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# SPELEOLOGICAL HYPOTHESIS OF SALT CONTAMINATION IN THE AQUIFER OF PORT MIOU (MARSEILLE-CASSIS, SOUTH OF FRANCE)

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Resumen

Los manantiales submarinos de Port Miou y Bestouan (Marsella y Cassis) corresponden a dos puntos de venta de un único acuífero. A pesar de un flujo de cerca de 7 m3 s-1, estos manantiales kársticos no se utilizan para el abastecimiento de agua porque son salobres. Intentos experimentales de recogida de las aguas no tuvo éxito en la eliminación de la salinidad residual que quedaba cerca de 3 g l-1. Sin embargo, estudios recientes muestran que esta salinidad es exclusivamente de origen marino. Los caudales de Port Miou nos llevan a pensar que drena un vasto karst profundo en toda la Baja Provenza, en un contexto paleogeográfica muy diferente del actual. Pistas kársticos demostrar que el sistema se ha desarrollado con un nivel freático muy bajo, probablemente durante el Messiniano (crisis de salinidad). El aumento del nivel del mar Mediterráneo bloqueado los flujos de aguas subterráneas kársticas y los obligó a utilizar los paleodrains, donde las pérdidas de carga eran casi nulas, para conectar con el actual nivel de base. La contaminación salina de Port Miou podría ser realizada por un flujo de entrada de agua de mar a través de un conducto kárstico profundo. El presente estudio describe el uso de técnicas biológicas de seguimiento destinadas a poner de relieve estos flujos de agua subterránea. La búsqueda de marcadores biológicos sólo ha permitido el descubrimiento de dos nuevas especies de crustáceos que no son particularmente indicativas de un mar profundo, o incluso origen marino.

Palabras clave: karst costero / agua de mar de flujo de entrada / Messina / rastreo / crustáceos stygobiotic
Keywords: coastal karst / seawater inflow / Messinian / tracing / stygobiotic crustaceans

**Abstract:**

The submarine springs of Port Miou and Bestouan (Marseille and Cassis) correspond to two outlets of a single aquifer. In spite of a flow of ca. 7 $m^3$ $s^{-1}$, these karstic springs are not used for water supply cause they are brackish. Experimental attempts at collecting the waters did not succeed in getting rid of the residual salinity which remained near 3 g $l^{-1}$. However, recent studies show that this salinity is uniquely of a marine origin. The flow rates of Port Miou lead us to believe a vast deep karst draining the whole Lower Provence, in a paleogeographic context very different to the current one. Karstic clues demonstrate that the system has evolved with a very low water table, probably during the Messinian Deep Stage (salinity crisis). The rising of the Mediterranean sea level blocked the groundwater karstic flows and forced them to use the paleodrains, where the head losses were almost nil, to connect to the current base-level. The saline contamination of Port Miou could be carried out by a seawater inflow through a deep karstic conduit. The present study describes the use of biological tracing techniques intended to highlight these groundwater flows. The search for biological tracers has only allowed the discovery of two new species of crustaceans which are not particulary indicative of a deep-sea, or even marine origin.

**Keywords: coastal karst / seawater inflow / Messinian / tracing / stygobiotic crustaceans**

## 1. INTRODUCTION

Coastal karstic aquifers are very widespread in the whole Mediterranean basin. It may represent a substantial groundwater resource. These systems can supply important submarine springs (Paloc et Potié, 1973). Unfortunately, these springs are rarely collected because of their strong salt concentrations. In fact, coastal karstic aquifers are submitted to a salt contamination phenomenon. The mechanisms of this contamination remain unclear. First interpretations have been provided by recent studies on the residual salinity of karstic outlets (Bonacci et Bonacci, 1997 ; Arfib, 2001).

A new approach of this problematic, by the use of tracing techniques, is presented in the present study of the salt contamination of the Port Miou coastal karstic aquifer. The background knowledge about the salinity origin of the Port Miou submarine karstic spring and the presentation of new hypotheses on the salt contamination process of this karstic network are presented in the first part, then the tracing method employed and results are described and interpreted.

## 2. STUDY CASE: THE PORT MIOU COASTAL KARSTIC AQUIFER

### *2.1. Description*

The karstic massif of the Calanques, near Marseille (south of France), displays many submarine freshwater emergences. The two main outlets of Port Miou and Bestouan, are located in the bay of Cassis respectively to the east and west of the creek of Port Miou (Fig.1). The immediate catchment area of these springs, defined by tracing, (Durozoy et Paloc, 1969) includes the Urgonian and Jurassic NW part of the Beausset unit. Thus, the immediate watershed represents a surface of 200 km².

The average flow rate of these springs is estimated at 7 $m^3$ $s^{-1}$. This would actually require a watershed of approximately 1500 km² (Gilli, 2001). These springs represent the largest stream between the Rhône and Argens.

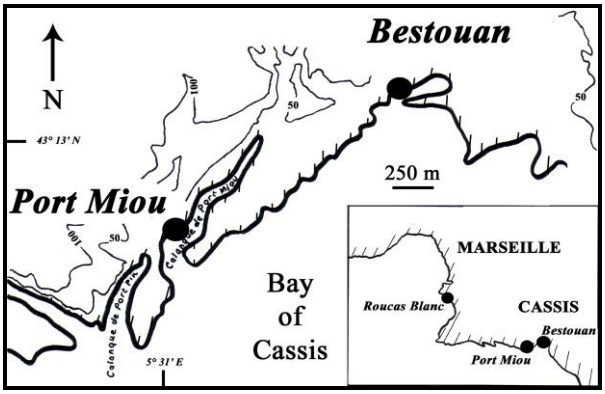


Figure 1: Location of the studied karstic springs.

### *2.2. Speleological explorations*

The network of drowned galleries has been explored for the first time in the mid-fifties by the O.F.R.S. (Corroy *et al.,* 1958). From 1964, the exploration campaigns have been carried out by the Port Miou Research Syndicate, S.R.P.M. (Potié, 1974). Between 1970 and 1990, Port Miou and Bestouan will be the occasion for many teams of divers to push back the limits of exploration. The final limits of human exploration were reached in 1992-1993 by the team of

Marc Douchet: the gallery of Bestouan was explored up to 2500 m from the sea (Douchet, 1992); In Port Miou a vertical well was discovered farther than 2 km of the entry. At this point, the speleodiver Marc Douchet will perform the feat of reaching the depth of 147 m under the sea level (Fage, 1993).

### *2.3. Salt contamination of Port Miou spring: evolution of the ideas*

The brackish waters of Port Miou have been the subject of many studies and several projects of collecting since the beginning of the sixties. At the end of the seventies, the S.R.P.M. set up currentmeters and obtained discrete measurements of the spring salinity. The first results showed a contamination of the Port Miou network by a seawater inflow compensating for the freshwater outflow, penetrating by the outlet and circulating at the low part of the underground gallery (Potié et Ricour, 1971). The discovery, in 1968, of the so-called "cloche 500" (a natural diving bell located 530 m from the outlet) marked the beginning of an important project of experimental freshwater collecting. In 1972, the gallery was partially obstructed by a light dam sit on an important layer of karstic sediments. The current speeds and salinity recordings indicated that the seawater inflow was blocked downstream of the dam. However, upstream waters maintained a salinity of 6 g $l^{-1}$ at the low water level of 1973. The hypothesis of a contamination by a complex network of fissures and conduits upstream of the dam has then been suggested to explain the residual salinity (Auriol et Bonnet, 1972).

In 1976, the gallery was completely obstructed and the augmentation of the water head in the aquifer was more than 3 m. However, the water salinity upstream of the dam seldom went down below 2 g $l^{-1}$ (Ricour, 1981).

The results of an isotopic study on sulphates in Port Miou, (Vernet et Vernet, 1980) allotting a continental origin to salinity by leaching of continental evaporites, will contribute to put an end to the collecting attempts of the spring by S.R.P.M. Recent results of an isotopic and chemical study on Port Miou waters have allowed to give a decision on the real origin of the salinity. This work shows that brackish waters of the spring are uniquely the result of a karstic and sea water mixture (Blavoux *et al.*, 2004).

### *2.4. Salt contamination process of the Port Miou aquifer: a speleogical model*

A speleological hypothesis was put forward to explain the contamination of the Port Miou spring. The seawater inflow in the Port Miou system would be carried out trough a paleodrain probably located more than 250 m below the sea level (Gilli, 2002).

Such a model of karstification is possible considering the Messinian origin of the Port Miou system (Gilli, 2001). Indeed, discharge rates of Port Miou suggest the existence of a vast karst draining the whole Lower Provence, now partly immersed 150 m below the sea level. The system could have evolved with a very low water table during the Messinian Deep Stage (salinity crisis). The deep-sea canyon of Cassidaigne could have been hollowed out by the paleospring waters of Port Miou 250 m below the present sea level. The later rising of the Mediterranean sea level would then have blocked the deep karstic drainages. Karstic flows would have been forced to run trough paleodrains, where the head losses were almost nil, to connect to the current base-level (Fig.2).

Several clues seem to confirm this hypothesis:

- The demonstration of the marine origin of the salinity in Port Miou (Blavoux *et al.*, 2004);
- The inverse relationship between discharge and salinity measurements (Potié, 1974);

- The development of the Port Miou karstic network deeper than 150 m below the sea level ;
- The description of karstic paleolandscape down to 150 m below sea level in the Bay of Marseille (Collina-Girard, 1992);
- The existence of deep-sea canyons, such as the Cassidaigne, off Port Miou, which has a karstic reculée morphology and is not linked to any major continental valley.

The present study was undertaken from this set of clues.

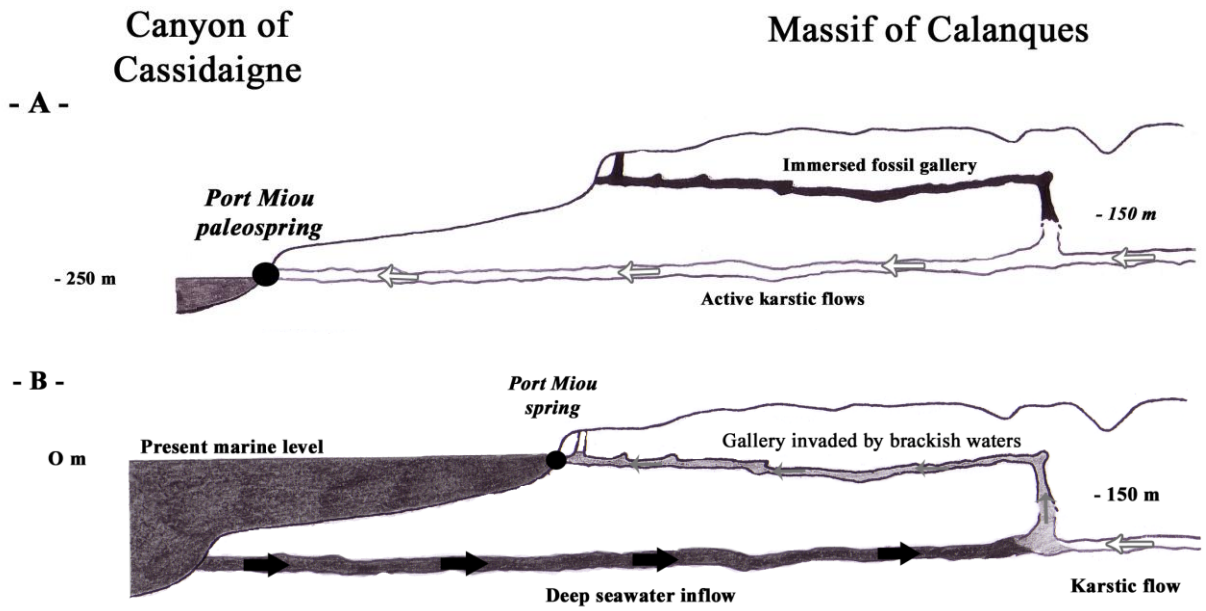


Figure 2: Explanatory diagrams of the Messinian hypothesis of the salt contamination of the karst of Port Miou. A – During the Messinian the fall of the water table level involves a sinking of the karstic network: the paleospring of Port Miou emerges more than 250 m below the present sea level. B – The raise of the sea level in the Mediterranean causes a seawater inflow in the karstic system, the deep karstic drainages are readjusted to the present sea level.

## 3. MATERIALS AND METHODS

### *3.1. Tracing of the seawater inflow: a biological approach*

The salt contamination of the Port Miou system by a hypothetical deep karstic gallery is difficult to establish with the current techniques of exploration. The method tested here to identify this phenomenon consists in seeking natural markers of a deep seawater inflow.

The main objective of a biological survey of Port Miou karstic waters upstream of the dam, is to look for faunal components with a deep-sea signature in relation with a 200-300 m-deep submarine canyon. The presence of such faunal components would strongly support the hypothesis of seawater inflow through a deep karstic aquifer. It is indeed highly unlikely that deep-sea organisms would be able to find their way upriver and reach the waters upstream of the dam. Possible life-forms to be encountered include passive or active swimming animals (adults or larvae), or sessile (fixed) organisms established on the gallery walls after their larvae have transited through the deep aquifer. Established organisms would have to be particularly tolerant

to salinity fluctuations (eurythermal), but the finding of swimming animals in suboptimal conditions is nevertheless possible. Temperatures recorded in the gallery (15-17°C; PC observations) are however suitable for Mediterranean deep-sea (200-300 m) organisms.

### *3.2. Methodology*

First-time direct observations by a biologist (PC) were conducted within the submerged gallery upstream of the dam using SCUBA on two occasions (19 and 27 August 2003). Only two dives totalling 1h47' of underwater observation could be organised for this preliminary assessment. The area directly located upstream of the dam was extensively surveyed, and a single exploration 120 m upriver was done. The gallery walls, and the sedimented bottom were carefully examined for sessile animals, while swimming organisms could be collected using a specially-designed, diver-operated suction bottle with a 400 µm mesh-size filter. In addition, a trap was designed and laid down for 8 days at 15 m depth, 1 m above the bottom near the dam area. It was baited with crushed mussels in order to attract swimming scavengers, which are usually present in caves and in the deep sea.

## 4. RESULTS

The 120 m explored upstream of the dam and the area immediately adjacent to the dam appeared devoid of any sessile organism on the walls, rocks, or sediment. On the other hand, captures using the suction bottle at depths ranging from 15 to 23 m, near the dam, as well as 120 m upstream, yielded 19 specimens of a 3 mm-long species of crustacean belonging to the order Thermosbaenacea. They represent a new species of the genus *Tethysbaena* currently being described (H.P. Wagner & P. Chevaldonné).

Together with the *Tethysbaena* n. sp., 5 specimens of a 5 mm-long new species of the amphipod (Crustacea: Amphipoda) genus *Niphargus* were captured immediately near the dam. They are also currently being described (V. Iannilli & P. Chevaldonné). The baited trap allowed to recover the remains of a single *Niphargus* n. sp.

No other life form could be seen in this environment although one sample recovered the ecdysis (moult) of an undetermined copepod.

## 5. DISCUSSION

The lack of sessile fauna is not entirely surprising, since such organisms are relatively rare in the oligotrophic waters of underground systems. However, before the construction of the dam, mussels have been reported to be abundant up to 740 m from the entrance, that is 200 m upstream of today's dam, by the 1964 and 1968 expeditions (Martin, 1968 ; Vernette, 1968). The absence of mussels at these levels today demonstrates that the construction of the dam efficiently blocked the direct inflow of seawater from the entrance, and therefore any possibility for larvae of marine colonisers to swim further upstream of the dam. Therefore, if any animal of clear marine origin were to be found upstream of the dam it would be more likely to come from a deeper underground network.

The finding of *Tethysbaena* n. sp. was expected since the 1993 Marc Douchet expedition already brought back a single thermosbaenacean from a secondary gallery, 330 m upstream of the dam (Schmit, 1993). The specimen was too damaged to allow its formal description, but it belonged to the same species currently being described (Wagner & Chevaldonné, in preparation). *Niphargus* amphipods had never been reported from Port-Miou, but it must be noted that the gallery upstream of the dam had never been directly observed by a biologist prior to this study.

*Tethysbaena* is a strictly stygobitic genus of crustaceans, only found in continental or littoral subterranean waters. Some species are restricted to fresh waters, but most have a salinity preference towards brackish waters of variable salinity as in Port Miou (Wagner, 1994). *Niphargus* species are also almost exclusively found is subterranean waters, and they are usually living in fresh waters (Karaman et Ruffo, 1986). Neither species is likely to have come from deep marine waters, they are just natural inhabitants of this peculiar ecosystem. Therefore the only rare faunal components recovered so far from Port Miou do not support the hypothesis of a deep-water aquifer. However, they do not allow us to discard it either, since very little time has been devoted to finding biological tracers to date. More exploration time is needed, as well as further baited trap deployments. Additionally, it would be useful to deploy sediment traps in an attempt to trap larvae or microorganisms coming from upstream of the dam.

## 6. CONCLUSIONS

The search for biological tracers of seawater circulation through a deep aquifer has not yielded definitive evidence yet. The two groups of crustaceans sampled in Port Miou, represented by two species new to science, are not particularly indicative of a deep-sea, or even marine origin. Rather, they are stygobitic, euryhaline species (subterranean waters with variable salinity).

Results of biological are not contradictory to the proposed hypothesis. But, new measurement campaigns are necessary to validate the mechanism of possible seawater inflow by a deep karstic paleoconduit in the Port Miou aquifer.

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