

## SPATIAL AND TEMPORAL ASPECTS OF BENTHIC THANATOCOENOSSES IN A MEDITERRANEAN INFRALITTORAL CAVE

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*Key-words:* Benthic thanatocoenoses, Submarine caves, Confinement, Holocene, Mediterranean.

*Riassunto.* È stato condotto uno studio sedimentologico, faunistico e radiometrico su tre carote prelevate all'interno della Grotta dell'Accademia (Ustica, Mar Tirreno meridionale).

Notevoli differenze spaziali si notano fra le carote più esterne, campionate vicino alle aperture (con sedimenti più grossolani) e la più interna (con sedimenti più fini) prelevata in una zona più riparata. Analoghe differenze sono adombrate dalle tanatocenosi. Nella carota più interna, queste sono più omogenee, essenzialmente autoctone e dominate da specie indicative di ambienti di grotta. Nelle carote prossime alle aperture, le tanatocenosi sono invece più eterogenee e contaminate da bioclasti provenienti da ambienti esterni. Ciò testimonia un confinamento legato prevalentemente all'idrodinamismo.

Al contrario, sono scarse le evidenze di variazioni paleoambientali verificatesi durante la storia recente della grotta, almeno negli ultimi 1.000 anni, come documentato dalla datazione radiometrica dei sedimenti studiati. La lieve tendenza verso un maggiore confinamento, evidenziata nella parte sommitale della carota più interna, sembra legata a cambiamenti morfologici locali che hanno presumibilmente indotto variazioni sia nel circuito idrodinamico che nella penetrazione della luce.

*Abstract.* Sedimentologic, faunistic and radiometric analyses were performed on three bottom cores from the Accademia Cave (Ustica, Southern Tyrrhenian Sea).

The two outermost sites (near the cave openings) contain coarser sediments, while the innermost sample (from a sheltered area) consists of noticeably finer sediments. Similarly, differences are present in the benthic thanatocoenoses at these sites. The innermost core is more homogeneous, essentially autochthonous and dominated by "cave species" while the cores near the entrance of the cave are more heterogeneous and contaminated by external bioclasts. These differences indicate a confinement gradient mainly affected by hydrodynamics.

Conversely, radiometric data indicate few signs of temporal variations, at least for the last 1,000 years recorded in the sediments studied. A slight topward confinement increase in the innermost core may be related to local changes in cave topography.

### Introduction.

The cave environment resembles in some respects the aphotic deep-sea zone, due to the similarity of some

ecological factors (Harmelin et al., 1985, 1995; Vacelet et al., 1994). However, the cave environment shows a higher structural complexity and sensitivity even to slight environmental changes. Community composition, structural changes and (eco)phenotypic variations of species may occur in the same cave within different microhabitats. These spatial changes may also be recorded temporally in cave bottom sediments and benthic thanatocoenoses. Sediments and skeletal remains may therefore document the recent history of the cave and its biodiversity through time (Di Geronimo et al., 1993; Harmelin et al., 1995). This information may also provide insight into the recent geological evolution of the area in which the cave is located (Taddei-Ruggiero et al., 1996). In such studies, and particularly when shallow water caves are involved, it is important that appropriate cave and sampling sites are selected according to cave typology and morphology which strongly affect hydrodynamic level, sedimentation, and thanatocoenosis accumulation pattern (autochthonous vs. allochthonous).

The Accademia Cave, located on the eastern shore of the Ustica Island (Southern Tyrrhenian Sea), is a shallow-water cave, well-known both morphologically (Colantoni et al., 1989) and ecologically (Giacccone & Drago, 1989). Striking differences between a benthic community and a thanatocoenosis present in a bottom sediment sample (sandy-gravels swept by currents) from this cave have been highlighted by Di Geronimo et al. (1993). The former is biologically homogenous, representing a "typical" cave community, while the latter is very rich in allochthonous species, mainly linked to photophilic infralittoral biocoenoses. Since it is unlikely that the cave presently receives skeletal remains from the outside, a different paleotopography, with wider connections to the open sea, was hypothesized. The present study provides

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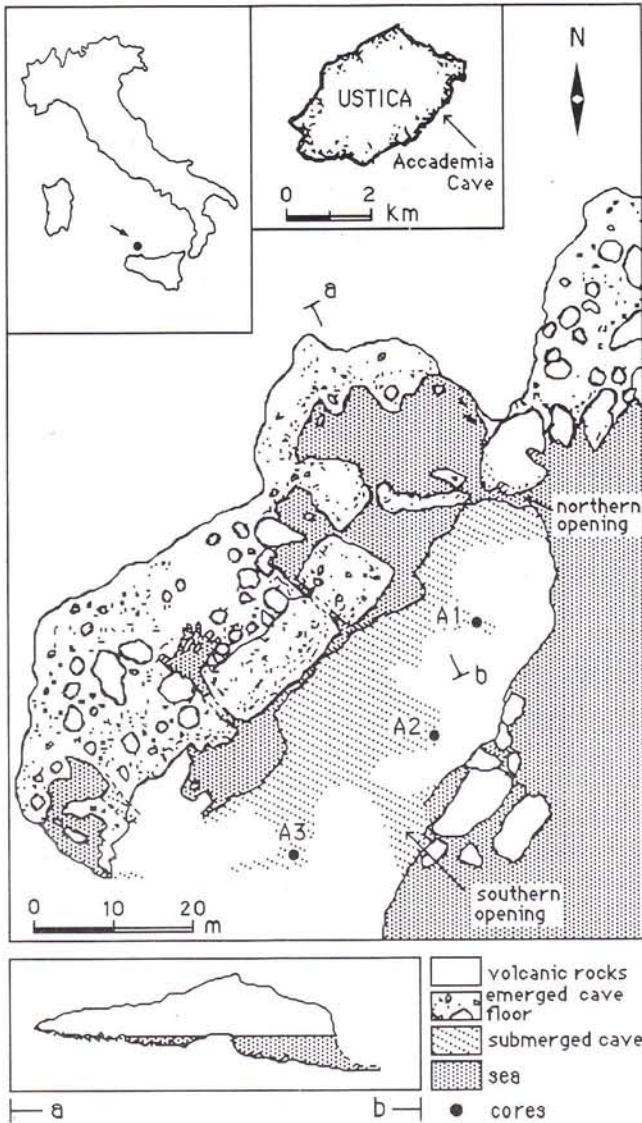


Fig. 1 - Topography of the Accademia Cave (modified from Colantoni et al., 1989) and location of the sampled sites.

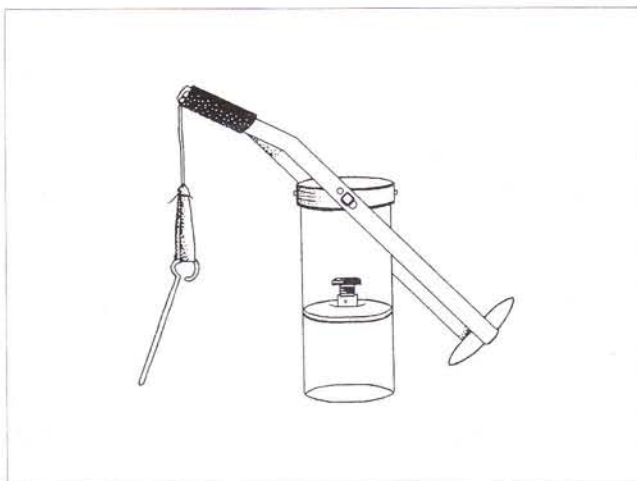


Fig. 2 - Hand-corer, consisting of a plexiglass tube (15 cm long) and a steel closing system.

more detailed observations of this location. To investigate recent temporal and/or spatial changes reflected by sediments and thanatocoenoses, three bottom cores from three different sites within the cave were analysed. Methodological problems related to sampling and site selection were also addressed.

#### Materials and methods.

The Accademia Cave belongs to an underground semi-submerged system, developed in volcanic breccias mixed with marine carbonatic sediments along the southeastern coast of Ustica (Fig. 1). It extends mainly in a NE-SW direction, probably outlining a tectonic line. It is a "mixed cave", according to the genetic scheme of Colantoni (1976), its genesis linked to both karstic and marine erosion. At present, the cave has two openings. The larger entrance (northern) is a partially emerged slit while the second (southern) consists of a submerged, narrow vertical "tunnel", 3 to 7 m deep, that is partially formed by large boulders obstructing the original opening. The cross-sections of both openings are enlarged in their lower parts. The eastward cave area, between the two entrances, is completely submerged (3-4 m) and is deeper than the westward portion of the cave. There, a series of aligned rooms or "lakes" (about 1 m deep) interrupt the emerged flat floor, mainly covered by downfall accumulations. Coarse and fine-grained sediments occur on the bottom, with the latter prevailing in the inner and sheltered areas.

A preliminary scuba diving exploration was made in the submerged eastern part of the cave to select suitable sampling sites. A small, specially designed hand-driven corer, consisting of a plexiglass tube and a steel mobile closing system (Fig. 2), was used to obtain samples in the confined cave environment.

A core sample for sedimentologic and faunistic analyses was taken from three selected sites (A1, A2 and A3), all located in the eastern area of the cave (Fig. 1). Each core, 10 cm in diameter and about 15 cm long, was subdivided into several samples (50 to 200 cc) (Fig. 3) based on visible changes in texture and/or colour.

Sedimentologic analysis was carried out following standard procedures. The biogenic content was sorted from the sieved fractions coarser than 250  $\mu\text{m}$ . Molluscs, bryozoans and serpuloids were listed together with their relative abundance and the total number of specimens for each sample (Tables. 1, 2, 3).

Four additional cores from site A1 and A3 were used for radiometric analyses. Chronologic data were based on the  $^{14}\text{C}$  method. The samples analyzed (top and bottom layers of A1 and A3), made up of shell fragments, were first pretreated with 3% HCl to eliminate surface contaminants. Each sample was then converted

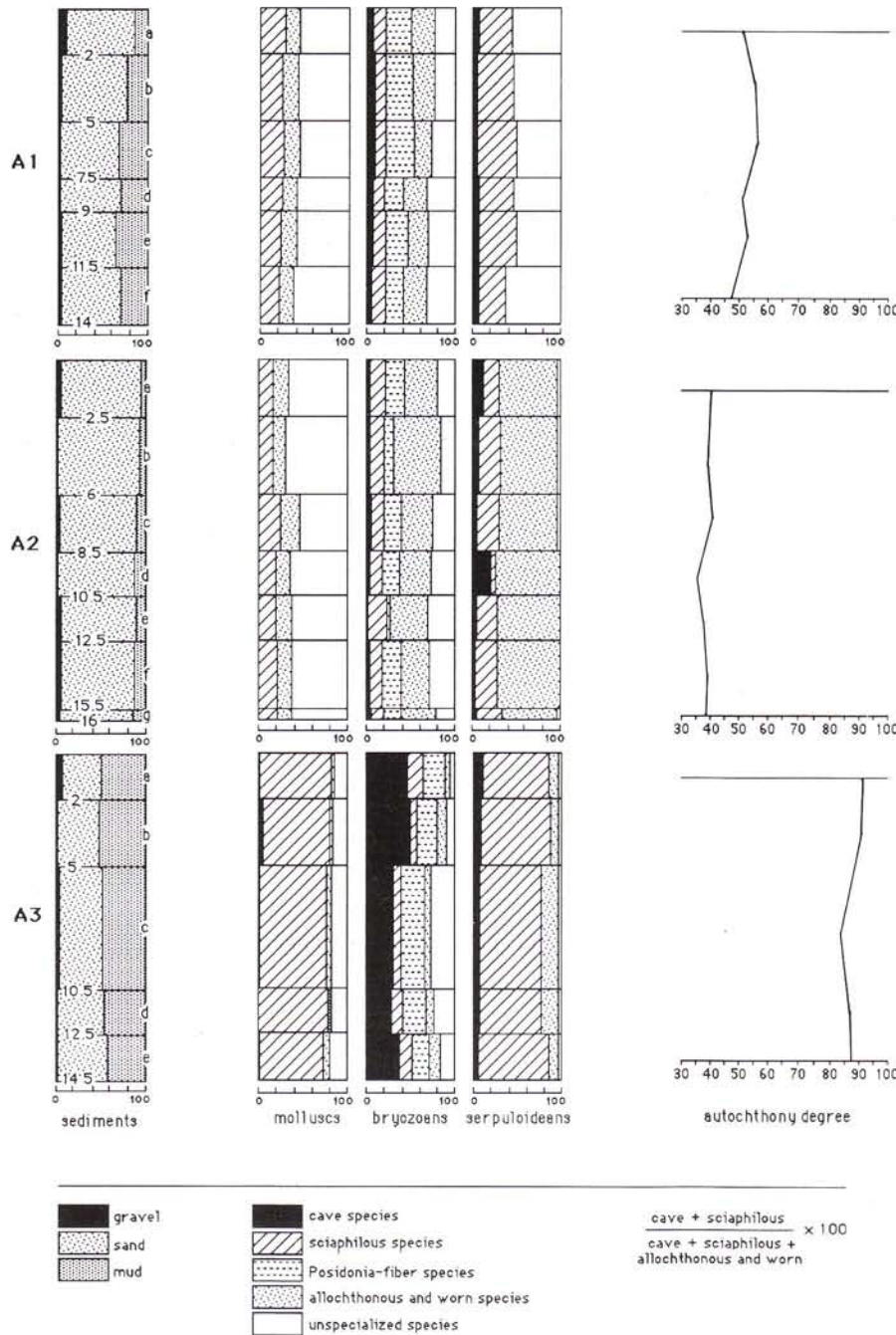


Fig. 3 - Scheme of the cores with: (left) textural features samples marked with letters (thickness in cm), (centre) ecological groups and (right) autochthony degree of thanatocoenoses.

into CO<sub>2</sub>, the chemical form used for direct radiometric measurements, following standard procedures (hydrolysis with HCl). The gas was forced to circulate through KMnO<sub>4</sub> and Ag<sub>2</sub>S solutions and through metallic Ag at 350°C. Traces of radon were routinely eliminated from the CO<sub>2</sub> by storing the samples in pyrex flasks for about 30 days. CO<sub>2</sub> proportional counters were used to determine residual <sup>14</sup>C concentration in the samples, based on β activity measurements. Background and "modern standard" levels were measured using CO<sub>2</sub> from samples of Carrara marble and Australian National University Sucrose respectively, as suggested by IAEA (1991). Due to insufficient sample quantity, it was necessary to add inactive CO<sub>2</sub> from the same marble used for background measurements. As a consequence, a larger

statistical counting error was obtained. Conventional ages were converted to absolute ages using the calibration program "revised Calib 3.0" (Stuiver & Reimer, 1993).

**Results.**

**Sediments.**

From a textural point of view (Fig. 3 left) cores A1 and A2 are similar, both consisting of silty sands. The silty fraction is scant (often less than 15%) throughout core A2, whereas it is more abundant in core A1, ranging from about 30% (lowermost samples) to 15%. Core A3 shows a finer texture. The silty frac-





core sample	A1						A2							A3				
	a	b	c	d	e	f	a	b	c	d	e	f	g	a	b	c	d	e
<i>Vexillum ebenus</i> (Lamarck)	0.2																	
<i>Vexillum tricolor</i> (Gmelin)		0.1				0.4												
<i>Gibberula miliaria</i> (Linnè)	0.5	0.3	0.2	0.9	0.3	1.1												
<i>Gibberula philippi</i> (Monterosato)	0.5	0.3	0.2	0.9	0.3	1.1	1.6	0.7	1.2	0.5	1.4	0.9						
<i>Volvarina mitrella</i> (Risso)	0.7	0.3		0.5					0.2	0.2		0.7			0.5			1.6
<i>Granulina marginata</i> (Bivona)		0.4	0.2		0.3	1.1	1.1	0.2	1.9	0.5	0.5	0.9	5.7					0.4
<i>Conus mediterraneus</i> Hwass								0.2	0.2									
<i>Clathromangelia quadrillum</i> (Dujardin)		0.3	0.5			0.4	0.3		0.2	0.2								
<i>Mangelia taeniata</i> (Deshayes)	0.5	0.3					0.2	0.2			0.5							
<i>Raphitoma linearis</i> (Montagu)	0.2						0.2											
<i>Mitrolumna crenipicta</i> Dautzenberg										0.2		0.2						
<i>Rissoella inflata</i> Locard	0.5		0.7	0.5	0.7		0.5				0.5	0.2						0.4
<i>Chrysallida doliolum</i> (Philippi)	0.4	0.3				0.7	0.7	0.2	0.5	0.5	0.5	0.5	1.1					
<i>Chrysallida intermixta</i> (Monterosato)		0.1	0.2	0.5			0.3	0.2										
<i>Folinella excavata</i> (Philippi)				0.5														
<i>Careliopsis modesta</i> (De Folin)							0.2	0.2										
<i>Odostomia striolata</i> Forbes & Hanley	0.2				0.3	0.4			0.5									
<i>Odostomia carrozzai</i> Van Aartsen	0.4		0.5	0.5		0.4			0.2	1.4	0.9		2.3					
<i>Ondina diaphana</i> (Jeffreys)		0.4								0.2								
<i>Turbonilla striatula</i> (Linnè)		0.1			0.3		0.2					0.2						
<i>Retusa truncatula</i> (Bruguiere)						0.7												
<i>Haminoea navicula</i> (Da Costa)	0.4			0.5			0.2		0.2									
<i>Trimusculus mammillaris</i> (Linnè)	0.4	0.1	0.2		0.7		0.3	0.5	1.2	0.5	1.8	0.7					0.6	0.4
<i>Ovatella myosotis</i> (Draparnaud)																0.6		
<b>BIVALVIA</b>																		
<i>Nucula recondita</i> Gofas & Salas				0.1					0.1			0.2			0.3			
<i>Arca noae</i> Linnè	0.5	0.3	0.5	0.5	0.3				0.5	1.0	0.5	0.5	0.5					
<i>Barbatia barbata</i> (Linnè)	0.5	0.6	0.7	1.4	0.3	0.4	0.5	0.5	1.4	0.7	0.5	1.5	1.1					
<i>Acar pulchella</i> (Reeve)	15.0	12.7	9.5	11.0	12.1	8.3	7.5	5.4	8.8	6.4	6.0	7.4	5.7	61.8	58.3	45.6	39.3	41.5
<i>Striarca lactea</i> (Linnè)	0.4	0.3	0.2		0.3	1.1	0.2	0.2	0.5			0.5	1.1					0.4
<i>Mytilaster minimus</i> (Poli)											0.9	0.2						
"Crenella" sp.														1.0	1.0			
<i>Musculus costulatus</i> (Risso)	0.5	0.9	0.2	0.5	0.3													
<i>Dacrydium</i> sp.														2.0	3.0	2.3		0.8
<i>Lissopecten hyalinus</i> (Poli)	0.2	0.3																
<i>Spondylus gaederopus</i> Linnè		0.1																
<i>Anomia ephippium</i> Linnè	0.2																	
<i>Lima lima</i> (Linnè)			0.2															0.4
<i>Limatula subauriculata</i> (Montagu)	0.4	0.6	0.7	0.5		0.7									0.5	1.2	1.2	
<i>Ostrea edulis</i> Linnè																		
<i>Ctena decussata</i> (O.G. Costa)	2.1	1.8	2.9	0.9	3.1	1.1	0.7	0.7	0.7	0.2	1.4	0.9		0.5	0.6			0.4
<i>Lucinoma boreale</i> (Linnè)					0.3													
<i>Chama gryphoides</i> Linnè						0.4				0.2								
<i>Bornia sebetia</i> (O.G. Costa)	0.2																	
<i>Lasea rubra</i> (Montagu)	0.5	1.0	1.4	0.5			0.3	0.2	0.5	1.6	0.5	0.3						
<i>Neolepton sulcatulum</i> (Jeffreys)	0.2	0.1	0.5		0.3		0.2											
<i>Gouldia minima</i> (Montagu)					0.3													
<i>Cardita calyculata</i> (Linnè)	0.2	0.1					1.1	1.5	3.1	2.1	0.5	2.1	1.1	2.0	1.5	2.3		3.9
<i>Glans trapezia</i> (Linnè)	0.5	0.4	0.2		1.0		0.2				0.5	0.5						
<i>Kelliella abyssicola</i> (Forbes)															0.5			
Total specimens	559	676	421	217	289	276	610	441	421	435	217	584	88	204	202	171	168	258

Tab. 1 - Mollusc systematic list from the thanatocoenoses of the Accademia cave cores.

tion ranges from 40% in the lowermost to 50-52% in the topmost samples and a negligible clayey fraction (less than 2%) also occurs. The sandy fraction is finer (mainly <125 µm) in core A3 than in cores A1 and A2. A gravelly fraction, often less than 10% and consisting of volcanic and biogenic clasts, occurs throughout all three cores. Biogenic elements prevail in core A3.

#### Radiometry.

Radiometric data for the bottom and the top of core A1 indicate an age of between 537-484 years BP and 268-0 years BP, respectively (Table 4). The bottom and top of the innermost core A3 dated between 907-

773 years BP and 575-501 years BP, respectively. These results are somewhat puzzling and might be biased by a low rate of biogenic accumulations related to the low production of cave communities and/or by the mixing of older and younger skeletal remains, probably caused by burrowing organisms.

#### Biogenic content.

Some general trends in the biogenic content may be outlined. Cores A1 and A2 are similar, both containing particularly abundant molluscan, bryozoan and serpuloidean thanatocoenoses. For all groups, a general bottomward decreasing trend, both in number of species



core sample	A1						A2							A3				
	a	b	c	d	e	f	a	b	c	d	e	f	g	a	b	c	d	e
<b>CYCLOSTOMATIDA</b>																		
<i>Crisia fistulosa</i> Heller											0.2							0.5
<i>Crisia sigmoidea</i> Waters	1.0	0.7	0.7	0.7		0.4	3.5	1.2	1.1	0.7	1.3	0.6		1.5				
<i>Crisia ramosa</i> Hammer							1.4											
<i>Crisia</i> sp. II Harmelin	0.2								0.2									
<i>Annectocyma indistincta</i> Canu & Bassler	0.7	0.6	1.0	1.8	1.1		0.8	0.4	1.7	1.4	0.6	1.5	0.9			1.7		
<i>Annectocyma major</i> (Johnston)	2.3	0.9	0.7	0.7	1.6	1.2	0.4	0.3	0.9	0.5	0.6	3.2	2.7	1.5				1.1
<i>Entalporoecia</i> sp.	0.2	0.1					0.1		0.9			0.3						
<i>Diplosolen obelium</i> (Johnston)	0.2	0.1					0.1		0.4	0.5	0.6	0.1		3.0		1.7	1.6	1.6
<i>Eurystrotos occulta</i> (Harmelin)	0.2			1.1		0.8		0.1	0.2			0.1			1.6			
<i>Eurystrotos compacta</i> (Norman)	0.3													4.5				3.8
<i>Plagioecia dorsalis</i> (Waters)							0.3											
<i>Plagioecia patina</i> (Lamarck)																		4.8
<i>Plagioecia sarniensis</i> (Norman)	1.3		0.5	0.7	1.1							0.1						
<i>Mecynoecia delicatula</i> (Busk)	1.0	0.9	1.5	0.4	1.6		0.3	0.3	0.4	0.7	0.6	0.4						1.6
<i>Platonea stoechas</i> Harmelin	2.0	1.9	3.2	2.8	2.5	2.8	3.8	1.3	2.6	2.6	1.9	3.1	1.8			1.7	1.6	
<i>Tubulipora aperta</i> Hammer	0.2								0.4	0.2		0.3			1.6			
<i>Tubulipora hemyphragmata</i> Harmelin	0.2	1.0	2.2	1.4	1.4	1.2	0.3		0.4	0.2		0.6	0.9	3.0	3.2			
<i>Tubulipora liliacea</i> (Pallas)								0.1										
<i>Tubulipora ziczac</i> Harmelin		0.1																
<i>Lichenopora radiata</i> (Audouin)	7.3	7.7	11.8	10.3	11.0	9.2	6.1	4.5	6.4	5.4	5.8	6.8	5.4	3.0	1.6	5.1	3.2	4.3
<b>CHEILOSTOMATIDA</b>																		
<i>Hincksina flustroides</i> (Hincks)	0.2										0.5							0.5
<i>Copidozoum tenuirostre</i> (Hincks)							0.3	0.1	0.9									
<i>Crassimarginatella crassimarginata</i> (Hincks)							0.3	0.9	0.2	0.2		0.6	0.9					
<i>Crassimarginatella solidula</i> (Hincks)	0.7	1.6	2.2	0.7	1.1	2.4	0.7		0.4			0.3		1.5		8.5	1.6	0.5
<i>Parellisina curvirostris</i> (Hincks)	0.3	0.3	0.2	0.4		0.4				0.2	0.6	0.3						
<i>Onychoecella marioni</i> (Jullien)	0.2	0.5	0.7	0.7			1.8	2.7	1.1	0.5	0.6	0.4	3.6					0.5
<i>Calpensia nobilis</i> (Esper)					0.3													
<i>Coronellina fagei</i> (Gautier)	5.8	7.2	6.6	3.2	3.8	1.2	1.1	0.7	2.1	0.7	0.6	1.3		29.9	41.9	20.3	25.8	34.4
<i>Mollia patellaria</i> (Moll)								0.1										3.2
<i>Cellaria salicornioides</i> Audouin							0.1											
<i>Caberea boryi</i> (Audouin)	0.2	0.1	0.5		0.3		0.3	0.1		0.2								
<i>Scrupocellaria delili</i> (Audouin)	0.2	0.6	0.2	0.7		0.4	2.0	0.9	0.8	1.4	0.6	0.6				1.7		0.5
<i>Scrupocellaria reptans</i> (Linnaeus)							0.3	0.1									3.2	
<i>Collarina balzaci</i> (Audouin)		0.1																0.5
<i>Puellina (Cribrilaria) hincksi</i> (Friedl)		0.1			0.5				0.4	0.2		0.1	0.9	1.5				
<i>Puellina (Cribrilaria) innominata</i> (Couch)		0.7	0.5			0.4	0.1		0.2	0.5		0.4		1.5				
<i>Puellina (Cribrilaria) minima</i> (Harmelin)													0.9					
<i>Puellina (Cribrilaria) radiata</i> (Moll)	0.7						0.1					0.4	0.9					
<i>Puellina (Cribrilaria) venusta</i> (Canu & Bass.)	0.2	0.3		0.4	0.3		0.1	0.3	0.8	0.5		0.1						
<i>Puellina</i> sp.							0.1											
<i>Umbonula ovicellata</i> Hastings	0.2	0.6	0.5			0.4			0.2		0.6	0.3						1.6
<i>Hippopleurifera pulchra</i> (Manzoni)					0.5	0.8	0.1					0.4						
<i>Escharoides megarostris</i> (Canu & Bassler)							0.3				0.6							
<i>Escharoides mamillata</i> (Wood)	0.5	0.7	0.5	0.4			0.3	0.1		0.2					3.2		1.6	0.5
<i>Reptadeonella violacea</i> (Johnston)	0.3			0.4	0.3	0.4	1.0	1.2	1.1	0.7	1.3	0.8						
<i>Watersipora subovoidea</i> (d'Orbigny)	4.0	3.3	1.2	6.7	4.7	4.4	2.0	1.9	3.4	2.8	4.5	2.9	1.8			3.4	3.2	2.2
<i>Pentapora ottomulleriana</i> (Moll)	3.5	4.0	2.7	2.5	3.0	5.2	6.1	6.1	4.7	5.9	3.9	6.4	9.0		4.8		1.6	1.6
<i>Cosciniopsis ambita</i> (Hayward)	0.7	0.8		1.1	0.5		1.4	1.1	1.3	1.9	0.6	1.3	1.8					0.5
<i>Hippomenella mucronelliformis</i> (Waters)	0.3	0.5		0.4	0.5	0.4		0.1		0.2		0.1		7.5			1.6	1.6
<i>Smittina cervicornis</i> (Pallas)				0.4														
<i>Prenantia cheilostoma</i> (Manzoni)						0.4												
<i>Parasmittina</i> sp.	1.8	1.0	1.0	1.1	1.6	0.8	1.4	2.2	2.4	1.4	3.2	1.5	1.8		3.4			1.1
Smittinidae sp.			0.2															
<i>Escharella ventricosa</i> (Hassal)	0.2					0.4	0.1			0.2		0.3						
Escharellidae sp.		0.2									0.6	0.1		1.5				
<i>Artropoma cecilii</i> (Audouin)		0.2			0.5													
<i>Cribellopora trichotoma</i> (Waters)	0.3								0.2	0.5		0.1						1.6
<i>Escharina dutertrei</i> (Audouin)	0.8	1.0	0.7	1.8	2.2	0.8		0.8	0.8	0.2	0.6	0.6	0.9	3.0	3.2	1.7		1.1
<i>Escharina vulgaris</i> (Moll)	1.3	0.7	1.0	1.1	2.5	0.8	0.1	0.4	0.2	0.2		0.3	0.9	1.5	1.6			2.2
<i>Metoperiella lepralioides</i> (Calvet)		0.2		0.4														
<i>Schizobrachiella sanguinea</i> (Norman)	0.3	0.2	0.2	0.7	0.3		1.3	1.2		0.7	0.6	0.8	0.9					
<i>Schizomavella cuspidata</i> Hincks	3.5	1.4	2.7	1.8	1.6	5.6	0.6	1.2	3.0	1.6	6.5	2.9	1.8	3.0			1.6	2.2
<i>Schizomavella rudis</i> (Manzoni)							0.7				0.6							
<i>Schizoporella longirostris</i> Hincks	1.3	0.7	0.5	0.4	0.8		1.4	3.1	2.3	0.9	3.2	1.7	1.8				1.6	1.1
<i>Schizoporella mutabilis</i> (Calvet)												0.1						

core sample	A1						A2							A3					
	a	b	c	d	e	f	a	b	c	d	e	f	g	a	b	c	d	e	
<i>Schizoporella unicornis</i> (Johnston)			0.2																
<i>Hippopodinella kirchenpaueri</i> (Heller)	0.5	0.2	0.7		1.1		0.3	0.1	0.6		3.9		0.9						
<i>Fenestulina malusi</i> (Audouin)	0.5																		
<i>Haplopoma bimucronatum</i> f. <i>occiduum</i> (Wat.)	6.3	6.6	3.7	5.0	4.7	4.8	5.9	3.2	2.6	3.5	3.9	2.9	2.7	3.0	3.2		1.6	2.7	
<i>Microporella ciliata</i> (Pallas)	0.3	0.3	0.7	0.7	0.5	0.8	1.1		0.2			0.3		1.5	1.6	1.7		0.5	
<i>Microporella pseudomarsupiata</i> Aristegui	1.2	0.1	1.5		0.3	0.4	0.6	0.3	0.4	0.7		0.1	0.9						
<i>Chorizopora brongniarti</i> (Audouin)	0.2	1.0		0.7	0.3			0.3	0.2	0.2		0.1	0.9		1.6	6.8		0.5	
<i>Savignielia lafonti</i> (Audouin)	0.2																1.6		
<i>Stephanollona armata</i> (Hincks)				0.4															
<i>Rhynchozoon</i> sp. A	0.3	0.2	0.3	0.7	0.3	0.4	0.6	1.1	1.3	1.7	1.9	0.6	0.9				1.6	0.5	
<i>Margaretta cereoides</i> (Ellis & Solander)	1.8	1.8	1.2	1.1	1.9	3.2	3.8	3.2	2.1	3.3	1.3	2.2	3.6						1.1
<i>Cellepora pumicosa</i> Auct.		0.1				0.8	0.1					0.6	0.6						
<i>Celleporina caminata</i> (Waters)	1.0	1.6			2.2	3.2	4.6	5.7	4.1	4.2	6.5	2.1	2.7			3.4		1.1	
<i>Celleporina hassalli</i> (Johnston)	2.2	1.1	2.5	1.4	2.2	4.0	1.0	0.7	2.8	3.3	5.2	3.6	2.7		1.6	1.7		3.2	
<i>Celleporina hassalli</i> f. <i>tubulosa</i> (Hincks)	5.0	6.6	3.7	6.4	3.8	7.2	1.7	1.3	3.0	3.1	6.5	6.1	1.8						
<i>Celleporina lucida</i> (Hincks)							2.0	2.0	0.2					3.0	1.6			0.5	
<i>Celleporina</i> sp. A	3.5	4.9	2.9	5.3	5.2	4.0	0.8	1.5	4.1	1.4	2.6	1.7	1.8		1.6		6.5	3.8	
<i>Turbicellepora avicularis</i> (Hincks)	0.2																		
<i>Turbicellepora magnicostata</i> (Barroso)	1.3	1.1	2.7	2.8	1.6	1.6	0.1	0.4	1.7	3.1		2.9	0.9						
<i>Myriapora truncata</i> (Pallas)	0.8	0.2		0.4	0.5	0.8	1.4	1.3	0.8	1.6	1.3	1.4				1.7			
undetermined	30.2	33.2	35.9	30.5	29.4	28.3	34.9	45.1	34.0	38.8	25.2	33.0	40.5	25.4	25.8	35.6	30.6	20.4	
total specimens	600	884	407	282	364	251	557	741	532	425	155	718	111	67	62	59	62	186	

Tab. 2 - Bryozoan systematic list from the thanatocoenoses of the Accademia cave cores.

and specimens, was recorded. Core A3 shows an opposite trend, as both species and specimen abundance, markedly lower than in the previous cores, generally increases with depth. These trends appear closely related to textural features as shown by the significant negative correlation of species and specimen number versus muddy percentage ( $p > 0.05$ ; Fig. 3). Core A1 and A2 faunal lists (Tables 1, 2, 3) share many species, which are also abundant and frequent throughout all cores. Many molluscs show such a wide occurrence, including *Scissurella costata*, *Sinezona cingulata*, *Gibbula turbinoides*, *Jujubinus striatus*, *Homalopoma sanguineum*, *Tricolia speciosa*, *Cerithium rupestre*, *Bittium reticulatum*, *Alvania cimex*, *A. subcrenulata*, *A. scabra*, *Crisilla* sp. 1 and *Acar pulchella*. Among the bryozoans, *Coronellina fagei* (Pl. 1, fig. 2), *Escharina dutertrei* (Pl. 1, fig. 6), *Crassimarginatella solidula*, *Hippomenella mucronelliformis*, *Margaretta cereoides*, *Schizomavella cuspidata*, *Watersipora subovoidea*, *Pentapora ottomülleriana*, *Haplopoma bimucronatum* f. *occiduum*, *Crisia sigmoidea*, *Lichenopora radiata*, *Platonea stoechas*, *Tubulipora hemiphragmata*, *Schizoporella longirostris*, *Turbicellepora magnicostata*, *Celleporina hassalli* and *C. hassalli* f. *tubulosa*, are also well represented, as well as the serpuloides *Semivermilia crenata* (Pl. 1, fig. 6), *S. agglutinata*, *Spirorbis cuneatus*, *Janua pagenstecheri* and *Janua* sp. 1 (Pl. 1, fig. 8).

Many of these species also occur in core A3, but with different relative abundances. Among the molluscs, *Scissurella costata*, *Homalopoma sanguineum* and *Acar pulchella* are the most abundant species. The bryozoan *Coronellina fagei* is extremely abundant, followed by *Crassimarginatella solidula*, *Escharina dutertrei* and *Hip-*

*pomenella mucronelliformis*, while the serpuloides *Semivermilia crenata*, *Protula* sp. 2 and *Janita fimbriata* prevail. There is a more or less marked drop in abundance among the remaining species, whereas some are absent, at least in some samples.

Other noteworthy skeletal remains occur, such as worn Soritinae foraminifers (Pl. 1, fig. 10-11) as well as elements of articulated coralline algae, sometimes still joined by encrusting colonies of the bryozoan *Haplopoma bimucronatum* f. *occiduum* (Pl. 1, fig. 5). Thanatocoenoses also include corals, brachiopods and echinoids.

#### Ecological observations.

Some ecological groups were recognized and their relative abundance within each core sample was calculated (Fig. 3):

1) The first group is represented by species which appear closely related to the cave biotope. They will be referred to here as "cave species".

Among them, the serpuloides *Serpula massiliensis* and *Filigranula annulata* (Belloni & Bianchi, 1982), as well as the bryozoan *Coronellina fagei* (Harmelin, 1969; 1985a; 1986) should strictly be regarded as "cave species".

Other species are coelobitic (*sensu* Harmelin, 1986) and cryptic or crevicular, and are known from a variety of cryptic infra-circalittoral or bathyal environments. They include several bryozoans, such as *Annectocyma indistincta*, *Tubulipora hemiphragmata*, *Onychocella marioni*, *Crassimarginatella crassimarginata*, *C. solidula*, *Hippomenella mucronelliformis* and *Escharina dutertrei*, previously considered "indicative" of cave environments (Harmelin, 1985b; 1986), and the serpuloides *Metavermilia multicristata* (Zibrowius, 1971). Other species, such as the serpuloides *Janita fimbriata*, *Protula* sp. 1 and *Filigranula gracilis*, are known from caves and deep-shelf to bathyal bottoms (cf. Zibrowius, 1971). Three molluscan species appear referable to this group, i.e. *Dacrydium* sp., "*Crenella*" sp. and *Kelliella abyssicola*, all



core sample	A1						A2							A3				
	a	b	c	d	e	f	a	b	c	d	e	f	g	a	b	c	d	e
<b>SERPULIDAE</b>																		
<i>Serpula vermicularis</i> (Linnè)							0.1											
<i>Serpula concharum</i> Langehrans							0.4											
<i>Serpula lobiancoi</i> Rioja	0.6									1.1						3.4	1.4	
<i>Serpula massiliensis</i> Zibrowius	0.6	1.2	0.3	1.5	1.0	3.0	1.0	0.4	1.6			0.8		1.2	1.0			
<i>Vermiliopsis labiata</i> (O.G.Costa)							0.4	0.2	0.4		1.8	0.5				1.7	2.1	0.8
<i>Vermiliopsis</i> sp.	0.3						0.2	0.4	0.8						1.0			1.2
<i>Metavermilia multicristata</i> (Philippi)		0.5	0.3			1.2	0.2	0.4	0.8			1.1		1.2			0.7	2.0
<i>Semivermilia crenata</i> (O.G. Costa)	29.7	34.9	41.7	34.8	37.9	24.1	11.5	19.5	16.6		19.6	14.4	22.4	63.1	64.6	62.7	59.4	71.7
<i>Semivermilia agglutinata</i> (Marenzeller)	3.6	2.1	3.2	4.0	5.1	2.4	11.9	6.1	3.2	20.3	7.1	9.6	6.1		2.0		0.7	0.4
<i>Semivermilia cribrata</i> (O.G. Costa)		0.2	0.3		2.0	0.6	0.2	0.2	0.4									
<i>Filogranula annulata</i> (O.G. Costa)	0.6	1.9	0.9	1.0			1.6						1.1					0.8
<i>Filogranula gracilis</i> Langerhans				0.5				0.2								0.8		0.4
<i>Janita fimbriata</i> (Delle Chiaje)	1.2	0.5		0.5	1.0	1.8	0.1	0.4					0.8	9.5	7.1	1.7	3.5	1.2
<i>Spirobranchus polytrema</i> (Philippi)			1.4	1.0	2.0	0.6	2.4	1.1	1.6	1.1	3.6							
<i>Placostegus crystallinus</i> , sensu Zibrowius					0.5	1.2			0.1									
<i>Filograna</i> sp.	1.2	2.8	2.6	1.0	1.0		6.7	4.6	5.3	5.5	1.8	3.7	2.0					
<i>Protula</i> sp.1	0.6			0.5			1.3							2.4				
<i>Protula</i> sp.2	3.3	2.1	1.4	1.0	1.5	3.6	0.7	0.4	1.2	0.5		3.2		6.0	13.1	7.6	9.8	7.8
Serpulidae sp. 1														3.6	1.0	1.7	4.2	2.9
<b>SPIRORBIDAE</b>																		
<i>Spirorbis infundibulum</i> Harris & Knight-Jones		0.2			0.5													
<i>Spirorbis cuneatus</i> Gee	4.8	5.2	3.5	3.5	8.6	6.0	2.7	1.3	3.2	3.8		1.1	2.0	2.4		0.8	2.1	2.0
<i>Protolaeospira striata</i> (Quiévreux)				0.5		0.6	0.6	0.2					0.3	2.0				
<i>Pileolaria militaris</i> Claparede	1.8			0.5			0.6	0.9	2.0	0.5		1.1						
<i>Pileolaria</i> sp.	0.6		1.2				0.1								1.0			
<i>Pileolaria koehlerii</i> (Caullery & Mesnil)	1.2	2.3	0.9		2.0	0.6	0.9	4.6	3.6	3.3		0.8	4.1	1.2	1.0			0.8
<i>Pileolaria pseudomilitaris</i> (Thiriou-Quévreux)				1.5			0.2			0.5	1.8	0.8	6.1					
<i>Janua pagenstecheri</i> (Quatrefages)	41.2	37.5	36.5	40.9	26.8	50.0	32.2	26.7	43.3	56.0	55.4	48.4	44.9	7.1	2.0	8.5	7.0	4.5
<i>Janua pseudocorrugata</i> (Bush)	0.9	4.7	2.6	4.5	1.0		0.6	0.6	0.8		3.6	0.8			4.0	1.7	0.7	1.2
<i>Janua</i> sp. 1	6.6	2.6	0.9	2.5	6.1	4.2	9.7	12.0	8.9	5.5	5.4	9.6	10.2	2.4		4.2	1.4	2.0
undetermined	0.9	1.4	2.3		3.0		13.5	20.1	6.1	1.6		2.1			2.0	5.1	7.0	
total specimens	330	427	345	198	198	166	817	543	247	182	56	376	49	84	99	118	143	244

Tab. 3 - Serpuloidean systematic list from the thanatocoenoses of the Accademia cave cores.

from core A3. *Kelliella abyssicola* is a well-known mud-dwelling deep-sea species, while the other taxa are known from epibathyal fine-grained bottoms (La Perna, unpubl. data).

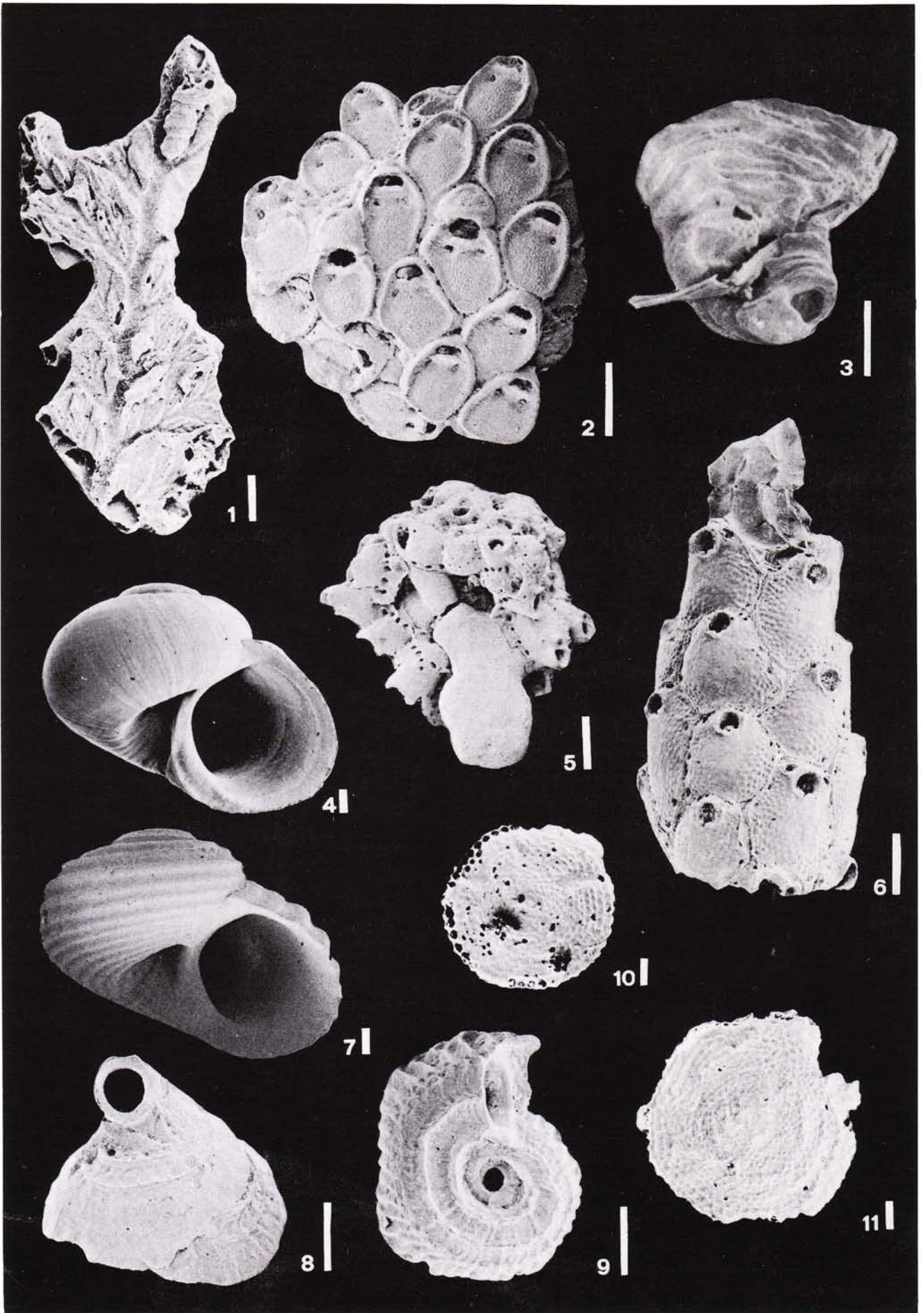
2) The second group is the richest and includes "shelf ubiquitous sciaphilous species". A few of them have a cryptic habit in shallow-water biotopes, such as the mollusc *Sinezona cingulata* (within mesolittoral *Lithophyllum* crevices). Other species are widespread in infralittoral (*Posidonia* rhizomes, overhangs, crevices, etc.) and circalittoral sciaphilous biotopes, both on hard and coarse grain bottoms. They are the bryozoans *Margaretta cereoides*, *Mecynoecia delicatula*, *Celleporina*

*caminata* (globose morphotype), *C. lucida*, *Schizomavella cuspidata*, *Schizoporella longirostris*, *Escharoides mamillata*, *Escharella ventricosa* and species belonging to the genus *Puellina* (cf. Gautier, 1962; Harmelin, 1976; Zabala, 1986; Rosso, 1989; Rosso, 1996, *inter alia*); the serpuloides *Semivermilia crenata*, *Pileolaria koehlerii* (Pl. 1, fig. 9), *Protula* sp. 2 and the molluscs *Scissurella costata*, *Homalopoma sanguineum* and *Acar pulchella*. The last species (= *Barbatia* or *Acar clathrata* quoted in studies on Recent molluscs, see Oliver & Von Cosel, 1992) is one of the most abundant suspension-feeders within cave communities (Cattaneo Vietti & Russo, 1987; Balduzzi et al., 1989). *Homalopoma*

## PLATE 1

- Fig. 1 - Dorsal side of a cyclostomate bryozoan colony clearly showing the cast of the algal thallus on which it grew. Core A2. Scale bar=250 µm for all figures in the plate.
- Fig. 2 - Fragment of *Coronellina fagei* showing the overgrowth of colonies of the same species. Note the presence of two ovicelled zooids in the central part. Core A3.
- Fig. 3 - Young colony of a cyclostomate bryozoan growing on a small *Posidonia* fiber. Core A3.
- Fig. 4 - Smooth shell of *Homalopoma sanguineum* regarded as a "cave ecotype". Core A2.
- Fig. 5 - Encrusting colony of *Haplopoma bimucronatum* f. *occiduum* growing on an articulate coralline alga. Note the still adjacent internodes. Core A2.
- Fig. 6 - Colony of the cheilostome bryozoan *Escharina dutertrei* encrusting the erect part of the serpuloides *Semivermilia crenata*. Core A3.
- Fig. 7 - A typically sculptured shell of *Homalopoma sanguineum*. Core A1.
- Fig. 8 - Specimen of *Janua* sp. 1 (spirorbidae). Core A2.
- Fig. 9 - *Pileolaria koehlerii* (spirorbidae), a sciaphilous ubiquitous shelf species. Core A2.
- Fig. 10, 11 - Worn specimens of Soritinae. Core A2.







*sanguineum* was regarded by Ledoyer (1966) as typical of the Dark Caves Biocoenosis. It is worth noting the occurrence of some smooth and light coloured or whitish shells of *Homalopoma sanguineum* (Pl. 1, fig. 4). The smooth and pale specimens should be regarded as belonging to a peculiar cave ecotype, since this well-known species usually has a bright red and heavily sculptured shell (Pl. 1, fig. 7). The presence, in all cores, of *Nucula recondita*, a recently described paedomorphic bivalve (Gofas & Salas, 1996) from algal and *Posidonia* beds developed at depths of 5-40 m, also deserves mention. This species should be regarded as cryptic, due to its small size (about 1.0 mm).

Specimens are generally well-preserved, as observed for the small and fragile shells of *Sinezona cingulata* and *Scissurella costata*, or the delicate tile-roof sculpture of young *Acar pulchella*.

3) A third group is composed of species lacking a particular ecological meaning. They are:

a) Species here termed "unspecialized", to stress their particularly wide ecological distribution. These species are widely found on infra-circalittoral bottoms, without a marked preference towards sciaphilous biotopes. Only a few are well represented (the molluscs *Bittium reticulatum* and *Alvania subcrenulata*, and the bryozoans *Platonea stoechas*, *Lichenopora radiata*, *Microporella ciliata* and *Celleporina hassalli*) whereas most are scarce. No serpuloid species has been referred to this group.

b) Species whose ecological meaning is generally not well known or uncertain, probably representing new taxa. They are very subordinate.

4) A fourth group is represented by several species which appear to have entered the cave from the outside and are here regarded as "allochthonous". Most are typically known from infralittoral biocoenoses (*Posidonia* and algal grasses). These species are probably not directly photophilic, although linked to photophilic communities for substrate preference or trophic habits. Several gastropods, such as *Rissoa auriscalpium*, *R. variabilis*, *R. similis*, *Alvania cimex*, *Pisinnia glabrata* and *Columbella rustica* can be referred to this group, as well as several bryozoans, such as *Umbonula ovicellata*, *Watersipora subovoidea*, *Pentapora ottomülleriana*, *Schizobrachiella sanguinea*, *Hippopodinella kirchenpaueri*, *Haplopoma bimucronatum* f. *occiduum* and *Turbicellepora magnicostata* (cf. Gautier, 1962; Harmelin, 1976; Zabala, 1986; Rosso, 1989, *inter alia*) and the serpuloid *Janua pagenstecheri*, *Filograna* sp. and *Spirorbis cuneatus*. The basal surface of some specimens shows casts of the alga (Pl. 1, fig. 1) or the *Posidonia oceanica* leaves on which they originally settled. A few species clearly come from supra-littoral or meso-infralittoral biotopes, such as the molluscs *Truncatella subcylindrica*, *Littorina neritoides* and *Patella* spp. Moreover, some particularly worn fragments belonging to bryozoans and serpuloid species have been included in this group. Their appearance suggests a "bioclast life", subject to high energy hydrodynamic conditions, likely to be found in shallow-water open environments. This last group is not represented among the molluscs, due to a different method of counting specimens (undeterminable gastropod and bivalve fragments were not scored). It should be noted, however, that the "external" mollusc shells are generally worn.

5) The final group is represented by predominantly juvenile specimens, almost exclusively belonging to cyclostomate bryozoans. They are generally indeterminate species, whose very small colonies settled on *Posidonia* fibers that previously floated into the cave. The colonies are often preserved on the algal fibers or their existence may be inferred by the presence of their casts (Pl. 1, fig. 3).

None of the three taxonomic groups investigated shows any marked trend throughout the cores, whereas strong differences occur between cores A1-A2 and core A3 (Fig. 3).

In core A3, a clear dominance of "cave" and "sciaphilous" species was recorded, the former being represented mainly by bryozoans and the latter by mol-

luscs and serpuloid species. The bryozoans on *Posidonia* fibers are very abundant as well, whereas "unspecialized" and "allochthonous" species are subordinate.

In cores A1 and A2, the "unspecialized" (represented mainly by molluscs and bryozoans) and "allochthonous" species (often with worn specimens) strongly prevail. The "cave species" are rare, and molluscs are not represented. In core A2 the bryozoans on *Posidonia* fibers are markedly scarce.

The degree of autochthony of thanatocoenoses was evaluated, taking into account "cave" (1<sup>st</sup>), "sciaphilous" (2<sup>nd</sup>) and "allochthonous" (4<sup>th</sup>) stocks, i.e. those whose ecological meaning is more obvious. Their relative abundance was entered in a percent ratio as 1+2/1+2+4, whose mean values are plotted in Fig. 3 (right). It is clear that thanatocoenoses A1 and A2 are heavily affected by external input (low values), whereas thanatocoenoses A3 are quite exclusively autochthonous (high values). The lowermost values were recorded for core A2 and not for core A1, despite the location of the latter near the main opening of the cave.

## Discussion.

Integrating textural, faunistic and ecological data, two distinct kinds of environmental conditions can be recognized. Sites A1-A2 are characterized by coarser sediments and by abundant and ecologically heterogeneous thanatocoenoses. In contrast, site A3 shows finer sediments but much more homogeneous, although scantier thanatocoenoses. The negative correlation between faunistic and muddy content (Fig. 4), supported by the available ecological data, suggests that both thanatocoenose abundance and sediment "cleaning" were influenced by the same process, i.e. the hydrodynamic level. It should be stressed that the Accademia Cave is a tunnel-cave in the zone between the two openings, where sites 1 and 2 are located. The water movement in this area is stronger than in the innermost part of the cave, which may be considered a blind cave (cf. Harmelin, 1969, 1980, 1985a, 1985b, 1986; Harmelin et al., 1985, 1995; Balduzzi et al., 1989; Bianchi & Morri, 1994; Morri et al., 1994).

Water movements within a cave strongly influence a variety of physico-chemical factors (oxygen, suspended organic matter, sedimentation, etc.) which in turn affect biological aspects. Both light rate and hydrological confinement are therefore essential in determining the structure and composition of cave communities (Harmelin, 1980). Hydrological confinement in marine caves has been stressed recently by Bianchi & Morri (1994), who developed a bionomical zonation and a confinement scale according to trophic depletion. Sediment deposition is also strongly related to water movements or, more generally, to hydrological confinement, as recently



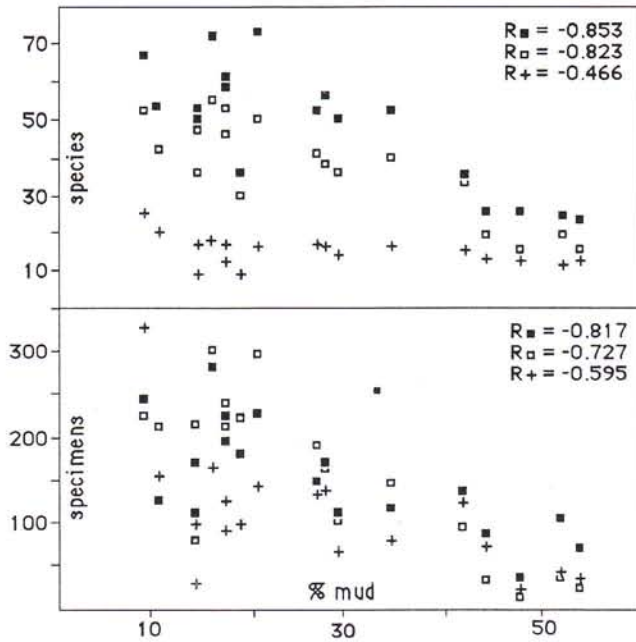


Fig. 4 - Scatter diagram showing the number of species and specimens versus mud percentage, for molluscs (closed squares), bryozoans (open squares) and serpuloids (crosses). The number of specimens is referred to a constant sample volume. R=correlation coefficient.

shown for sediment texture by Morri et al. (1994) using a tunnel-cave in which current speeds up to 12-20 cm/s were recorded.

Site A3 is much more sheltered or confined than the other areas, due to its innermost location in the cave, far from both openings. This is indicated also by the extremely high dominance of *Coronellina fagei*, a species which is particularly abundant in the most sheltered cave areas (cf. Harmelin, 1969). Site A3 represents a favourable location not only for sedimentation of silts and clays, but also for accumulation of *Posidonia* fibers. Indeed, these fibers are found in larger numbers here than at the other two sites. Ecological group 5 also increases with mud content, suggesting that fibers floating into the cave sank to the bottom in the most sheltered areas, where they could be colonized. The hydrodynamic confinement also allows an *in situ* preservation of skeletal remains, as shown by the very high values in the autochthony percent scale (Fig. 3), reflecting a strong dominance of "cave" and "sciophilous" species. These species probably detached from the cave walls,

Sample	Lab. code	Conventional Age (years BP)	$\delta^{13}\text{C}$ (‰)	Calibrated Age (years BP)
A1 bottom	R-2592	537 ± 85	1.86	268 - 0
A1 top	R-2593	914 ± 48	1.98	537 - 485
A3 bottom	R-2589	1306 ± 52	2.60	907 - 773
A3 top	R-2590	953 ± 59	2.60	575 - 501

Tab. 4 - Radiometric data from the bottom and top samples of the two cores tested from the Accademia cave.

since the bottom is too fine-grained for vagile species requiring "hard" substrates as well as epibyssate species (*Acar pulchella*) and other encrusting faunas, i.e. serpuloids and bryozoans. The latter often overgrow each other (Pl. 1, figs. 2, 6), indicating low availability of suitable substrata. These conclusions are consistent with the markedly homogeneous features of the thanatocoenoses from this core. The mud-dwelling epibyssate (*Dacrydium* sp. and "Crenella" sp.) and the infaunal (*Kelliella abyssicola*) bivalves should be referred to the sediment fauna.

In contrast, the autochthonous assemblage is markedly reduced at sites A1 and A2. These species probably detached from the surrounding walls and roof, but may also have originated from the scant coarse bottom fraction, suitable for both vagile and byssate molluscs. Many other "allochthonous" species (as shells and bioclasts) are associated with this autochthonous assemblage. Most of these species, such as those belonging to the fourth group, as well as the articulated coralline algae and the Soritinae foraminifera (containing algal symbionts) cannot live in the cave environment.

Di Geronimo et al. (1993) studied a sample from a sandy-gravel bottom located between the main opening and site A1 and considered unlikely a present-day introduction of skeletal remains from the outside. The presence of "allochthonous" species even in the topmost core samples necessitates a re-evaluation of this hypothesis and a present-day biogenic input from the outside is suggested. In addition to bottom drifting of skeletal remains, "allochthonous" species may have encrusted *Posidonia* leaves or other algal tissues that subsequently floated into the cave as suggested by bryozoan fragments showing tissue scars (Pl. 1, fig. 1). This process probably involved the small spirorbid tubes as well, abundant in the A1 and A2 "allochthonous" stock. Besides these displacement processes, a "reworking" of skeletal remains and sediment mobilization by water movements and/or faunal activity should also be expected.

A slight increase in the hydrodynamic level towards the top of cores A1 and A2 is recognizable, while core A3 shows a slightly opposite trend. The paleoenvironmental interpretation of these trends must consider the strong spatial heterogeneity of the cave. A cave often represents a "closed" depositional system, quite different from an open-sea bottom. A coarse deposition, or the removal of fine fractions together with a muddy sedimentation may occur together in different areas within a cave, according to confinement degree and morphology. Such strong spatial heterogeneity is well recorded by the composition of communities and thanatocoenoses of the Accademia cave. Differences can be seen not only among the sites studied, but also between these sites and the sandy gravel sample described by Di Geronimo et al. (1993). Moreover, these different biotopes show a



marked confinement and no evidence of displacement of large-sized particles such as granules and cobbles together with any bryozoan and serpuloidan epibionts. Some species that occur in the gravel sample are absent at the other sites. This might be related to currents largely influenced by the physiography and recent evolution of the cave.

### Conclusions.

The detailed ecological analysis of faunistic data derived from benthic thanatocoenoses may provide a useful tool for outlining environmental trends within a cave. In the Accademia Cave a short time span cannot be reliably "resolved" using paleoecological data, although some spatial trends may be defined. These trends are important in "mapping" the markedly heterogeneous environmental conditions within a cave, involving light and hydrodynamics, sedimentation process and an array of biologically/ecologically related aspects.

The confinement model, proposed for cave communities (Harmelin, 1980; Bianchi & Morri, 1994), can therefore be applied to thanatocenoses. In this view, the bionomic confinement scale seems to follow the same trend of autochthony to allochthony ratio, as far as faunas are concerned, and fine to coarse fraction ratio, as far as sediments are concerned.

The geological history of the Accademia Cave may be summarized as follows. A continental phase, characterized by karstic and mass downfalls, created the cave, as indicated by efforative pipes perpendicular to the coastline (including the two present openings) and, in the innermost parts, by the presence of stalactites,

stalagmites and a higher vault. During the Würmian regression, the sediments present within the cave may have been washed out. The sea level oscillated around the present-day level up to the Late Holocene. Consequently, the cave was exposed to alternating phases of submersion and emersion which resulted in sediment deposition and removal. Therefore, it should be assumed that the sampled sediments, dating back to about 1,000 years B.P. according to radiometric measurements, are related to the last ingressive phase.

A slight trend towards a higher confinement degree, recorded in core A3, might be related to morphological changes rather than to sea-level changes (minimal in the last 1,000 years; Pirazzoli, 1991), or to local vertical land movements (Bousquet & Lanzafame, 1995). Such morphological changes are probably related to large downfalls, like the one that partially closed the southern opening. Downfalls might have been caused by earthquakes, e.g. those recorded in northwestern Sicily from 1,000 to 1,500 AD (CNR, 1985), i.e. within the lifetime of the sediments studied.

### Acknowledgements

The authors are grateful to R. Leonardi (I.P.O.P., Catania), who technically supported cave exploration and sampling; to O. Torrisi (C.N.R. International Institute of Volcanology, Catania) for SEM assistance and to M. Mola (Centro studi Quaternario ed evoluzione ambientale, Roma) for technical assistance in  $\delta^{15}$  measurements performed in the Laboratory of Stable Isotopes (Earth Science Department, Roma) directed by Prof. B. Turi. This paper was improved by review of an earlier version by E. Robba, Milano and A. Waren, Stockholm. H. Zibrowius, Marseille, also gave helpful suggestions. Linguistic revision by E. Fois, Cleveland.

The work was supported financially by CNR grants.

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Received November 20, 1996; accepted February 28, 1997