Black Holes of the Bahamas: what they are and why they are black

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Abstract

Black holes are vertical cave systems, which have no known lateral passages and form in the interior stable regions of the larger Bahamian islands. They are found where the land is transitional between submerged and dry land, not dissimilar to saltmarsh environments. Most Black Holes are located in the central to western side of the island of South Andros in the Bahamas, although one has been found on the northern transitional shore of Grand Bahama Island. The water in these holes appears black in colour due to the presence of a 1 m thick microbial layer located within the upper third of the water column (18–19 m) at the boundary between the oxic low salinity upper water mass and the denser anoxic saline water layer. The boundary between the two water masses is characterised by sharp discontinuities in physico-chemical gradients: salinity increased from 12 to 35 psu; temperature from 29°C to 36°C; pH decreased from pH 8.6 to 6.45 and dissolved O_2 from 6 mg/l to < 1 mg/l. Anoxygenic phototrophic bacteria belonging to the genera *Allochromatium* and *Thiocapsa* have been identified as the dominant members of this warm (36°C), saline, sulphide rich layer and achieve population densities $> 10^7$ viable cells/ml. Calculations reveal that this layer of anoxygenic phototrophic bacteria, in the South Andros Black Hole may have a biomass content of approximately 5.06 ton dry weight.
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1. Introduction

The islands that today comprise the Bahamas began to form some 200 million years ago at about the same time as the North Atlantic Ocean. The islands are composed of modern-day carbonates and have a similar chemical composition to those recovered by drilling from a depth of 6.1 km (Sealey, 1994). Virtually, the entire rock platform is composed of limestone. Although the Bahamian islands are considered to be stable a number of studies have demonstrated that the platform is slowly sinking (Mullins and Lynts, 1977; Garrett and Gould, 1984). Because of their geographical location on the boundary between the temperate and tropical zones summers are wet and winters relatively dry. Temperatures range from 25–32°C in summer to 17–24°C in winter.

Topographically, the Bahamian islands can be divided into four different zones: the ridgelands, the wetlands, the rocklands and the coastal zone (Sealey, 1994). Ridges vary in height from 10 to 45 m above ordnance datum and several have relict cave systems formed during the late Pleistocene when sea levels were 6 m higher than today (Mylroie and Carew, 1990). Wetlands

can be found in the interior of the islands often as hypersaline lakes or along the coastal margins as tidal flats. Because of the elevated salinity and sediment instability plant growth is severely restricted and cyanobacterial mats are a common feature (Neumann et al., 1988). The coastal tidal flats often have tidal creeks running through them. On Grand Bahama one such creek is hydrologically connected to the "Lucayan Caverns" (Palmer, 1985). The rocklands of the Bahamas have a varied topography. The highly altered surface is inundated with dissolution features such as solution pits and surface collapse. Some of these pits vary in depth from 1 m to several metres (Pace et al., 1992). In some areas the surface rock has collapsed into small channels, which is the result of the dissolution of the supporting rock a few centimetres below the surface. These features commonly start near ridge tops and can be followed to the base of the ridge where these channels drain into brackish/hypersaline lakes. The drainage of meteoric water into the brackish/hypersaline lakes creates a more reactive water mass around the edge of the lake resulting in aggressive dissolution of the surrounding limestone and leading to the formation of a phyto-karst landscape, a feature referred to as "moon rock" (Davis and Johnson, 1988).

Within the porous carbonate platform of these low-lying islands some of the world's most spectacular

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underwater cave systems have developed. These cave systems can be laterally and vertically very extensive. Lateral passages can extend for several kilometres whilst the vertical depth may range from 10 to several hundred metres (Schwabe et al., 1997). The submerged cave systems can be classified into three distinct types depending on their mode of formation; (i) horizontal caves, which have formed within the depth range of the freshwater lens often with lateral passages connecting to the sea; (ii) fracture-guided caves which develop along bank margin failures and (iii) vertical caves with no known lateral passages. The former are collectively known as blue holes and as a subgroup of the vertical caves, the latter as black holes. Black holes were first observed during a flight over the south-western interior of South Andros Island (Palmer, 1985). They are particularly striking natural features in that the openings at the surface are almost perfectly circular. The initial belief was that these features were created by meteor impact. One especially spectacular black hole has been named, "The Black Hole of South Andros", (GPS coordinates $23° 58' 03''N/077°42' 22''W$). The entrance to this cave is the largest found in the Bahamas. The opening is $300 \pm 15\,m$ in diameter with a maximum water column depth of $47\,m$ (Fig. 1b). Within the vertical opening of the South Andros Black Hole, from the surface to a depth of approximately $17.6\,m$ the walls are covered with a $\sim 0.5\,m$ thick layer of algae. The top $17.6\,m$ of water column supports small fish populations along with zooplankton comprising species of ostracods, thermosbaenaceans, copepods and decapods. At $17.8\,m$ depth, a wispy, thin white bacterial veil overlies what initially appears to be a muddy floor. More detailed investigation show that in reality this is a $1\,m$ thick layer of phototrophic bacteria, which in situ appears black in colour. Where the layer makes contact with the rock, there is a sharply defined dissolution notch in the cave wall.

In this paper we describe the first investigation of the South Andros Black Hole, and endeavour to explain what black holes are, how they form, the physico-chemical gradients which develop in the water column and the identity of the dominant phototrophic bacterial populations present within the microbial layer.

2. Material and methods

2.1. Description of sampling site

Fig. 1 shows the location of the South Andros Black Hole on the island of South Andros. Because of the difficult terrain the site could only be accessed by air. Water samples were collected at selected depths using self contained underwater breathing apparatus (SCUBA) and depth profile measurements in the South
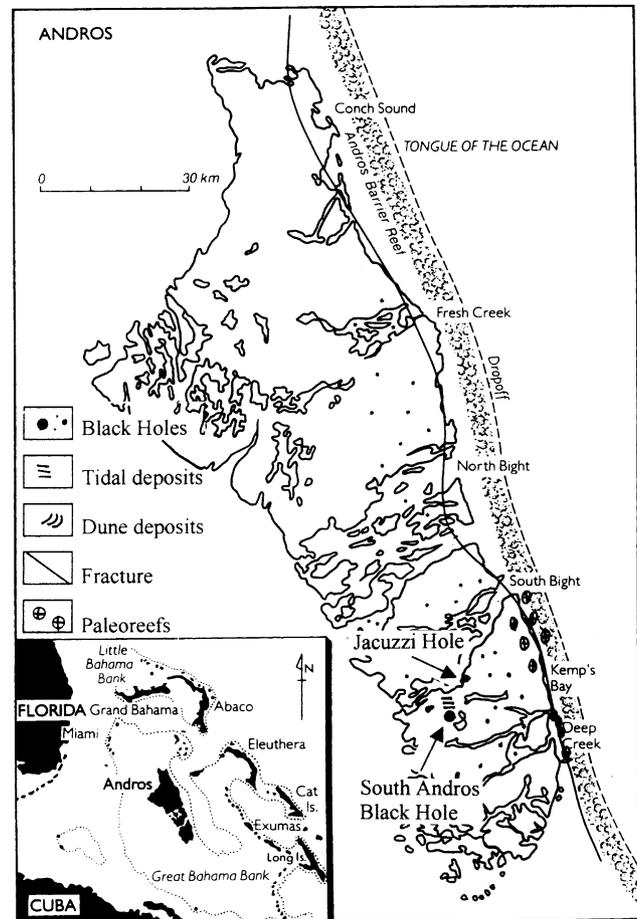

Fig. 1. Map of Andros Island showing the location of the South Andros Black Hole. Inset map shows the location of Andros Island in relation to the Bahamas Islands group.

Andros Black Hole were obtained using an inflatable dinghy positioned in the centre of the opening (GPS $23°58'03''N/077°42'22''W$). Depth profiles of the prevailing physico-chemical gradients were made in the early afternoon on 27 June 1999 and water samples collected the following day. The bathymetry of the South Andros Black Hole was determined along a NE to SW transect (see Fig. 2b) using a plumb line deployed from an inflatable along the line of the transect. Accurate position fixes for each depth measurement point were made from the shore using a Geo-Fennel FET 200-1 theodolite (EO-Fennel Gmbh, Germany). The ambient air temperature at the time of sampling was $35°C$.

2.2. Measurement of physico-chemical gradients

Depth profiles of the physico-chemical gradients present in the water column were measured using a Datasonde 3 Multiprobe Logger (Hydrolab Corp. Inc., Austin, Texas). Measurements were made by slowly lowering the Hydrolab, whilst in the dinghy, with its sensing probes and taking readings at $20\,cm$ depth
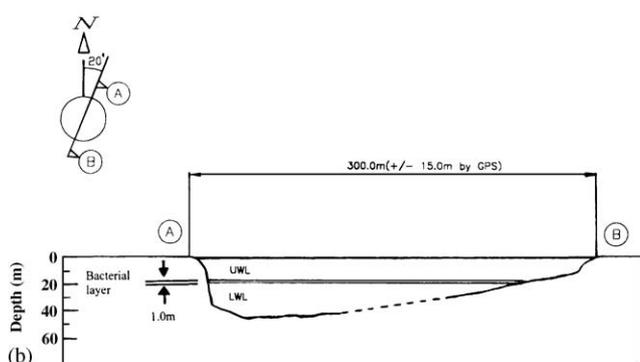
Fig. 2. Appearance of the South Andros Black Hole, (a) aerial view and (b) bathymetry. UWL, upper water layer; LWL, lower water layer; —floor area not surveyed.

increments until the bottom was reached. Prior to deploying the Hydrolab the individual sensors (pH, dissolved O_2 and salinity) were calibrated according to the manufacturer's instructions. For dissolved O_2 measurements the probe was additionally calibrated for the local barometric pressure on the day of deployment. The temperature probe was calibrated and pre-set by the manufacturer and required no further adjustment.

2.3. Collection of water samples

SCUBA was worn into the sample site to collect water samples. Duplicate samples were collected using sterile, O_2 free N_2 gas (OFN) filled 500 ml Duran laboratory bottles (Schott Glass GmbH, Germany). The bottles were opened at measured depths (surface, 8, 12, 17, 18, 19 and 34 m). Once full, the screw cap was replaced. The collected samples were placed on ice prior to transfer to the laboratory for subsequent analysis. Collection took place at mid-day on 28 June, 1999.

2.4. Sulphide determination

Sulphide concentrations were determined by the methylene blue method (American Public Health Association, 1975) using a HACH DR/2010 Spectrophotometer (Hach Corp. Inc., Loveland, Colorado). The detection limit for S^{2-} is 0.1 mg/l. Samples were diluted in degassed distilled water where necessary.

2.5. Enrichment and isolation of phototrophic bacteria

Aliquot volumes (1 ml) of water collected from the dense microbial layer at 17.8 m depth were used to inoculate enrichment cultures for anoxygenic phototrophic bacteria. The enrichment media used was prepared according to the method of Pfennig and Trüper (1992) and dispensed into 50 ml Wheaton vials (Alltech Associates Inc, Deerfield, Illinois). The enrichment cultures were incubated at 30°C and light intensity of 500 lx from a tungsten lamp (16 h light and 8 h dark). At selected time intervals samples were removed for microscopical examination using an Olympus BH2 phase-contrast microscope. When significant numbers of bacterial cells with the characteristic cell morphology of purple sulphur bacteria had developed in the enrichment cultures 1 ml samples were aseptically removed and transferred to deep-agar shake tubes in order to obtain pure cultures. Pure cultures were obtained by repeated passage through agar shake dilution series according to the method of Pfennig and Trüper (1992). The purity of the cultures was checked by both microscopical examination and growth tests in Difco AC medium (Difco Laboratories, Michigan, Illinois).

2.6. Characterisation and identification of the anoxygenic phototrophic bacteria

The phototrophic bacteria were characterised on the basis of their cell morphology, photopigment composition and carbon source utilisation. They were identified to genus and species level according to the taxonomic schemes of Imhoff et al. (1998) and Pfennig and Trüper (1989, 1992).

3. Results

Bathymetry and physico-chemical gradients of the South Andros Black Hole. Data presented in Figs. 2a and b show the physical appearance and bathymetry of the South Andros Black Hole. In addition to the characteristic dark almost black appearance of the surface water the most striking feature of this 300 m diameter water-filled cave system is its almost perfect circular symmetry. An underwater survey of the system shows that the floor of the Black Hole shelves more gently from the southern side whereas the northern face is much steeper. No lateral passages have been observed in this or any other black hole cave system that has so
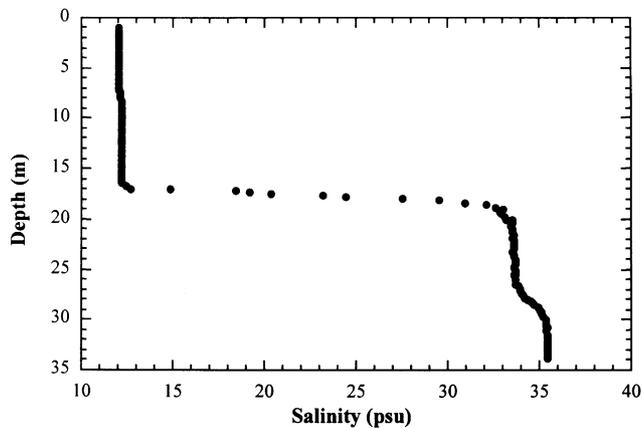
Fig. 3. Salinity profile of the South Andros Black Hole measured in the early afternoon on 27 June 1999.
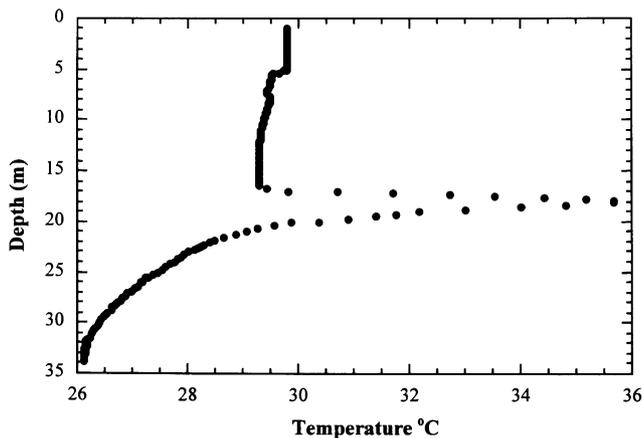

Fig. 4. Temperature profile of the South Andros Black Hole measured in the early afternoon on 27 June 1999.
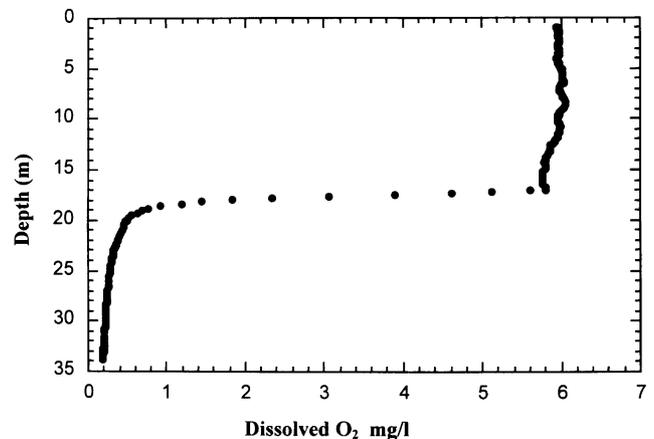

Fig. 5. Dissolved oxygen profile of the South Andros Black Hole measured in the early afternoon on 27 June 1999.
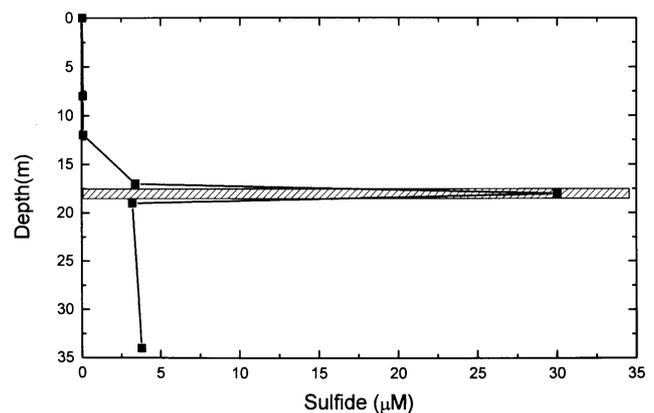

Fig. 6. Free sulphide profile of the South Andros Black Hole and position of the dense microbial layer in the water column determined in the early afternoon on 27 June 1999. Hachured area shows the position of the metre thick bacterial layer in the water column.

far been surveyed. The maximum measured water depth of the areas so far surveyed is 47 m. Depth profiles of salinity (Fig. 3) show that the water column had an upper brackish layer with an almost uniform salinity of 12 psu overlying a deeper saline layer with a salinity of 33–35 psu. The boundary between these water masses at 17.8 m was sharp indicating that little mixing occurs. Temperature profiles (Fig. 4) show an almost uniform 29°C in the upper water layer with a very marked increase at the thermocline to 36°C followed by a progressive decrease reaching a minimum of 26°C at 35 m depth. Dissolved oxygen profiles follow a similar pattern (Fig. 5) with the upper brackish water mass having an almost constant dissolved O_2 concentration of 6 mg/l which decreases sharply at the thermocline to <1 mg/l and further declines with increasing depth. Sulphide was as expected almost undetectable in the oxic upper water mass and reached a maximum, albeit low concentration of 30 μM at the 17.8 m depth horizon (Fig. 6). The pH profile (Fig. 7) also exhibited a sharp

discontinuity at the thermocline decreasing to a value of pH 6.45 at 18 m depth whereas the overlying brackish water mass was alkaline with an almost constant value of pH 8.6.

3.1. Distribution of phototrophic bacteria in the South Andros Black Hole

A significant feature of the water column in the South Andros Black Hole was the presence of a 1 m thick layer of bacteria at 17.8 m depth (Fig. 6). The water samples collected from this layer had a distinct pinkish/reddish coloration suggesting the presence of anoxygenic phototrophic bacteria. Although no quantitative determination cell numbers were determined on site subsequent laboratory studies conducted in the UK indicated that the population densities of the phototrophic bacteria were ~1 to 5×10^7 viable cells/ml. Microscopical observation by both bright-field and phase-contrast microscopy showed the presence of phototrophic purple
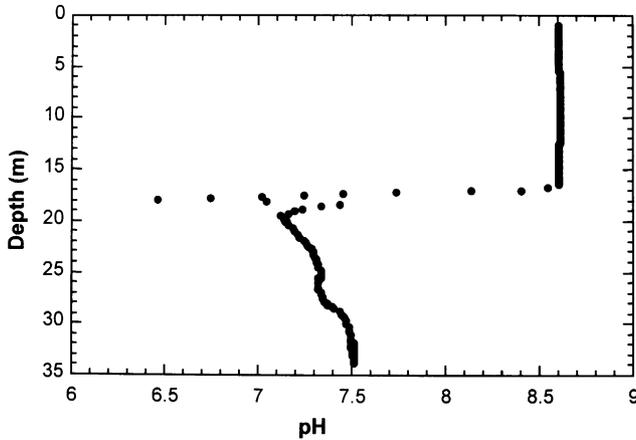
Fig. 7. The pH profile of the South Andros Black Hole measured in the early afternoon on 27 June 1999.

sulphur bacteria characterised by the presence of intracellular sulphur granules. The depth distribution of these bacteria at 17.8 m depth in the South Andros Black Hole is consistent with their requirements for micro-oxic conditions, sulphide and light for photosynthesis (Pfennig, 1967; Caldwell and Tiedje, 1975; Guerrero et al., 1987; Overmann et al., 1996).

3.2. Isolation and characterisation of the dominant purple sulphur bacteria

From enrichments inoculated with water samples collected from the microbial layer from the 17.8 m depth horizon pure cultures of the dominant phototrophic bacteria were isolated in pure culture by repeated passage through agar shake tubes. Data presented in Fig. 8 shows the morphology of the two dominant purple sulphur bacteria isolated. Isolate BH-1 is a nonmotile spherical purple sulphur bacterium, which accumulates elemental sulphur intracellularily. Densely grown cultures are pink in colour when the cells were loaded with sulphur globules. The in vivo absorption spectrum of sulphur-free cells exhibited the typical absorption maxima of bacteriochlorophyll a containing phototrophs (maxima 851, 799, 375 and 590 nm). Additional photopigment absorption maxima of 480, 515 and 550 nm are typical of carotenoids of the normal spirilloxanthin series. On the basis of the characteristic cell morphology, absence of motility, photopigment composition and absence of gas vacuoles isolate BH-1 was identified as a strain of *Thiocapsa roseopersicina* according to the taxonomic scheme of Pfennig and Trüper (1992). Isolate BH-2 is a motile rod-shaped purple sulphur bacterium which like isolate BH-1 accumulates sulphur globules when grown in the light in the presence of sulphide. Mass cultures are brownish–red in colour when full of elemental sulphur. In vivo absorption maxima of cell suspensions of sulphur
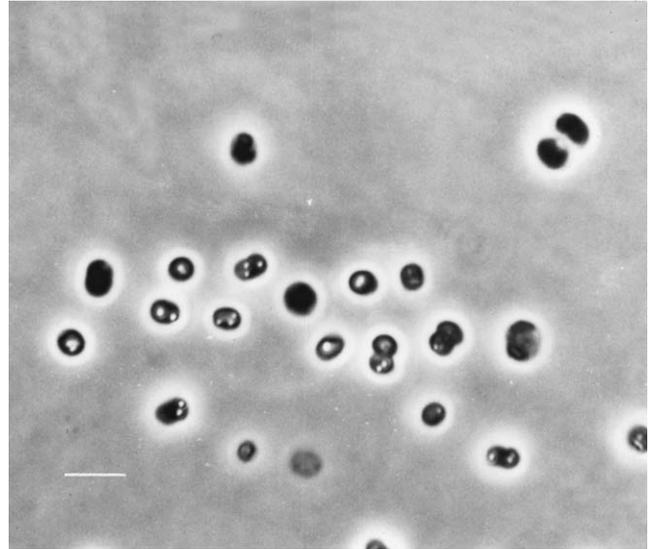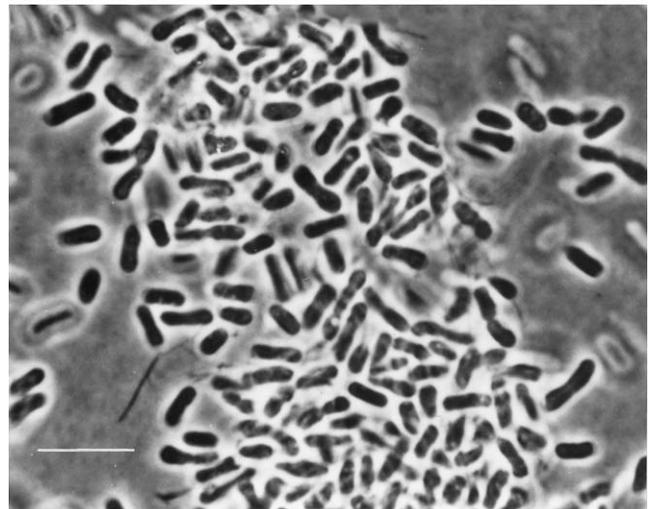
Fig. 8. Phase-contrast photomicrographs showing the morphological appearance of the dominant purple sulphur bacteria (a) *Thiocapsa* strain BH-1 and (b) *Allochromatium* strain BH-2. Bar marker = 10 μm.

depleted cells are typical of bacteriochlorophyll a (maxima 853, 800, 592 and 375 nm) and similarly the carotenoids are of the normal spirilloxanthin series (488, 515 and 550 nm). These data indicate that this bacterium is a member of the genus *Chromatium* (Pfennig and Trüper, 1989, 1992). More recently the taxonomic position of members of the *Chromatiaceae* has been reassessed on the basis of their salt tolerance (Imhoff et al., 1998). Isolate BH-2 grows optimally at 20 psu (Herbert and Schwabe, unpublished data) and according to the scheme of Imhoff et al. (1998) would be considered to be a marine species belonging to the genus *Marichromatium*. However, molecular studies (Herbert and Schwabe, unpublished results) indicate that isolate BH-2 is more closely related to the freshwater species

Allochromatium vinosum. An unusual feature of isolate BH-2, which distinguishes it from *A. vinosum* is that although it has the normal spirilloxanthin series of carotenoids as photopigments, the level of spirilloxanthin compared to lycopene and rhodopin is unusually high. In this respect the carotenoid composition is similar to that found in isolate BH-1 and may reflect the spectral composition of the light penetrating to these depths in the South Andros Black Hole.

4. Discussion

The Bahamas platform consists of a series of carbonate banks, which have built up since Jurassic times along the subsiding continental margin of eastern North America. The sequence of shallow water limestones consisting of dolomite, aragonite, calcite and gypsum have accumulated over the last 200 million years to a thickness >6 km. It is these deposits which today form the low-lying islands of the Bahamas. Andros Island, the largest of the group, lies near the eastern border of the Great Bahama Bank. The Tongue of the Ocean trough, which is 1.8 km deep at its deepest point, separates the Great Bahama Bank into western and eastern sections. Below sea level, extensive cavern systems develop within these carbonate platforms. Three main types of cave system have been described of which two are known as blue holes (Carew, manuscript in preparation, Schwabe, manuscript in preparation). As their name implies they appear blue due to a combination of reflection of the blue sky from the water surface and the white carbonate sand deposited on the cave floor and walls. In the horizontal cave systems tidally driven water exchange occurs. However, only the marine section is exchanged during each tidal cycle and the physico-chemical and biological gradients remain relatively unchanged.

The third type of cave, a vertical cave, is the black holes, which form in the estuarine and coastal areas of Andros and Grand Bahama Island (Schwabe, 1998). These recently discovered vertical cave systems are distinct from blue holes in that they develop from the surface downwards and appear to have no direct link to the sea except through rock fractures and local porosity. A further distinctive feature is that do not appear to have any lateral passages leading away from the entrance which distinguishes them from sinkholes (Sealey, 1994). Water exchange is as a result severely restricted and the physico-chemical gradients that develop are therefore stable for long periods of time. This is clearly evident from the data presented in Figs. 3–7. Whilst the depth profiles of salinity and dissolved oxygen are typical of the water column of a meromictic lake the temperature profile (Fig. 4) with a maximum of 36°C at the boundary between the upper

brackish water mass and the saline lower layer is highly unusual. Equally unusual is the relatively uniform temperature of the upper water mass. This can be explained by the fact that at the time of sampling a strong breeze was blowing across the surface which was sufficient to induce mixing of the upper water column.

The observation that the recorded sharp increase in temperature is coincident with the 1 m thick microbial layer and other significant changes in measured physico-chemical parameters indicate that this anomaly was not an artefact. Other investigators have also reported similar high temperatures below the pycnocline in other cave systems in the Bahamas. For example, Marano-Briggs (2000) reported temperatures up to 41°C in the Tarpon Blue Hole in Stafford Creek and Schwabe (unpublished data) has recorded a temperature of 37°C in the Jacuzzi Black Hole. In the absence of recent or ongoing igneous activity within the Bahamas carbonate platform there is no immediate geological explanation for the recorded temperature anomaly in the South Andros Black Hole and alternative mechanisms need to be considered (Mullins and Lynts, 1977). One theory worthy of detailed consideration is that the mass populations of anoxygenic phototrophic bacteria present at this depth horizon may be dissipating excess light energy as heat. Evidence to support this concept is that light absorption by carotenoids is recognised to be of major ecological importance in deeper bodies of water, because light wavelengths between 450 and 550 nm penetrate deepest into the water column (Pfennig, 1967; Culver and Brunskill, 1969). Data presented in this study show that the dominant anoxygenic phototrophic bacteria in the microbial layer are members of the Chromatiaceae. Both have carotenoids of the normal spirilloxanthin series, which strongly absorb light between 480 and 550 nm. As stated earlier *Allochromatium* isolate BH-2 is somewhat unusual in that it has a higher spirilloxanthin content than other related *Allochromatium* species (Guyoneaud, personal communication). Spirilloxanthin absorbs maximally at 550 nm which is optimal for capturing the light wavelengths that penetrate to 17.8 m in the South Andros Black Hole. Several studies have shown spirilloxanthin has a relatively low efficiency ($\sim$30%) in channelling captured light energy to the photosynthetic reaction centres in purple sulphur bacteria (Goedheer, 1959; Cogdell and Frank, 1987). The remaining captured light energy (>60%) is therefore potentially available for dissipation as heat. Population densities of the purple sulphur bacteria in the microbial layer are in the order of 10^7 viable cells/ml which is equivalent to a biomass of $\sim$100 mg dry wt/l. Extrapolating this value to the volume of the whole microbial layer (50.650 m^3) and assuming that the cell density is uniform, yields a conservative biomass estimate of 5.06 ton dry wt. It is not inconceivable therefore that dissipation of captured

light energy as heat by such a large biomass of photosynthetic bacteria over a sustained time period could lead to the recorded temperature maxima at 17.8 m. Since mixing within the water column is severely restricted the physico-chemical gradients which develop in the South Andros Black Hole are very stable which would account for the observed sharp temperature transition at the thermocline.

The presence of dense phototrophic populations of purple sulphur bacteria also explains why the South Andros Black Hole appears black and not blue. Strong light absorption by the carotenoid-rich cells prevents light scattering and hence viewed from the air the water surface appears black. The sulphide profile data (Fig. 5) show that sulphide concentrations in the microbial layer are low (30 μM) suggesting that biomass production by the purple sulphur bacteria is sulphide rather than light limited. This is not surprising given the large standing stock of phototrophic bacteria and the daily sulphide demand of these organisms. The development of dense populations of purple sulphur bacteria at the thermocline is, however, not unique to the South Andros Black Hole system. Marano-Briggs (2000) reported a dense layer of purple sulphur bacteria at 4.5–5.5 m depth in the estuarine Tarpon Blue Hole. In Tarpon Blue Hole however, the dominant phototrophic bacterium was identified as a novel strain of *Marichromatium purpuratum*, which has okenone rather than spirilloxanthin as its major carotenoid. Okenone containing purple sulphur bacteria are commonly found in stratified lakes where light intensities are low (Guerrero et al., 1987).

4.1. Formation of black hole caves

In order to develop a satisfactory theory to explain the origins of the Bahamas Black Holes it is first necessary to establish where they are found in the Bahamas, the geological formations which could contribute to their development and the topography and bathymetry of these hitherto undescribed systems. To date Black Holes have only been observed in low-lying areas which during the Pleistocene period were subjected to a number of marine inundations resulting from changes in sea level (Fig. 1). These changes in sea level may have occurred as many as 30 times over the past 1.8 million years (Crowley and Kim, 1994). In these transitional land areas large quantities of carbonate mud have been deposited (Boss, 1991). These deposits are principally of aragonite and imply that precipitation was rapid (Buczynski and Chafetz, 1990). In some areas of South Andros this mud is > 1 m thick. During glacial periods rainfall, at times, was substantially greater in the Bahamas than interglacial periods as evidenced by the development of extensive stalactite and stalagmite formations in fracture guided Blue Hole cave systems on both Andros and Grand Bahama Island (Palmer,

1985). During each glacial period, meteoric water had the opportunity to accumulate on the exposed undulating surface of these soft mud deposits initially forming shallow freshwater pools, which as they progressively increased in size would have increased in depth to form larger bodies of water which today we see as black holes. In the absence of major rock fractures this accumulated CO_2 saturated water would have slowly infiltrated the porous limestone leading to the progressive dissolution of the underlying rock. Such a process would account for the almost perfect circular symmetry of the Black Holes which is in sharp contrast to the fracture guided cave systems found at the coastal margins in the Bahamas which have elongated entrances and horizontal caves that have irregular circular openings due to roof collapse and or slope retreat. This theory would also explain the parallel sided, flat floored bathymetry observed in the South Andros Black Hole which is totally different from the funnel shaped sink-holes found in Florida and Mexico which arise by sub-surface roof collapse into subterranean voids in the limestone (Tihansky, 1999). As the water column becomes progressively deeper due to limestone dissolution physico-chemical gradients would have become established, initially transiently and then more permanently, as the less dense freshwater water mass first meets and then interacts with denser sulphate-rich seawater seeping through the porous carbonate bed rock. This in turn would have led to zonation of the indigenous microflora and the formation of bands of phototrophic bacteria where conditions were optimal for their growth. Once dense populations of purple sulphur bacteria have become established they would absorb visible light wavelengths giving rise to the characteristic dark/black appearance of the water surface. The bathymetric profile of the South Andros Black Hole (Fig. 2b) suggest that once stable physico-chemical gradients had become established more rapid lateral widening rather than vertical deepening of the cave occurred creating a bowl shaped entrance. This would suggest that a highly reactive chemical environment with enhanced dissolution properties was established relatively early on in the genesis of these vertical cave systems. The dense populations of purple sulphur bacteria present at the thermocline plays an important but as yet unquantified role in enhancing carbonate dissolution by providing a source of particulate and dissolved organic matter at this depth horizon. The production of readily degradeable organic carbon would stimulate heterotrophic mineralisation processes with concomitant CO_2 production thereby enhancing limestone dissolution. The recorded sharp decrease in pH at the thermocline (Fig. 7) is consistent with enhanced microbial activity at this depth horizon. The concomitant increase in acidity would enhance the carbonate dissolution potential of the water and account for the very pronounced

dissolution notch in the rock wall observed at the boundary between the two water masses (Schwabe, 1999). Bacteria are known to be actively involved in carbonate precipitation and dissolution (Ehrlich, 1996). In nature limestone deposits are rapidly degraded or dissolved as a result of microbiological activity (Golubic and Schneider, 1979). The chemical reason for carbonate dissolution is the inherent instability of carbonates in weak acid solution. Paine et al. (1993) demonstrated that metabolically generated CO_2 during respiration of organic matter significantly enhanced limestone dissolution under laboratory conditions. The key role played by bacteria in enhancing carbonate dissolution in the mixing zone of Bahamian cave systems was first promulgated by Smart et al. (1988) in order to explain the elevated CO_2 partial pressures recorded in the mixing zone of Evelyn Green's Blue Hole. Whilst most caves and karst features are considered to be formed as a result of abiotic dissolution of carbonate rocks by infiltrating CO_2 saturated rainwater, this is not the only process operating in cave systems (Egemeier, 1981; Palmer, 1991). Several recent studies have shown that sulphide can be oxidised to sulphuric acid either abiotically by reacting with oxygen-rich water or biotically by chemoautotrophic sulphur-oxidising bacteria (Mattison et al., 1998; Vlasceanu et al., 1997, 2000). In the South Andros Black Hole most of the biogenically generated sulphide is consumed by the purple sulphur bacteria as e^- donor in anoxygenic photosynthesis but the presence of a thin white veil of bacteria at the upper boundary between the sulphidic micro-oxic saline layer and the oxic brackish water mass is indicative of the presence of mat forming sulphur-oxidising bacteria such as *Beggiatoa*. Sulphur-oxidising bacteria such as *Beggiatoa* are widely distributed in brackish water, including blue holes, and marine environments, where sulphide is present and oxygen is present at low concentrations (Jorgensen and Revsbech, 1983; Bernard and Fenchel, 1995; Schwabe, 1999; Brune et al., 2000). However, confirmation of the role of sulphur oxidising bacteria actively in the formation of cave systems such as the South Andros Black Hole must await a more comprehensive microbiological investigation.

5. Summary and conclusions

The data from this preliminary study provide the first description of the hitherto unexplored South Andros Black Hole and explains why this body of water appears dark/black when observed from the air compared to the more familiar blue holes which are found in the Bahamas. Whilst blooms of purple sulphur bacteria are not uncommon in karstic lakes (Guerrero et al., 1987; Overmann et al., 1996) the presence of dense populations at 18 m depth is unusual. Equally unusual in this system is the observed temperature maximum of 36°C at this depth horizon which is coincident with the 1 m thick layer of phototrophic bacteria. The dominant phototrophic purple sulphur bacteria identified as members of the genera *Thiocapsa* and *Allochromatium* contain spirilloxanthin as a major photopigment which strongly absorbs light wavelengths between 480 and 550 nm but is relatively inefficient in channelling captured light energy to the photosynthetic reaction centres in these bacteria. We postulate that the excess captured light energy is dissipated as heat which would account for the observed increase in temperature. Further, more detailed field and laboratory studies are now required in order to investigate this unique ecosystem and establish the geological timescale over which such large cave systems form.

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