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Cyanobacterial desert crusts in the Dead Sea Valley, Israel

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With 1 map, 2 figures, 2 tables and 2 plates in the text

Abstract: Desert crust samples were collected in the Dead Sea Valley along gradients of microtopography, at wadi bottoms where the habitat is periodically destroyed by the winter floods and on progressively more elevated terraces, where the habitat is more stable for a long time. Crust subsamples were examined for species composition and for chlorophyll *a* and polysaccharide content. At the lowest, and thus geologically youngest terraces only two cyanobacterial species *Microcoleus vaginatus* GOM. and *Schizothrix friesii* GOM. were found. On the elevated terraces cyanobacteria were more numerous, accompanied by a lichen (*Collema* sp.) and one green alga (*Chlorococcum* sp.). Chlorophyll *a* and polysaccharide concentrations were lowest close to the wadi bottom and increased with the degree of elevation. This increase in the number of species and biomass concentration should be interpreted as a biotic succession, leading from the scanty, pioneer community of the low biomass at the unstable, topographically lower places, toward the gradually more mature community, composed of numerous species and richer biomass in the more stable habitat of the elevated terraces.

Key words: Desert crusts, cyanobacteria, Dead Sea Valley

Introduction

Cyanobacteria are widely distributed in the hot deserts of the world. Their ability to form stable crusts on desert soil surface was recognized early in this century (BOOTH 1941). The crusts are formed chiefly by filamentous cyanobacteria, with both, entangle the sand grains and adhere to them owing to the excreted slimy polysaccharides, so consolidating the upper, inhabited soil layer (DANIN et al. 1989, de WINDER 1990, BELNAP & GARDNER 1993). Crust formation has important effects not only on desert soil stability, but improves also soil fertility and humidity balance (HARPER & PENDLETON 1993, METTING 1981, PAINTER 1993).

Certain soil cyanobacteria have a cosmopolitan geographic distribution. For example species of *Microcoleus, Schizothrix, Nostoc, Scytonema, Phormidium* and

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several additional genera are repeatedly reported from a variety of soils all over the world, e.g. North America (ASHLEY et al. 1985); Brazil (AZEVEDO 1991); equatorial Africa (FRÉMY 1930); Europe (STARMACH & SIEMIŃSKA 1979); India (TIWARI 1975); Himalayas (WATANABE & KOMÁREK 1988); China (YING et al. 1992). Similar cyanobacteria were recently reported by LANGE et al. (1992) from the Negev desert soils in Israel. Species composition and thickness of desert crusts may differ considerably from place to place, following local environmental conditions such as soil texture and fertility, ionic strength and pH, amount of annual precipitation and degree of local disturbance (HOFFMANN 1989, METTING 1981, YING et al. 1992).

The present study deals with desert crusts collected along a sequence of alluvial terraces in the arid area of the Dead Sea Valley. According to our field observations crusts developing on the wadi bottom or at any lower point of microtopography are frequently destroyed by the seasonal floods, while those established on the consecutively more elevated terraces enjoy progressively more stable conditions. Accordingly it was assumed that the observed differences in crust composition and biomass richness represent successional stages of colonization, leading from young to more mature communities. The work analyzes species composition together with the chlorophyll and polysaccharide concentrations along two topographical transects in the above area.

Materials and methods

Crusts established on the fine grained sediments of the alluvial material and Lisan Formation characterizing the Dead Sea Valley were sampled at Mt. Sodom and at Almog site, at the southern and northern parts of the Valley respectively (Map 1). The sampling points are situated 240 and 320 m below sea level respectively, with mean annual temperature of 25° C, mean annual rainfall of 70 mm at Mt. Sodom (average of 17 rainy days), and 100 mm at the Almog site (26 rainy days) (Meteorological Service, Israel).

At Mt. Sodom the samples were taken from the bottom of a small wadi and from six consecutively more elevated terraces. The highest terrace was located only 50 cm above the wadi bottom. At Almog the position of the six sampling points also differed with respect to their altitude, however the microtopography was less pronounced. At both places the differences in terrace elevation were in the scale of several centimeters. Three crust samples collected from each terrace were subjected to several tests:

a) Subsamples of the crusts were placed in Petri dishes, wetted with distilled water and incubated (Lab-Line Biotronette Environmental Chamber), under light of 10–15 $\mu E\ m^{-1} s^{-1}$, at 22° C. Greening of the crust appeared usually after a few hours, but the emerging microbiotic flora was studied microscopically (BH-2

Map 1. Location of the sampling sites: the Almog site at the northern and Mt. Sodom at the southern Dead Sea Valley.

Olympus) only after a week, when fully developed. Cyanobacteria were identified according to the classical taxonomic literature (e.g. Geitler 1932, Frémy 1930, Desikachary 1959).

b) Chlorophyll *a* content was measured in 2 × 2 cm duplicate subsamples of the various crusts incubated for one week. The crusts were crushed in a mortar and extracted in boiling methanol for approximately 2 min. After centrifugation optical density was measured at 665 nm (Cary 1 E Spectrophotometer) and mean content of chlorophyll *a* per square cm was calculated according to Vollenweider (1969).

c) Polysaccharide concentration was determined according to the sulfuric acid-anthrone method (Brink et al. 1960). Duplicate pieces of 4 × 4 cm of the crust samples were incubated as above, then crushed and extracted for 24 hr in

Table 1. Cyanobacteria and lichens listed in the order of appearance in the desert crust successional stages, Mt. Sodom, Dead Sea Valley.

Microorganism	Sample Number					
	1	2	3	4	5	6
Schizothrix friesii GOM.	*	*	*	*	*	*
Microcoleus vaginatus GOM.		*	*	*	*	*
Scytonema hofmannii AG. ex BORN. et FLAH.				*	*	*
Schizothrix arenaria (BERK.) GOM.					*	*
Nostoc punctiforme (KÜTZ). ex HARIOT					*	*
Chlorogloea microcystoides GEIT.					*	*
Collema sp.					*	*

hot sulfuric acid. After addition of anthrone solution to the hydrolyzate, optical density was measured at 625 nm and mean concentrations were calculated according to the corresponding glucose standards.

Results

Lists of the cyanobacteria, one green alga and one lichen identified are given in Tables 1 and 2. At Mt. Sodom, the wadi bottom was bare. On the first terrace (No. 1) only traces of *Schizothrix friesii* were found. On the second and third terraces (Nos. 2 and 3) *Schizothrix friesii* and *Microcoleus vaginatus* were present. On the dry soil they were invisible, covered by a layer of dust. Only after wetting did they emerge, forming a sparse green network of filaments on the soil surface. On the higher terraces additional cyanobacteria, and one lichen, were identified.

Table 2. Cyanobacteria, one green alga and one lichen listed in the order of appearance in the desert crust successional stages, Almog, Dead Sea Valley (three samples represent each stage).

Microorganism	Sample Number																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Microcoleus vaginatus GOM.	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
Schizothrix friesii GOM.			*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
Chroococcidiopsis sp.								*					*				*	*
Collema sp.								*			*	*	*					*
Protococcus sp.												*					*	
Scytonema hofmanni AG. ex. BORN. et. FLAH.											*			*	*	*		
Nostoc punctiforme (KÜTZ.) ex HARIOT												*	*	*	*	*	*	
Petalonema velutinum (RAB. ex BORN. et FLAH.) MIG.													*					
Phormidium fragile (MENEGH.) GOM.											*	*						
Chlorogloea microcystoides GEIT.															*	*		
Aphanothece sp.																		*

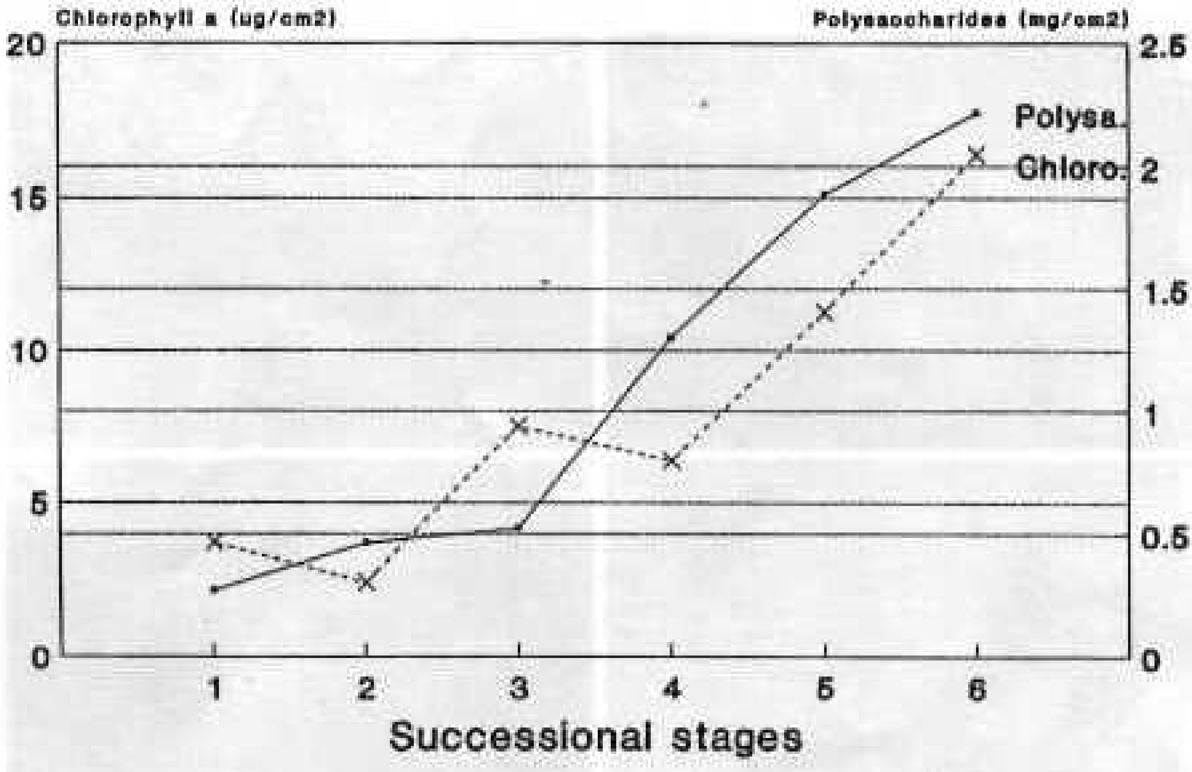

Fig. 1. Polysaccharides and chlorophyll *a* in incubated desert crusts from Mt. Sodom six consecutive terraces.

At the highest point, dark, compact colonies of *Nostoc, Chlorogloea* and a species of cyanophylous lichen *Collema* prevailed, forming an almost continuous black crust on the soil surface.

Similar species distribution was found at the Almog site: *Microcoleus vaginatus* and *Schizothrix friesii* appeared in samples from the lower places. At the higher points, a progressively richer community was found and again the black, superficial thalli of *Nostoc, Chlorogloea, Chroococcidiopsis* and *Collema* prevailed. The Almog site was richer in species than was the site at Mt. Sodom. In addition, several mosses (investigated separately by I. HERRNSTADT, The Hebrew University of Jerusalem) appeared at this site.

Figs 1 and 2 show chlorophyll *a* and polysaccharide concentrations in the samples from the two sites studied. Comparison of the crusts from the above sites reveals certain qualitative and qantitative differences, which may result from the slightly different amounts of annual precipitations. At the more arid Mt. Sodom only 7 microphytic species were identified with chlorophyll *a* and polysaccharide not exceeding 16.5 $\mu g.cm^{-2}$ and 2.3 $mg.cm^{-2}$ respectively. At the more moderate Almog site, 11 species appeared and the corresponding concentrations of chlorophyll *a* and polysaccharide reached 27 mg/cm2 and 6.5 $mg.cm^{-2}$ respectively. Moroever, mosses, totally absent at Mt. Sodom were represented by a number of species at Almog, indicating better environmental conditions.

Colour Plates 1 and 2 show a sample of the dry desert crust and microphotographs of the predominant microbiota.

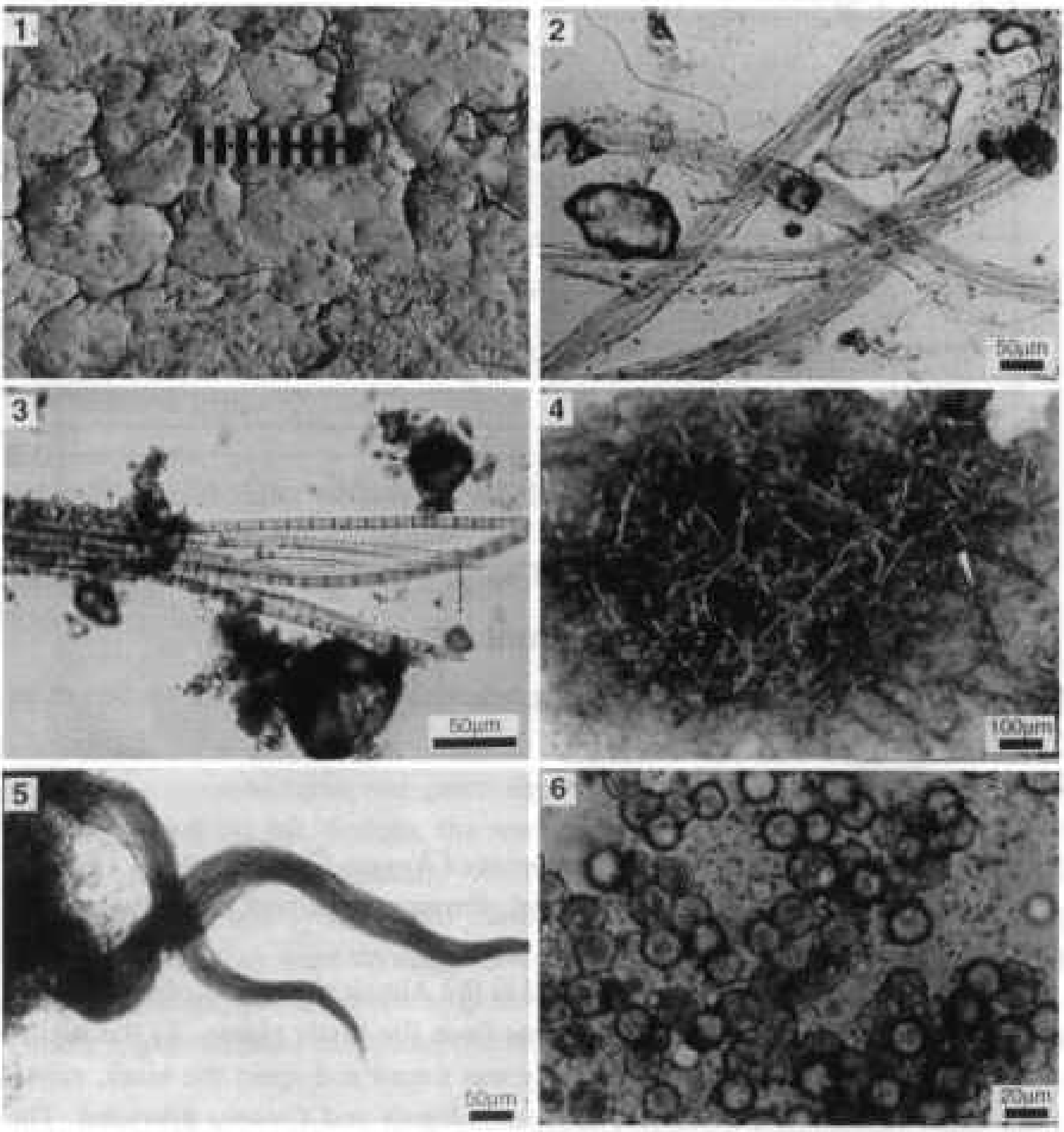

Plate 1. 1 – Dry desert crust from Almog site, the lowest terrace. 2 and 3 – filaments of *Microcoleus vaginatus* Gom. 4 and 5 – filaments of *Schizothrix friesii* Gom. 6 – *Protococcus* sp.

Discussion

The present study is based on the concept that the desert crusts sampled along the micro-topographic gradients in the Dead Sea Valley differ in their age. The wadi bottom and the low places drain water from the surroundings, and thus the soil surface and the crust are frequently disturbed or totally destroyed by seasonal floods. Consequently at these places the cyanobacterial crust community is the youngest, composed of a few pioneer species, able rapidly to reestablish their growth and colonize desert soil after destruction. Since the winter rains, even of a modest intensity, cause floods almost every year, violently destroying soil structure, the above community composed of sparse filaments of *Microcoleus vaginatus*

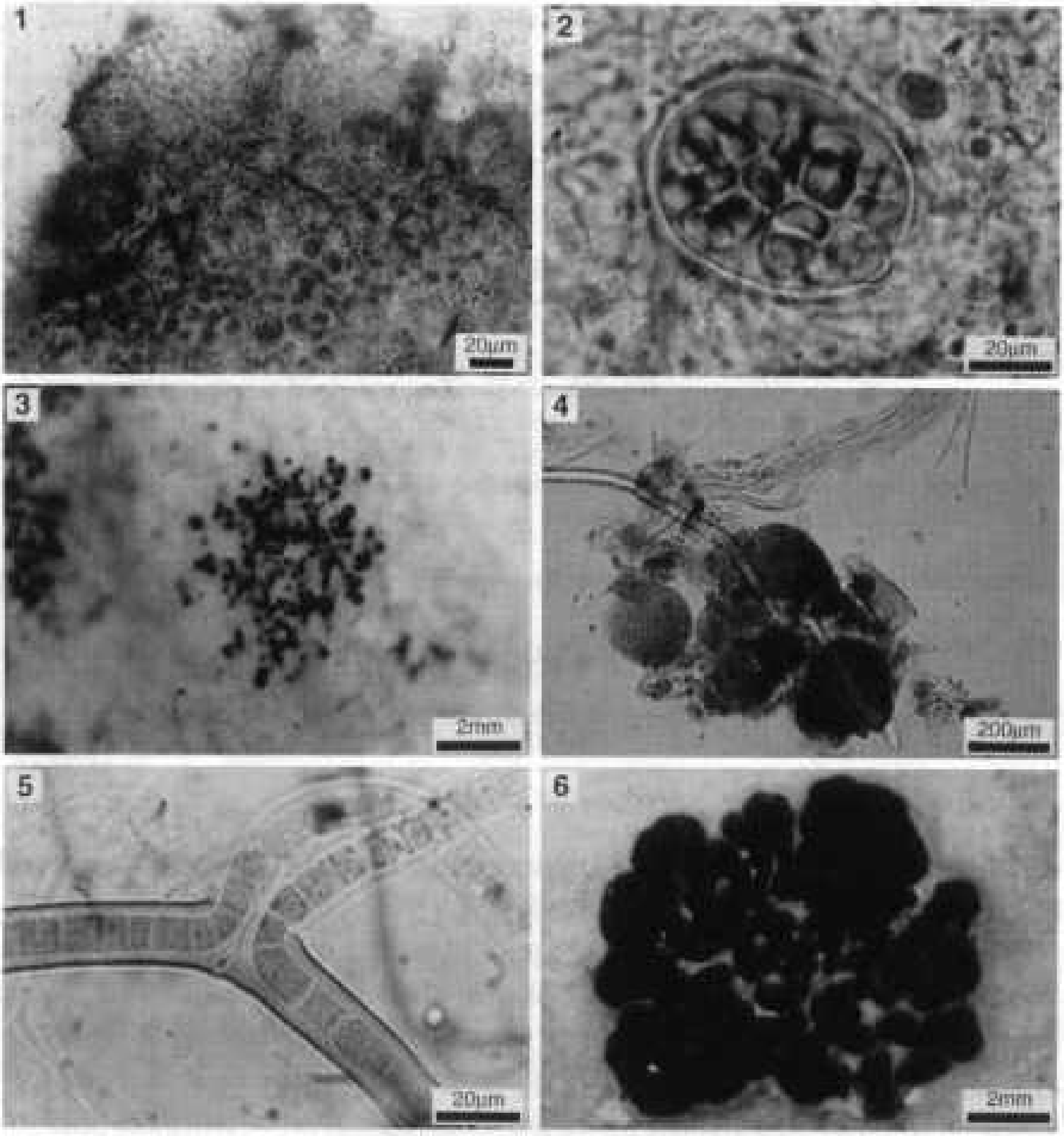

Plate 2. 1 – *Chlorogloea microcystoides* GEITLER. 2 – *Chroococcidiopsis* sp. 3 and 4 – *Nostoc punctiforme* (KÜTZ.) HARIOT. 5 – *Scytonema hofmanii* AG. 6 – *Collema* sp.

and *Schizothrix friesii*, must be only one year old. Identical cyanobacterial species were identified in soils in Oklahoma (USA), constituting an initial stage in plant succession (BOOTH 1941).

At terraces located progressively higher above the wadi bottom and at any places elevated to some degree, the seasonal disturbance is more moderate. Prolonged periods of stability (presumably several to many years) allow more species to establish themselves and this older community is more complex, including higher numbers of taxa together with higher accumulation of biomass, thus presenting more advanced successional stages of desert soil colonization.

Finally the most elevated places, remaining stable indefinitely, are colonized by additional species of cyanobacteria, lichens and mosses, constituting suppos-

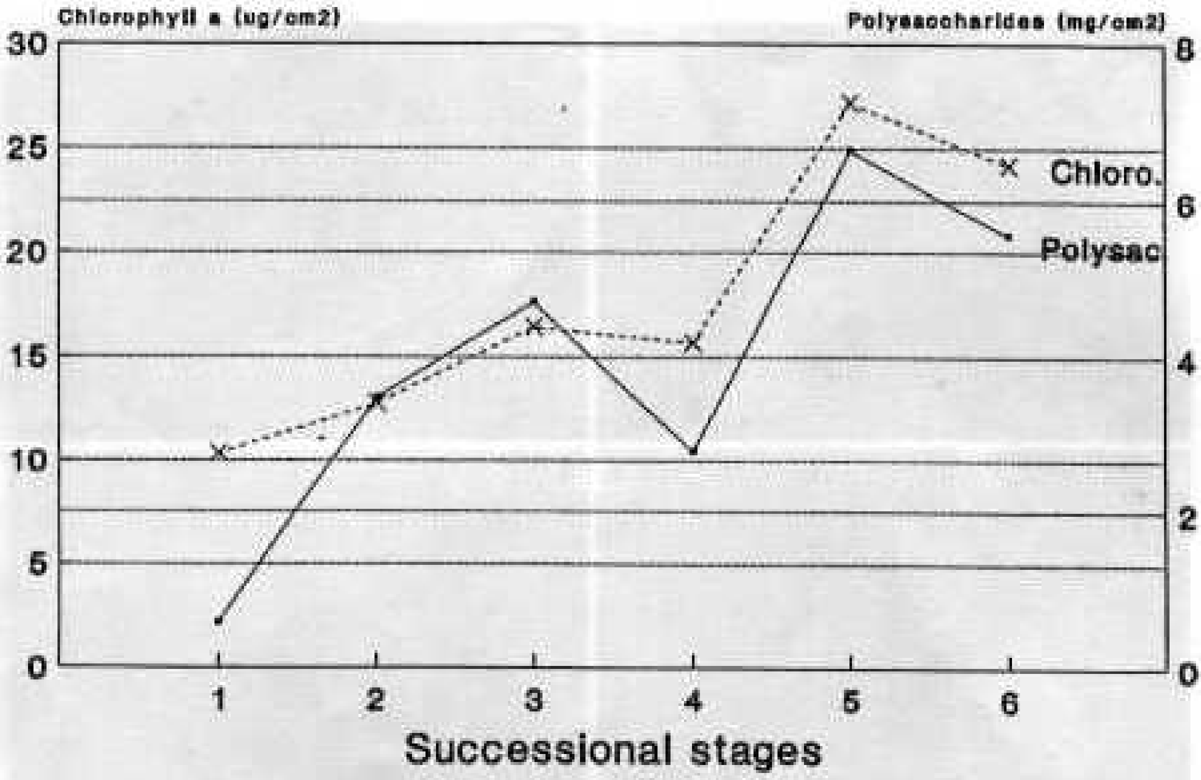

Fig. 2. Polysaccharides and chlorophyll *a* in incubated desert crusts from six consecutive terraces at the Almog site.

edly the climax crust community. However, the time needed for establishment of this complex community remains unknown.

Young and mature crusts differ not only in respect of their species composition and biomass concentration but also in their external habit: after being moistened the young crusts appear as a green network of filaments (*Microcoleus, Schizothrix*, Plate 1, Nos. 2–5), horizontally expanded beneath a thin layer of desert soil, where they remain partly protected against solar radiation. Mature crusts are predominantely composed of brown to black colonial species (*Nostoc, Chroococcidiopsis, Chlorogloea, Collema*, Plate 2, Nos. 1–6), with compact, gelatinous thalli, located at the soil surface. Strains of *Nostoc* sp. and *Chroococcidiopsis* sp.) were isolated and tested for their absorbtion spectra (unpublished). Both showed a pronounced absorbtion peak around 320–330 nm, i.e. within the wavelength of UV-B radiation. Obviously the above peak indicates the presence of a UV absorbing pigment recently described from cell walls of a number of terrestrial cyanobacteria (GARCIA-PICHEL & CASTENHOLZ 1991, PROTEAU et al. 1993). This dark pigmentation provides photoprotection to species exposed to direct solar radiation.

Two main conclusions can be derived from the above findings: a) desert crusts in the Dead Sea area can be characterized according to their taxonomic diversity and biomass richness, which reflect the successional stages of biotic colonization; b) crust composition within local gradients, expresses the degree of environmental stability with respect to disturbance at the given site.

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