Netherlands Journal of Sea Research
7: *223–232 (1973)*
7th European Symposium on Marine Biology

OXYGEN AND CARBON DIOXIDE IN INTERSTITIAL WATER OF TWO LEBANESE SAND BEACHES

by

J. C. MAKEMSON
(Department of Biology, American University of Beirut, Lebanon)

CONTENTS

I. INTRODUCTION

The coastline of Lebanon is marked by its steepness; behind beaches, the mountains reach up to 1,500 m. Consequently there is considerable fresh water input to the Lebanese sand beaches as ground water; in fact it is not uncommon to observe the Schlieren optics created by fresh water mixing with salt water from the rocky areas of Lebanon's shore. To investigate the nature of oxygen and carbon dioxide concentrations in interstitial water of the fresh and marine water zones of open, fully exposed and tideless sand beaches; two beaches were chosen: Sindbad beach, located 30 km south of Beirut, had no obvious signs of pollution, and, Khalde beach, located 5 km south of Beirut, received on the average 700 litres of untreated sewage per second some 70 m from shore (unofficial governmental estimate). The site chosen on Khalde beach was 0.45 km north of the sewage outfalls in the middle of the about 3 km long beach. The site chosen on Sindbad beach was near the center of the about 1.5 km long beach. Both beaches are composed of sand of medium grain size (1.32 mm diam.; range 0.98 to 1.62 mm) that is well sorted (GOWING, 1972; HULINGS, unpublished data).

Acknowledgment.—The author gratefully acknowledges the help of N. C. Hulings and P. W. Basson, and especially Marcia M. Gowing for her expert technical assistance.

II. MATERIALS AND METHODS

Interstitial water sampling.—Interstitial water was sampled by a glass sampler (Makemson, 1972) which draws interstitial water into a modified glass volumetric pipette through nylon mesh. The mesh size is chosen so that the effective pore size is smaller than the smallest grain sizes; 20 micron pore size was used. Suction is applied with a pipette safety manipulator and interstitial water for oxygen analysis is drawn into the sampler under a layer of mineral oil. The sampler draws samples from about 10 to 15 cm below the surface of the water saturated sand. For samples other than in the wave wash zone, holes were dug to a level which did not pierce water saturated sand; sample order was oxygen, bacteria, carbon dioxide, nutrients, and meiofauna respectively. After taking the oxygen sample, a thermometer was inserted about 10 cm below the surface of the water saturated sand to record the temperature.

At each site samples were taken in the wave wash zone (WWZ), 10 m (—10) and 20 m (—20) up on the beach from the WWZ.

Oxygen determination.—The oxygen content of interstitial water was estimated by a modification of the standard Winkler procedure (Strickland & Parsons, 1968) adapted to 35 to 36 ml samples titrated in 10 ml aliquots (in duplicate) by 0.005 N thiosulfate with a microburette. Whether the Winkler procedure used was measuring exclusively oxygen was determined by a modification of the Ohle method (Brafield, 1964) by titration of the water sample less the addition of the manganese solution, but with a small amount of iodine added to the alkaline-iodide solution. Each sampling site was routinely sampled in duplicate.

Carbon dioxide.—Carbonate, bicarbonate, carbon dioxide gas and total carbon dioxide were determined within one hour by the addition of 0.010 N HCl to 20 ml samples monitored with a Beckman Field lab pH meter. Carbon dioxide partition and content was calculated from the tables in Strickland & Parsons (1968) or by the formula given by Barnes (1959).

Phosphate.—Inorganic phosphate was determined by the method of Strickland & Parsons (1968) on 25 ml aliquots in duplicate within a week of sampling. The samples were frozen in the field and maintained so until analysis.

Ammonia.—Ammonia was determined by the indolephenol blue method (Solorzano, 1969) on frozen samples within a week of sampling.

Protein content.—The protein content of sand samples were obtained by the method of Lowry (Lowry, Rosebrough, Farr & Randall,

1951) on sand samples that were stored in the frozen state until analysis (within a month of sampling). Samples were assayed in duplicate and corrections were made for turbidity.

Bacterial titers.—Viable and total bacterial titers were estimated in interstitial water by retaining the bacteria on HA-millipore membranes (Millipore Field Samplers). Two ml of PYE broth: peptone (Oxoid), 0.5%; yeast extract (Oxoid), 0.05% made with either sea water or distilled water were added to each filter; all filters were incubated at room temperature (25 to 30° C). The filters were counted after 24 to 36 hours of incubation. Total counts were made by adding 2.0 ml of 2% erythrosin in 5% phenol-water to fix and stain the bacteria on the millipore fitters. Total counts from sand were estimated from 10 grams of sand shaken for one minute in 25 ml of 0.004 N NaOH; 1 or 5 ml of the supernate was then filtered through a millipore sampler, fixed and stained with erythrosin-phenol. Total count filters were counted with the oil immersion lens. Interstitial bacteria accounted for over 90% of the viable bacteria present at Sindbad beach (Khyami, 1972) and is the most accurate reflection of the actual total number of viable bacteria present.

Meiofauna.—Total meiofaunal counts as well as counts of certain taxa were done quantitatively by the method of Hulings & Gray (1971).

III. RESULTS AND DISCUSSION

Table I shows the oxygen concentrations of interstitial water from both

TABLE I

Oxygen temperature and salinity in interstitial water of Khalde and Sindbad beaches for 3 sampling dates; oxygen in ml per litre and (in brackets) in percentage saturation for the salinity-temperature conditions (Strickland & Parsons, 1968: Table XIV).

Station	*Oxygen (ml/l)*			*Temperature (C°)*			*Salinity (‰)*		
	17-1	18-6	29-7	17-1	18-6	29-7	17-1	18-6	29-7
Khalde									
WWZ	3.00 (54)	0.41 (9.2)	2.96 (69)	17	28	30	33.1	36.3	36.4
—10	0.93 (14)	0.45 (9.2)	2.61 (53)	16	28	29	37.2	20.2	16.2
—20	3.88 (69)	1.17 (22)	2.79 (52)	15	25	28	37.2	13.3	6.0
Sindbad									
WWZ	4.18 (76)	3.74 (86)	3.24 (74)	17	28	28	35.9	40.5	36.5
—10	4.42 (77)	2.26 (46)	3.48 (77)	16	28	28	33.0	18.4	32.4
—20	4.00 (59)	3.46 (66)	1.41 (27)	15	27	28	6.6	10.5	5.3

Sindbad and Khalde beach for 3 sampling dates. Note the variability from 9.2% saturation to 69% saturation (Khalde, WWZ). There appeared no correlation with season, but rather to the weather conditions. After storms and during moderately windy (wavy) conditions elevated oxygen concentrations were found and after periods of calm, low oxygen concentrations were found. However, a sulphereta was never found. The oxygen concentrations were always higher for Sindbad beach interstitial water than for Khalde beach. This difference between Sindbad and Khalde may be related to the total biomass, the nutrient input, or both. Fig. 1 shows that the numbers of meiofauna were almost identical for each beach. There exist differences in the taxa of each beach. Khalde beach is a *Protodrilus* beach: *Protodrilus* accounts for 40% of the meiofauna in WWZ while this organism only accounts for 0.04% of the Sindbad WWZ meiofauna. Species difference may in part account for the difference in the oxygen present in that the mean rate of oxygen uptake per species could be different. In addition each beach may have different *in situ* respiration rates.

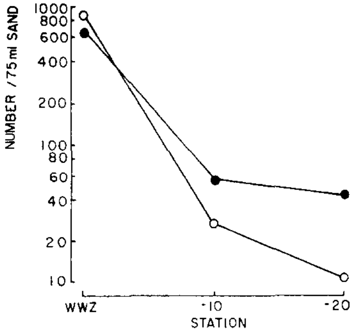

Fig. 1. Distribution of meiofauna in water saturated sand of Khalde (●) and Sindbad (○) beach. The number of meiofauna are the totals that were sampled 18-6-1972.

The numbers of bacteria in each beach were indeed different. Khalde contained a larger number of marine as well as fresh water bacteria. The fresh water bacterial numbers were always greater in the Khalde WWZ (Fig. 2) probably due to the volumnous sewage input to this beach. Characteristically, viable bacteria were on an average 10^{-4} that of the total number of bacteria present. This is a common feature of marine waters as well as soil (Wood, 1965; Gray & Williams, 1971). These data would suggest that although each beach has appreciable amounts of bacteria, the bacteria in Khalde beach are probably consuming more oxygen than the bacteria in Sindbad beach sand due to the sheer difference in numbers of viable bacteria per ml. The total numbers of bacteria relate to the amount of bacteria present as meiofaunal food, which were high for both beaches although Khalde had a greater number.

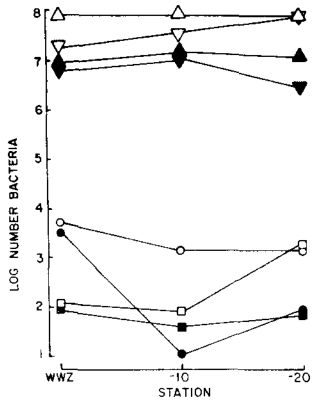

Fig.2. Distribution of bacteria in sand and interstitial water of Khalde and Sindbad beach. Totals per g, interstitial totals per ml, viable fresh water bacteria per ml, and viable marine bacteria per ml for Khalde (△▲ ● and ○, respectively) and Sindbad (▽ ▼ ■ and □, respectively).

The carbon dioxide content of the interstitial water of both Sindbad and Khalde was not exceedingly high (Table II). The *in situ* pH of the interstitial water was low for marine waters which may be a reflection of the quantity of respiration coupled with the amount of anaerobic acid production by the bacterial flora. That the latter is or could possi-

TABLE II

Carbon dioxide content of interstitial water of Khalde and Sindbad beaches on 29-7-1972.

Station	*pH in situ*	*Carbonate alkalinity meq./l*	*HCO_3^- mmol/l*	*CO_3^{-2} mmol/l*
Khalde				
WWZ	7.82	2.311	2.172	0.141
—10	7.55	3.516	3.475	0.054
—20	7.64	3.861	3.801	0.060
Sindbad				
WWZ	7.73	2.628	2.399	0.236
—10	7.75	2.165	1.990	0.179
—20	8.16	3.84	2.06	1.78

TABLE III

Protein content of Khalde and Sindbad sand. Samples in parentheses taken on June 18, the others on July 29, 1972.

Station	*Core depth cm*	*μg protein per g wet sand*		
		WWZ	*—10*	*—20*
Khalde	0–5	193 (242)	45 (23)	10 (62)
	5–10	340	98	10
	10–15	304	31	25
	15–20	266	74	36
Sindbad	0–5	132 (118)	100 (31)	71 (32)
	5–10	107	160	30
	10–15	213	153	52
	15–20	82	119	36

bly be an important factor was demonstrated by KHYAMI (1972) who showed that 41% of the bacteria which were aerobically isolated from Sindbad beach were fermentative. Moreover, regardless of station, Sindbad beach sand packed into sterile test tubes developed a sulphereta within 2 to 10 days given an external carbon source (yeast extract-glucose) but unenriched samples required a prolonged incubation time (28 days). This study was not repeated on Khalde beach.

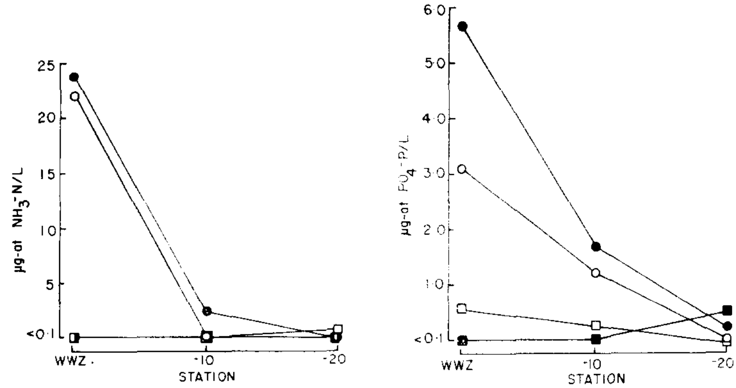

Fig.3. Ammonia content and phosphate (soluble) content of Khalde (○ ●) and Sindbad (■ □) interstitial water on 18-1-1972 (solid symbols) and 29-7-1972 (open symbols). The low limits of detection were 0.1 μgat NH_3–N/l and 0.1 μgat PO_4–P/l, respectively; all values obtained were either below the low limits or above but never exceeding the upper limits of detection.

With regard to the protein of the sand and nutrient content of interstitial water, Khalde beach was richer than Sindbad (Table III, Fig. 3). The protein content of WWZ sand was noticeably higher than that of the other sands in both beaches. However the gradient in Khalde beach was greater; the WWZ contained more protein than the WWZ of Sindbad, but the —10 and —20 stations contained less protein than Sindbad eventhough the Khalde bacterial numbers at these stations are higher (Fig. 2). Analysis of phosphate and ammonia in the interstitial water showed a similar pattern: the WWZ having the larger concentrations of ammonia and phosphate for Khalde beach, but for Sindbad such a gradient was not as noticeable. These data emphasize the basic difference between Khalde and Sindbad beaches: nutrient input. Khalde beach nutrient input appears to be exclusively from polluted sea water driven to the interstitial environment by wave action (swash) (Riedl, 1971). Although the phosphate gradient is not as steep as the ammonia gradient, this indicates that the ground water may

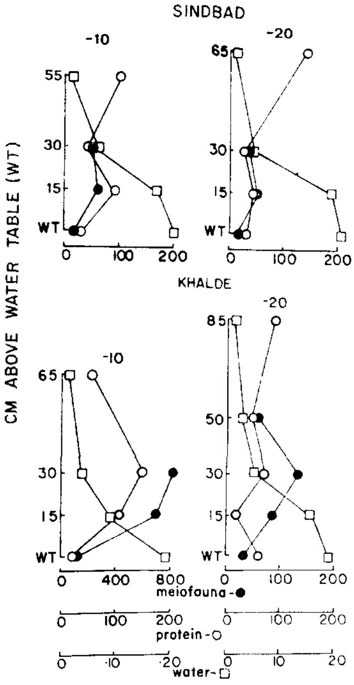

Fig.4. Distribution of meiofauna, water and protein in sand above the water saturated zone. Note that the meiofaunal scale for Khalde —10 is 4 times that of the other sites. Meiofaunal numbers (●) per 75 ml sand, protein content (○) in μg protein per gram of sand, water content (□) in grams of water per gram of sand.

possibly supply quantities of phosphate. Sindbad's interstitial nutrients probably entered by both mechanisms, however, the ground water probably played a more important role on this beach than Khalde beach since the carbon (protein) gradient as well as phosphate and ammonia gradients were not as steep.

Nutrient input from salt (mass) transport from the sea to the dry overlying sand may be a third mechanism and is supported by the fact that large numbers of meiofauna were routinely found above the water saturated sand (Fig. 4). In addition, this sand contained appreciable organic carbon. The nutrients in this sand can come from seaspray or bubbles from the sea as well as human pollution. Thus, the water unsaturated zone represents an ecologically important zone, especially on nontidal beaches where this zone has permanence. Preliminary work on this zone has shown it to contain appreciable quantities of salt (up to 0.04 grams salt per gram of dry sand), but at this juncture it is not known what fraction of this salt is in solution or simply present as dry salt. That there are copious amounts of salt present in this zone is also demonstrated by the unusual high salt content of the Khalde −20 site on the 18–1–1972 sampling which just followed a heavy rain (Table I).

Thus, the model for the amount of oxygen present in these nontidal sand beach interstitial water involves several rate phenomena:

Oxygen entry mechanisms: (*a.*) Oxygen carried by ground water (probably small, if any unless the ground water percolates through the surface just prior to entry to the beach. (*b.*) Oxygen carried by wave action (swash). This is a rich source of oxygen to the WWZ but dependent in turn by wave hight, frequency, beach slope and grain size (BRAFIELD, 1964; JANSSON, 1967; RIEDL, 1971). (*c.*) Oxygen carried by air to the water unsaturated and water saturated zone; the rate of entry would be dependent upon air speed, porosity and the packing of sand.

Oxygen removal mechanisms: respiration of meiofauna, bacteria, protozoans, and other macrobes. This is perhaps the only oxygen removal system of consequence as spontaneous chemical oxidations seemingly do not appear to be present (all the Brafield-Ohle corrections in the Winkler procedure were for oxidants). The rate of respiration would depend upon nutrient input (BRAFIELD, 1964; MCINTYRE, MUNRO & STEELE, 1970). A high nutrient input would increase the rate of bacterial respiration, the rate of bacterial reproduction and consequently the rate and amount of meiofaunal respiration. The data presented here clearly show that regardless of the weather conditions, Khalde beach always had a lower amount of oxygen present in interstitial water at all stations, due most probably to its exceedingly high nutrient (sewage) input supporting a large number of viable bacteria and active meiofauna well into the beach (−10 and −20 sites).

Carbon dioxide content of interstitial water would be a reflection of net respiration (CO_2 fixation) in combination with dissolution of carbonates from the soil and sand. Unlike oxygen, carbon dioxide did not appear to be dependent upon obvious nutrient input (Khalde's sewage). EDMONDSON (1970) showed that the carbon dioxide level and alkalinity of Lake Washington were not affected by loss of sewage input. Certainly interstitial water contains the potential for saturating conditions of carbon dioxide due to its low salinities and increased amounts of organic carbon, both of which increase the solubility of carbon dioxide (CHAVE & SUESS, 1970; BERNER, SCOTT & THOMLINSON, 1970). It was impossible to determine whether the carbon dioxide in Sindbad and Khalde water was respiratory product or a product of solubilization. More of Khalde's carbon dioxide was probably due to respiration since the interstitial pH was lower suggesting input as CO_2 or HCO_3^-.

IV. SUMMARY

Oxygen and carbon dioxide were measured in interstitial water at station along transects perpendicular to the sea on two Lebanese sand beaches. Both beaches were tideless, open marine, and fully exposed to wave action; one was polluted with domestic sewage and the other showed no obvious signs of sewage pollution. Interstitial water was sampled by a glass sampler that had been designed to minimize contamination. Wave wash zone interstitial water was near oxygen saturation on both beaches when moderate waves were present. Interstitial water 10 to 20 m back (ground water) contained appreciable amounts of oxygen and were low in oxygen content only when corresponding to conditions of high nutrient input coupled with calm sea (low wave activity) and wind conditions.

Samples on these transects were also taken to quantify the bacteria (total and viable) and meiofauna along with sand samples for protein determination and interstitial water samples for phosphate and ammonia determinations. The relationship of oxygen and carbon dioxide to their rates of entry and removal are discussed.

V. REFERENCES

BARNES, H., 1959. Apparatus and methods of oceanography. Allen and Unwin, London: 1–341.

BERNER, R. A., M. R. SCOTT & C. THOMLINSON, 1970. Carbonate alkalinity in the pore waters of anoxic marine sediments.—Limnol. Oceanogr. **15:** 544–549.

BRAFIELD, A. E., 1964. The oxygen content of interstitial water in sandy shores.—J. Anim. Ecol. **33:** 97–116.

CHAVE, K. E. & E. SUESS, 1970. Calcium carbonate saturation in seawater: effects of dissolved organic matter.—Limnol. Oceanogr. **15:** 633–637.

EDMONDSON, W. T., 1970. Phosphorus, nitrogen, and algae in Lake Washington after diversion of sewage.—Science **169:** 690–691.

GOWING, M. M. 1972. A spatial study of the meiofauna on a seawage-polluted Lebanese sandy beach. Thesis, American University of Beirut, Beirut, Lebanon: 1–93.

GRAY, T. R. G. & S. T. WILLIAMS, 1971. Soil microorganisms. Oliver and Boyd, Edinburgh: 1–234.

HULINGS, N. C. & J. S. GRAY, 1971. A manual for the study of meiofauna. Smithsonian Contributions to Zoology No. 78, Washington: 1–83.

JANSSON, B. O., 1967. The availability for oxygen for the interstitial fauna of sandy beaches.—J. exp. mar. Biol. Ecol. **1:** 123–143.

KHYAMI, H., 1972. The bacterial populations of a Lebanese sandy beach. Thesis, American University of Beirut, Beirut, Lebanon: 1–53.

LOWRY, O. H., N. J. ROSEBROUGH, A. L. FARR & R. J. RANDALL, 1951. Protein measurement with the Folin phenol reagent.—J. biol. Chem. **193:** 265–275.

MAKEMSON, J. C., 1972. An interstitial water sampler for sand beaches.—Limnol. Oceanogr. **17:** 626–628.

MCINTYRE, A. D., A. L. S. MUNRO & J. H. STEELE, 1970. Energy flow in a sand ecosystem. In: J. H. STEELE. Marine food chains. Oliver and Boyd, Edinburgh: 19–31.

RIEDL, R. J., 1971. How much water passes through sandy beaches?—Int. Revue ges. Hydrobiol. Hydrogr. **56:** 923–946.

SOLORZANO, L., 1969. Determination of ammonia in natural waters by the phenolhypochlorite method.—Limnol. Oceanogr. **14:** 799–801.

STRICKLAND, J. D. H. & T. R. PARSONS, 1968. A practical handbook of seawater analysis.—Bull. Fish. Res. Bd Can. **167:** 1–311.

WOOD, E. J. F., 1965. Marine microbial ecology. Reinhold Publishing Corporation, New York: 1–243.