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«Apulian marbles» of the Ostuni District (south-eastern Murge, Apulia, Italy). Identification and characterisation of ancient quarries for archaeometric purposes

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ABSTRACT. — The so-called «Apulian marbles» have been, and still are, widely used as both building and ornamental materials. The lithotypes exploited in antiquity in nine quarries identified in the Ostuni district (South-Eastern Murge, Apulia, Italy) were studied. This research aims at: i) characterising, from minero-petrographic and geochemical points of view, the outcropping lithotypes (this kind of study being scarce or lacking in literature); ii) attributing them to their geological formation of provenance; iii) furnishing a data-base for comparisons (features of quarry materials), in order to solve archaeometric problems related to the various archaeological sites and monuments occurring in South-Eastern Murge. With these aims, on quarry samples, minero-petrographic, palaeontological, chemical and, only for some samples, isotopic and scanning electron microscopy analyses were carried out. The results allow us to conclude that, of the nine quarries, two (Lamasanta Grande and Costamerlata) are open in the «Calcare di Caranna» Formation (Campanian-Maastrichtian), two (Viale Oronzo and Ostuni-Villanova) in the «Calcare di Altamura» (Coniacian-lower Campanian); one (Via dei Colli) in the «Calcare di Ostuni» (Campanian-Maastrichtian); two (behind the Messapic Rosara quarry) in the «Calcare di Caranna» Ostuni variety (Campanian-Maastrichtian); and the last two (Tre Torri Hotel and Melpignano) in the megabreccia (Maastrichtian-Paleocene).

RIASSUNTO. — Come è noto, i cosiddetti «marmi pugliesi» sono stati e sono a tuttoggi largamente utilizzati sia come materiale da costruzione che come materiale ornamentale. Nel presente lavoro vengono studiati i litotipi anticamente coltivati in nove cave riconosciute nel distretto di Ostuni (Murge sud orientali, Puglia, Italia). Finalità della ricerca è caratterizzare dal punto di vista minero-petrografico e geochimico i litotipi affioranti - essendo carenti e/o assenti in letteratura studi in tal senso - ed attribuirli alla Formazione geologica di appartenenza; s'intende inoltre fornire una base di confronto per la risoluzione di problematiche archeometriche inerenti i numerosi siti archeologici e monumenti delle Murge sud-orientali. A tal fine, sui materiali di cava si sono effettuate analisi petrografiche, paleontologiche, diffrattometriche, chimiche e, per alcuni campioni, chimico-isotopiche ed al microscopio a scansione elettronica.

I risultati ottenuti hanno permesso di concludere che delle nove cave studiate due (Lamasanta Grande e Costamerlata) sono aperte nel «Calcare di Caranna» (Campaniano-Maastrichtiano), due (Viale Oronzo e Ostuni-Villanova) nel «Calcare di Altamura» (Coniaciano-Campaniano inferiore), una (Via dei Colli) nel «Calcare di Ostuni» (Campaniano-Maastrichtiano), due (dietro la cava messapica della Rosara) nel «Calcare di Caranna»

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varietà Ostuni (Campaniano-Maastrichtiano) e due (cava dopo Hotel Tre Torri e Melpignano) nella megabreccia (Maastrichtiano-Paleocene).

KEY WORDS: *Ostuni, Murge, Apulia, limestone, ancient quarry, archaeometry, petrography, geochemistry*

INTRODUCTION

The «Apulian marbles», carbonatic rocks outcropping all over the region (Fig. 1), have been, and still are, widely used as both building and ornamental materials. Nowadays, the Apulian mining industry produces 500.000 t/year of these materials (in «Marmi di Puglia», 1982). The occurrence and fame, in the region, of several important archaeological sites (Canosa, Herdonia, St. Giusto, Egnazia, etc.) and buildings, cathedrals, sculptured works (Castel del Monte, Cathedrals of Trani and Troia, Celestini building, Obelisk, etc.) dated to Messapic, Roman, Medioeval, Renaissance and Modern ages have recently led the authors to undertake systematic study of ancient limestone quarries which are, still today, recognisable in Apulian territory (Tucci *et al.*, 1994; Barbieri *et al.*, 1995; Borghi *et al.*, 1996; Tucci and Morbidelli, 1999; Tucci *et al.*, 2002).

This study aims at giving minero-petrographic, geochemical and palaeontological parameters to researchers in archaeometry and/or restoration of works made of these «marbles». Such parameters, compared with those resulting from study of the remains, will allow us to attribute the materials to their proper geological formation and, when possible, to their ancient quarry of provenance.

In the present paper, the limestones mined in antiquity in nine quarries identified in the Ostuni district (South-Eastern Murge, Ostuni) were characterised.

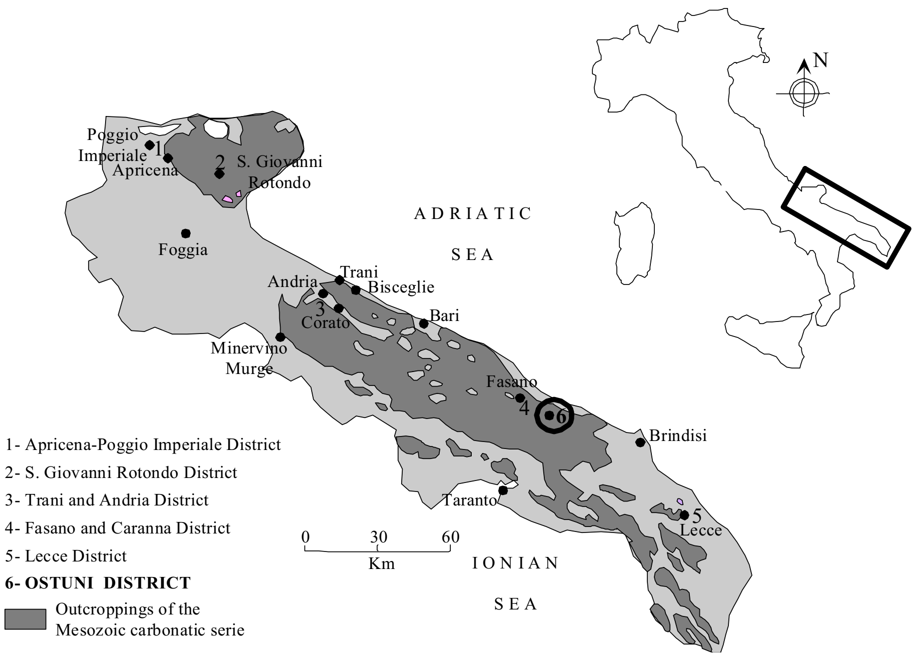

Fig. 1 – Location of «Apulian marble» districts (from «Marmi di Puglia», 1982, modified).

Sampling and analytical procedures

Representative rock samples, measuring up to 15x15x15 cm, were taken from nine ancient quarries near Ostuni and its surroundings (taking into account portions where working traces are missing), from bottom to top of the stratigraphic sequence. Samples of megabreccia come from white, chalky, compact mega-stone (up to 4-5 m^3; Fig. 2). Samples were ground in a steel mortar, the complete crush was subdivided into four portions and one portion was powdered in an agate mortar to a final grainsize of less than 30 μm.

The following examinations were carried out on quarry samples: petrographic analysis of thin sections; qualitative phase analysis, using a PHILIPS PW 1830 diffractometer with unfiltered CuK_α radiation (40 KV, 2θ mA), data recorded in the 3°-70° 2θ range, scan speed 1°/min, step time = 2 s/step, 1° divergence slit, 0.1 mm receiving slit, 2° antiscatter slit (in the case of clay minerals, samples were treated with glycolic acid); loss on ignition (LOI) 900°C; major, minor and trace element contents determined by XRF (SIEMENS spectrometer, Cr anticathode tube) according to the method of Franzini *et al.* (1972, 1975) and Leoni & Saitta (1976); international standards were used for calibration (GFS 400, 401, 402, 403; NBS 1b, 88a); precision for major elements was usually estimated at below 3% except for Mg and Mn (<10%). Analytical precision was better than 10% for trace elements. Qualitative and quantitative determination of insoluble residue was determined after powder chemical attack with acetic acid, due to the absence (diffractometrically evidenced) of dolomite.

Only on some samples, for their better characterisation, were scanning electron microscope (SEM) analyses carried out on a Cambridge Stereoscan model 250 MK3 equipped with EDS link model AN 10/55.

Sr isotope analyses were determined on one stone fragment by mass spectrometry following routine procedures (McCrea, 1950; Turi *et al.*, 1976); results are reported against the PDB standard (Craig, 1957). Lastly, Sr isotope ratios were measured on the carbonate fraction obtained by quick dissolution in 2.5 N ultra-pure HCl. After centrifugation, the solution was passed through a cation exchange column following standard procedures. Isotopic analyses were carried out on a VG-54E mass spectrometer; data acquisition and reduction were performed according to the procedure of Ludwig (1994). Repeated analyses on standards gave averages and errors (2σ) as follows: NBS 987, $^{87}Sr/^{86}Sr$=0.710262±15; $^{87}Sr/^{86}Sr$ normalised to 0.1194. Analytical uncertainty was ± 0.00005.

Fig. 2 – White, chalky megabreccia. Mega stones are compact and may reach 4-5 m^3 (e.g., block in centre of picture).

GEOLOGICAL FORMATIONS OUTCROPPING NEAR OSTUNI

The evolutionary scenario of the sedimentation basin of the Ostuni district (South-Eastern Murge; Fig. 3), from the Coniacian to the Maastrichtian may be summarised as follows: in the Coniacian a neritic platform environment arose, characterised initially by very scarce terrigenous supply; in this environment algal flora developed which, very rarely, then gave way to Rudist bioconstructions in which life was favoured by hydrodynamic variations.

Thus, cyclic sequences, characterised by rhythmic alterations of algal laminites and Rudist wackestone – «Membro Stromatolitico» – were established. Later, the neritic environment became progressively more favourable to the development of Rudists – «Membro a *Goryanovicia*» –, («Calcare di Altamura» Formation).

In the Upper Campanian, a distensive tectonic phase drowned a portion of the carbonate platform, leading to the development of a edge-slope-basin system (Fig. 3). Throughout the Maastrichtian on the border zones, Rudist bioconstruction developed («Calcare di Ostuni» Formation), whereas the slope-basin areas were filled by a biochemical precipitation carbonate («Calcare di Caranna» Formation).

These two heteropic and interfingered formations show gradual facies according to their proximity or otherwise to the bioconstruction.

Thus, in the Ostuni district (Luperto Sinni and Borgomano, 1989; Pieri and Laviano, 1989), the outcropping Upper Cretaceous carbonatic complex is represented by the upper portion of the «Calcare di Altamura», «Calcare di Ostuni» and «Calcare di Caranna» Formations (Fig. 3).

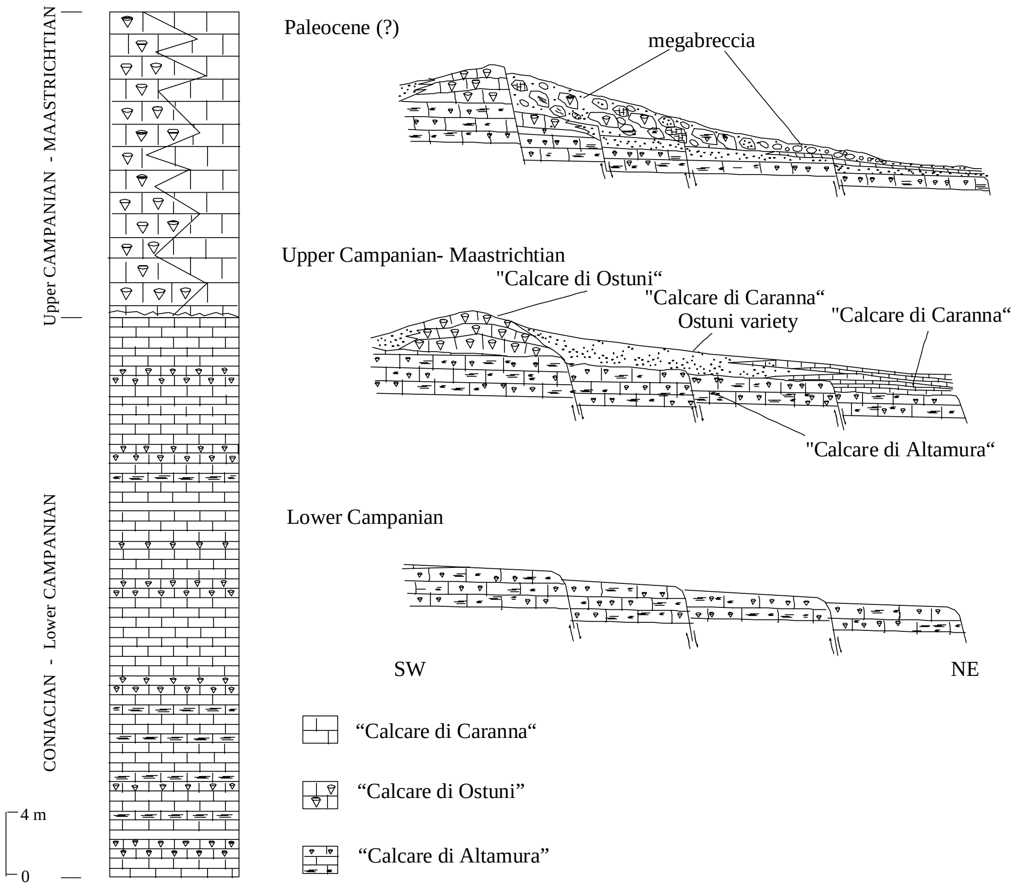

Fig. 3 – Ostuni district. Cretaceous carbonatic complex. Stratigraphic sequence and basin evolution.

The latter two heteropic formations show a term which, because of verified differences, mainly in its abundant fossiliferous content and in its petrographic features, is called «Calcare di Caranna» Ostuni variety, by the authors (Fig. 3; Tucci *et al.*, 1994).

All these formations, from km 882 of the Adriatica state road (SS 16), in the direction of Carovigno, are covered by a megabreccia (Figs. 2, 3), due to a tectonic event (Maastrichtian-Paleocene) (Pieri and Laviano, 1989), composed of blocks of various sizes (up to 4-5 m^3) coming from all the limestones of the already-mentioned Formations. The megabreccia extends as far as San Vito dei Normanni (near Brindisi, about 14 km from Ostuni).

Since ancient times and still today, these limestones, including the megabreccia blocks (and, in particular, due to their workability, those of the «Calcare di Caranna» - better known, locally, as *Pietra Gentile*), have been widely used for building. The remains of many ancient quarries are found not only near Ostuni but also in the town itself. Some of them (e.g., «La Rosara», Fig. 4) have been exploited since the Messapic age (Tucci *et al.*, 1994).

Experimental results and discussion

Nine ancient quarries (Fig. 5) belonging to the Ostuni district were identified and studied.

Fig. 4 – Detail of «La Rosara» quarry: ancient step working.

Lamasanta Grande and Costamerlata quarries (label C)

The remains of two ancient quarries, with evident traces of working, are visible at Lamasanta Grande, near the flying club, and between Costamerlata and Villanova, behind the Tanzarella missworking quarry (Tucci *et al.*, 1994). In both outcrops, the upper portion is characterised by transgression with yellowish bioclastic calcarenite, containing pectinaceans, ostracods and echinids («Tufi delle Murge» Formation; Calabrian). The lower portion is made up of very fine, whitish, chalky calcarenite, with few bioclasts.

Microscopic observation identified two lithotypes:

1) intrabiomicrite (C2, C4, C5, C7) (Folk, 1959, 1962), with a fabric between mud- and grain-supported (wackestone-packstone) (Dunham, 1962) with a low matrix/grain component ratio; morphologically it has a low degree of evolution, and is generally poorly sorted. Calcite, the most representative mineral, is mainly micro-crystalline. The scarce non-carbonate fraction, diffractometrically

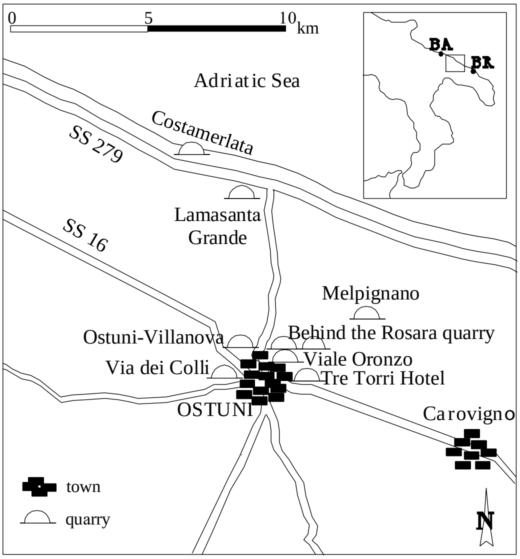

Fig. 5 – Location of studied quarries.

identified in insoluble residue, is mainly due, only in samples C4, C5 and C7, to montmorillonite, kaolinite, subordinate illite, and Fe, Mg and Mn oxides. The diffuse porosity is given by small voids partially filled with micro-sparitic calcite. Organogenic contents are limited to *Stomiosphaera sp.* (Fig. 6) and bryozoan and bivalve fragments (at Lamasanta Grande).

2) The second lithotype is a micritic limestone (C1, C3, C6, C8, C9) with detrital material intercalations (wackestone) (Dunham, 1962), also of organogenic nature, occurring as more compact layers and/or levels with intraclasts of trapezoidal shape, tendentially isoriented (Fig. 7). The latter are poorly sorted and show low morphological maturity. The few occurring small voids are mainly due to fossil marks. Palaeontological contents are miliolids, rotaliids, echinoids, and the Rudist *Sabinia*. Calcite is the most representative mineral; diffractometric analysis of insoluble residue shows the occurrence in samples C3, C8 and C9 of sporadic quartz and the same clay minerals occurring in the above intrabiomicrite; samples C1 and C6 have a very low content of plagioclase.

Chemically (Table 1), both lithotypes correspond to pure limestone (average $CaCO_3$ content: 99.74 wt%).

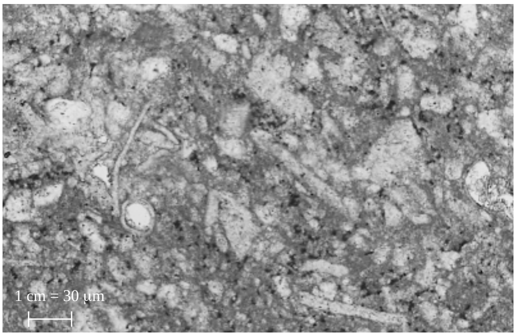

Fig. 6 – Optical microscopy, plane-polarised; intrabiomicrite with fabric between mud- and grain-supported. *Stomiosphaera sp.* occurs (left side of picture). Scale bar = 30 µm.

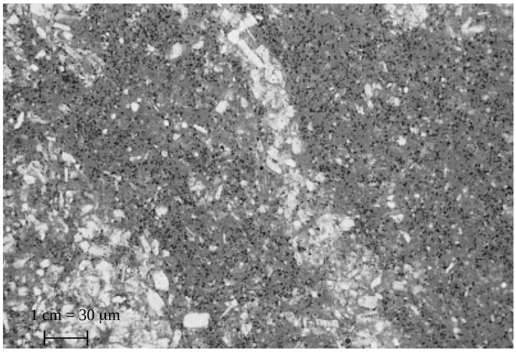

Fig. 7 – Optical microscopy, plane-polarised; micritic limestone with intercalations of detrital material. Scale bar= 30 µm.

Viale Oronzo and Ostuni-Villanova quarries (label A)

Two ancient quarries may be identified along Viale Oronzo in Ostuni, one near the lay-by under the ancient city walls, and one along the Ostuni-Villanova road (about 150 m from state road SS 16; crossing near the petrol station, on the left). These quarries are characterised by stratified beds, of decimetric to metric thickness, interbedded with marly-clayey layers of a light-brown, compact, sometimes macro-fossiliferous limestone.

Above the first quarry, the transgressive (Fig. 8) «Calcare di Ostuni» Formation occurs (*facies* recifale; Upper Campanian-Maastrichtian; Fig. 3; Luperto Sinni and Borgomano, 1989); the second quarry is partially covered by agricultural land and the above transgression is not visible. The appearance of the rock, lacking deformations, and still evident traces of the same type of step working, all indicate that it is the same lithotype.

Microscopic observations reveal the massive, sometimes macro-fossiliferous levels of a biomicrite (Folk, 1959, 1962), with a mud-supported and intraclast-poor fabric (wackestone) (Dunham, 1962). The thinner, sometimes sterile levels are composed of intrabiosparite (Folk, 1959, 1962), with grain-supported fabric with scarce carbonate mud

Fig. 8 – Viale Oronzo, «Calcare di Altamura» Formation; transgressive passage with «Calcare di Ostuni» Formation.

(packstone) (Dunham, 1962). The biomicrite, made up of abundant carbonatic mud with very minute crystals, has poor porosity and rare intraclast grains and fossil remains (*Thaumatoporella parvovesciculifera*, *Dicyclina schlumbergeri*, *Aeolisaccus kotori*, Rudist and gastropod bioclasts; Fig. 9). Voids, some partially and others totally filled with euhedral spathic calcite crystals, forming a typical drusy mosaic, sometimes reveal true *fenestrae* (Tebutt *et al*., 1965).

Instead, the intrabiosparite is enriched with micritic and biogenic clasts with slightly sub-rounded rims, separated by diffuse intragranular spaces sometimes filled by spathic calcite. The result is widespread, high primary porosity of the rock. Palaeontological components are scarce and poorly preserved. Mineralogically, calcite is very abundant; the scarce insoluble residue (average IR content: 0.14 wt%) is mainly given, in almost all samples, by kaolinite, subordinate illite, montmorillonite, and sporadic quartz and plagioclase grains.

Chemical data (Table 1) confirm that these lithotypes are almost pure limestone (average $CaCO_3$ content 99.48 wt%).

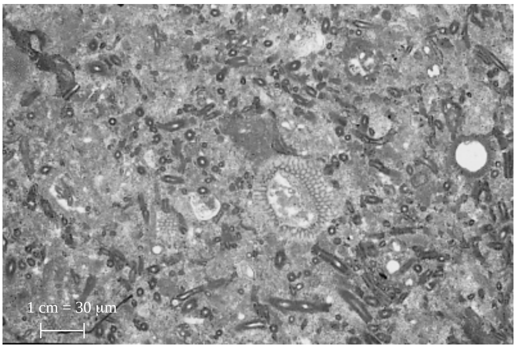

Fig. 9 – Optical microscopy, plane-polarised; biomicrite composed of abundant carbonatic mud. *Dicyclina schlumbergeri* (centre) and *Aeolisaccus kotori* occur. Scale bar = 30 µm.

Via dei Colli quarry (label OS)

A quarry wall, about 10 m long and 2 m high, is clearly visible at the beginning of Via dei Colli. It is composed of massive limestone rich in macrofossils (Fig. 10).

In thin section, this rock, which is a intrabiomicrite (Folk 1959, 1962), is mainly composed of micrite and micritic and biogenic intraclasts. The fabric is completely mud-supported; the allochems consist of Rudists (wackestone) (Dunham, 1962). Many fractures, totally or partially filled with calcite, occur. The rare voids are minute and well distributed. Compositionally, besides prevalent calcite, non-carbonatic minerals include kaolinite, illite, quartz and plagioclase. The abundant

Fig. 10 – Via dei Colli. Quarry wall, about 10 m long and 2 m high, with evident traces of working. Composed of massive limestone rich in macro-fossils.

TABLE 1

Chemical analyses (XRF). Major (wt%) and trace element (ppm) contents of studied samples; $CaCO_3$ was calculated. C = «Calcare di Caranna»; A = «Calcare di Altamura»; OS = «Calcare di Ostuni»; CO = «Calcare di Caranna» Ostuni variety; CM = megabreccia blocks. CM2 and CM5 are from

	C1	C2	C3	C4	C5	C6	C7	C8	C9	A1	A2	A3	A4	A5	A6
SiO_2	-	-	0.02	-	-	-	-	0.02	0.14	-	0.01	0.04	0.04	0.07	0.04
TiO_2	-	-	0.01	0.01	-	-	0.01	-	-	-	0.03	0.02	-	-	0.04
Al_2O_3	-	-	0.01	0.09	0.06	-	0.03	0.04	0.07	-	0.02	0.06	-	0.11	0.04
Fe_2O_3*	-	-	-	0.01	-	-	-	-	-	-	-	0.01	0.03	0.03	0.01
MnO	0.02	0.02	-	0.01	-	0.02	-	-	-	0.02	-	-	0.02	-	-
MgO	0.07	0.05	0.16	0.10	0.08	0.13	0.11	0.05	0.09	0.07	0.14	0.22	0.32	0.21	0.25
CaO	55.97	55.95	55.91	55.89	55.89	55.86	55.77	55.93	55.80	55.94	55.88	55.63	55.62	55.70	55.66
Na_2O	0.01	-	-	-	-	0.03	-	-	-	-	0.02	0.03	0.01	-	0.02
K_2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LOI	43.94	43.98	43.88	43.99	43.95	43.94	44.09	43.95	43.88	43.95	43.98	43.97	43.95	43.88	43.92
Tot	100.01	100.00	99.99	100.10	99.98	99.98	100.01	99.99	99.98	99.98	100.08	99.98	99.99	100.00	99.98
S	-	-	331	144	181	260	112	153	110	-	338	446	88	333	495
Rb	12	10	-	-	-	11	-	3	3	11	-	-	10	-	-
Sr	93	110	87	123	72	178	113	139	125	52	52	62	85	79	71
Ba	4	-	-	10	-	2	13	10	20	2	-	-	4	25	-
La	34	41	-	-	-	34	-	-	-	38	-	-	33	-	-
Cr	26	15	-	-	-	16	-	12	-	18	-	-	20	-	-
IR	0.01	-	0.10	0.16	0.10	0.01	0.05	0.11	0.27	0.03	0.18	0.27	0.10	0.14	0.12
$CaCO_3$	99.89	99.86	99.79	99.75	99.75	99.70	99.54	99.82	99.59	99.84	99.73	99.29	99.27	99.41	99.34

Fig. 11 – Via dei Colli. «Calcare di Ostuni» Formation. Detail of *Youfia* rudist fragment.

palaeontological components are miliolids, foraminifers, Rudist fragments (*Youfia*; Fig. 11), and rare gastropods and corals.

Chemical analyses of samples (average $CaCO_3$ content: 99.34 wt%; average IR content: 0.14 wt%) are listed in Table 1.

Quarries along road parallel to state road SS 279, behind Messapic Rosara quarry (label CO)

Along the road parallel to state road SS 279, behind the Messapic Rosara quarry (Tucci *et al.*, 1994), near the fort of Ostuni, remains of two ancient quarries may be identified. One shows mixed working between hole and amphitheatre, with traces of step-working using chisels (below farm buildings; Fig. 12); the

Tre Torri Hotel outcrop; other CM samples are from Melpignano;
** = total; IR = insoluble residue; - = under detection limit.*

OS1	OS2	OS3	OS4	OS5	OS6	OS7	CO1	CO2	CO3	CO4	CM1	CM2	CM3	CM4	CM5
-	0.11	-	0.11	0.12	-	0.2	-	-	-	-	-	-	-	-	-
-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.08	0.05	0.05	-	-	0.04	-	0.04	-	-	-	-	-	-	-	-
-	-	-	0.02	0.04	-	-	-	-	-	-	-	-	-	-	-
-	0.01	0.02	0.02	-	-	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
0.09	0.28	0.09	0.40	0.40	0.12	0.30	0.08	0.08	0.09	0.01	0.19	0.14	0.15	0.20	0.10
55.81	55.63	55.82	55.51	55.53	55.78	55.55	55.89	55.91	55.87	55.99	55.79	55.89	55.94	55.81	55.90
-	0.14	-	0.02	0.03	0.15	-	-	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44.02	43.89	44.03	43.93	43.95	43.92	43.89	43.96	43.95	43.98	43.95	43.98	43.93	43.86	43.97	43.98
100.00	100.00	100.01	100.01	100.07	100.00	99.98	99.99	99.98	99.98	99.98	100.00	99.99	99.98	100.01	100.01
180	160	164	-	70	130	189	-	145	-	-	80	304	-	-	-
20	20	21	8	9	9	9	9	12	14	13	12	12	18	12	11
124	80	67	-	20	19	-	127	144	118	93	101	118	144	270	135
10	12	15	5	4	3	3	-	3	2	2	2	2	-	3	2
24	23	23	22	22	21	20	36	40	39	44	47	38	44	46	37
-	19	20	21	14	13	20	18	20	17	18	22	22	18	20	17
0.17	0.25	0.15	0.08	0.08	0.16	0.10	0.10	0.04	0.08	0.01	0.06	0.11	0.03	0.06	0.07
99.61	99.29	99.63	99.07	99.11	99.55	99.14	99.75	99.79	99.71	99.93	99.57	99.75	99.84	99.61	99.77

Fig. 12 - Road parallel to state road 279. Remains of ancient quarry with mixed working between hole and amphitheatre, and traces of step working by chisel.

Fig. 13 - Road parallel to state road 279, Belvedere house. Remains of ancient quarry with *festone* working.

other shows *festone* working (Belvedere house; Fig. 13). In thin section, two lithotypes, both corresponding to almost pure carbonatic rocks were identifed (Table 1, average $CaCO_3$ content: 99.79 wt%; average IR content: 0.06 wt%).

The most representative lithotype is an intrabiomicrite (Folk, 1959, 1962), with grain-supported fabric (packstone) (Dunham, 1962), well-constructed matrix, and subordinate spathic calcite. It contains poorly distributed, poorly sorted micritic intraclasts, with mainly angular rims, and bioclasts up to 1 cm long, generally with sub-rounded rims. Abundant intergranular voids occur (Ø =2-3 mm), irregularly distributed and often filled with euhedral spathic calcite crystals. Biogenous contents, very abundant, are given by Rudists *Youfia* and *Hippurites*.

The second lithotype (Belvedere house) is an intrabiosparite (Folk, 1959, 1962), with a fabric (grainstone-packstone) (Dunham, 1962) made up of micritic clasts and heterometric bioclasts, chaotically arranged and sometimes sub-rounded, and with a lower content, with respect to the previous lithotype, of micritic matrix. Many voids of various dimensions, often completely cemented by spathic calcite, are observed. On the whole, the rock appears highly crystallised. Besides abundant Rudist fragments, corallineaceous algae and some gastropods were also found (Fig. 14).

Mineralogically, the rocks are composed of calcite, with Mg- and Mn-oxides as accessory phases.

Tre Torri Hotel and Melpignano quarries (label CM)

At Ostuni (along Corso Vittorio Emanuele II), just after the Tre Torri Hotel and at Masseria Tamburroni (Figs. 2 and 15; active quarry of Melpignano), there are quarry walls with evident traces of ancient working (Fig. 16). These quarries are open on the typical structure of the megabreccia occurring in the Ostuni district, which formed as a result of post-Maastrichtian tectonic events (upper slope

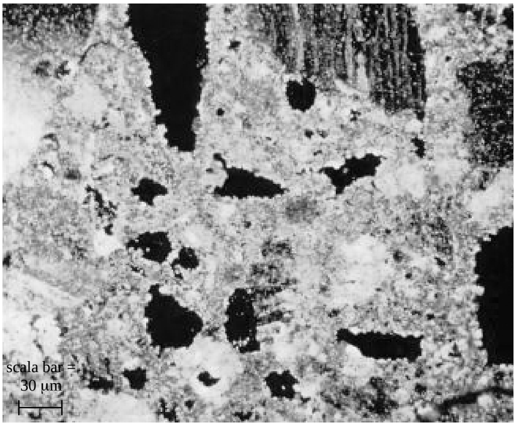

Fig. 14 – Optical microscopy, cross-polarised; intrabiosparite composed of micritic clasts, enriched in supplies deriving from demolition of a bio-construction. 1 cm = 30 μm.

Fig. 15 – Tre Torri Hotel. Walls with evident traces of ancient working on typical structure of megabreccia.

Fig. 16 – Melpignano (Masseria Tamburroni). Megabreccia open quarry.

facies) (Pieri and Laviano, 1989). Among the blocks of megabreccia (up to 4-5 m^3), those related to a lithotype which is whitish, tender, chalky, and thus macroscopically similar to the well-known *Pietra Gentile*, were studied.

This rock was widely used for building in the past and is still employed today. Petrographical and palaeontological data indicate that these blocks correspond to 3 lithotypes, classificable as intrabiomicrite and chemically (Table 1) corresponding to pure limestone (average $CaCO_3$ content 99.71 wt%; average IR content 0.07 wt%): i) sample CM4; for minero-petrographic and palaeontological description, see Lamasanta Grande and Costamerlata (samples with label C), ii) samples CM3, CM5; for minero-petrographic and palaeontological description, see quarries along the road parallel to state road SS 279 behind the Messapic Rosara quarry; samples labelled CO), and iii) samples CM1, CM2; with intermediate features between samples C and OS. In fact, in thin section, this rock displays mud-supported structure (wackestone) (Dunham, 1962), with micritic and organic intraclasts, extremely heterometric and morphologically poorly evolved. The many cavities are very variable in size, up to about 3 mm, and are inter-communicating, independent of their dimensions, forming long, branched channels. The scarce palaeontological component is limited to *Stomiosphera sp.*, Rudist fragments, and a few other unidentifiable fossil remains (Fig. 17). The very rare non-carbonate fraction of these two samples, analysed by SEM, is represented by quartz, clay minerals, Ca-and Fe-silicates, and Al- and Fe- silicates.

The lithotypes identified in the nine quarries, which are, as shown above, stratigraphically, macroscopically, microscopically and palaeontologically well distinguishable from each other, are not clearcut from the mineralogical and chemical points of view, being all almost pure limestone, compositionally very similar to each other (Table 1), and with constantly low IR amounts (max value = 0.27 wt%; sporadic occurrence of illite, kaolinite, montmorillonite, quartz, plagioclase and rare Fe-, Mg- and Mn-oxides). However, some mineralogical and chemical features allow us to make some hypotheses about the evolution of the ancient basin of sedimentation.

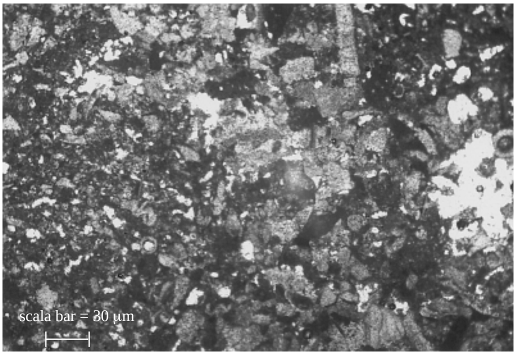

Fig. 17 - Optical microscopy, plane-polarised; mud-supported structure with micritic and organic intraclasts, extremely heterometric and morphologically poorly evolved. *Stomiosphaera sp* occurs in right side of picture. 1 cm = 30 µm.

Generally, the Sr contents of all the studied limestones are low, compared with those of marine analogs (average value = 510 ppm for Cretaceous carbonates from Italy, Fornaseri and Grandi, 1963; average value = 450 ppm, Wedepohl, 1974) but similar to contents of other Apulian Cretaceous carbonate outcrops studied by Garavelli and Moresi (1973). In samples OS and A, the very low Sr amount is interpreted as the consequence of diagenesis controlled by Sr-poor groundwaters (Brand and Veizer, 1980), in fact: i) the abundant occurrence of Rudist shells, originally of aragonitic nature and thus Sr-rich, found in samples OS (Kinsman, 1969); ii) the evidence, both macroscopic and microscopic, confirmed by very low Mn content, that the original sediments of samples A were carbonate sediments, mainly aragonitic in composition, deposited in a neritic environment (Bencini and Turi, 1974; Renard, 1979), all indicate that this kind of depletion in Sr in these rocks can only be explained by the above process.

The fact that the scarce non-carbonate component is mainly composed of clay minerals suggest that the carbonate platform was either far from the mainland or, if near to it, that the erosion rate was very low, probably because the continent was a peneplain and/or the climate was arid.

Attribution of lithotypes to formations of provenance

Besides macroscopic observations in the field, the features so far described indicate that:

– samples C are limestone, sedimented in a high-energy slope depositional characterised, however, by scarce terrigenous supply (Luperto Sinni and Borgomano, 1989). These characters allow these lithotypes to be attributed to the «Calcare di Caranna» Formation (Upper Campanian-Maastrichtian; Fig. 3) and in particular to the bottom portion (white, gravelly, chalky limestone) of the «Membro ghiaioso a *Sabinia*» (Luperto Sinni and Borgomano, 1989);

– samples A showing cyclic alternation, clearly recognisable in the field, in lithotype and stratigraphic position (biomicritic beds and intrabiosparites), as well as the low insoluble residue content found in all samples, are typical of a low-energy, shallow environment, where conditions sometimes allowed isolated Rudist groups to grow. Thus, these limestones, which were deposited in an internal-platform depositional environment, are attributable to the «Calcare di Altamura» Formation (Coniacian-lower Campanian), and in particular to the upper part («Membro a *Goryanovicia*») of the «Membro Stromatolitico» (Luperto Sinni and Borgomano, 1989);

– samples OS, both macroscopically and microscopically, show the typical characters of an edge association of biogenous limestone, alternating with calcarenite and calcirudite (typical «Calcare di Ostuni» Formation; Upper Campanian-Maastrichtian) (Luperto Sinni and Borgomano, 1989);

– the peculiar features of CO limestones suggest a genesis similar to that of the «Calcare di Caranna» (outcropping at Costamerlata and Lamasanta Grande; products of a slope-basin depositional system) (Luperto Sinni and Borgomano, 1989; Pieri and Laviano, 1989), but enriched with an abundant palaeontological component (Fig. 14) typical of the demolition of a bioconstruction. The same lithotype, recognised by the authors in previous studies (Fiorucci, 1992; Tucci *et al.*, 1994), in the ancient Messapic Rosara quarry (Fig. 4), was called «Calcare di Caranna» Ostuni variety. This term identifies a gradual facies («Calcare di Caranna» and «Calcare di Ostuni» heteropic Formations), formed in the slope-basin area nearer the bioconstruction. Thus, the result is a mix between the chemical precipitate (Caranna limestone) and the products of the demolition of the bioconstruction (Ostuni limestone);

– the blocks collected in the megabreccia are attributable as follows: sample CM4 to the «Membro ghiaioso a *Sabinia*» of the «Calcare di Caranna» Formation (Luperto Sinni and Borgomano, 1989); samples CM3 and CM5 to the «Calcare di Caranna» Ostuni variety (Tucci *et al.*, 1994). As for samples CM1 and CM2, their peculiar features, typical of a slope sedimentary environment (hemipelagites, resediments), compared with those of the lithotypes outcropping in Ostuni and its surroundings (Luperto Sinni and Borgomano, 1989; Pieri and Laviano, 1989, Tucci *et al.*, 1994) lead the authors to consider them one of the gradual facies typical of the passage between the two heteropic Formations of «Calcare di Caranna» and «Calcare di Ostuni». (Fig. 3), but not comparable with the typical «Calcare di Caranna» Ostuni variety. To confirm this hypothesis, since this lithotype was never found outcropping either in Ostuni or its surrounding areas, isotope dating was carried out on sample CM1. The occurrence of this lithotype, dated to the upper Campanian- late Maastrichtian ($^{87}Sr/^{86}Sr$ = 0.707602±15), agrees with the peculiar geological history (Fig. 3) of the Ostuni district.

Conclusions

Nine ancient quarries in the Ostuni district (South-Eastern Murge) were characterised, with the aim of creating a data-base for the solution of archaeometric and/or restoration problems on Apulian *operae* of historical-artistic interest.

The identified lithotypes are all almost pure limestone ($CaCO_3$ average value = 99.60 wt%), chemically very similar to each other, with constantly low IR amounts (average value = 0.10 wt%) and almost exclusively composed of rare clay minerals. These rocks are not distinguishable from each other from mineralogical and chemical points of view, although the amount or amount variations of some elements (Sr and Mn) and some minerals (sporadic clay minerals) allow us to make some hypotheses about the history of the ancient sedimentation basin. Instead, the stratigraphic position, macroscopic characters, petrographic features and palaeontological components clearly attribute them to their formations of provenance.

The comparison between these parameters and those of the literature (Luperto Sinni and Borgomano, 1989; Pieri and Laviano, 1989, Tucci *et al.*, 1994) allow us to ascribe the lithotypes to the following geological formations:

1. lithotypes from Lamasanta Grande and Costamerlata, to the «Calcare di Caranna» Formation (late Campanian-Maastrichtian) and in particular to the bottom portion (white, gravelly, chalky limestone) of the «Membro ghiaioso a *Sabinia*», on the basis of the following parameters: occurrence of *Sabinia* in the palaeonological component, slope depositional high-energy environment, scarce terrigenous supply;

2. lithotypes from the city of Ostuni (Viale Oronzo and Ostuni-Villanova), to the «Calcare di Altamura» Formation (Coniacian-lower Campanian) and in particular to the upper part («Membro a *Goryanovicia*») of the «Membro Stromatolitico», on the basis of the following: occurrence of *Thaumatoporella parvovesciculifera, Dicyclina schlumbergeri, Aeolisaccus kotori* in the palaeontological component, stratified beds divided by compact, sometimes macro-fossiliferous, marly-clayey layers, and low insoluble residue content typical of a low-energy shallow environment (internal-platform);

3. lithotypes from Via dei Colli, to the «Calcare di Ostuni» Formation (Upper Campanian-Maastrichtian). Both macroscopically and microscopically, these rocks show typical characters of an edge association of biogenous limestone, alternating with calcarenite and calcirudite;

4. lithotypes behind the Messapic Rosara quarry, along the road parallel to state road 279, to the «Calcare di Caranna» Ostuni variety Formation (a variety of the «Calcare di Caranna», rich in organogenic components deriving from the demolition of the «Calcare di Ostuni» Formation) (Tucci *et al.*, 1994);

5. lithotypes from the Tre Torri Hotel and Melpignano quarries to the megabreccia (Maastrichtian-Paleocene).

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