REVIEW

A REMARKABLE FINDING THAT SUGGESTS THE EXISTENCE OF A NEW GROUNDWATER BIOME BASED ON CHEMOAUTOTROPHIC RESOURCES, NAMED "OPHEL" BY F.D. POR

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Abstract. An important work of subterranean biology, signed by FRANCIS DOV POR, *Ophel: a groundwater biome based on chemoautotrophic resources. The global significance of the Ayyalon cave finds, Israel* is presented and discussed in the present paper. The subject is a remarkable discovery suggesting the existence of a new aquatic subterranean biome autonomous energy based the author calls *Ophel*, the Hebrew word for "darkness" and "netherworld". For F.D. POR, this biome links different marine chemosynthetic ecosystems in a global biospheric entity. Finally, F.D. POR hypothesizes on the existence of three overlapped biospheres: the *bacteriosphere* in the depths of the planet's crust, which does not require light or oxygen; the aphotic, subterranean *deuterobiosphere*, formed of bacterial chemosynthesis based eukaryotes and limited-supplied dissolved oxygen from above-ground; the above-ground *eubiosphere*, based on aerobic photosynthesis.
I would like to emphasize that, at my suggestion, Prof. Dr. F.D. POR participated at the 18th International Symposium of Biospeleology from Cluj-Napoca (Romania) at 10th to 15th July 2006 where he mentioned for the first time orally some data on the Ayyalon Cave and the Ophel biome.

The work that I analyze in the present paper is named *Ophel: a groundwater biome based on chemoautotrophic resources. The global significance of the Ayyalon cave finds, Israel* and it was published in the 2007 "Hydrobiologia", vol. 592, pages 1–10. The author, Dr. FRANCIS DOV POR, Emeritus Professor of Zoology at the Hebrew University of Jerusalem, is a specialist of Copepoda, Harpacticoida, marine biology, saline water bodies and mangroves. His Brazilian experience is synthesized in the book "Biomes of Brazil" (2005) and his ideas on Mediterranean biogeography and human impact in the book "Mare Nostrum" (2006).

Although he is not a biospeleologist, F.D. POR had his first contact with Israel's subterranean crustacean fauna since the early 60's.When M. TSURNAMAL and his assistants broke into a water-saturated karstic system, I quote: "they ventured into the saline and thermal artesian river Tabgha of Galilee mentioned above by scuba-diving, until they reached a water-filled cave, with walls covered by bacterial films. We proposed the hypothesis that the rich fauna of subterranean crustaceans there feeds on the sulfur bacteria (TSURNAMAL & POR, 1968). However, this line of research has been

abandoned for more than 30 years". This testimony is to keep in mind because, until April 2006, when the Ayyalon Cave has been discovered, the Movile cave from our Dobrogea was considered as the only subterranean cavity to contain a diversified subterranean community feeding mainly on autochthonous films of sulfur bacteria (SARBU *et al*., 1996) – such being an exception. Parallels have been drawn between the Movile cave community and the chemosynthesis based communities of the hot oceanic vents. In the same context, POR reminds of the discovery in thermohaline, mostly sulfurous springs, of some stygobitic crustaceans, mostly thermobaenaceans and isopods. From the given examples I will remind *Tethysbaena relicta* (Por) and *Turcolana reichi* (Por) found in springs of the Dead Sea Rift valley, while *Tethysbaena relicta* and the blind prawn *Typhlocaris galilea* Calman were both reported from the saline and worm artesian stream of Tabgha (POR, 1963).

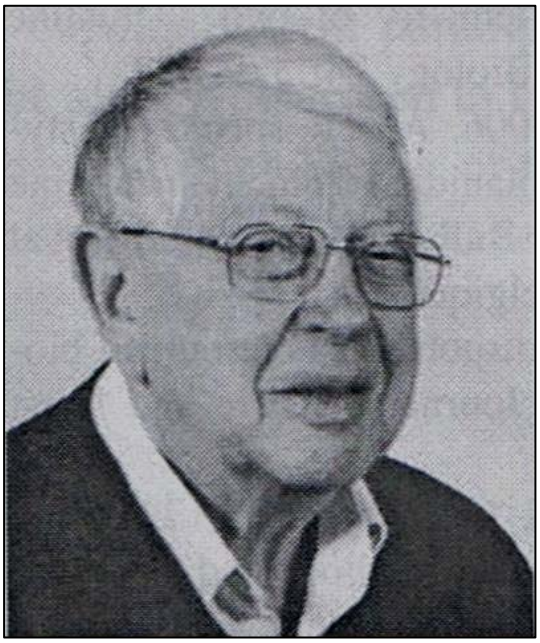

Fig. 1. – Dr. FRANCIS DOV POR, Emeritus Professor of Zoology.

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Along with the discovery of the Ayyalon Cave in the inner coastal plain of Israel, 24 km from the Mediterranean coast, the Movile Cave cannot be considered an exception anymore, when speaking of chemosynthesis-based ecosystems. As the Movile Cave, accidentally discovered by a geological drill, the Ayyalon Cave has also been accidentally intercepted during the exploitation of a limestone quarry near Ramla. Excavating down to over 100 m, the quarry reached the level of the ground water, part of the Yarqon-Tanninim aquifer – the second most important freshwater source in Israel. This aquifer is impacted by saline and warm water upsurgences, the so-called Ayyalon Saline Anomaly. The intercepted system of galleries is situated in a Turonian limestone and leads to a cavity with a small pond, 4 m deep, formed of brackish waters (over 1300 mg/l), warm up to 30°C and rich in H_2S. Dissolved oxygen is present only to a depth of 1 m. A thick mat of sulfide oxidizing bacteria float in the water and cover the receding shores of the pool.

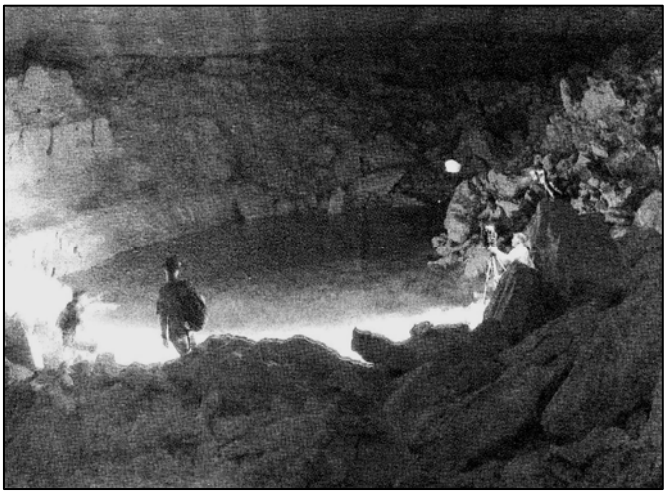

Fig. 2. –The pool in Ayyalon Cave, partial view. The two researchers in the front serve as scale (Photo I. NAAMAN).

As to the crustacean fauna observed until now by F.D. POR and his colleague Dr. CH. DIMENTMAN, it consists of immense populations of *Tethysbaena* n.sp. (Wagner in prep.), a new genus of cyclopoids and a new species of *Metacyclops* (DEFAYE & POR in press), hundreds of large *Typhlocaris ayyaloni* Tsurnamal prawns.

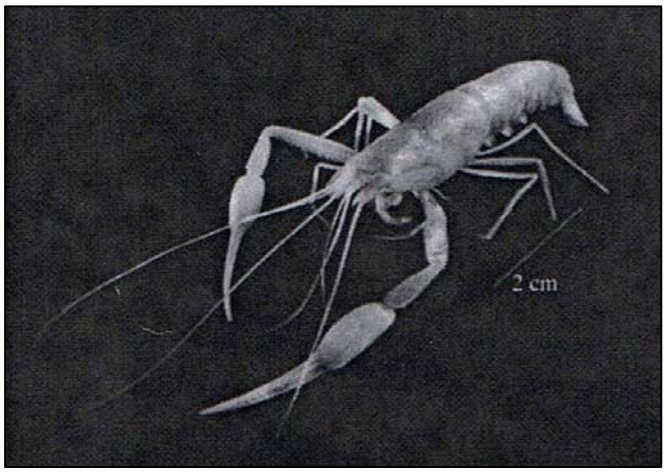

Fig. 3. – Typhlocaris ayyaloni. Male from Ayyalon Cave (photo D. DAROM).

Beside crustaceans, there are also present, on the bacterial growths, numerous ciliates and amoeboid protozoans. F.D. POR admits that "the bacterial films are obviously the sole food basis of the system, completely isolated for long geologic periods from the distant outer world". As in nature there cannot be *completely* isolated systems, this hypothesis is yet to demonstrate. It was the same for the Movile Cave that was first considered as a cavity completely isolated sometimes in geological past, which favored the speciation in the speleic environment. But the latter research demonstrated that the Sarmatian lumachellic and oolithic limestone presents an extended fissures network which enabled then and still does the vertical flux of specimen from the surface to the "bells" of the Movile Cave drowned gallery, down to a depth of 14 m and the colonization of the speleic environment took this way. At least, this is the case for some terrestrial species, as the chilopod *Cryptops anomalans*, present in the edaphic environment but also in a troglobitic population in the Movile Cave (details in NEGREA, 2004). At his turn, NITZU (2001), using isotopic C15 and C14 analysis, argued that "*C. anomalans* has access to two alternative trophic sources: a subterranean one (based on the primary chemo-autotrophic production) and an epigean one (mainly photo-autotrophic). These sources are used depending on the vertical migrations of the specimens in the net of fissures from the limestone". As a conclusion, NITZU considers that *C. anomalans* "has been selected as an ecological indicator for testing the refuge

role and the trophic support of the deep subterranean environment". The Ayyalon system though, remarks POR, is buried deep under a more than one hundred meters thick massive slab of Senonian chalk. He compares it with the equally deep and secluded Edwards Aquifer of Texas, which has already been called the most biodiverse subterranean environment.

Unlike the Movile Cave, where the terrestrial fauna is represented by dozens of species (most of them new for science, first time described from this location) and the aquatic fauna represented by few species (some of them new) – in the Ayyalon Cave the aquatic fauna is well represented (especially in quantity) while the terrestrial fauna is poorly diversified. The latter is composed from some unidentified species of mites, a pseudoscorpion representing a new tribe (ČURČIČ, in prep.), collembolans and thysanurans, as well as an interesting scorpion (*Akrav israchanani* Levy, representative of a new family).

From the observations made until now, the author concludes that "the typically subterranean crustacean fauna of Ayyalon lives in redox interphase between the oxygenated and the cross-formational rising anoxic water, where the chemosynthetic sulfide-oxidizing bacteria thrive" and that "we are probably dealing with a worldwide system, *a new biome*, which is found in groundwater networks of the continents and islands, primarily in the karstic aquifers and probably also in the basaltic tube systems". He thinks that "wherever there is an interphase between fresh underground water and juvenile sulfidic water, there are probably such self maintained subterranean bacterial-animal ecosystems, fed by chemolithotrophic primary production.[…] In many places on Earth, under our very feet, such a doppelganger biome probably exists with its throbbing, mainly aquatic macrofauna. Like in Ayyalon, encounters with groundwater life must have happened in countless mineshafts over the world, but speleologists were not present". Persuaded that his hypothesis will be confirmed by scientists of all continents, "like any other biome of the classical biosphere", F.D. POR proposes for this "continental subterranean chemoautotrophic biome the name *Ophel*, the Hebrew word for 'darkness' and 'netherworld'". Maybe a Greek or Latin derived term – as customary in Biology – would have been more suitable, but why not in the other classical language, the language of the country of the Ayyalon Cave is and where the author resides?

In the following section, called "Interphase with the bacterial world", POR is first referring to some specifications of "the interphase between the aerobic surface world and the deep "bacteriosphere" [which] is supposedly the cradle of bacterial bioproduction on which the subterranean metazoan fauna of the Ophel thrives". There are numerous caves with sulfurous fumes or hot water with nearby volcanism, but until now there are only two other cases, besides the Movile Cave already mentioned, where the animals feed on bacterial mats: the Frasassi Cave in

Italy and in Lower Kane Caves, Wyoming, USA. In both cases the species are only trogloxenes. In the case of the Ayyalon Cave, water from a deeper confined aquifer penetrates under pressure into the Ayyalon phreatic system. The geothermic heating would be the source mildly warm water. Another source for the sulfurous groundwater admixture would be the fossil fuel which supplies hydrogen sulfide for a bacterial as well as for a fungal biomass. For the Ayyalon Cave, one proposed possibility is that a confined aquifer in the bituminous Mount Scopus formation empties into the Ayyalon aquifer and supplies the sulfurous water.

In the following part, POR reviews the literature referring to "other continental interphase biomes". Before analyzing the content of this section, it is necessary to introduce the biome definition according to *Environmental Encyclopedic Dictionary* (C. PARVU, coord., 2005) as well as the classification of the aquatic subterranean environments according to the *Short dictionary of terms for the underground terrestrial and aquatic environments and their fauna* (ŞT. NEGREA, 2004). *The biome* is defined as a complex of biocoenosis interacting within complex, interdependent ecological systems which are manifesting the same kind of interaction with the climate and the regional substratum. Most important, this term must not be mistaken for the *ecobiome* or the *macroecosystem*.

As to the classification of the aquatic subterranean environments (*Stygal*), it can be presented shortly as follows:

1. *Aquatic permeable hypogeic environments "in big*" (*Karstostygal*). Here are included all the water bodies that use the fissures and the cavities from the karstifiable rocks:

- *Speleic waters* from the three areas: the percolation or vadose area (gours, stalagmite heads water, stalagmitic dam lakes etc.); the circulation, epiphreatic or amphibious area (permanent or temporary subterranean water courses, the water remained in the temporary dried riverbed); the drowned, phreatic or saturated area (accessible or not through sump lakes or drilling pits); in the Movile case, the water is mesothermal (21°C).
- *Artificial karstic cavities waters* (mines, salt mines, quarries).
- *Inaccessible natural karstic sinkholes waters* (surfacing through rock cut galleries, deep drilling pits etc.)
- *Caves and other anchialine habitats form the intertropical zone*, containing marine water and being sometimes open to the surface (cenotes in Mexico, grietas and casimbas in Cuba etc.).

2. *Aquatic permeable hypogeic environments "in small" (interstitial waters).* This category includes various types of water that fill the porous or granular sedimentary rock interstitions:

- *Groundwater soaking the porous rocks* at large and very large depth, artesian or not.

- *Phreatic waters s.str*. (*Eustygal*) that fill the pores of the sediments situated above the impermeable layer and forms the water table from small and medium depth, accessible through wells and drills.
- *Mobile sediments interstitial waters*. This category includes a large variety of interstitial waters in the hypogeic area: hyporrheic waters that accompany running epigean waters under their main riverbed or river armor, including the ones in the caves (*troglorhithrostygal*); interstitial waters that fill the sediments from the shores of the stagnant freshwater bodies (*limnostygal*); interstitial waters from sand and gravel artificial filters (used for drinking water processing); interstitial waters of the marine sand beaches (*mesopsammal* or *thalassomesopsammal*); interstitial waters of the marine sublittoral; interstitial waters of salty and brackish lakes bank sediments.
- *Trickling colluvial and eluvial areas waters*. This is the biotope described by M. NESTROV (1962) under the name of "*hypothelminorheic*" (syn. *Pedostygal*).
- *Antropic installations groundwaters*. This includes drinking water from pipes with sediment deposits, water tanks and all kind of reservoirs, coming mainly from the phreatic environment.
- *Spring upwelled groundwater*. This includes all types of springs: limnocrene, reocrene and helocrene springs aquifer supplied, karstic springs, thermo-mineral springs etc. Being an ecotone, the springs are inhabited by a mixture of subterranean and epigean fauna.

As noticed by F.D. POR, the continental hypogeic biome, Ophel, "is connected to another worldwide chemoautotrophic biome: the interstitial waters of the sandy shores of the sea and inland waters" – in other words, to some of the waters mentioned above as belonging to the "mobile sediments interstitial waters" category. I would like to point out the statement of the author that "in the deeper layers of the sandy sediment, or in the presence of excessive organic matter, the sand turns anaerobic and sulfide bacteria take over". According to the literature, it is here, at the contact between the aerobic and the anaerobic sands that the so-called *thiobios* is developing, with its characteristic fauna, mainly ciliates, flatworms and nematodes. Numerous crustacean species inhabit the anoxic sands, the most characteristic being those of the microaerobic ancestral order of the Cephalocarida. In this thiobios, there are even species that live in symbiosis with sulfide bacteria. Por is also reminding us the rich fauna recently discovered in the hydrological stratified subterranean salt pools of the Australian calcaretes which is also feeding on bacterial films as well as the so-called anchialine habitats, which are subterranean bodies of marine water unavailable for research except occasional openings to the continental surface, classically called cenotes in Mexico, unless accessed by submarine diving. (In my biospeleological expeditions in Cuba in 1969 and 1973 I had the opportunity to take part, together with L. BOTOSANEANU and T. ORGHIDAN at a subterranean fauna sampling in this cenotes, casimbas and grietas).

POR is also quoting L. BOTOSANEANU and T.M. ILLIFE which described, in 2006, from an anchialine cave in Bahamas, 7 species of Remipedia and 2 Thermobaenaceans. This cave presented a halocline several meters thick "with wispy clouds of hydrogen sulfide" – which demonstrate that only the chemosynthetic bacteria can provide the energy for the large populations in the anchialine caves. In the anchialine systems, bacterial concentrations develop in the halo- and chemocline that separates the freshwater from the underlying marine water. At the end of this section, POR states that "one may assume that countless 'subterranean estuaries' accompany continental shores and islands which, unlike the classical anchialine habitats, are not open and accessible from land. In this hidden estuaries", concludes Por, "the interaction between the inflowing seawater and the out flowing fresh water occurs. […] One can therefore suppose that there exists interfingering between the aquatic animal world of Ophel and that of the anchialine and subterranean estuaries, the presence of the Thermobaenacea in both systems argues for this."

In the seventh section of his work, called "The ancestry of Ophel", F.D. POR emits a series of interesting and, some, daring hypothesis. Supposing that the global existence of Ophel is a reality, it means we are dealing with a water-based biome (although a part of its fauna is terrestrial) with a characteristic fauna, mainly composed of crustacean species. The associate terrestrial fauna feeds on the water surface, on the mats of the walls surrounding the water or preys on the bacteria-eaters. It is possible that Ophel is as old as the surface biomes and one can assume that the animal invasion of Ophel started back in the Paleozoic."The hot bacteriosphere might have been at the origin of life, on even be present on planet Mars, but animals appeared on the scene only secondarily, since they need free oxygen" concludes POR. "the old evolutionary history of Ophel can be inferred from the fact that there are several tens of crustacean taxa at the family, order and even class level, which live exclusively in subterranean waters. Examples are class Remipedia, superorder Pancarida, the orders Speleogriphacea and Bathynellacea and others. Another argument would be that several of these exclusively subterranean taxa have a worldwide, Pangean distribution (as the Parabathynellidae, the Parastenocaridae and the Bogidiellidae) and a pan-Gondwanian distribution (such as orders Remipedia and Speleogriphacea). The stygobionts are thus not accidental relics or living fossils, states Por. Despite its old age, the colonization of Ophel and of the other chemotrophic subterranean environments has been and still is an active process, in the opinion of some reputed biospeleologists like R. ROUCH and D. DANIELOPOL.

The last section of the presented work is suggestively entitled "Three biospheres". I quote: "The concept of Ophel, a world-wide continental subterranean chemosynthesis-based biome, is like a missing piece of a puzzle, linking up with the different previously known marine chemosynthetic systems into a world-embracing

biospheric entity". The provided scheme is also very explicit. In the conclusion of his work, F.D. POR states that, in fact, there are three superposed biospheres: the *bacteriosphere* from the depths of Earth's crust, which does not require light or oxygen; the aphotic subterranean *deuterobiosphere*, formed of eukaryotes based on the bacterial chemosynthesis and very little dissolved oxygen from above-ground; the eubiosphere from the Earth's surface, based on aerobic photosynthesis. In my opinion, the fact that these three proposed biospheres are interfingered it means that there is actually only one and unique biosphere, composed of three interdependent "sub-biospheres", forming a united whole, and I consider the three divisions as purely conventional.

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