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NATIONAL REPORT FOR PORTUGAL

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1. INTRODUCTION

Ground water resources play an important role in urban supply, industry and agriculture. Recent estimates indicate that ground water contributes about 70% of the total of water used in continental Portugal (Lobo-Ferreira and Oliveira, 1993). However, in some regions its contribution can be much more important, reaching sometimes more than 90%. Despite the small portion of the Portuguese territory (<2.5%) occupied by karst aquifers, its importance is very significant. This is so, because the major part of the country (4/5) is formed by rocks of low or very low permeability (eg granites, schists, greywakes) and because the most important karst aquifers are located in the more populated areas. The main karstic spring has been used, since the last century and until recently (about 40 years ago), as the most important source of water to the town of Lisbon. Even in Pre-cambrian and Palaeozoic terranes, where limestones outcrops are scarce and small, most of them are used as water source, especially in Alentejo province.

Due to the scarcity of data it is hard to estimate the contributions of karst aquifers for urban supply and agriculture, but almost surely it is more than 50% in the western region whereas in the southern region is about 80%.

2. GEOLOGICAL SETTING

The major part of the Portuguese territory is formed by pre-Mesozoic terranes belonging to the Hesperian (or Iberian) Massif that is the most extensive segment of the hercynian basement in Europe (Ribeiro *et al*., 1979). The Iberian Massif consists of pre-Cambrian and Paleozoic formations, essentially metasediments and plutonic rocks, mainly granites, and also extrusive rocks, more abundant in the southern part. The most important limestone outcrops in the Iberian Massif are located in the Alentejo Province. Their age range from the Cambrian to the Middle Devonian.

Two important sedimentary basins were formed during the Upper Triassic (fig. 1). The most important, the so called *Orla Ocidental*, where the pilot area is situated, is located in the west of country begins near Aveiro and ends near Setúbal. In the south of Portugal is located the so called *Orla Meridional* (Algarve Province). The most extensive and typical karst areas are located in these two regions (fig. 2).

The Orla Ocidental is composed of a thick series of sediments with a variety of facies with ages ranging from Upper Triassic to Recent. These sediments were deposited in an elongated basin with the orientation NNE-SSW.

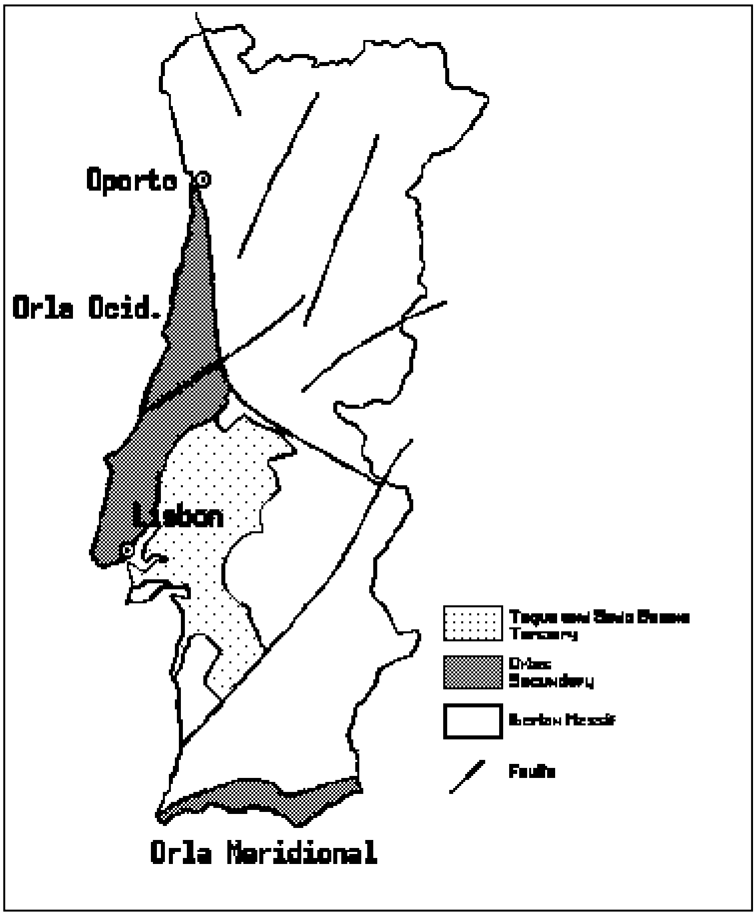

Fig. 1 – Morphostructural units of Portugal

On the eastern edge of the basin, unconformable sedimentary rocks lie on the pre-Cambrian and Palaeozoic basement of the Iberian Massif. They include the oldest secondary terrains and are formed by conglomerates and sandstones, generally red, belong-ing to the Triassic (Keuper), exposed in a narrow band with the N-S direction.

The overlying deposits show increasing marine influence, initially belonging to a shallow marine facies (Pereiros Formation) followed then by dolomitic limestones, marly limestones and Liassic marls.

Dogger terraines are represented, mainly, by compact limestones, oolithic limestones and dolomitic limestones forming the most important topographic features of the Orla Ocidental: Maciço Calcário Estremenho, Alvaiázere and Sicó mountains.

The regression starting during Calovian time is responsible for the lack of Lower Oxfordian deposits. Post-Upper Oxfordian pelagic facies are only represented south of Torres Vedras - Montejunto; the remainder is either of platform or detrital facies.

Lower Cretaceous is represented mainly by argilaceous sandstones that discordantly overlain Jurassic terraines. The Cenomanian transgression reaches its peak by Turonian time. Limestones of this age are largely represented in the borderland.

About 80 Ma ago (Upper Cretaceous) was formed the sub-volcanic massif of Sintra. A volcanic complex, 70 Ma, composed of flow lavas and pyroclasts occur in the region of Lisbon-Mafra.

Tectonics of the sedimentary cover is conditioned by late-Hercynian faults that affected the basement and by the evaporitic complex deposited at the bottom of the sedimentary series. So, the fracture sets found at the cover correspond mainly to the activation of faults in the basement with the following directions:

- "N-S, mainly along the western border of the Hesperian Massif;
- ENE-SSW, parallel to the Guadalquivir fracture and the Bethic Chain;
- NNE-SSW, the predominant trend of the diapiric axes;
-NNW-SSE, orientation of secondary faults inside blocks bounded by major faults".

Deformation is at a maximum along the main faults, but within the blocks the structure has a sub-tabular style with deformation of a great radius of curvature.

Thick Hetangian evaporitic series formed numerous diapiric structures.

2.1 The Maciço Calcário Estremenho

2.1.1 Stratigraphy

The Portuguese pilot area, the so called *Maciço Calcário Estremenho* (MCE), is a geomorphologic unit with well-defined limits. It is mostly formed by middle Jurassic limestones (Fig. 3). In the west, the Candeeiros mountain emerges abruptly from the platform of Aljubarrota reaching approximately the altitude of 600 m over a length of about 30 km; the southern and eastern slopes contact with terrains of the tertiary Tagus Basin along an extensive fault scarp.

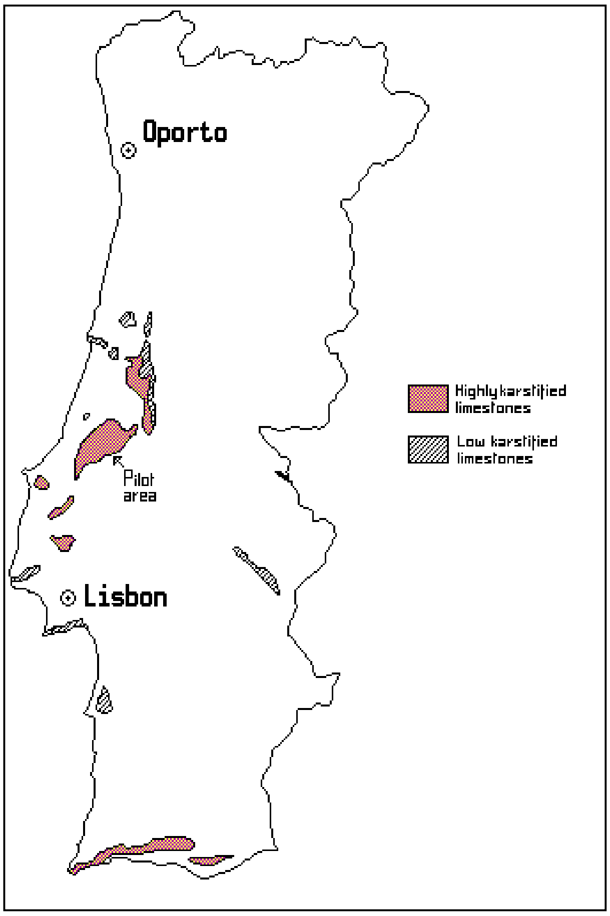

Fig. 2 – Distribution of the main karstic areas

To the North the limit is not so obvious. The relief of the MCE decreases gradually, changing to a basin (Vila Nova de Ourém basin).

The stratigraphy of the region can be summarised as follows (Zbyszewski *et al.*, 1974; Manuppella *et al.*, 1985):

Synemurian dolomitic limestones and dolostones forming thin beds, sometimes argilaceous, at the bottom, changing gradually to thick beds of compact fissured or reticular dolomites;

Lotaringian compact and fossiliferous marly limestones;

Alternating beds of marl and marly limestones, aged from Carixian to Aalenian;

Compact, oolithic, calci-clastic and dolomitic Dogger limestones. The highest relief of the region (Serra de Aire) is formed by this unit;

Malm marly limestones, marl and sandstones, forming a unit separated from the Dogger limestones by a stratigraphic discontinuity. This unit comprises fluvial sandstones with plants and vertebrates, coal levels, limestones and marl of shallow marine and neritic facies. Lower Cretaceous sandstones, conglomerate and mudstones.

These detrital deposits infill in some karst depressions in the Dogger limestones.

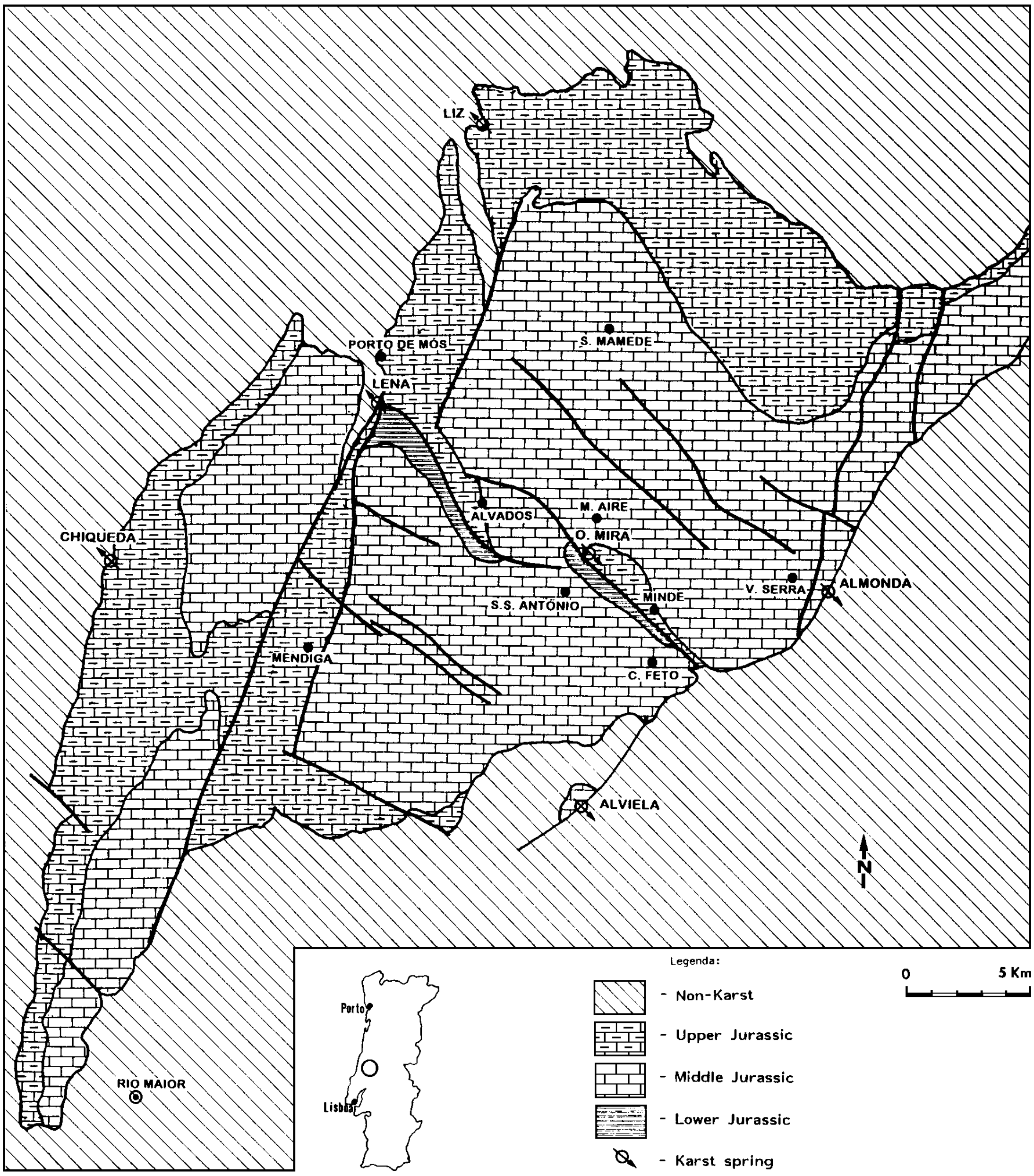

Fig. 3 – Geological map of Maciço Calcário Estremenho (simplified from Manuppella *et al.*, 1985)

2.1.2 Tectonics

The NNE faults are represented by the Fonte da Bica (Rio Maior) - Porto de Mós-Batalha diapiric structure that individualise the Candeeiros mountain and the Reguengo fault that is the west limit of the S. Mamede plateau.

Faults with NW-SE orientation cut the massif at the area of Alvados - Mira de Aire - Minde, controlling two grabens corresponding the poljes of Alvados and Minde. Those NW-SE faults and the Mendiga fault, with NNE direction, mark the limit of an elevated zone called the Santo António Plateau. Between the Mendiga fault and the one controlling the aforementioned diapiric structures it is located the polje of Mendiga, where are exposed limestones belonging to the Malm.

Geologic maps (Zbyszewski *et al.*, 1974) show three main fracture directions, NW-SE, NNE-SSW and NE-SW, which are the result of the reactivation of late Hercynian basement faults in the Mesozoic sedimentary cover. The area is an inverted zone limited southward by a long thrust over the Cenozoic Tagus Basin.

Microtectonic studies in the area have revealed post-Cretaceous WNW-ESE elongation direction, NNE-SSW Eocene and NW-SE Miocene shortenings.

Mesozoic compressive directions have rotated since Cretaceous times to a NW-SE Quaternary direction. The study of striated planes confirms this rotation and reveal that about 70% of the fault planes in the region have been formed or reactivated under N-S maximum compressive stresses (Crispim, 1993).

The comparison of cave passage directions (part of Almonda and Moinhos Velhos caves), photogeological data (region of Mira de Aire) and outcrop fracture directions (Fig. 4) show two distribution maxima around NE-SW to ENE-WSW and NW-SE to NNW-SSE (Drogue and Almeida, 1984).

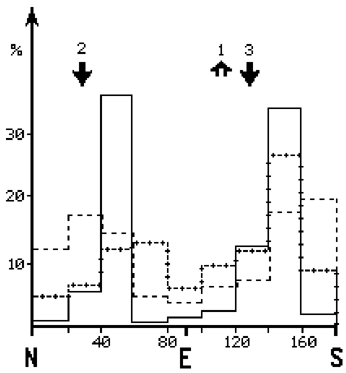

Fig. 4 - Photogeological data (a), cave passage (b) and outcrop fracture (c) distribution. The stresses trend is given by: (1) stretching of Late Cretaceous; (2) shortening of Eocene; (3) shortening of Miocene (Drogue and Almeida, 1984).

3. GEOMORPHOLOGY

The three uppermost regions of Maciço Calcário Estremenho, Serra dos Candeeiros, Santo António Plateau and S. Mamede Plateau, have different karst characteristics. However,

in all of them, dolines are more frequent and have greater dimensions in the north areas, piercing the high (500 m a.s.l.) old (late Cretaceous?) planation surfaces. On the other hand, the southern bound of the massif is bordered by a low surface (200 m a.s.l.) where occasional runoff sinks through terra rossa rich deposits into impenetrable swallets.

Most dolines have a close structural control, following NW-SE and NE-SW trends.

The two different altitude surfaces are linked by slopes with dry (Santo António Plateau) or occasional active (Serra de Aire) valleys.

Fossil caves are perched at different levels, as opened caves, collapsed dolines or sandy deposits. Some, mainly those situated along important faults, have been reactivated by later cycles, constituting temporary or permanent conduits.

Recently formed potholes show no particular distribution, sometimes being developed on the line of reactivated joints in the ancient ones.

Recently active passages are recognised only at some places, generally linking temporary active conduits.

Karstification crosses all the massif (200 meters maximum known depth) and several submerged conduits are known at least to a depth up to 80 meters beneath the present level of springs (Crispim, 1992).

One of the most impressive features of the MCE is the Minde polje. This karst depression is about 4 km by 2 km and its bottom has an average altitude of 200 m. Several temporary springs, all of them associated with important caves (Crispim, 1987), are located on its NW and NE limit. Periodically the ponors located near the town of Minde are insufficient to drain the polje and it becomes transformed into a lake.

4. HYDROGEOLOGY

4.1 General characteristics

Ground water flow in the MCE can be considered as having a high degree of organisation. This assumption is supported by the fact that its recharge area of about 700 km^2 is drained only by 5 perennial springs and a few more temporary springs. Superficial drainage is almost absent. The discharge regime of the main springs presents very rapid and significant changes. In the Mangin's classification (Mangin, 1975) Alviela spring ($i \approx 0.75$; $k \approx 0.20$) is situated in the complex karst / important saturated karst domain (Crispim, 1995). The five main springs are located at the limits of the massif at the contact with the less permeable rocks of Tertiary and Cenozoic. Two of them are located at the western margin (Liz and Chiqueda) and three in eastern and southern margin (Almonda, Alviela and Alcobertas). Some temporary springs can have an important discharge.

The definition of watersheds corresponding to each of the main springs was done using lithologic, structural and morphologic criteria and some water tracing experiments.

The spring of Olhos de Água do Alviela is the most important of all MCE. Its maximum discharge is over 1 Mm^3/day and the dry season discharge is very seldom below 30 000 m^3/day. The mean anual discharge is 120 Mm^3/year. The spring used to be one of the most important contributors in water supply to the Lisbon region through an aqueduct 120 km long. Even at present it contributes with about 12% of the total supplied.

Following in importance the aforementioned spring are the Almonda and Liz springs. The data available do not allow an estimate of the total discharge. By comparison with Alviela the total discharge of Almonda spring could be between 80 and 100 Mm^3/year and the Liz between 60 and 70 Mm^3/year.

About one hundred wells were inventoried. The majority is located in low areas near the border of the massif or the main karst depressions. They are used for water suplly to small industrial units, domestic use and cattle raising. Wells discharge is in general low, almost always less than 10 L/s. One exception is the well used for water supply to Mira de Aire, which was drilled in such a way as to intersect the Olho de Mira spring conduit in its active course. It is 100 m deep and maximum discharge exceeds 50 L/s.

In some areas piezometric data obtained from wells show abrupt changes in a short distance that seems to indicate the existence of several independent hydrogeological units.

The chemical composition of the water from Alviela spring can give a good impression of the general characteristics of karst waters from the area (mean values in 1992).

Temperature 17 ºC; Conductivity 458 µS/cm; pH 7.3; chloride 39 mg/L; nitrate 10.4 mg/L; sulphate 13.5 mg/L; fluoride 0.08 mg/L; phosphate 0.28 mg/L; calcium 72 mg/L; magnesium 6.2 mg/L; sodium 23.6 mg/L; potassium 2.2 mg/L; aluminium 0.045 mg/L; iron 0.02 mg/L; silica 4.4 mg/L. Mn, Cu, Zn, Co, As, Cd, Cr, Ni, Pb, Sb and Se are below detection limits.

4.2 Karst water tracing

Two sectors have been traced with sodium fluorescein (Fig. 5).

The northern one is the Chão das Pias area, located on the northern edge of the Santo António plateau, draining three resurgence areas that include about fifteen springs. All but one are temporary exsurgences and the total maximum discharge is about 2 m^3/s. Travel distances are 1 to 4 km for a total drop of about 300 meters. Fluorescein was found to appear on the northern resurgence area, at the river Lena springs. The average velocity of ground-water flow is between 7 m/h to 60 m/h and the maximum velocity attains 100 m/h.

The second traced area was Minde polje (Crispim, 1986). Two swallets located at the south end of the polje floor and a cave were used as injection points. One cave, two bore holes and four springs were sampled.

One temporary and two permanent springs were found to be connected with the swallets. Their discharge was about 1 to 3 m^3/s (temporary Vila Moreira spring), 8 to 10 m^3/s (perennial Olhos de Água do Alviela spring) and 2 to 10 m^3/s (perennial Almonda spring). The travel distance between the floor polje swallets and the springs is, respectively, 4 km, 8 km and 7 km. The drop is about 150 meters.

The polje was found to function as a diffluence zone, discharging simultaneously to south-eastern and south-western springs. Mean velocities shift from about 120 m/h to 240 m/h and the highest value to the maximum velocity was about 450 m/h.

Tracing performed in Moinhos Velhos cave revealed an average velocity of 16 m/h for a travel distance of 800 meters up to Contenda cave. The flow direction found in this sector is north to south up to the south main thrust, where an impervious barrier controls the circulation along it to the main springs located east and west of the transversal NW-SE fractures.

The amounts of dye recovery vary from 40% to 80%.

4.3 Pollution sources

In the plateau areas the human occupation is scarce practically without industries. So, the main types of pollution are domestic (many houses do not have septic tanks or other types of treatment), agriculture, cattle, feedlots, piggeries and chicken-rearing.

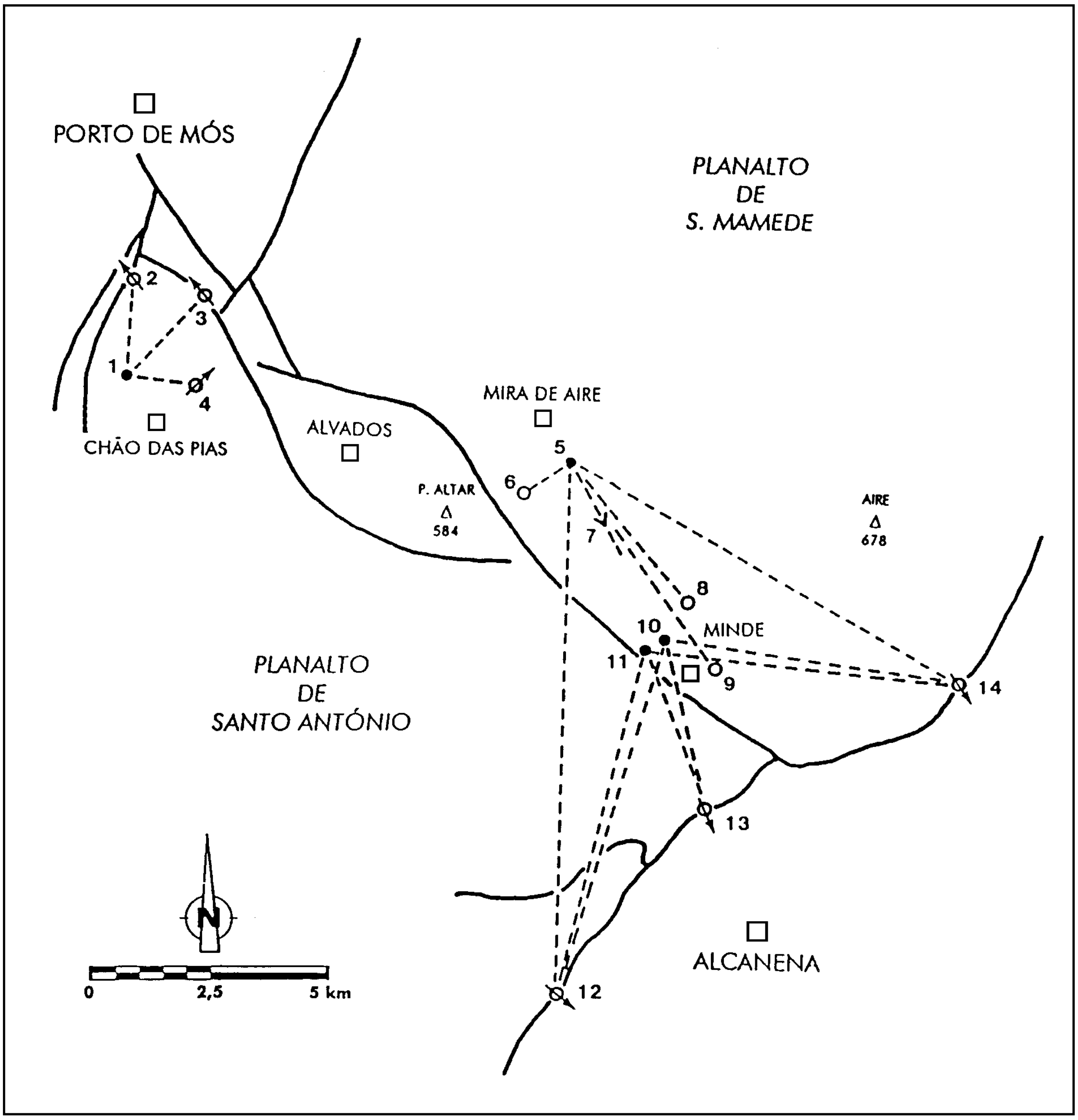

Fig. 5 – Traced flow routes. Solid line: proved connection; Dashed line: connection not verified (*in* Crispim, 1995).

The valleys and the more important karst depressions, covered with soil, attract more people and for that reason the most important towns are located there (Mira de Aire, Minde, Vale da Serra, Alvados, Covão do Coelho, Covão do Feto). In Mira de Aire and Minde are concentrated the majority of industries.

The dominant type of industry is textiles, followed by tanneries, wool washing plants, and leather plants. Great number of industrial units have little importance. The pollution produced by many of them are domestic sewage.

Until now the sewage produced has gone directly underground without any kind of treatment. This situation will be changed in the future because a system of treatment will be implemented. Other sources of pollution are piggeries, olive oil processing plants (about 30 in

all the massif) and highways. The more important highways cross the MCE in the region of karstic depressions, and in south-eastern border.

The microbiological pollution is the most important type of pollution. The impact produced by the different sources of pollution on the water quality can be summarised as follows:

- microbiological contamination: revealed by the presence of abundant colonies of coliform and other types. *Escherichia coli* frequently present. Before 1993 the presence of *Salmonella* is hardly noticeable but in 1993 was detected in 30% of the samples. The wet semester is almost always worse than the dry one. It was found that microbiological content is greater in the southeastern springs than in the interior ones (Crispim and Monteiro, 1990).
- hydrocarbons: their presence is episodic, the maximum analysed 0.3 mg/L
- heavy metals: Cr, Zn Pb, Fe, Mn has been analysed. In Alviela spring Mn, Cr, Zn and Pb are practically always below detection limit. Incidentaly some high values were detected (lead, up to 0.61 mg/L, and zinc).
- fats: up to 154 mg/L, originating from the injection of sewage of olive oil presses.
- COD
- nitrites and ammonia: sometimes their presence above MPC is noticed.

This data allow the conclusion that the most important source of pollution is urban waste water and piggeries, followed by industry and highways.

REFERENCES

Crispim, J. A. (1986). Traçagens com uranina em Minde. II Congresso Nacional de Geologia, Maleo, 2 (13): 16-17. Lisboa.

Crispim, J. A. (1987). Evolução da hidrologia subterrânea na Gruta de Moinhos Velhos (Mira de Aire). Algar, Bol. Soc. Port. Espeleol., 1: 3-8. Lisboa.

Crispim, J. A. (1992). Características cársicas das rochas carbonatadas da região central do Maciço Calcário Estremenho (Portugal). Algar, Bol. Soc. Port. Espeleol., 3: 9-18. Lisboa.

Crispim, J. A. (1993). Algumas considerações sobre a estrutura geológica dos poljes de Alvados e Minde (Estremadura, Portugal). Algar, Bol. Soc. Port. Espeleol., 4: 13-26. Lisboa.

Crispim, J. A. (1995). Dinâmica cársica e implicações ambientais nas depressões de Alvados e Minde. Ph. D. Thesis. Univ. Lisboa.

Crispim, J. A. and Monteiro, A. R. (1990). Nota preliminar sobre a contaminação bacteriológica de algumas nascentes do Maciço Calcário Estremenho. Geolis, IV(1-2): 173-176. Lisboa.

Drogue, C. and Almeida, C. (1984). Déformations cassantes et structures de magasins dans la couverture mésozoïque du Centre du Portugal (Est du Plateau de Fátima). C. R Ac. Sc. Paris, 299 (2), 9: 577-579.

Lobo-Ferreira, J. P. and Oliveira, M. (1993). Desenvolvimento de um inventário das águas subterrâneas de Portugal. Caracterização dos recursos hídricos subterrâneos e mapeamento DRASTIC da vulnerabilidade dos aquiferos de Portugal. Relatório final, 179/93-GIAS, Lab. Nac. Eng. Civil. Lisboa, 285 pp.

Mangin, A. (1975). Contribution à 1'étude des aquifères karstiques à partir de 1'analyse des courbes de décrue et tarissement. Ann. Spéléol., 25(3):581-610.

Manuppella, G., Moreira, J. B., Costa, J. G., and Crispim, J. A. (1985). Calcários e dolomitos do Maciço Calcário Estremenho. Est. Notas e Trab. do Serv. Fom. Mineiro, 27: 3-48. Lisboa.

Ribeiro, A., Antunes, M. T., Ferreira, M. P., Rocha, R. B., Soares, A. F., Zbyszewsky, G., Almeida, F. M., Carvalho, D., and Monteiro, J. H. (1979). Introduction à la Géologie Géneral du Portugal, Serv. Geol. Portugal, Lisboa, 121 pp.
Zbyszewski, G. Manuppella, G. and Veiga-Ferreira, O. (1974). Notícia Explicativa da Carta Geológica na escala 1:50 000, Folha 27-A Vila Nova de Ourém. Lisboa, 82 pp.