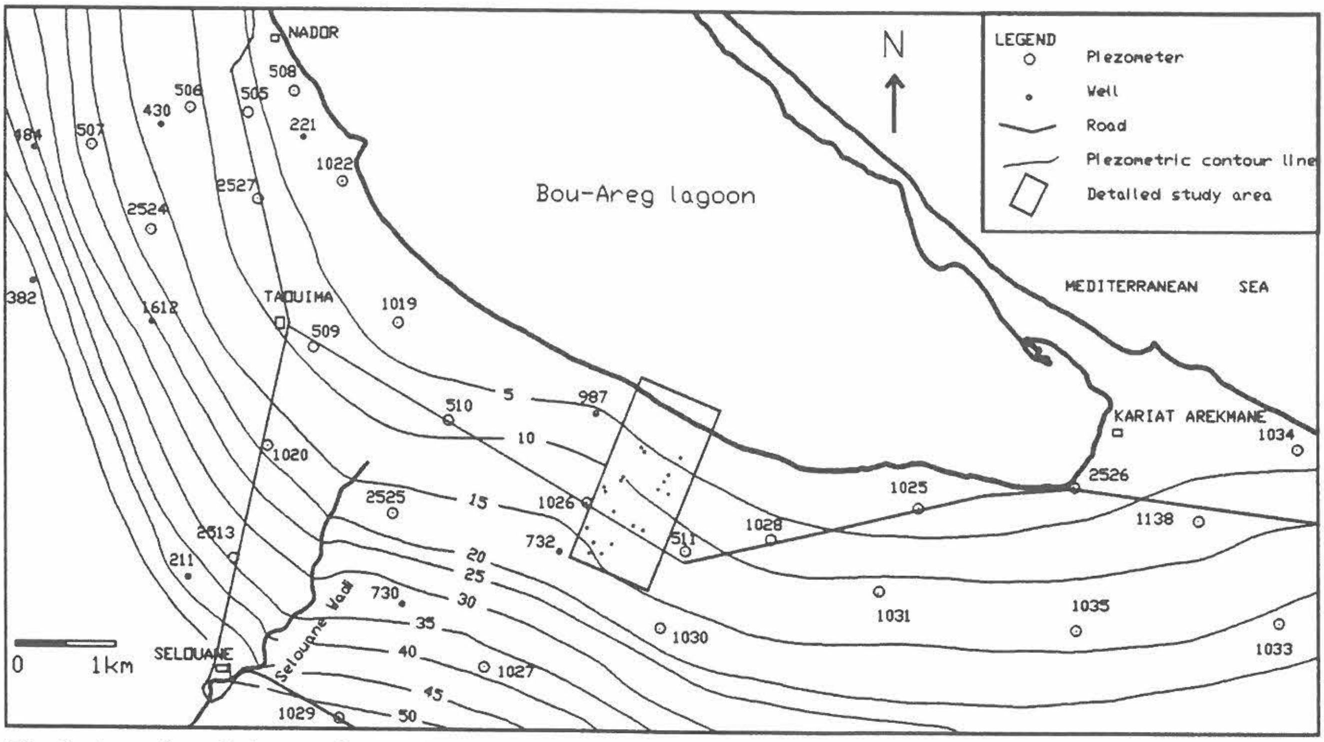


Fig. 9 - Location of observation wells and piezometric surface of Bou-Areg aquifer.

The regional distribution of groundwater types (according to the Stuyfzand, 1986, classification), based on sampling in 1963, has been represented in figure 10. A slow regional freshening is indicated, progressing from the borders in the west, the south and the south-east, towards the lagoon. In the south, along and east of Selouane River, freshening has apparently been more intensive, leading to a cation exchange equilibrium (0) in the water type.

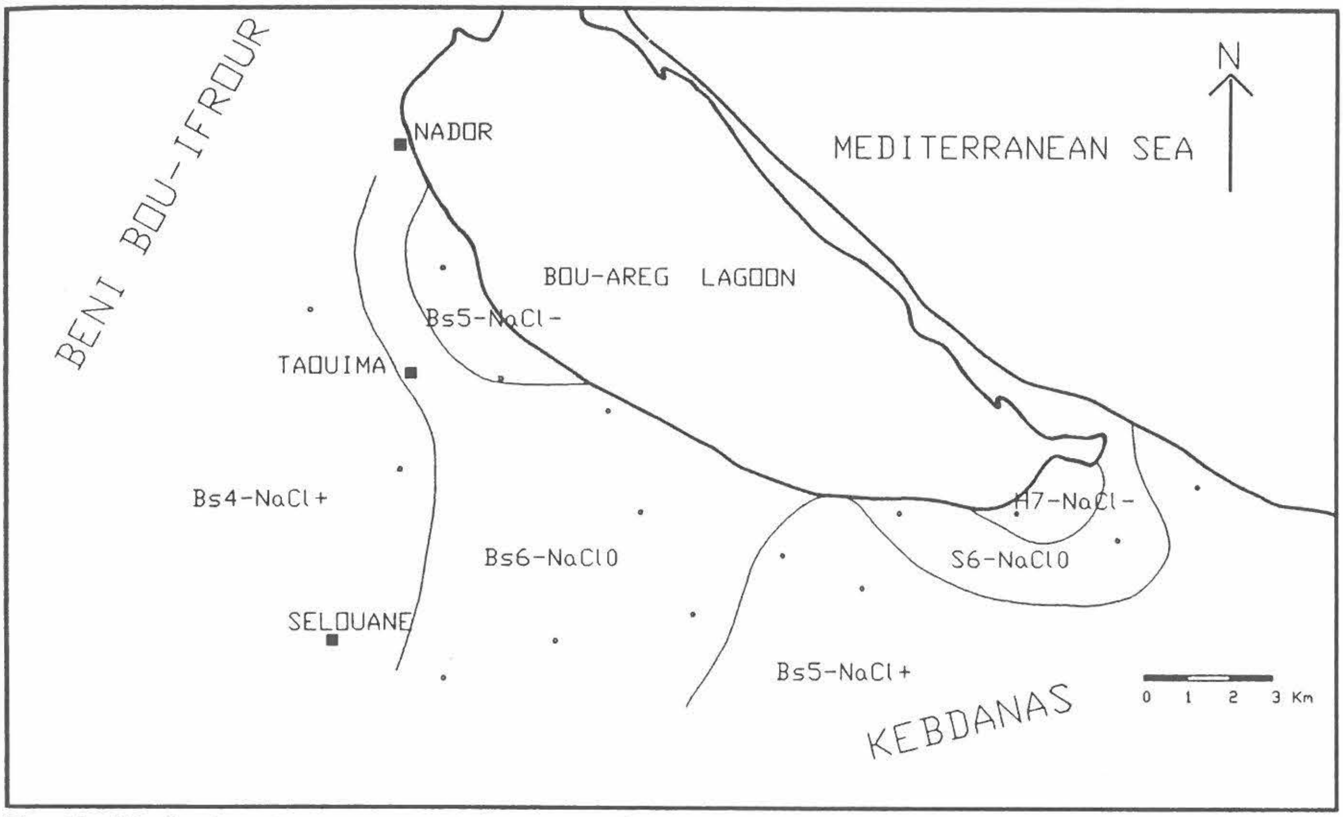


Fig. 10 - Distribution of water types of Bou-Areg aquifer (1963).

DETAILED STUDY: In a detailed study area (indicated in fig. 9), all available (shallow) wells and two irrigation waters have been sampled in November 1995. The distribution of groundwater types is shown is figure 11. Against the background of the regional groundwater quality, which is B_s4-NaCl+, a freshening tongue has been observed. Certainly in part, this phenomenon could be ascribed to the percolation of irrigation water to the water table. The water type of irrigation water is F_b3-$CaSO_4$. The freshening is turning the original B_s4-NaCl+ groundwaters into the following successive water types: B3-NaCl+, B3-NaMix+, F_b3-NaMix+ and finally F_b3-MgMix+. In stead of the last water type, also the F_b3-$NaSO_4$+ type has been observed. Important cation exchange is clearly reflected by the groundwater type and by the magnitude of the cation exchange parameter $(Na+K+Mg)_{measured}$ - 1.061 Cl (in meq/l) (Stuyfzand, 1986), which is ranging in between +6.5 and +50 in the studied groundwaters.
Figure 12 shows the distribution of electrical conductivity, Cl^--content, Na^+-content and HCO_3^--content in the groundwater. These parameters are confirming the freshening tendency of figure 11.

Conclusion

Moderate recharge is inducing a slow freshening in the coastal plains of Saidia and Bou-Areg.
In Saidia plain, this freshening mainly results from recharge in both dune belts. Recharge from Ouled Mansour hills by less saline waters may also bring about some freshening. In Bou-Areg plain, a slow regional freshening takes place by groundwater flow from the mountains of Gourougou and Beni Bou-Ifrour, the hills of Selouane and the mountain chain of Kebdanas. A strikingly stronger freshening is observed locally. It is probably (partly) related to the percolation of irrigation water to the water table.

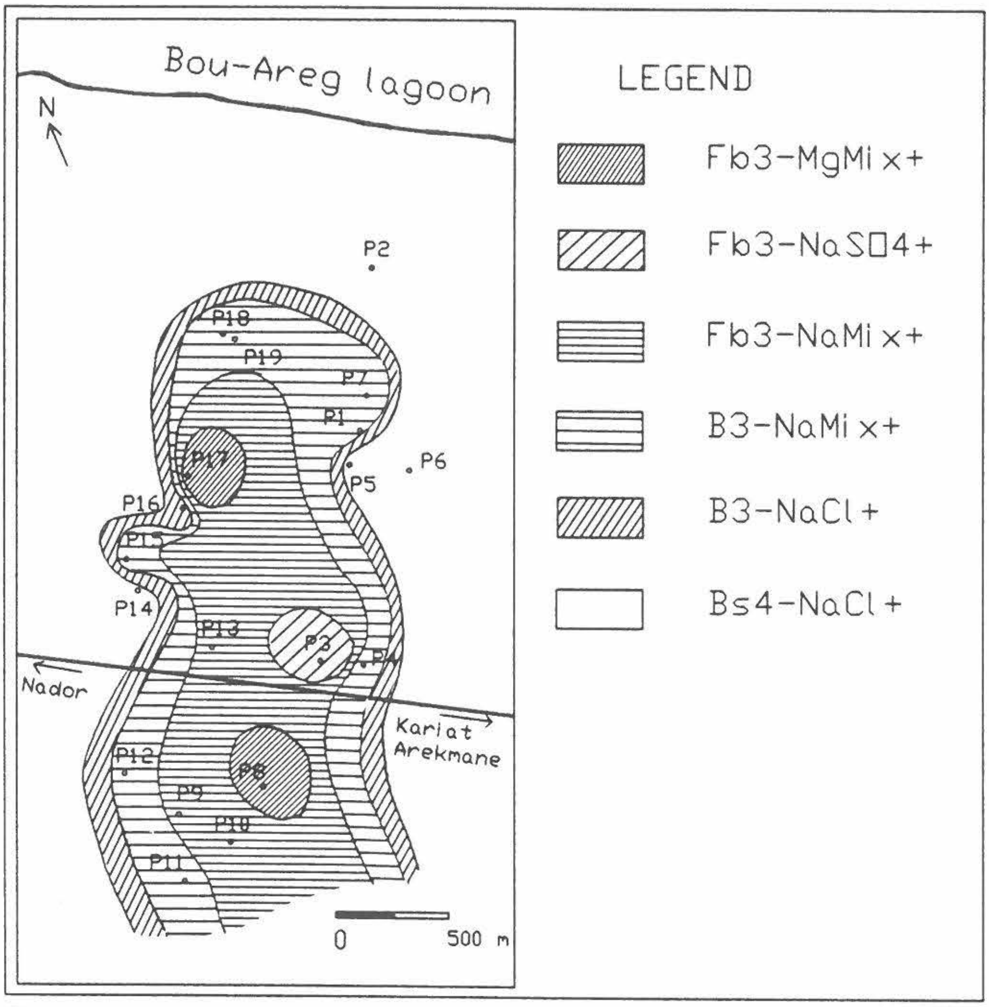
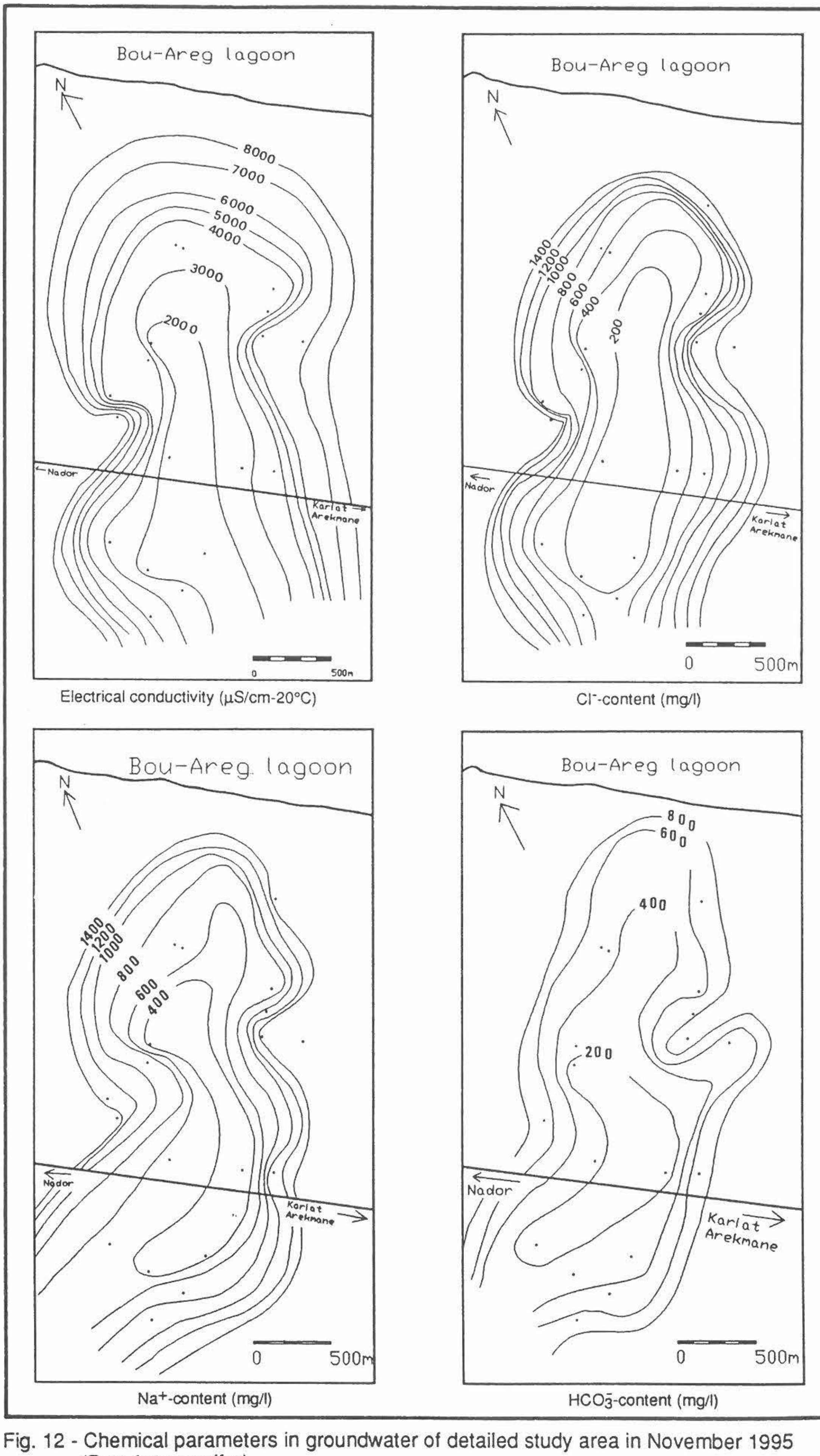


Fig. 11 - Distribution of water types in detailed study area in November 1995 (Bou-Areg aquifer).



Electrical conductivity (µS/cm-20°C)

Cl^--content (mg/l)

Na^+-content (mg/l)

HCO_3^--content (mg/l)

Fig. 12 - Chemical parameters in groundwater of detailed study area in November 1995 (Bou-Areg aquifer).

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