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Intertidal endolithic fauna and it's relationship to the mineralogical, physical and chemical characteristics of the substrate

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Abstract. Mineral composition, granulometry, cohesion, relative and absolute density, and the pH of samples of the Santa Elena sedimentary rock shoal (37°56′02″ S; 58°11′35″ W; Argentina) were determined in order to relate the endolithic fauna with the properties of the substrate. Twenty three samples were collected in December 1987, applying a systematic sampling method to an intertidal area of 5 500 m^2. The mineral composition was determined using x-ray diffraction. Cohesion was determined by visual evaluation of the disintegration of the sample following various periods of immersion in water and by recording the resistance to compressive fracture according to the American Society for Testing and Materials (ASTM) standard. The ASTM standard was also followed for measurement of absolute and relative densities and porosity. The rock was ground up in distilled water and the pH of the resulting liquid measured over a period of 24 h. The data were analysed using numerical taxonomy, and in a supplementary study a granulometric analysis was attempted using five representative samples. The endolithic species selected were: the sipunculan *Themiste petricola*; the polychaetes *Polydora* sp. and *Pherusa* sp., and the bivalves *Lithophaga patagonica, Petricola patagonica, Saxicava solida, Barnea lamellosa,* and *Pholadidea darwini*. The mineral analysis indicated heterogeneous composition and spatial distribution characteristic of a loess. In terms of cohesion, the substrate displayed varying degrees of disintegration, with resistance ranging from zero to very high (254.6 kg/cm^2). The endolithic fauna *Themiste petricola, Polydora* sp., *Pherusa* sp., *Lithophaga patagonica, Petricola patagonica,* and *Saxicava solida* were found in areas of low to very high cohesion, with or without calcite. The Pholadidae were found in areas of zero to low cohesion, with absence or traces of calcite. This study indicates the important role of cohesion in determining the distribution of the endolithic fauna.

Introduction

One of the goals of the "Bioturbations of the Buenos Aires Loess" program, initiated in 1987 by a multidisciplinary research group, was to study the dependence of the endolithic fauna on the type of substrate. The nature of the hard substrate is a fundamental element in the distribution of benthic marine invertebrates (Pérès 1961, Dayton 1971). As a consequence, the mineral composition, granulometry, and physical and chemical characteristics of the substrate should have a close relationship to the distribution of endolithic organisms in the intertidal zone.

To test this hypothesis, we investigated the mineral composition, granulometry, cohesion, relative and absolute densities, and the pH of the hard substrate of the Santa Elena shoal (province of Buenos Aires, Argentina).

The results of these studies were then related to the different endolithic species which were well-represented in the zone.

Materials and methods

The rocky substrate studied is located at Santa Elena (37°56′02″S; 58°11′35″W). It is a compact sedimentary rock, sometimes cemented by crystalline calcium carbonate, and is of variable color and hardness. In some sectors of the beach it is fragile and can be broken up by hand whereas in other sectors it is more solid and can be broken only by a hammer. The color of the dry rock which disintegrates in water is "buckthorn brown" and that which does not is "light buff" (see Plate XV of Reedway 1912).

The beach consists of a 5 m-high embankment and a gently shelving floor (0.866°) with drainage channels running perpendicular to the coast (Fig. 1). The sea rises 50 cm up the embankment at normal high tide, but under southeast storm conditions can completely cover it.

In order to analyze the properties of the substrate and determine its endolithic fauna, samples were taken at low tide on December 1987 (tabulated low water 0.29 m) using a systematic sampling plan (Krumbein and Graybill 1965) which consisted of tracing seven transects perpendicular to the coastline: A, AB, BA, B, BC, CB and C (distance between A and C = 132 m; see Fig. 3b). Transects A, B, and C extended from the top of the embankment to the sea (length

Fig. 1. Study area on coast of Santa Elena, Argentina

approx 41m each), and the remaining transects, AB, BA, BC, and CB (length approx 6 m each) ran from the upper inhabited level towards the sea. No samples were taken from the sandy beach zone lacking epilithic flora and fauna (Fig. 1).

On Transects A, B, and C, three samples were taken from the embankment (Levels 1, 2 and 3; Fig. 3b) and two from the beach (Levels 4 and 5; Fig. 3b). On Transects AB, BA, BC, and CB, two samples were taken from each, corresponding to Levels 4 and 5. The total number of samples taken was 23, with a volume of approx 27000 cm^3 per sample.

In the laboratory, each sample was divided into three subsamples: one for examining the mineral composition, one for physical and chemical determinations, and the remaining sample for determining the most abundant endolithic species.

The mineral composition was determined with a Philips DRX x-ray diffractometer, Model PW 1011/00, with a copper tube, wavelength 1.5414 A, 18 mA, 40 kV, goniometer velocity 2°/min; 1 200 mm/h paper speed. Semiquantitative determinations of the components of each sample were made.

The clay fraction was studied in oriented preparations (normal, ethylene glycol-saturated, and calcined). In samples containing abundant clay, the percentage contributions of its various components were recorded. This was not possible for samples containing little clay. The crystallinity of the clay was determined on the basis of the sharpness and symmetry of the diffraction peaks, which indicate the internal atomic order of the minerals.

The mineralogical study generated a basic data matrix.

The physical study of the samples consisted of a quali-quantitative evaluation of cohesion, determination of relative densities in dry and saturated states and of the absolute density, and the calculation of porosity from the densities in dry and saturated states and of the absolute density.

The qualitative analysis of cohesion consisted of the visual evaluation of the disintegration of the sample after various periods (0.5, 1, and 24 h) of immersion in tapwater at ambient temperature (20°C). The quantitative study was made by recording the resistance to compressive fracture following Methods C-42 and C-39 of the ASTM standard.

The chemical parameter studied was pH, measured on the solution resulting from grinding the sample and leaving it in contact with distilled water for 24 h.

The cohesion analysis generated a second basic data matrix.

The two basic data matrices (mineralogic and cohesion studies) were processed using the NT-SYS system (Rohlf et al. 1972) on an IBM 4361 (National University of La Plata, CESPI Center). In those samples for which the clay was not quantifiable (traces only) "not comparable" was entered. To both matrices was applied the cluster-analysis method (unweighted pair-group method of analysis) based on a matrix of taxonomic-distance coefficients (Sneath and Sokal 1973). To analyze the degree of correspondence between the phenograms obtained from the mineralogical and physical data, a strict consensus tree was calculated (Smith and Phipps 1984).

For the granulometric analysis, we selected a sample of each of the five groups delimited in the phenogram of mineral components belonging to Levels 4 or 5. The samples selected were: B4, CB4, AB5, C5 and CB5. The equipment used was a Sedigraph 5000ET Micromeritics. The sample preparation technique consisted of grinding in a mortar and sieving through a 60 µm net to retain the sandy fraction. The sieving were immersed in hydrogen peroxide and dilute hydrochloric acid for 2 h to eliminate organic matter and calcium carbonate.

The endolithic species selected were: the sipunculan *Themiste petricola*, the polychaetes *Polydora* sp. and *Pherusa* sp., and the bivalves *Lithophaga patagonica, Petricola patagonica, Saxicava solida, Barnea lamellosa,* and *Pholadidea darwini* (Fig. 2).

Results

The result of the analysis of the 23 diffractograms revealed the principal components of the material sampled to be illite, kaolinite, smectite, feldspar, quartz and calcite.

Using numerical techniques, the samples were compared by semiquantitative analysis of their mineralogical components (Table 1).

The resulting phenogram distinguished five groups (I–V in Fig. 3a).

Group I consisted of samples containing nonquantifiable clay of poor crystallinity and abundant feldspar, quartz and calcite.

Group II samples were comprised of illite and smectite in equal proportions; they were of poor to moderate crystallinity, and included abundant feldspar and quartz.

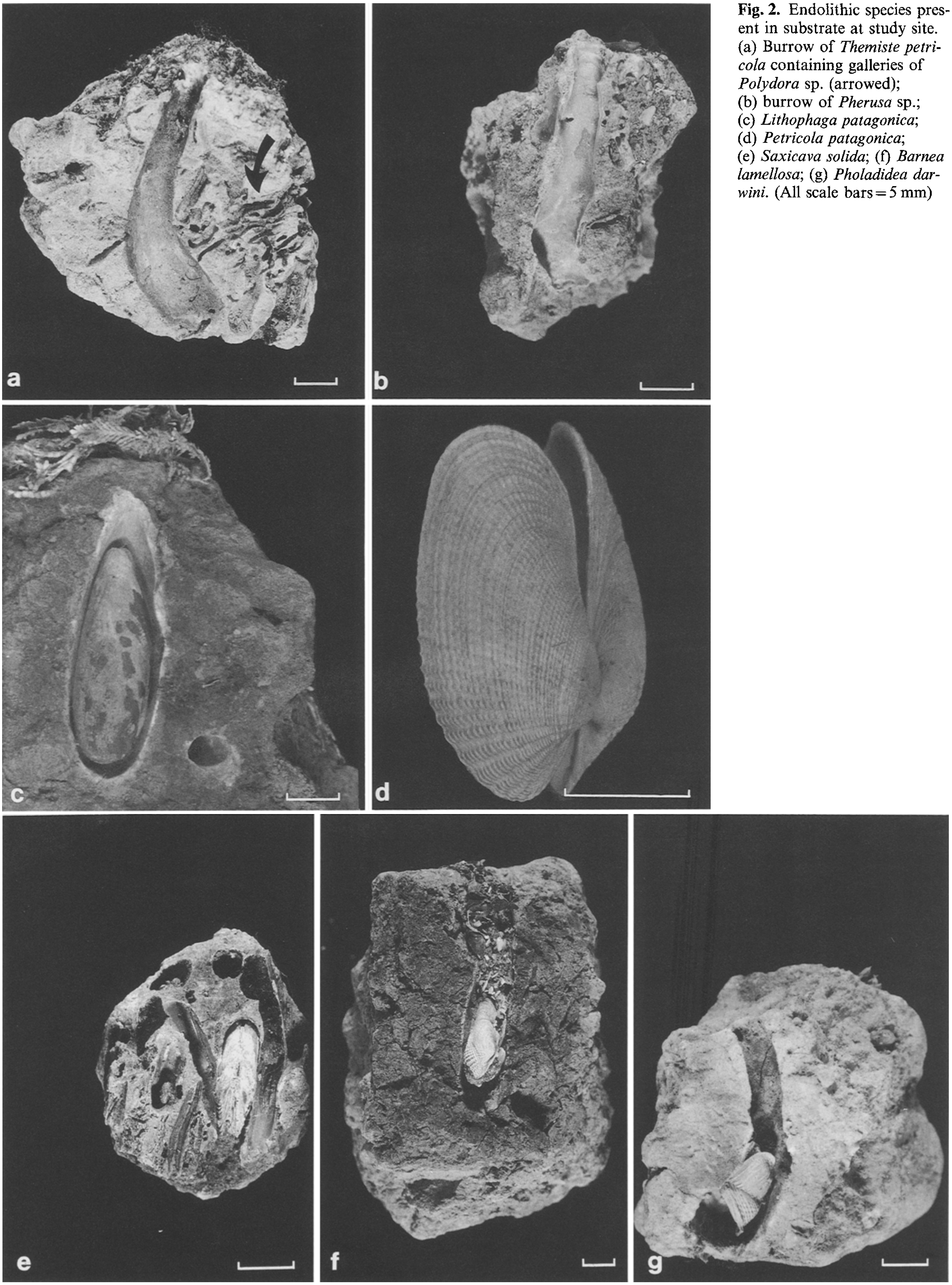


Fig. 2. Endolithic species present in substrate at study site. (a) Burrow of *Themiste petricola* containing galleries of *Polydora* sp. (arrowed); (b) burrow of *Pherusa* sp.; (c) *Lithophaga patagonica*; (d) *Petricola patagonica*; (e) *Saxicava solida*; (f) *Barnea lamellosa*; (g) *Pholadidea darwini*. (All scale bars = 5 mm)

Table 1. Basic matrix of 23 samples of substrate in study area and six mineralogical characteristics. Samples listed by transect and level (e.g. A1 = Transect A, Level 1; AB4 = Transect AB, Level 4, etc.). Clay crystallinity = 1: very poor; 1.5: poor; 2: moderate; 2.5: good. Abundance of feldspar, quartz, calcite = 0: absent; 0.5: trace; 1: sparse; 1.5: abundant; 2: very abundant. nc: not comparable (clay was not quantifiable)

Parameter	A1	A2	A3	A4	A5	AB4	AB5	BA4	BA5	B1	B2	B3	B4	B5	BC4	BC5	CB4	CB5	C1	C2	C3	C4	C5
Estimated illite content (%)	nc	50	50	60	30	nc	nc	50	70	60	nc	60	nc	nc	nc	nc	50	nc	40	nc	50	70	40
Estimated kaolinite content (%)	nc	0	0	0	20	nc	nc	0	0	20	nc	0	nc	nc	nc	nc	0	nc	20	nc	0	0	20
Estimated smectite content (%)	nc	50	50	40	50	nc	nc	50	30	20	nc	40	nc	nc	nc	nc	50	nc	40	nc	50	30	40
Clay cristallinity	1	1.5	2	1.5	2.5	1	1	2	2	2	1	2	1	1	1	1	1.5	1	2	1	2	1.5	1.5
Feldspar and quartz abundance	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	1.5	1.5	1.5	1.5	1.5	2	1	1.5	2	1.5	2	1.5	1.5	1.5
Calcite abundance	1.5	0.5	0	0	0	0	0	0	0	0	1	1	1.5	0.5	0	2	0	0	0.5	0.5	0	0.5	0.5

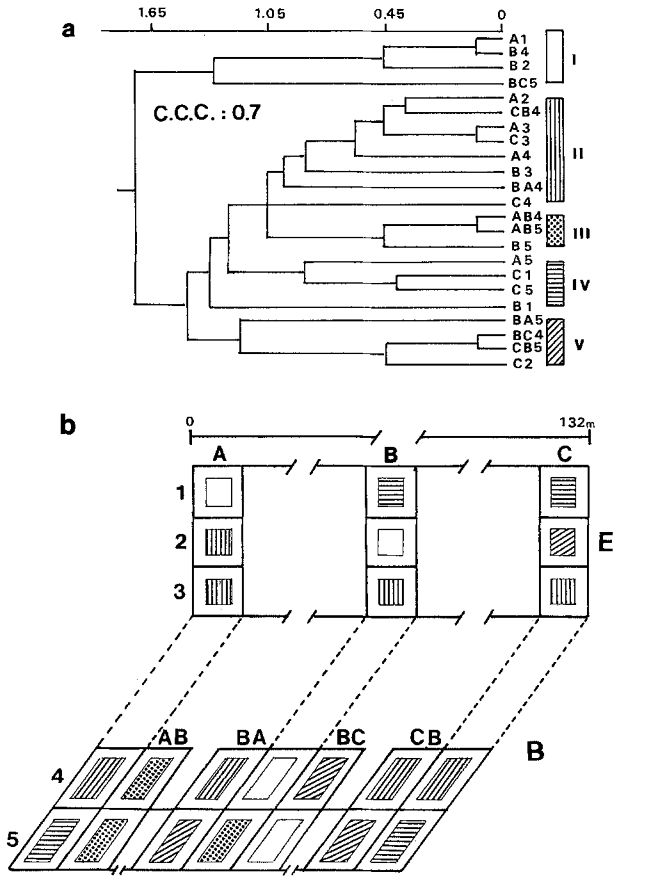


Fig. 3. (a) Distance phenogram of 23 samples along Transects A, AB, BA, B, BC, CB, C, divided by mineralogical characteristics into five groups (I–V); characteristics of Groups I–V described at beginning of "Results", numerals following transect designations are collection levels in (b); C.C.C.: cophenetic correlation coefficient; top abscissa shows distance values of phenogram. (b) Spatial distribution (Levels 1–5) of mineralogical Groups I–V in study area; Levels 1–3: embankment samples; Levels 4 and 5: beach samples. Study area was 132 m wide, embankment 5 m high, beach 36 m long, and sampled beach was 6 m long

Calcite was absent from the majority of the samples except Samples B3 (sparse) and C4 (traces).

Group III was composed of samples with nonquantifiable clay of poor to very poor crystallinity; they contained abundant feldspar and quartz but no calcite, except for traces in Sample AB5.

Group IV samples contained quantifiable amounts of illite, kaolinite and smectite; they were of poor to good crystallinity, and included abundant amounts of feldspar and quarz, with little (traces) or no calcite.

Group V samples possessed nonquantifiable clay of very poor crystallinity, and abundant feldspar and quartz, with little (traces) or no calcite.

Fig. 4 presents the diffractograms of Samples B4, CB4, AB5, C5, and CB5, which are representative of Mineralogical Groups I, II, III, IV, and V, respectively.

Fig. 3b shows the spatial distribution of Groups I–V to be heterogeneous in the study area.

Granulometric evaluation revealed the rock to consist of three components: sand, silt and clay.

Table 2. Physical and chemical characteristics of 23 sediment samples in study area. Transect and level abbreviations as in Table 1. Qualitative: 0, disintegrated immediately; 1, disintegrated in 0.5 h; 1.5, disintegrated in 1 h; 2.5, disintegrated in 24 h; 3, did not disintegrate. Quantitative: 0, resistant to compression; 1, 1 to 21 kg cm^2 resistance; 2, >21 kg cm^2 resistance. Density and porosity could only be determined for those samples which did not disintegrate upon submersion in water

Sediment characteristic	A1	A2	A3	A4	A5	AB4	AB5	BA4	BA5	B1	B2	B3	B5	B4	BC4	BC5	CB4	CB5	C1	C2	C3	C4	C5
Qualitative (disintegration)	0	1	2.5	1	3	1	1	1	1	0	1	3	1	1.5	1	3	1	1.5	1	1	1	1	1
Quantitative (cohesion)	0	0	0	0	1	0	1	1	1	0	0	1	0	1	0	2	0	1	0	1	1	0	0
Relative density in:																							
dry state					1.25							1.47				2.15							
saturated state					1.58							1.82				2.38							
Absolute density	2.56	2.54	2.51	2.43	2.44	2.43	2.49	2.43	2.43	2.59	2.59	2.54	2.4	2.45	2.38	2.55	2.39	2.36	2.56	2.55	2.49	2.33	2.33
Porosity					48.8							39.6				15.7							
pH	7.4	7	7.3	8	8.2	8	8.3	7.6	7.7	8.1	7.8	7.6	8.2	8.3	8	8.3	8	8.2	7.5	7.6	7.4	8.1	8

The technique used did not allow granulometric analysis of four of the five samples selected because it was impossible to achieve their total disperison. Work is continuing with a view to solving this problem.

Sample B4, however, contained abundant calcite, which was attacked by the hydrogen peroxide and dilute hydrochloric acid, liberating the sedimentary particles and thus achieving complete dispersion for analysis.

Fig. 5a shows the particle-size distribution for Sample B4. The histogram in Fig. 5b reveals that the sediment was composed of 12% clay (ϕ 0 to 2 μm) and 88% silt (ϕ 2 to 60 μm). In the silt fraction, 62% of the particles were 2 to 20 μm, 23% were 20 to 40 μm, and 3% were 40 to 60 μm.

As for the mineralogical components, numerical techniques were applied to classify the samples on the basis of qualitative/quantitative cohesion (Table 2).

The resulting phenogram (Fig. 6a) reveals, at a distance of 1.295, three cohesion groups (I, II, III) and an isolated sample (A3).

Cohesion Group I was comprised of samples with zero to slight cohesion. These samples disintegrated immediately or within 30 min of submersion in water, and did not offer resistance to compression.

Group II samples displayed medium cohesion, disintegrating between 0.5 and 1 h of submersion in water and possessing a resistance to compression of between 1 and 21 kg/cm^2.

Group III samples did not disintegrate even after 24 h submersion in water, and resisted compression of between 1 and 254.6 kg/cm^2.

The isolated sample, Sample A3, disintegrated after 24 h submersion and did not resist compression.

Table 2 shows relative and absolute densities of the sediment under dry and saturated conditions, and its porosity. These parameters could be recorded only in those samples which did not disintegrate when submerged in water.

pH ranged from 7 to 8.3 (Table 2), indicating slight alkalinity of the substrate.

Fig. 6b shows that the spatial distribution of the samples varied as a function of cohesion.

Analysis to determine the degree of correspondence between the clusters defined by the two phenograms (minerals and cohesion) by means of a strict consensus tree revealed incongruency between the phenograms, indicating that the two sets of clusters were not comprised of the same samples.

Some samples from Levels 1, 2 and 3 displayed mineral and cohesion characteristics similar to samples from Levels 4 and 5, indicating the discontinuity of the substrate characteristics.

The samples from Level 4 were characterized by abundant feldspar and quartz, by the absence of calcite (except in Sample B4 which contained abundant calcite), by the presence of clay in variable quantities, and by slight cohesion. The species found in this level were *Themiste petricola, Polydora* sp., *Pherusa* sp., *Lithophaga patagonica,* and *Saxicava solida.*

The samples of Level 5, except for A5 and BC5 were characterized principally by the presence of varying

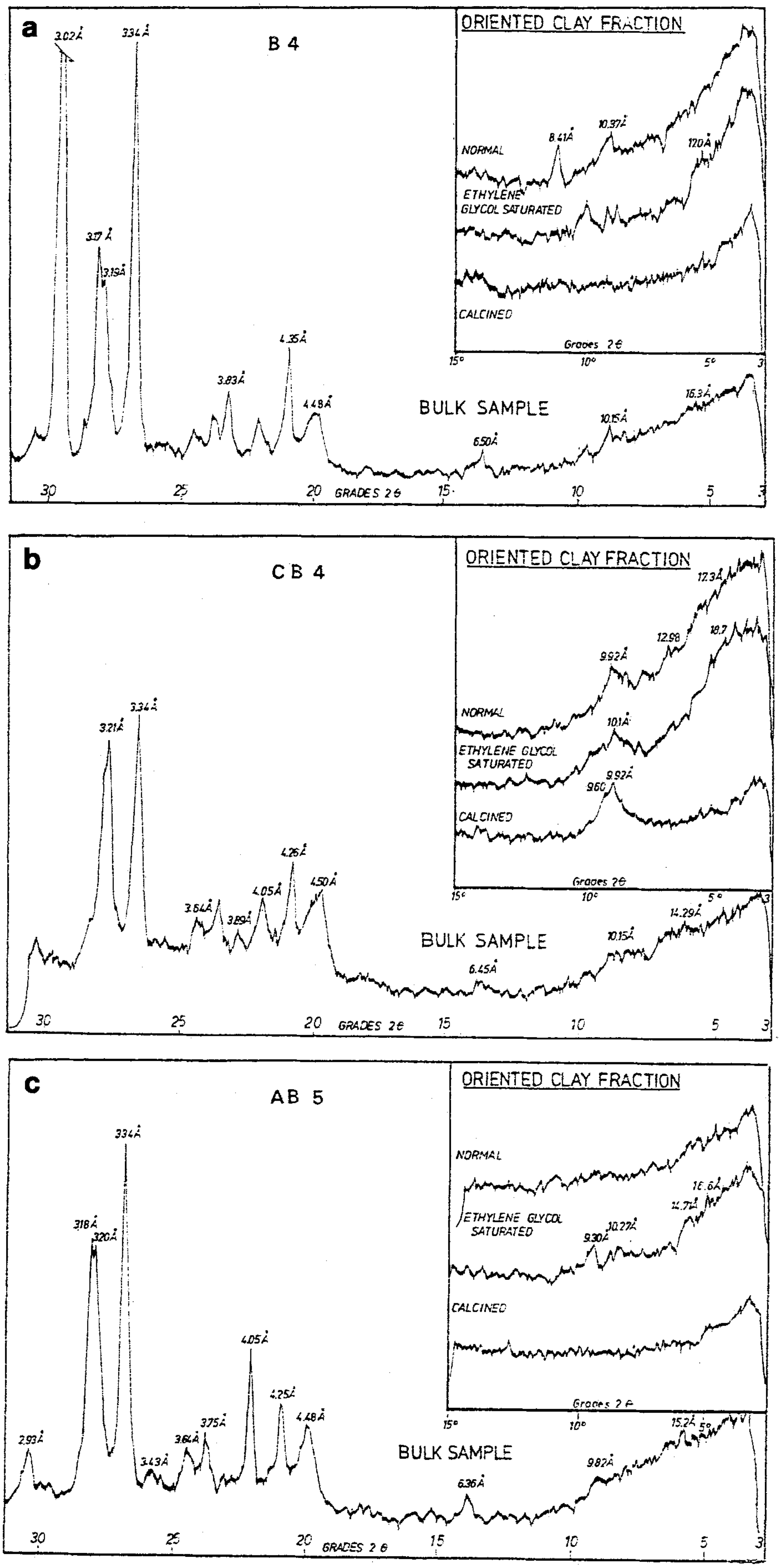


Fig. 4. Diffractograms of samples representative of the five mineralogical groups revealed by phenogram in Fig. 3a. (a) Sample B4, Group I; (b) Sample CB4, Group II; (c) Sample AB5, Group III; (d) Sample C5, Group IV; (e) Sample CB5, Group V

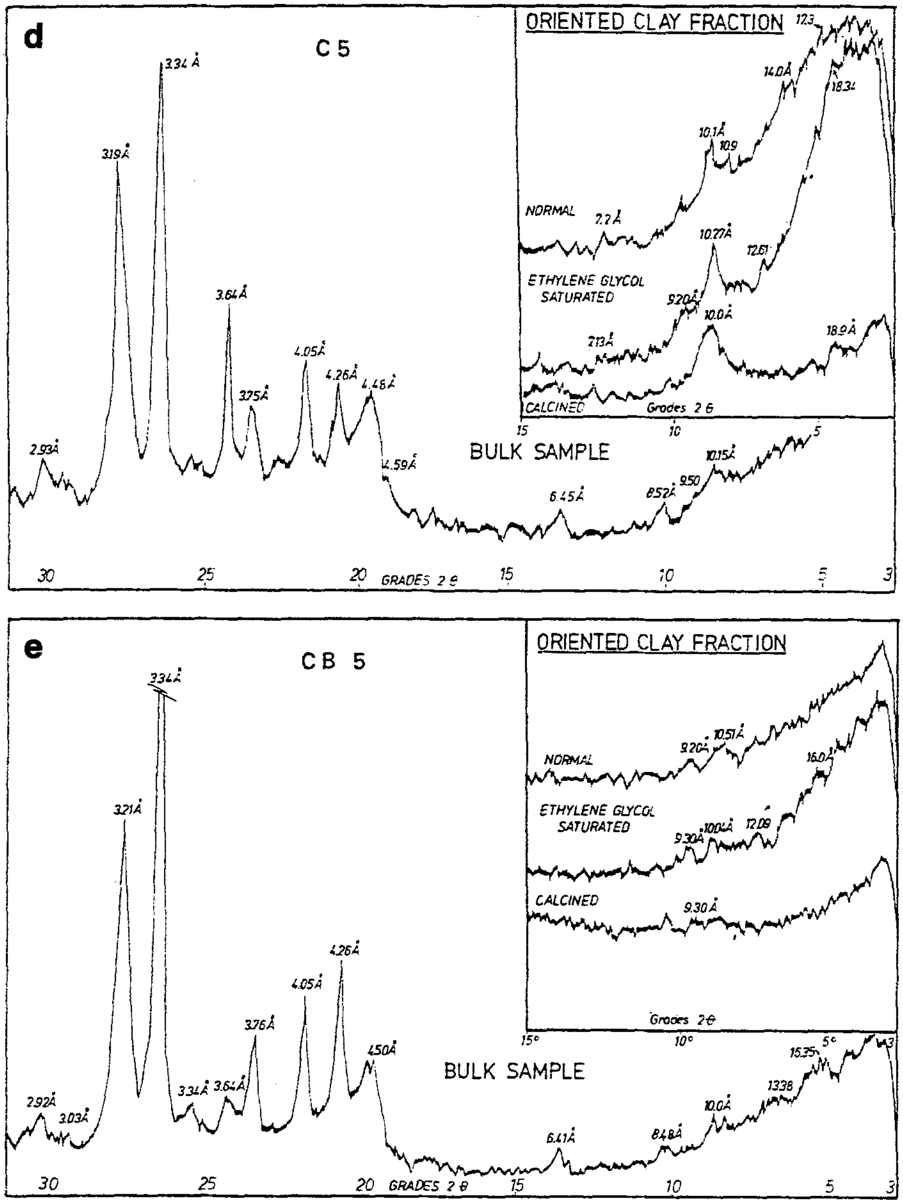


Fig. 4d, e

quantities of feldspar, quartz and clay, by the absence of calcite, and by complete lack of cohesion. In samples from this level we found *Themiste petricola, Polydora* sp., *Pherusa* sp., *Lithophaga patagonica, Petricola patagonica, Saxicava solida, Barnea lamellosa* and *Pholadidea darwini.*

Sample A5 had not disintegrated by 24 h; it contained *Polydora* sp. and *Pherusa* sp. Sample BC5 differed from the other samples by its very high resistance to compression (254.6 kg/cm^2), its abundant calcite content, and by containing the most fauna: *Themiste petricola, Polydora* sp., *Pherusa* sp., *Lithophaga patagonica, Petericola patagonica* and *Saxicava solida.*

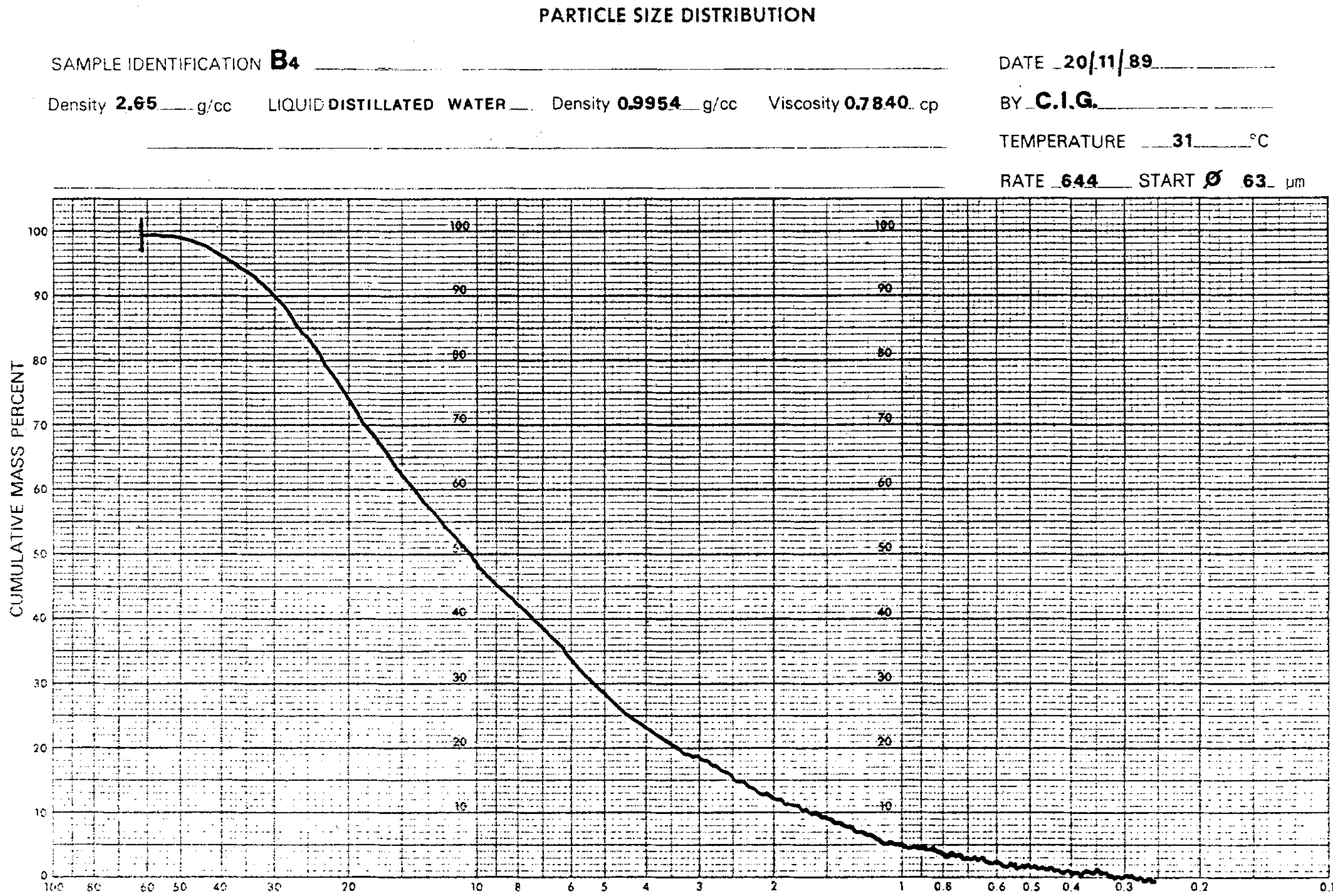
Table 3 clearly reveals that the samples from the embankment (Levels 1, 2 and 3) did not contain endolithic species, which were restricted to Levels 4 and 5.

Discussion and conclusions

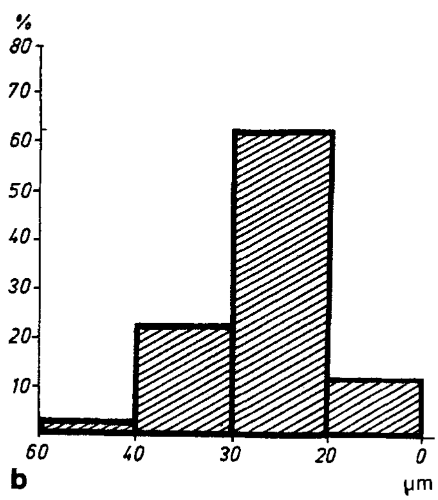
The heterogeneity of the composition and distribution of the rock, the presence of sand, silt and clay in different proportions but with a predominance of silt, and the presence of calcite in varing proportions, all indicate that the substrate is characteristic of a loess (Teruggi 1982).

The most variable physical properties of the substrate are its resistance to compression and disintegration. Of the total samples analyzed, 43.48% resisted compression and 86.96% disintegrated within 24 h of submersion in water.

Our attention was caught by the fact that here was no correlation between those samples comprising the groups defined on the basis of their mineral properties and those defined on the basis of their cohesion properties. This could result from the observed heterogeneity within the substrate.



a



b

Fig. 5. Granulometric analysis of Sample B4. (a) Particle-size distribution; (b) frequency distribution of particles as a function of size

The endolithic fauna *Themiste petricola, Plydora* sp., *Pherusa* sp., *Lithophaga patagonica, Petricola patagonica* and *Saxicava solida* inhabit substrate with low to high cohesion, with or without calcite, reflecting their capacity to colonize areas of extremely varied mineralogical and physical characteristics.

The presence of these species in association with substrates displaying very high resistance to compression (254.6 kg/cm^2) and abundant calcite content indicates that they possess a specialized boring mechanism.

On the other hand, it is evident that the Pholadidae are restricted to Level 5 and, within this level, to substrate characterized by zero to slight cohesion. The absence of *Barnea lamellosa* and *Pholadidea darwini* from a substrate with similar characteristics in Level 4 could be attributable to other factors not studied here.

Table 3. Presence (+) of endolithic species in 23 sediment samples arranged by collection levels. (e.g. A1 = Level 1 in Transect A, B2 = Level 2 in Transect B, etc.)

Sample	*Themiste petricola*	*Polydora* sp.	*Pherusa* sp.	*Lithophaga patagonica*	*Petricola patagonica*	*Saxicava solida*	*Barnea lamellosa*	*Pholadidea darwini*
A1	–	–	–	–	–	–	–	–
B1	–	–	–	–	–	–	–	–
C1	–	–	–	–	–	–	–	–
A2	–	–	–	–	–	–	–	–
B2	–	–	–	–	–	–	–	–
C2	–	–	–	–	–	–	–	–
A3	–	–	–	–	–	–	–	–
B3	–	–	–	–	–	–	–	–
C3	–	–	–	–	–	–	–	–
A4	–	+	–	–	–	–	–	–
AB4	+	+	+	+	–	–	–	–
BA4	–	+	–	+	–	–	–	–
B4	–	+	–	–	–	–	–	–
BC4	–	–	–	–	–	–	–	–
CB4	–	–	+	+	–	+	–	–
C4	–	–	–	–	–	–	–	–
A5	–	+	+	–	–	–	–	–
AB5	–	+	–	+	+	+	–	+
BA5	–	–	+	+	–	–	+	+
B5	+	+	+	+	–	–	–	–
BC5	+	+	+	+	+	+	–	–
CB5	–	+	–	+	–	+	+	–
C5	–	+	+	+	–	–	+	+

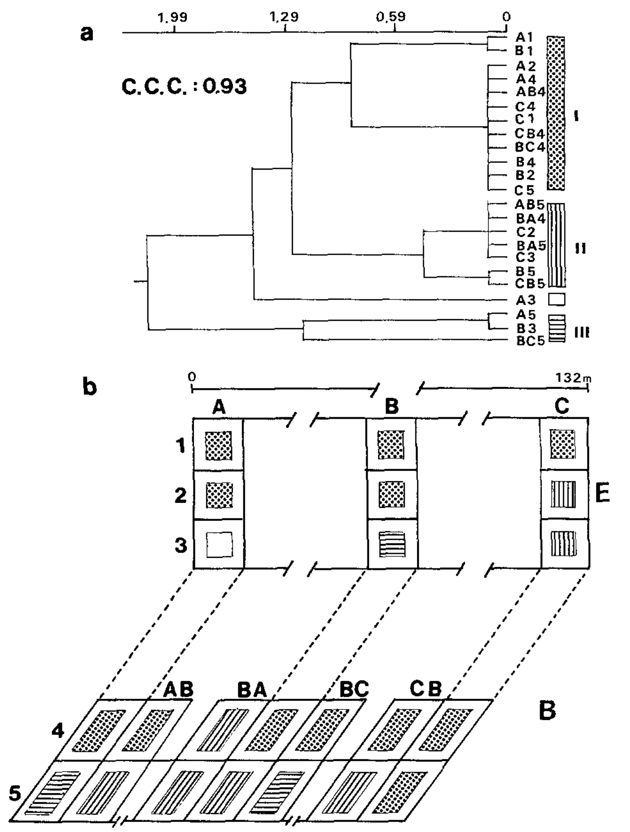


Fig. 6. (a) Distance phenogram of 23 samples along Transects A, AB, BA, B, BC, CB, C, divided by cohesion characteristics into three groups (I–III); characteristics of Groups I–III described in "Results"; numerals following transect designations are collection levels in (b); C.C.C.: cophenetic correlation coefficient; top abscissa shows distance values of phenogram; (b) Spatial distribution (Levels 1–5) of Groups I–III and of isolated Sample A3 in study area; Levels 1–3: embankment samples; Levels 4 and 5: beach samples

Our results appear to indicate that the Pholadidae recorded are not capable of penetrating a substrate with high compressive resistance and abundant calcite content.

It is inferred that *Themiste petricola, Polydora* sp., *Pherusa* sp., *Lithophaga patagonica, Petricola patagonica* and *Saxicava solida* must possess both physical and chemical penetration capabilities, whereas the Pholadidae are only capable of physical penetration. Studies of the tegumentary glands of endolithic bivalves and polychaetes using the Alcian blue technique have revealed the presence of acid mucopolysaccharides (Kühnelt 1930, Russell-Hunter 1949, Yonge 1955, Dorsett 1961). The literature thus proves the existence of a chemical method of penetration and supports our interpretation that the presence of some species is connected with a high degree of substrate cohesion.

In conclusion, our results confirm the close relationship between mineralogical, physical and chemical characteristics of the substrate and the distribution of endolithic organisms in the intertidal zone.

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Literature cited

Dayton, P. K. (1971). Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecol. Monogr. 4: 351–389

Dorsett, D. A. (1961). The behaviour of *Polydora ciliata* (Johnst.). Tube-building and burrowing. J. mar. biol. Ass. UK 41: 577–590

Krumbein, W. C., Graybill, F. A. (1965). An introduction to statistical models in geology. McGraw Hill Book Co., New York

Kühnelt, W. (1930). Bohrmuschelstudien. I. Palaeobiologica 3: 51–91

Pérès, J. M. (1961). Océanographie biologique et biologie marine. Presses Universitaires de France, Vendôme

Reedway, R. (1912). Color standards and color nomenclature. Published by the author, Washington, D. C.

Rohlf, F. J., Kishpaugh, J., Kirk, D. (1972). NT-SYS: numerical taxonomy system of multivariate statistical programs. Tech. Rep. NY. St. Univ. mar. Sci. Res. Cent. Stony Brook

Russell-Hunter, W. (1949). Structure and behaviour of *Hiatella gallicana* and *H. arctica*. Proc. R. Soc. Edinb. 63: 271–289

Smith, P. G., Phipps, J. B. (1984). Consensus trees in phenetic analyses. Taxon 33: 586–594

Sneath, P. H. A., Sokal, R. R. (1973). Numerical taxonomy – the principles and practice of numerical classification. W. H. Freeman & Co., San Francisco

Teruggi, M. E. (1982). Rocas clásticas y prioclásticas. Diccionario sedimentológico. Ediciones Científicas Argentinas Librart, Buenos Aires

Yonge, C. M. (1955). Adaptation to rock boring in *Botula* and *Lithophaga* (Lamellibranchia, Mytilidae) with a discussion on the evolution of this habit. Q. Jl microsc. Sci. 96: 383–410