PLANT BIOSYSTEMS, **137** (2) 203-214, 2003

Morphology and composition of mineral deposits of *Lithophyllum byssoides* (Lamarck) Foslie (*Corallinales, Rhodophyta*) from the Island of Ustica

A. M. MANNINO

received 3 September 2002; revised version accepted 13 March 2003

ABSTRACT - The present study is based on the analysis of thalli of *Lithophyllum byssoides* (Lamarck) Foslie (*Corallinales, Rhodophyta*) collected from the Island of Ustica (southern Tyrrhenian Sea). Both the composition of mineral deposits, and the morphology of the thallus were examined. Chemical-mineralogical analyses (by energy dispersive spectrometry, X-ray diffractometry and atomic absorption spectrophotometry) revealed the structure and organisation of the mineral deposits, mainly calcium carbonate, present within the cell wall. Calcium carbonate was mainly deposited as calcite with 15% of magnesium carbonate, but aragonite was also detected. A comparison with data referring to thalli collected from two localities along the north-western coast of Sicily (MANNINO, 1992, 1994) highlighted some differences, among the three populations, relative to composition of mineral deposits and population structure. Results from the present study also point to a relationship between composition of mineral deposits and environmental factors.

KEY WORDS - chemical-mineralogy, *Corallinaceae, Lithophyllum byssoides,* morphology, southern Tyrrhenian Sea

Nongeniculate coralline red algae (*Corallinales, Rhodophyta*) represent a fundamental component of intertidal and subtidal communities throughout the world, and also constitute important sources of carbonate sediment and habitats of high biodiversity.

Lithophyllum byssoides (Lamarck) Foslie, the species dealt with in this study, is a nongeniculate coralline red alga belonging to the subfamily *Lithophylloideae* Setchell (1943: 134, as *Lithophylleae*). It is a common intertidal to shallow subtidal species, previously considered to be exclusively occurring in the western Mediterranean Sea (HUVÉ, 1963). Recently, it has also been recorded from the Atlantic coasts of France and Spain, from the Azores, and from some localities of the eastern Mediterranean Sea (BABBINI & BRESSAN, 1997; CHAMBERLAIN, 1997).

When water movement and light intensity fall within its optimal range, *L. byssoides* forms a typical massive concretion called "trottoir" at the low intertidal/subtidal interface. When factors are less favourable, it forms small groups of cushion-like clumps more or less spread out.

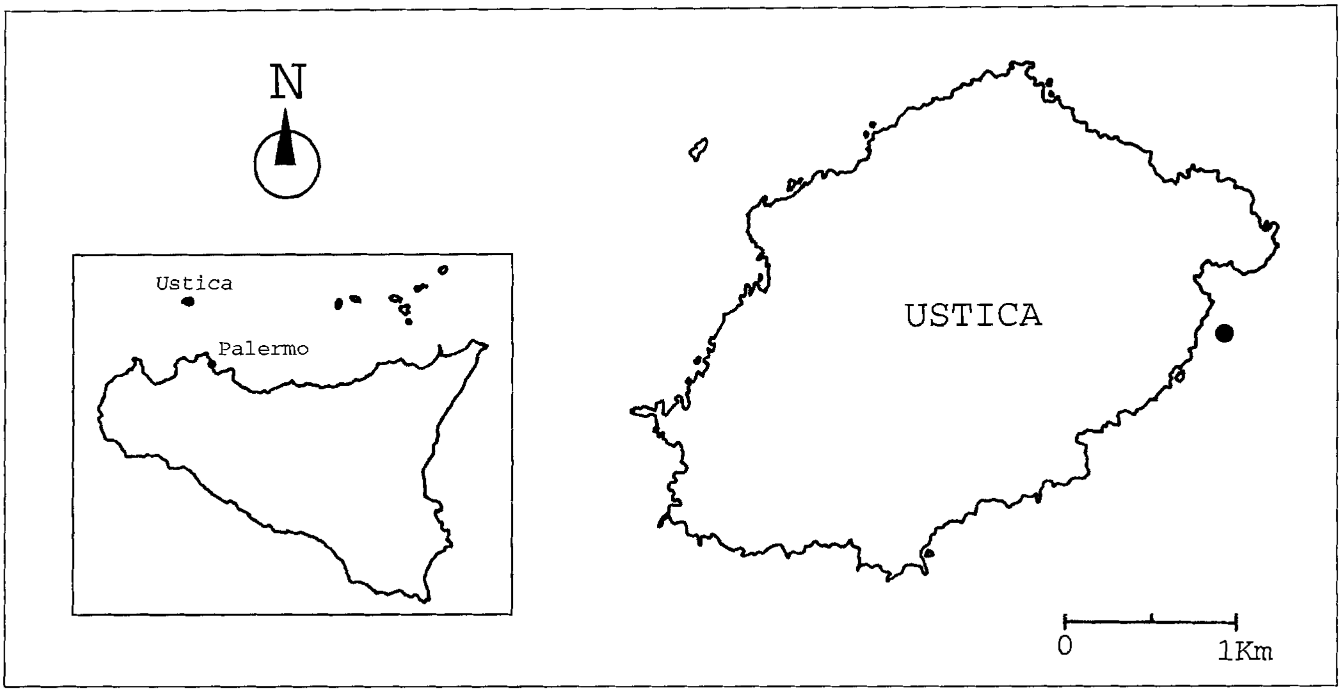

FIGURE 1 - Island of Ustica: sampling site is indicated.

For a long time, the species has been known both as *Lithophyllum tortuosum* (Esper) Foslie (1900: 20) and *Tenarea tortuosa* (Esper) Lemoine (1910: 368), until WOELKERLING (1983) established *Lithophyllum lichenoides* Philippi (1837: 389) as the earliest name for this species.

Recently, WOELKERLING & LAMY (1998: 259), after re-examining Lamarck's type collections, concluded that the name *L. byssoides* - whose basyonym *Nullipora byssoides* Lamarck was misapplied to define another species, currently known as *Lithophyllum trochanter* (Bory) Woelkerling - had nomenclatural priority.

Various publications contain data on the morphology and vegetative anatomy of *L. byssoides* and its heterotypic synonym *L. lichenoides* (HUVÉ, 1957; WOELKERLING, 1983; WOELKERLING *et al.*, 1985; MORHANGE *et al.*, 1992; LABOREL *et al.*, 1993; MANNINO, 1994; CHAMBERLAIN, 1997).

Little information, however, is available on the composition of the mineral deposits of this species (WALTER-LÉVY L. & STRAUSS R., 1954; MANNINO, 1992). Indeed, most data concern the genus *Lithophyllum* in general, other species of this genus (*Lithophyllum moluccense* (Foslie) Foslie), or other genera of *Corallinaceae* (e.g. *Amphiroa*, *Corallina*, *Jania*) (CHAVE, 1954; MILLIMAN *et al.*, 1971; BOROWITZKA *et al.*, 1974; MILLIMAN, 1974; KOLESAR, 1978). In all of these studies, the presence in the skeleton of coralline red algae of calcium carbonate, deposited as calcite, plus a high percentage of magnesian calcite, has been highlighted. A positive correlation between water temperature and percentage magnesium content in calcium carbonate has also been reported (CHAVE, 1954; MILLIMAN *et al.,* 1971). Little is also known about relationships and interactions between composition of mineral deposits and environmental factors.

The aim of the present work is to present new data on the composition of the mineral deposits and morphology of *L. byssoides* collected from the Island of Ustica (southern Tyrrhenian Sea). A comparison with data from two localities along the north-west coast of Sicily, Capo Gallo and Punta Barcarello (MANNINO, 1992, 1994), has also been made, to try to establish a relationship between chemical-mineralogical data and environmental factors.

MATERIALS AND METHODS

Study area

Specimens were collected along the south-eastern coast of the Island of Ustica (southern Tyrrhenian Sea), located at about 67 km N-NW off Palermo (Figure 1).

The Island of Ustica, a marine natural reserve, is of volcanic origin, rising to more than 2000 m from the bottom of the Tyrrhenian Sea. It is dominated by west and north-westerly winds, and currents have a predominant

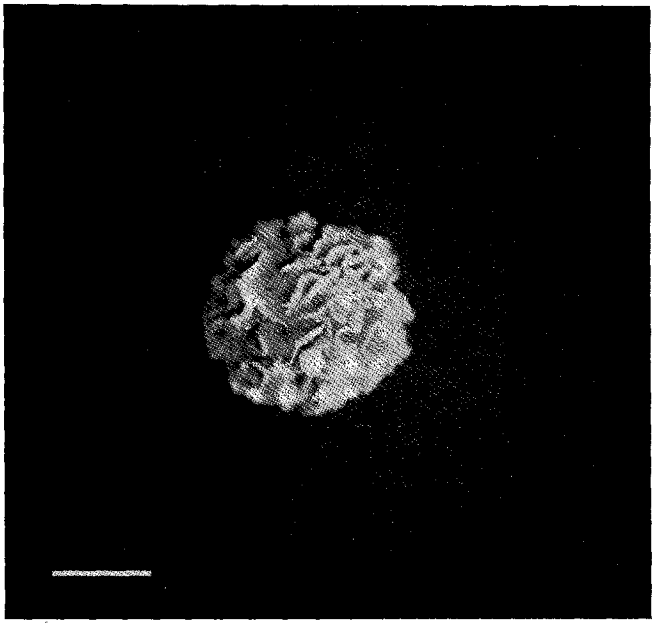

FIGURE 2 - Habit of *Lithophyllum byssoides:* growth form with erect lamellae. Scale bar = 15 mm.

SW-W-NW direction and a mean velocity of 8 cm/s; S-E currents occur only in October. The island is also influenced by the Atlantic current. Strong water movement keeps the waters very clear and transparent, making it an important shelter area for marine organisms (GIACCONE *et al.*, 1985).

Morphology

Samples were collected in winter (January) and summer (July) 1990, and indicated as (w) and (s), respectively. Material was rinsed in distilled water and then air-dried or preserved in 4% formalin in seawater. It was examined either under a stereo-microscope or under a scanning electron microscope (SEM Philips PSM 500 at 20 kv), after being coated with gold. Samples were identified according to CHAMBERLAIN (1997). Specimens of the examined material are deposited in the *Herbarium Mediterraneum* (PAL).

Chemical-mineralogy

The observations were carried out on thin sections prepared from air-dried fractured fragments, embedded in resin (Araldite), sectioned and ground up to a thickness of about 30 µm. Texture and structure of mineral deposits present in the thallus (calcium carbonate and rare elements) were examined both under a polarised microscope (PM) and a SEM (Cambridge Stereoscan 360).
Qualitative microanalyses by EDS (energy dispersive spectrometry), and X-ray diffractometric analyses were performed. Fragments taken from the outermost portion of the thallus (about 5 mm) were powdered, and then searched using meshes of <40 µm. According to the established annual growth rate of this species (HUVÉ, 1954; BOUDOURESQUE *et al.*, 1972), the portion used for the analysis was formed during the six month period prior to sampling.
Using EDS analysis, X-ray fluorescent emissions of specimens, produced by electronic bombardment, were analysed to determine the calcium and magnesium composition of the carbonate deposits. X-ray signals were recorded and translated into emission spectra, showing the peaks due to calcium and magnesium, and then into distribution maps, showing the exact spatial distribution of the element in the sample. Particular attention was directed to the analysis of the distribution map of magnesium.
Using X-ray diffractometric analysis (performed at 40 kv and 20 mÅ) and emissions of backscattered electrons (electrons of the incident beam coming back from the specimen after a collision with its atoms), translated into images, the mineralogical composition of carbonate deposits has been determined.
The X-ray diffractometric analysis allows the estimation of the intensity of signals of rays diffracted by the specimen's atoms after X-ray bombardment; the recorded signals, translated in diffractogrammes, show the emission peaks for each carbonate form present in the sample.
For the chemical analyses of powdered samples, organic substance and CO_2 were determined by combustion at 1000°C; another aliquot of samples, treated with 65% HNO_3 and then filtered, were used to determine the insoluble residue (R.I.). The filtrate - once brought to volume - was analysed by atomic absorption spectrophotometry (Perkin Elmer 2380) to determine major (Ca^{++}, CO_3^{-}), minor (Mg^{++}, Sr^{++}) and trace (Fe, Mn, Ni) elements contained in the mineral deposits.

RESULTS

Morphology

L. byssoides commonly grows in the intertidal zone. Living specimens, grey-violet in colour, form characteristic cushion-like clumps, composed of densely interweaving and anastomosing lamellae which are more or less smooth on the dorsal surface and ridged on the ventral one.
The examined population is dominated by the growth form characterised by erect lamellae (Figure 2), even though the growth form with spiniform lamellae has

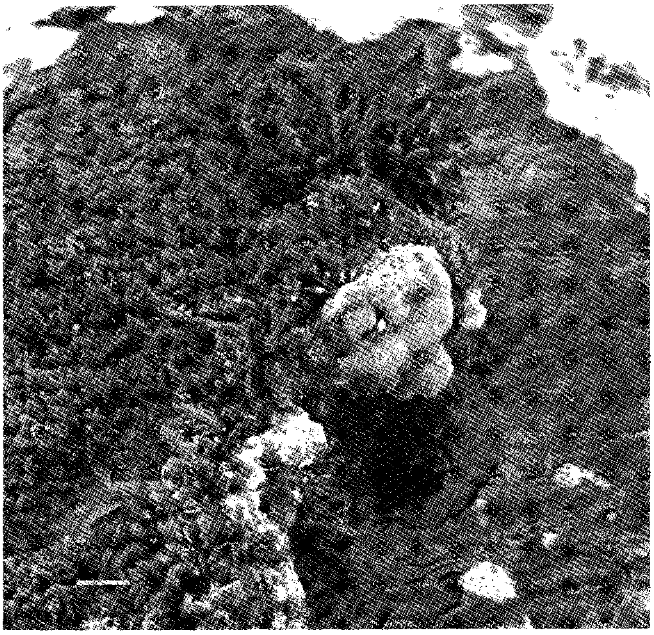

FIGURE 3 - Population of *Lithophyllum byssoides* at Ustica station. Scale bar = 50 mm.

also been observed. Thalli grow by forming concretions of approximately 10 to 20 cushion-like clumps (Figure 3); during the present investigation, the massive concretion commonly known "trottoir" was never found. All examined thalli exhibited a uniform vegetative and reproductive anatomy; only tetrasporangial conceptacles were found.

Chemical-mineralogy

The calcium carbonate deposits occurred within the cell wall. Crystals (1 µm in diameter) were deposited mainly as calcite (rhombohedral form), but aragonite (orthorhombic form) was also detected.
The X-ray diffractometric analysis (Table 1, Figure 4) shows that the main peaks correspond to calcite, and that smaller aragonite peaks are also present.
Approximately 15% magnesium carbonate was also detected. There were no differences between samples (s) and (w) (Table 1). The relatively large amounts of magnesium contained in the samples provide indirect evidence for the presence of calcite plus magnesian calcite.
Data from the magnesium distribution map (Figure 5), backscattered electron images (Figure 6), and the EDS analysis (Figure 7) overlap with each other, and confirm the results from X-ray diffractometric analyses, i.e., the presence of magnesium carbonate within the cell wall mineral deposits. The distribution map reveals a strong concentration of magnesium in the outermost portion of the sample.
The backscattered electron images show two zones of different opacity whose composition has been revealed by EDS analysis. In fact, EDS spectra (Figure 7) show the presence of calcium (main peaks) in both zones, whereas magnesium is present only in the spectrum taken close to the outermost portion of the sample.
The results of all these analyses thus confirm the presence of calcite plus magnesian calcite in the outermost portion of the sample, and only of calcite in the innermost portion.
Chemical analyses (Table 2) revealed either elements usually present in seawater carbonates (e.g. Al, Ti, Li, Rb and B) or elements that are incorporated into calcitic and organic skeletons according to their charge and ionic ray (e.g. Mn, Fe, Ni, Co, Zn, Sr, Ba, Pb and Cu) (DEMAJO, 1988).
Table 2 shows that sample (w) generally has a higher concentration of the elements than sample (s); moreover, Fe, Sr, Ti, Mn and Al present the highest values, Co, Rb and Cu the lowest.

TABLE 1
Mineralogical phases and % magnesium carbonate for samples of *Lithophyllum byssoides* from different stations

	Island of Ustica (s)	Island of Ustica (w)	Capo Gallo (s)*	Capo Gallo (w)*	Punta Barcarello (s)*	Punta Barcarello (w)*
Calcite	+++	+++	+++	+++	+++	+++
Aragonite	Tr	Tr	Tr	Tr	Tr	+
Dolomite	-	-	-	-	-	Tr
Magnesium carbonate	15	15	15	15	13	13

* data from MANNINO (1992);
w: winter; s: summer;
Tr: Trace; +++: abundant; +: present; -: absent.

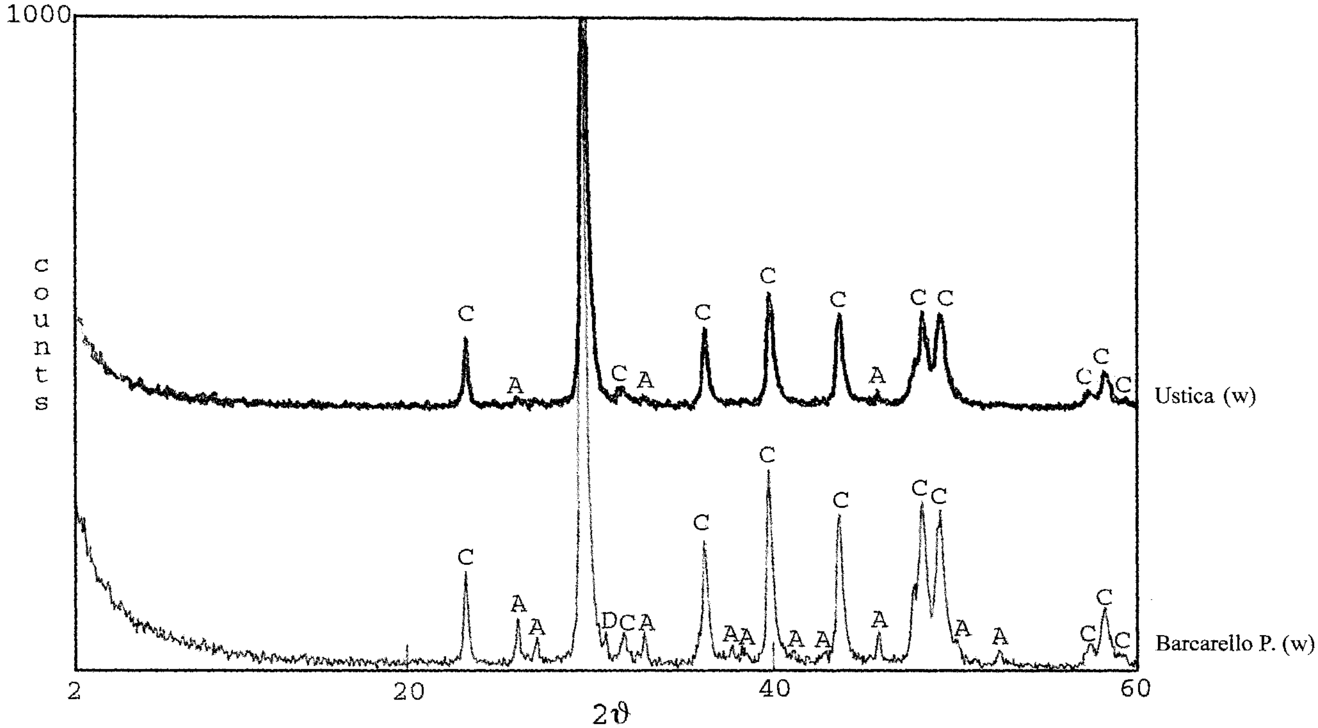

FIGURE 4 - X-ray diffractograms of Ustica (w) and P. Barcarello (w) samples. C: Calcite; A: Aragonite; D: Dolomite; 2ϑ: angle between incident and diffracted ray.

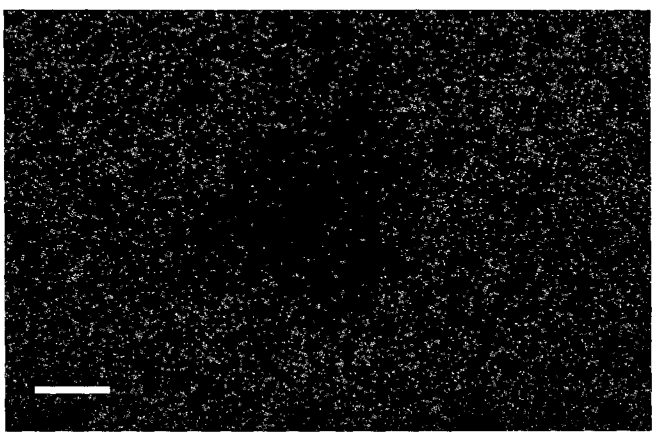

FIGURE 5 - Ustica (s) sample: map of magnesium distribution. Note in the inner area a zone of low density of magnesium. Scale bar = 12.5 μm.

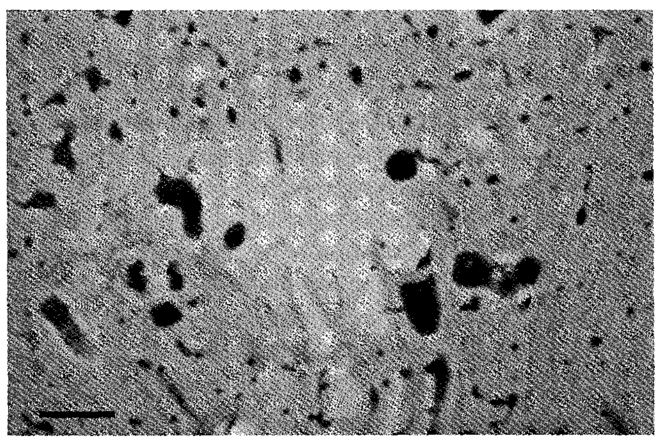

FIGURE 6 - Ustica (s) sample: image produced by the signals of the backscattered electrons. Note two areas with different intensities of grey, and the presence of Fe (dark spots). Scale bar = 12.5 μm.

DISCUSSION

Some differences in morphology and population structure were observed during the present study. Ustica and C. Gallo populations were similar, and both differed from that of P. Barcarello where groups of only 3-4 cushion-like clumps occur. The P. Barcarello clumps are also smaller than those observed in Ustica and C. Gallo stations. Thus, the populations of Ustica and C. Gallo stations were better structured than that of P. Barcarello. Such observations suggest that *L. byssoides* prefers environments with good water movement, protected from man-made pollution, as occurs at Ustica and C. Gallo. The C. Gallo coast is dominated by N-W currents with a mean velocity greater than 8 cm/s. These currents keep the waters very clear, transparent and scarcely influ-

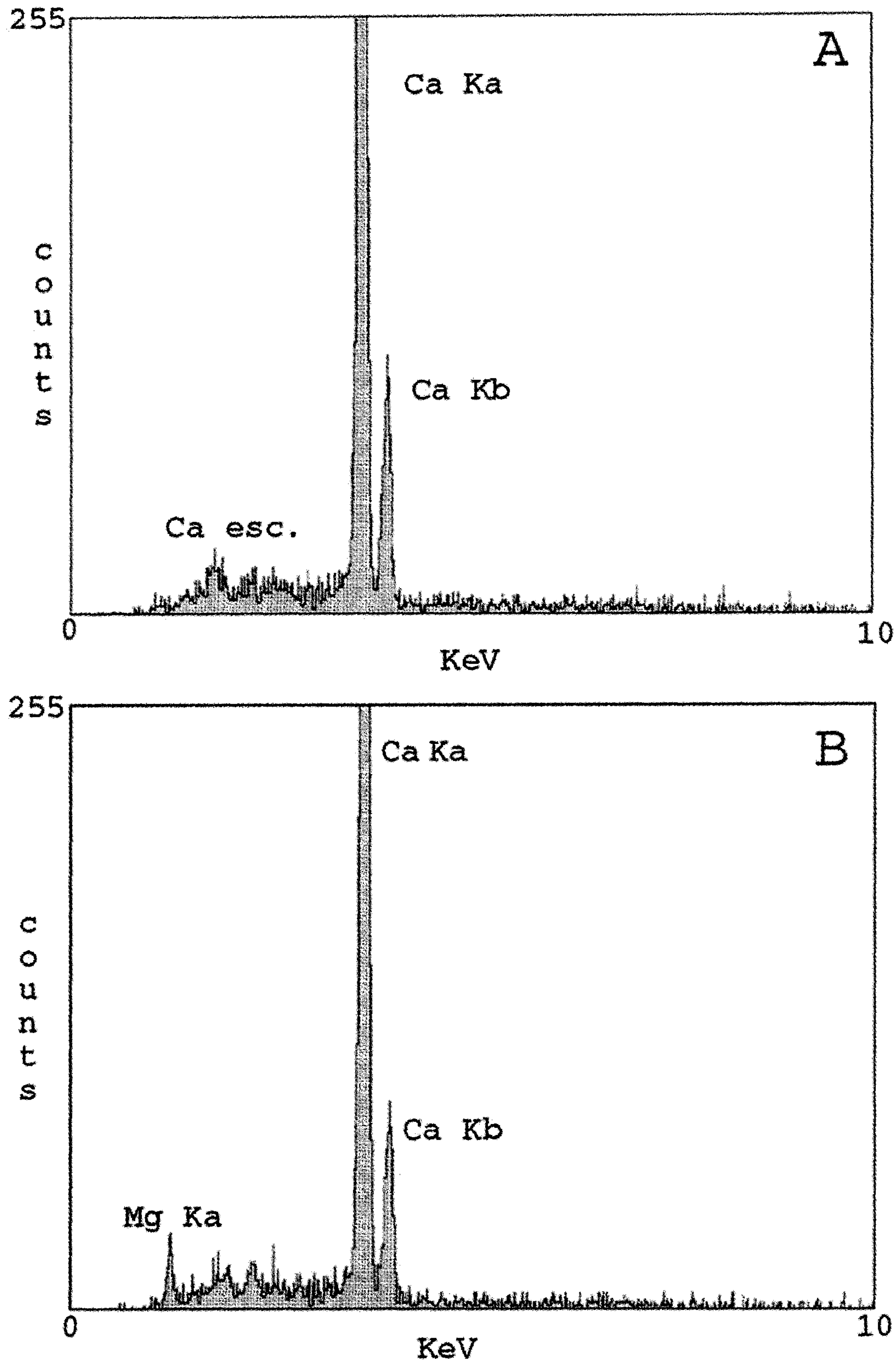

FIGURE 7 - Energy dispersive X-ray spectrum of Ustica (s) sample: A) spectrum taken close to the area of lower density; B) spectrum taken close to the area of higher density (see Figure 6). Esc.: escape peak (due to a radiation leak); a, b: electrons of the external orbitals (L,M) filling the gap in the K ionised orbital.

enced by the detritus-rich waters streaming from the nearby Gulf of Palermo. At the P. Barcarello station, the currents also have a N-W direction, but are less strong than those of C. Gallo, and human activities are more intense.

These observations are in agreement with those of previous authors (e.g. FELDMANN, 1937; BASSO, 1996; BABBINI & BRESSAN, 1997), who pointed out that this species prefers sites with a good water circulation and protected from high light intensity. FELDMANN (1937) also described a close relationship between the growth form with finger-like protuberances and strong water circulation. Therefore, the growth form with finger-like protuberances in the Ustica station provides indirect evidence for the presence in this area of a very strong water movement.

Finger-like protuberances might be an adaptation to strong water movement, by reducing damages to the thallus.

Results from chemical-mineralogical analyses confirm and extend observations reported by previous authors for *Lithophyllum* (LEWIN, 1962; BOROWITZKA *et al.*, 1974; MILLIMAN, 1974). The presence of aragonite, the most common crystalline form of calcium carbonate in seawater, is rather frequent. Indeed, although some authors believed that aragonite and calcite occurred together only in animals (CHAVE, 1954), they have been previously found together in the thallus of *L. byssoides* (WALTER-LÉVY & STRAUSS, 1954, as *Tenarea tortuosa*).

A comparison of the chemical-mineralogical data for the three populations shows that in P. Barcarello (w) sample peaks corresponding to calcite and aragonite are much higher than those observed in Ustica (w) and C. Gallo (w) samples; moreover, peaks corresponding to aragonite are more numerous in P. Barcarello (w) sample where a small peak corresponding to dolomite [$(CaMg)(CO_3)$] was also detected (Figure 4).

Although many other crystalline forms such as magnesite ($MgCO_3$), brucite [$Mg(OH)_2$] and strontianite ($SrCO_3$) have been already found in coralline algae, dolomite has never been recorded before in these algae (LEWIN, 1962; BOROWITZKA *et al.*, 1974; CRAIGIE, 1990). Therefore, caution must be exercised in the interpretation of the presence of dolomite in the sample. It needs

TABLE 2

Comparison of chemical-mineralogical data for samples of *Lithophyllum byssoides* from different stations

	Island of Ustica (s)	Island of Ustica (w)	Capo Gallo (s)*	Capo Gallo (w)*	Punta Barcarello (s)*	Punta Barcarello (w)*
(% dry weight)						
CaO	44.78	44.64	44.79	44.66	44.14	44.94
MgO	6.31	6.03	6.33	6.04	5.44	5.92
P.F.	45.21	45.51	45.23	45.53	47.15	46.79
R.I.	2.50	3.20	2.50	3.20	1.77	1.98
TOTAL	98.80	99.38	98.85	99.43	98.50	99.63
(parts per million)						
Mn	10.15	23.00	10.20	23.10	20.40	28.50
Fe	709.10	744.90	709.90	745.10	649.90	797.40
Ni	8.98	8.90	8.90	8.88	7.27	9.30
Co	0.40	0.50	0.43	0.55	0.20	0.36
Zn	9.20	10.98	9.26	11.00	10.10	10.39
Sr	2410.0	2170.0	2414.2	2176.0	1623.3	2210.8
Ba	10.70	14.80	10.77	15.00	9.16	12.60
Pb	1.39	2.19	1.42	2.22	1.80	2.55
Al	18.10	30.40	18.31	30.10	41.70	87.50
Li	4.30	4.40	4.33	4.43	4.18	3.55
Ti	214.40	143.80	213.60	145.50	135.70	161.40
Rb	0.15	0.24	0.14	0.26	0.12	0.13
B	6.10	7.60	6.30	7.85	11.46	18.50
Cu	0.46	0.55	0.48	0.57	0.50	0.69
Cr	1.23	2.15	1.20	2.10	2.80	2.00

* data from MANNINO (1992);
w: winter; s: summer.

to be clarified whether dolomite is the result of normal activities during the calcification process or if it could be due to a detritic contamination of particles.

Data on magnesium carbonate in general confirm those furnished by other authors (CHAVE, 1954; MILLIMAN *et al.*, 1971; BOROWITZKA *et al.*, 1974; MILLIMAN, 1974; KOLESAR, 1978; MANNINO, 1992), and summarised in Table 3. Indeed, calcite plus a high percentage of magnesian calcite have been found in all examined taxa, e.g. *Amphiroa*, *Corallina*, *Jania*, *Lithophyllum* and *Lithothamnion*. Moreover, only in *Goniolithon* brucite has also been detected. Seasonal changes in magnesium carbonate concentration, thought to be more closely related to water temperature and to growth rate of the thallus (HAAS *et al.*, 1935; CHAVE, 1954; MOBERLY, 1968; MILLIMAN *et al.*, 1971), have not been observed here. Results relating to the presence of magnesium carbonate overlapped with each other for all the samples (Table 1). The large amount of magnesium carbonate (14% on average) found in the samples is closely related to the abundance of this element in seawater (MILLIMAN, 1974; CRAIGIE, 1990), and is in accord with the large amount of magnesium found in all marine organisms. Moreover, the high percentage of magnesium carbonate also provides indirect evidence for the presence in *L. byssoides* of a large amount of calcite, since it has been demon-

TABLE 3
Selected publications on the composition of mineral deposits of *Corallinales*

	Investigated taxa	Methods	Results
CHAVE, 1954	*Amphiroa, Corallina, Goniolithon, Lithophyllum, Lithothamnion*	X-ray diffractometry	Calcite containing magnesium carbonate (7-30 %). Positive correlation between magnesium content and water temperature.
MILLIMAN *et al.*, 1971	*Amphiroa, Corallina, Jania, Goniolithon, Lithophyllum, Lithothamnion*	atomic absorption spectrophotometry, X-ray diffractometry	Differences between total magnesium (2.7-7.2%) and MgCO3 (6-16 molar %) content. Positive variation of magnesium content with water temperature.
BOROWITZKA *et al.*, 1974	*Corallina cuvieri, Goniolithon, Lithophyllum moluccense*	scanning electron microscopy	Calcium carbonate deposited within the cell wall as calcite plus magnesian calcite (7-30%). In *Goniolithon,* brucite [Mg(OH)2] also reported.
MILLIMAN, 1974	*Amphiroa, Corallina, Jania, Goniolithon, Lithophyllum, Lithothamnion*	chemical analysis, X-ray diffractometry	Presence of calcite, magnesian calcite (more than 25 molar %) and several elements (e.g. Sr, Na, K, Fe, Mn, Cu). In *Goniolithon,* brucite also present.
KOLESAR, 1978	*Calliarthron tuberculosum*	atomic absorption spectrophotometry, X-ray diffractometry	Analysis of calcite from field-collected and laboratory cultured specimens indicates that growth rate is probably responsible for changes in the magnesium content of calcite.
MANNINO, 1992	*Lithophyllum lichenoides*	EDS, X-ray diffractometry, atomic absorption spectrophotometry	Deposits of calcite plus magnesian calcite (13-15 molar %). Several elements (e.g. Mn, Fe, Sr, Al, Rb, Li, B) also detected.

strated that calcitic skeletons have more magnesium than those composed of aragonite (LEWIN, 1962: 460).
The presence of several elements in the cell wall carbonate deposits of *L. byssoides* is not uncommon. Indeed, numerous elements have been detected in deposits of coralline red algae (Table 3). Moreover, natural carbonates are usually not completely pure, and can incorporate cations, anions or other mineral phases; they can absorb elements on their external surface, or capture detritic particles (MILLIMAN, 1974).
It is well known that calcium biomineralisation in coralline red algae is a largely biological process. Thus, cation concentration in the thallus will depend either on cation concentration in water surrounding the algae or on the rate at which each cation will diffuse through the cells of the thallus. Calcium, for example, will diffuse more quickly than heavier and larger cations (e.g. Sr, Ba and Pb), and all cations less heavy and smaller than calcium (e.g. Mg, Fe, Mn, Zn and Cu) will diffuse together with it. Moreover, cations less heavy and smaller than calcium will be incorporated in calcitic skeletons more promptly, whereas heavier and larger cations will be preferably incorporated in aragonitic skeletons (MILLIMAN, 1974).
The differences in elemental concentration revealed within the (s) and (w) samples could be due either to variations in the supply of elements from the coast or to seasonal temperature changes. Indeed, it has been proved that carbonate composition is influenced by water temperature (MILLIMAN, 1974).
The comparison among the three populations highlighted some differences (Table 2), e.g. that Ustica (s) and C. Gallo (s) samples have higher Sr, Ni, Ti concentrations than (w) samples, that the P. Barcarello (s) sample has higher Li and Cr concentrations than (w) sample and that P. Barcarello samples have higher Mn, Al and B concentrations than Ustica and C. Gallo samples.
The presence of Al, Li, Rb, Cr and Ti, never recorded before in coralline red algae, could be due either to a detritic contamination of particles or to a direct incorporation from the seawater where, apart from Cr, they are well represented. The low concentration of Rb, Li and B, which are well represented in seawater, could be due to the difficulty of these elements to substitute calcium in calcitic skeletons. The presence of Pb, Ba and Sr, heavier and larger cations than calcium and thus preferably incorporated in aragonitic skeletons, could be simply due to the presence of aragonite in the samples (CRAIGIE, 1990).
The presence of Sr is not an uncommon finding; indeed it has been previously found (as $SrCO_3$) in coralline red algae (THOMPSON & CHOW, 1955). The seasonal changes in Sr concentration observed here might be due to a major supply of this element from the coast by winter rains. Conversely, the higher Sr concentration in the P. Barcarello (w) sample than in the (s) one could provide evidence for the presence in the former of a larger amount of aragonite, whose formation is positively correlated with surrounding water temperature (MILLIMAN, 1974).
In the P. Barcarello (w) sample, the concentration of Fe and Mn is greater than in the other samples, possibly because of the presence of dolomite in this sample. Indeed, these two elements are preferably incorporated into dolomitic skeletons where they substitute magnesium.
Finally, data relative to combustion, R.I., CaO and MgO concentration (Table 2), reveal no significant differences among samples.
This study and that by MANNINO (1992) reveal that Ustica and C. Gallo samples are very similar, and that both differ from those of P. Barcarello, in agreement with the environmental conditions of the three stations. This fact suggests that a close relationship exists between environmental factors and the chemical-mineralogical composition of the thallus. This is because the elements present in the thallus are taken up from the surrounding water.
Seawater composition can change depending on the nature and concentration/supply of exogenous material (deriving from human activities, erosion by rain, flow of detritic material transported by marine currents, water-reflux from the coast), and in relation to season and intensity of human activities. Therefore, mineral deposits in thalli can also change accordingly.
It is well known that phytobenthic organisms are able to memorise changes in environmental factors in their biological processes, therefore providing a valid short- to long-term documentation. If this relationship exists, we will be able to make use of coralline red algae, for their perennant nature and ability to memorise changes in seawater composition, as bioindicators. Indeed, the bioindicator potential of coralline red algae has previously been proposed (BRESSAN & BABBINI-BENUSSI, 1995). Thus, by studying the chemical-mineralogical composition of these algae, we would be able to gather information on environmental changes occurring with time.
Although results from the present study are not conclusive, they provide accounts and new data on *L. byssoides*. The present results also suggest some topics for future research, including studies on the influence of mineralogical composition of surrounding medium on thallus composition, and on processes of incorporation

of elements into cell wall carbonates.

ACKNOWLEDGEMENTS

I am very grateful to Prof. G. Giaccone for his critical reading of the manuscript as well as his helpful comments and suggestions.
Sincere thanks to Prof. F. Magne for his encouragement and constructive comments, to Dr. A. Athanasiadis and to the anonymous reviewer for their useful comments and suggestions.

REFERENCES

BABBINI L. & BRESSAN G., 1997 - *Recensement de Corallinacées de la Mer Méditerranée et considérations phytogéographiques.* Biblioth. Phycol., 103: 1-421.

BASSO D., 1996 - *Adaptative strategies and convergent morphologies in some Mediterranean coralline algae.* Boll. Soc. Paleontol. Ital., (special volume) 3: 1-8.

BOROWITZKA M.A., LARKUM A.W.D., NOCKOLDS C.E., 1974 - *A scanning electron microscope study of the structure and organization of the calcium carbonate deposits of algae.* Phycologia, 13: 195-203.

BOUDOURESQUE C.-F., AUGIER H., GUÉNON Y.-C., 1972 - *Végétation marine de l'Ile de Port Cros. VIII. Premiers résultats de l'étude de la croissance in situ de* Lithophyllum tortuosum *(Rhodophycées, Corallinacées).* Bull. Mus. Hist. Nat. Marseille, 32: 197-215.

CHAMBERLAIN Y.M., 1997 - *Observations on* Lithophyllum lichenoides *Philippi* (Rhodophyta, Corallinaceae) *and its reproductive structures.* Cryptog. algol., 18 (2): 139-149.

CHAVE K.E., 1954 - *Aspects of the biogeochemistry of magnesium, I. Calcareous marine organisms.* J. Geol., 62: 266-283.

CRAIGIE J.S., 1990 - *Cell walls.* In: COLE K.M. & SHEATH R.G. (eds.), *The Biology of the Red Algae.* Cambridge University Press, New York. pp. 221-257.

DEMAJO A., 1988 - *Elements in sea water.* In: *Handbook of chemistry and physics*, 65° edition. CRC Press, Boca Raton. F 149.

FELDMANN J., 1937 - *Recherches sur la végétation marine de la Méditerranée. La côte des Albères.* Rev. algol., 10: 1-339.

FOSLIE M., 1900 - *Revised systematical survey of the* Melobesieae. — K. norske Vidensk. Selsk. Skr., 5: 1-22.

GIACCONE G., ALESSI M.C., TOCCACELI M., 1985 - *Flora e vegetazione marina dell'Isola di Ustica.* Boll. Accad. Gioenia Sci. Nat., Catania, 18: 505-536.

HAAS P., HILL T.G., KARSTENS W.K.H., 1935 - *The metabolism of calcareous algae. II The seasonal variation in certain metabolic products of* Corallina squamata *Ellis.* Ann. Bot., 49: 609-619.

HUVÉ H., 1957 - *Sur l'individualité générique du* Tenarea undulosa *Bory 1832 et du* Tenarea tortuosa *(Esper) Lemoine 1911.* Bull. Soc. bot. Fr., 104: 132-140.

HUVÉ H., 1963 - *Données écologiques et biogéografiques relatives à quelques mélobésiées méditerranéennes caractéristiques des niveaux superficiels de la roche littorale.* Rapp. Procès-Verbaux Réun. Commiss. Int. Explor. Sci. Mer Médit., 17 (2): 147-160.

HUVÉ P., 1954 - *Étude expérimentale de la réinstallation d'un "trottoir à* Tenarea*", en Méditerranée occidentale.* C. R. hebd. Séanc. Acad. Sci., Paris, 239: 323-325.

KOLESAR P.T., 1978 - *Magnesium in calcite from a coralline alga.* J. Sediment. Petrol., 48 (3): 815-820.

LABOREL J., MORHANGE C., LABOREL-DEGUEN F., 1993 - *Dégradation récente des formations construites superficielles à* Lithophyllum lichenoides *Philippi dans la Réserve marine de Scandola (Parc Naturel Régional de Corse).* Trav. Sci. Parc nat. rég. Corse, 41: 19-23.

LEMOINE M., 1910 - *Essai de classification des Mélobésiées basées sur la structure anatomique.* Bull. Soc. bot. Fr., 57: 323-331.

LEWIN J.C., 1962 - *Calcification.* In: LEWIN R.A. (ed.), *Physiology and Biochemistry of Algae.* Academic Press, New York and London. pp. 457-465.

MANNINO A.M., 1992 - *Struttura e composizione mineralogica dei depositi calcarei in* Lithophyllum lichenoides *Philippi* (Rhodophyceae, Corallinales). Naturalista sicil., 16 (1-2): 27-38.

MANNINO A.M., 1994 - *Osservazioni morfo-anatomiche su* Lithophyllum lichenoides *Philippi* (Corallinaceae, Rhodophyta). Naturalista sicil., 18 (1-2): 57-71.

MILLIMAN J.D., 1974 - *Marine Carbonates.* Springer-Verlag. 375 pp.

MILLIMAN J.D., GASTNER M., MÜLLER J., 1971 - *Utilization of magnesium in coralline algae.* Geol. Soc. Am. Bull., 82: 573-580.

MOBERLY R., 1968 - *Composition of magnesian calcites of algae and pelecypods by electron microprobe analysis.* Sedimentology, 11: 61-82.

MORHANGE C., LABOREL-DEGUEN F., SARTORETTO S., LABOREL J., 1992 - *Recherches sur les bioconstructions à* Lithophyllum lichenoides *en Méditerranée occidentale.* Méditerranée, 3: 67-71.

PHILIPPI R., 1837 - *Beweis dass die Nulliporen Pflanzen sind.* Arch. Naturgesch., 3: 387-393.

SETCHELL W.A., 1943 - Mastophora *and the* Mastophoreae*: genus and subfamily of* Corallinaceae. Proc. Nat. Acad. Sci., Washington, 29: 127-135.

THOMPSON T.G. & CHOW T.J., 1955 - *The strontium-calcium ratio in carbonate-secreting marine organisms.* Papers in Mar. Biol. Oceanogr. Deep-Sea Res., 3 (suppl.): 20-39.

WALTER-LÉVY L. & STRAUSS R., 1954 - *Contribution à l'étude des concrétions minérales chez les végétaux.* C. R. Acad. Sci., Paris, 239: 897-899.

WOELKERLING W.J., 1983: *A taxonomic reassessment of* Lithophyllum *Philippi* (Corallinaceae, Rhodophyta) *based on studies of R. A. Philippi's original collections.* Br. Phycol. J., 18: 299-328.

WOELKERLING W.J., CHAMBERLAIN Y.M., SILVA P.C., 1985 - *A taxonomic and nomenclatural reassessment of* Tenarea, Titanoderma *and* Dermatolithon (Corallinaceae, Rhodophyta) *based on studies of type and other critical specimens.* Phycologia, 24: 317-337.

WOELKERLING W.J. & LAMY D., 1998 - *Non-geniculate Coralline Red Algae and the Paris Muséum: Systematics and Scientific History*. Publ. Scient. Mus./ A.D.A.C., Paris. 767 pp.

AUTHOR

Anna Maria Mannino, Dipartimento di Scienze Botaniche, Università degli Studi di Palermo, Via Archirafi 38, 90123 Palermo, Italy