Per. Mineral. (2007), 76, 1, 59-73 http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment*, *Archaeometry* and *Cultural Heritage*

Study for restoration purposes about the obelisk located in "Piazza della Libertà" at Ostuni (Brindisi, Southern Italy)

Patrizia Tucci[1]*, Paola Morbidelli[1], Claudio Imperatori[2] and Giancarlo De Casa[3]

[1] Dipartimento di Scienze della Terra, Università degli Studi di Roma "La Sapienza", P.le A. Moro, 5 I-00185 Roma, Italy
[2] Via XXI Aprile, 31 02036 Passo Corese (RI), Italy
[3] Dipartimento di Idraulica, Trasporti e Strade, Università degli Studi di Roma "La Sapienza", Via Eudossiana, 18 I-00195, Roma, Italy

Submitted, August 2006 - Accepted, January 2007

Abstract - Stone materials composing the St. Oronzo Rococò (local Baroque) obelisk, dedicated to patron saint of Ostuni in 1771 AD, were characterised. The monument is located in "Piazza della Libertà" at Ostuni (Brindisi, Southern Italy). The obelisk is composed of two different lithotypes, more or less pure Cretaceous limestone, with a variable porosity and biogenous component. Mineralogical, petrographical, geochemical and palaeontological and $^{87}Sr/^{86}Sr$ datation comparisons between finding lithotypes and Cretaceous limestones cropping out in four quarries already studied from some authors in the Ostuni sector, allow to ascribe obelisk samples to megabreccia quarry of Melpignano close to the ancient city wall of Ostuni.

On the most used lithotype, recognised and sampled in the quarry, physical, mechanical and ageing tests have been carried out. These tests have evidenced the high porosity of the materials and have furnished some indications about utilisation and restoration methods.

Riassunto - Sono studiati i materiali lapidei con cui è stato realizzato l'obelisco Rococò di S.Oronzo (Barocco locale) dedicato al santo patrono di Ostuni nel 1771 d.C.. Il monumento è localizzato in "Piazza della Libertà" ad Ostuni (Brindisi, Italia meridionale), ed è scolpito in due differenti litotipi calcarei Cretacei, più o meno puri, con porosità e componente biogena variabile. Il confronto, minero-petrografico, geochimico e paleontologico e le datazioni dello $^{87}Sr/^{86}Sr$, fra i calcari dell'obelisco e quelli affioranti in quattro antiche cave nel settore di Ostuni, precedentemente studiati da alcuni degli autori della presente ricerca, ha permesso di ascrivere i materiali riconosciuti alla cava di megabreccia (Melpignano) localizzata in prossimità delle antiche mura della città.

Sono state inoltre effettuate analisi fisico-meccaniche e *test* di invecchiamento sul litotipo, prelevato in cava, più utilizzato nella realizzazione del monumento. Tali *tests* hanno evidenziato l'alta porosità del materiale e hanno fornito utili indicazioni circa i migliori metodi di restauro e di utilizzo del calcare.

Key words: *Apulian Rococò, Archaeometry, Obelisk, limestone, petrography, physico-mechanical tests*

*Corresponding author, E-mail: *patrizia.tucci@uniroma1.it*

INTRODUCTION

The aim of this work is to characterise and to attribute to formation of provenance and/or to ancient quarries the stone materials used to build the Rococò obelisk of St. Oronzo, located in "Piazza della Libertà" at Ostuni (Brindisi, Southern Italy, Fig. 1). The evidences obtained (provenance quarries, minero-petrographic, geochemical and palaeontological features, $^{87}Sr/^{86}Sr$ dating; physico-mechanical and ageing test data) may provide a suitable base for monument restoration and conservation, and also for a better utilisation of limestone.

Restoration of the obelisk, which needed urgent reparation, was planned by the *Soprintendenza* for Environmental, Architectural, Artistic and Historical Heritage of Bari (Italy), according to Italian law 44/75, because of its considerable degradation (Fig. 2) (Normal 1/88), worsened by large cracks in one of the plinths supporting the statue of St. Oronzo.

Fig. 1– St. Oronzo obelisk located at "Piazza della Libertà", Ostuni (Brindisi, Apulia, Southern Italy).

HISTORICAL DATA AND DESCRIPTION OF THE OBELISK

The St. Oronzo column (Fig. 1) is one of the most characteristic Baroque art expressions at Ostuni. It is located in "Piazza della Libertà", and was erected in honour of the patron saint in 1771, after a widespread epidemics period, which affected nearby towns and spared Ostuni. The obelisk was designed by the architect and sculptor Giuseppe Greco; he was inspired by the Immacolata obelisk in "Piazza del Gesù" at Naples.

The obelisk is about 23.10 m high. At the present time only 20.10 m are visible, being the lower 3 m under ground, both because of materials infilling from surrounding demolished buildings, and because of low area levelling, carried out in 1870 after the Via Adriatica construction (between the church of Spirito Santo and the ancient Porta del Ponte, where the obelisk rises; Coppola *et al.*, 1990).

The visible portion is made up of four plinths on a pedestal (Fig. 1, 3), more or less in square cross-section, decreasing in dimension from bottom to top, thus forming a tall pyramidal structure.

At the present time, pedestal emerges for a height of about 1.5 m. It has four sharply jutting overhangs, oriented obliquely to the principal body, and finishing, upwards, with a series of frames on which first plinth rests. The latter has a plan similar to the basal section, but is more compact in shape. Instead of the overhangs of the square pedestal, here there are four large volutes, continuing plastically upwards in lively mouldings. There are *putti* in the centre of the four sides, holding scrolls with Latin inscriptions. The plinth finishes upwards with a balustrade; there are four statues of saints on the corners and another plinth is built above it. The second plinth is simpler in shape, and has four small angular volutes and decorative motifs inserted in long frames on the four sides (Greco *et al.*, 2000).

The corners of the third plinth have statues of four winged *putti*; the fourth, the uppermost, supports the St. Oronzo statue.

Sampling and Analytical procedures

Identification and sampling of the obelisk materials was based on macroscopic evidence such as colour, grain-size and consistency, and on the different deterioration degree and alteration products according to identical exposure and position on the monument (Fig. 2; note the lack of black crusts in the ornamental protected portion of the II plinth in contrast to both the statues and balustrade).

The obelisk was sampled (Fig. 3 and Tab. 1), according to the Normal 3/80 recommendation: already removed fragments of known provenance, small pieces from hidden portions and/or from the

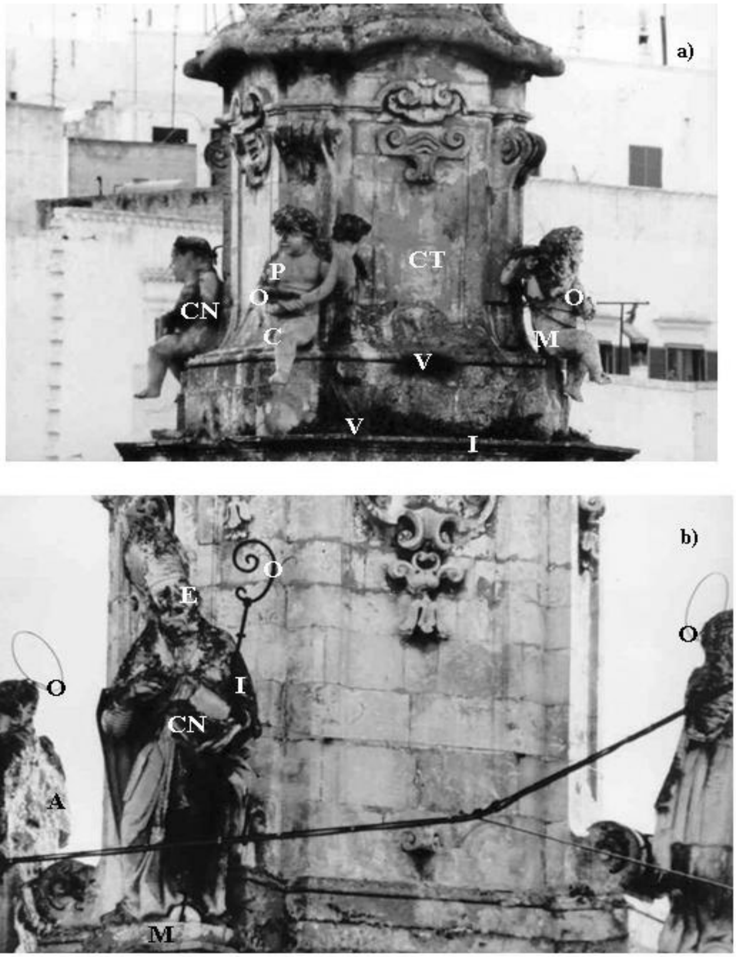

Fig. 2a, b – Details of degradation forms and alteration products found on St. Oronzo obelisk. A = alveolisation; C = detachment of stone portions; CN = black crusts; CT = cement; E = erosion; I = crustings; M = rust stains; O = oxidation of metal parts; P = pitting; V = moss and plants.

monument frequent cracks caused by deterioration, previous poorly executed restorations, and damages caused by seismic tremors was taken.

On all stone samples from the obelisk, the following examinations were carried out: thin sections petrographic analysis; X-ray diffraction (XRD) analysis, using a PHILIPS PW 1830 diffractometer with unfiltered CuK_{α} radiation (40 KV, 20 mA), data recorded in the 3°-70° 2θ range; where clay minerals occur, glycolic acid was used for a better characterisation of these minerals; loss on ignition (LOI) at 900°C; major, minor and trace element contents determined by X-ray fluorescence (XRF; SIEMENS spectrometer, Cr anticathode tube) according to the method of Franzini *et al*. (1972, 1975) and Leoni and 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 (IR) was determined after powder chemical attack with acetic acid (12%) due to the absence (diffractometrically evidenced) of dolomite. SEM analyses were carried out on a Cambridge Stereoscan model 250 MK3 with EDS link model AN 10/55.

Sr isotope analyses were determined on seven stone fragments by mass spectrometry following routine procedures (McCrea, 1950); 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 on a VG-54E mass spectrometer; data acquisition and reduction were performed according to Ludwig procedure (1994). Repeated analyses on standards gave averages and errors (2σ) as follows:

TABLE 1

St. Oronzo obelisk (Ostuni, Brindisi). List and location of collected samples

Sample	Location and description
O1	statue of St.Oronzo; upper portion of mantle
O2	statue of St.Oronzo; lower portion of mantle
O3	octagonal base of statue with heads of angels on smooth-edged ashlar among heads
O4	angel (right) at the base of obelisk; plinth IV
O5	fillet on upper band of plinth IV
O6	sculptured portion opposed volute under second metal band on plinth IV
O7	smoothed ashlar under second metal band
O8	angel (left) on moulding of bottom frame of plinth III
O9	bottom frame of plinth III
O10	Infant Jesus held in St. Antonio’s arms on square balcony of plinth II
O11	bottom frame; plinth II
O12	angel (right) holding an inscription; plinth I
O13	smoothed ashlar behind angel on the right; plinth I
O14	smoothed ashlar; plinth I
O15	volute (left) decorating edges of plinth I
O16	frame on the base of plinth I

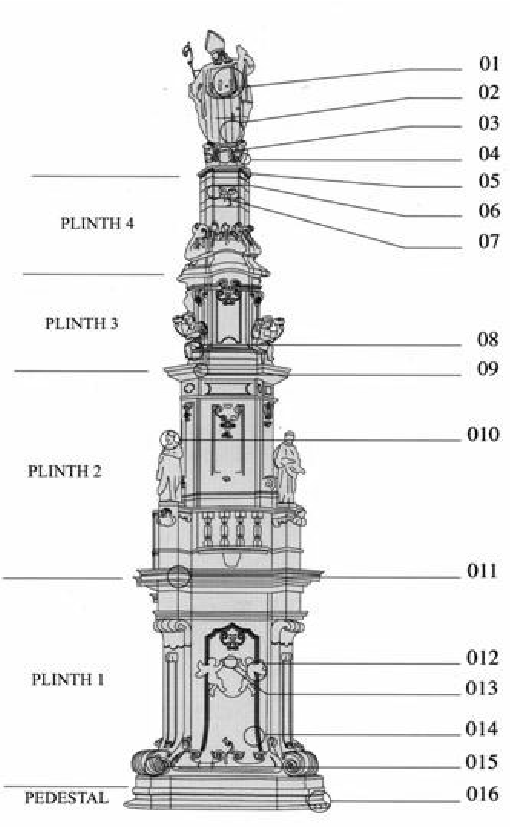

Fig. 3 – St. Oronzo obelisk . Location of the collected samples.

NBS 987, $^{87}Sr/^{86}Sr$=0.710262±15; $^{87}Sr/^{86}Sr$ normalised to 0.1194. Analytical uncertainty was ± 0.00002.

Physical, mechanical and ageing tests were carried out only on a quarry lithotype belonging to the "Calcare di Caranna" formation, recognised as mainly used to build the obelisk. The tests were determined following ASTM and Normal recommendations (see text for more details).

The principal instrument used for testing include: diamond core drilling apparatus; balance (0.01 g) and balance (0.0001 g); drying oven, thermostatically-controlled, forced-draft type. (specification E145); helium picnometer (ACUPIC) for specific gravity determination; loading device - hydraulic (2.000 kN) and mechanical (250 kN) servo-controlled presses; HBM strain gauges measurement instruments (10 Channels); PUNDIT (C.N.S. Electronics) Pulse Generator Unit and piezoelectric transducers (50 kHz and 1 MHz); determination of Pulse velocity; digital oscilloscope Tektronics (100 MHz) triggered, for wave shape registration.

Specimens (normal and parallel to stratification) were obtained, for each sample, from a single block of 15x15x30 cm taken from the quarry. Cores of 2 x 4.3 cm were extracted from the blocks, and then sawn so that the each specimen height was double of its diameter. Then specimen bases obtained in this way were rectified and made parallel (ASTM C568-89; ASTM D4583-85; ASTM D653-90).

Total porosity was determined by an indirect method evaluating specific gravity / apparent specific gravity ratio. Water saturation tests were carried out in different humidity conditions: environment humidity, and water-saturated atmosphere, by capillarity and immersion. Soluble salts were analysed according to Normal 13/83. These tests were carried out dipping rock samples in a saturated $Na_2SO_4*10H_2O$ solution at 20°C temperature for 5 hours. Samples were heated to 60°C for 16 hours, then cooled to 20°C for 3 hours. The cycle was repeated for 15 times; after each cycle the sample state was checked and every change in the sample aspect is recorded. Loss of material, pitting and "craterisation" on the exposed surface, microfracture appearance and sample breaking were taken into account. At the end of the cycles, the sample was put in running water for 96 hours to eliminate totally the salts, then dried and weighted; weight difference allow us to estimate material resistance to accelerate ageing.

Geological Context

The Ostuni district is morphologically characterised by a plateau (310 m high) connected to coast trough a tectonic slope. In the context of geological formations occurring in the south-eastern Murge (Luperto Sinni and Borgomano, 1989; Pieri and Laviano, 1989) the following ones crop out: upper portion of "Calcare di Altamura" (passage between "Membro Stromatolitico" and "Membro a *Goryanovicia*"), "Calcare di Ostuni" and "Calcare di Caranna" (lower portion of

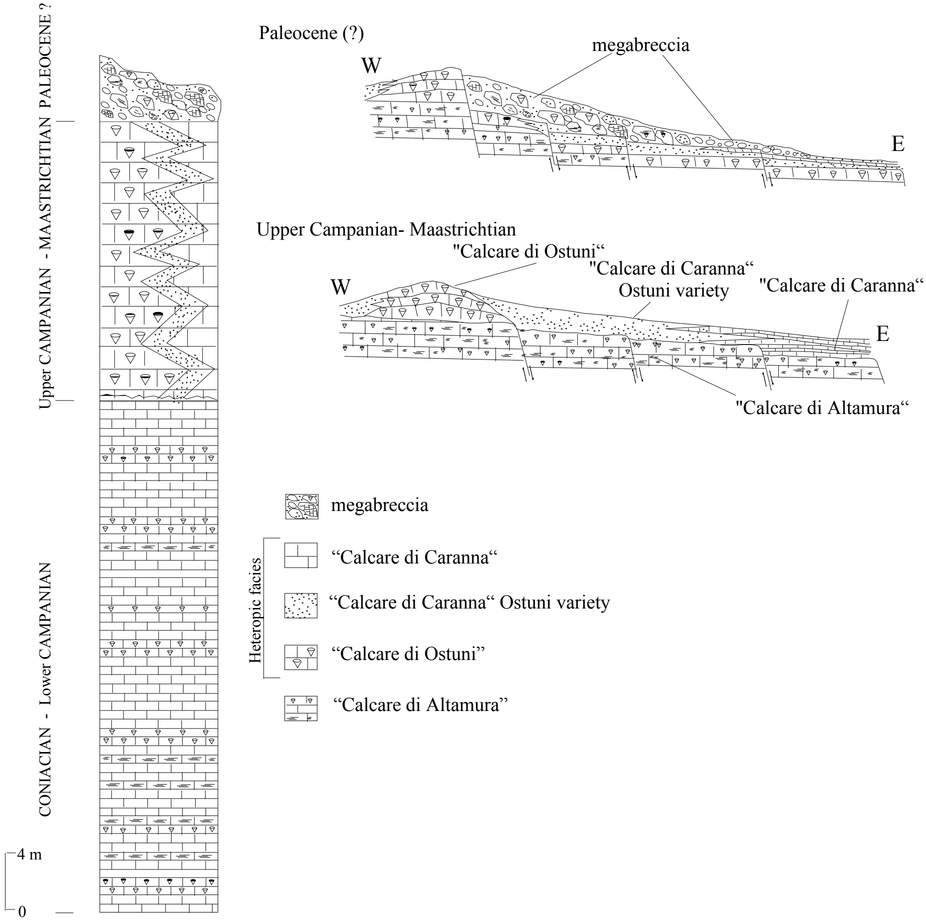

Fig. 4 – Ostuni sector. Carbonatic stratigraphic sequence and basin evolution in Late Cretaceous (Tucci and Morbidelli, 2004 modified).

"Membro ghiaioso a *Sabinia*") formations (Fig. 4).

The latter two heteropic formations show, as recognised by the Authors at Ostuni, a transitional facies which, because of its abundant fossiliferous content and petrographic features, "Calcare di Caranna" Ostuni variety was called (intrabiomicrite or packstone, grain supported fabric, good quantity of matrix and subordinate sparry cacite, sometimes sub-rounded micritic- and bio-clasts with typical fibrous structure, high porosity, abundant organic component; Tucci *et al.*, 1994). A megabreccia, due to a local tectonic event, also occurs. In fact, in the Late Maastrichtian-Paleocene (Pieri and Laviano, 1989), a downlift caused formation of a breccia, composed by different sizes blocks (up to 4-5 m^3; Guarnieri *et al.*, 1990; Tucci and Morbidelli, 2004) belonging to "Calcare di Altamura", "Calcare di Ostuni", "Calcare di Caranna", and intermediate terms. At Melpignano (near Ostuni) there are many abandoned and active quarries in the megabreccia showing typical chaotic and heterometric structure. The blocks occurring in megabreccia have been widely used to building since ancient times, in

TABLE 2

Chemical analyses (XRF). Major, minor (wt%) and trace element (ppm) contents of study samples. - = below detection limit; LOI = loss on ignition; I.R. = insoluble residue; Fe_2O_3 = Fe total; x = average value; σ = standard deviation*

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	x	σ
SiO_2	0.03	0.02	0.01	0.02	0.02	0.03	0.02	-	0.01	0.03	0.02	-	0.01	-	-	0.02	0.02	0.01
TiO_2	-	-	-	0.01	0.02	0.02	-	0.01	0.02	0.01	-	-	-	0.01	0.02	-	0.02	0.01
Fe_2O_3*	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	0.01	0.02	0.01	0.01
MnO	0.02	0.02	0.02	0.02	0.01	0.02	0.02					0.02	0.02	-	0.02	0.03	0.02	0.00
Mgo	0.09	0.08	0.05	0.11	0.23	0.27	0.1	0.05	0.07	0.19	0.23	0.1	0.01	0.03	-	0.02	0.11	0.08
CaO	55.89	55.84	55.87	55.79	55.68	55.57	55.7	55.95	55.98	55.62	55.70	55.81	55.98	55.87	56	55.98	55.83	0.14
Na_2O	0.01	0.02	0.01	0.03	0.02	0.01	-	-	-	0.01	0.02	0.02	-	-	-	-	0.02	0.01
LOI	44.64	44.56	44.66	44.01	44.84	44.52	44.38	44.06	44.36	44.86	45.77	44.07	44.04	45.07	44.06	43.99	44.49	0.49
Tot	100.68	100.54	100.62	99.99	100.82	100.44	100.22	100.07	100.44	100.72	101.74	100.02	100.07	100.98	100.11	100.06	100.47	0.47
S	-	230	150	-	-	-	3	150	245	-	-	-	220	30	145	150	147	84
Rb	10	11	10	11	-	-	10	-	-	-	-	10	8	11	12	13	11	1
Sr	103	110	97	90	62	53	44	115	109	58	49	89	183	121	70	75	89	35
Ba	4	-	3	2	10	9	-	19	3	9	8	2	5	8	15	17	8	6
La	42	30	25	20	-	-	-	-	30	-	-	21	37	15	12	15	25	10
Cr	30	15	30	22	2	3	-	-	17	2	2	23	19	14	19	20	16	10
I.R.	0.10	0.14	0.09	0.20	0.30	0.37	0.17	0.07	0.10	0.30	0.32	0.20	0.07	0.05	0.10	0.10	0.17	0.10
$CaCO_3$	99.75	99.66	99.71	99.57	99.38	99.18	99.41	99.86	99.91	99.27	99.41	99.61	99.91	99.71	99.95	99.91	99.64	0.25

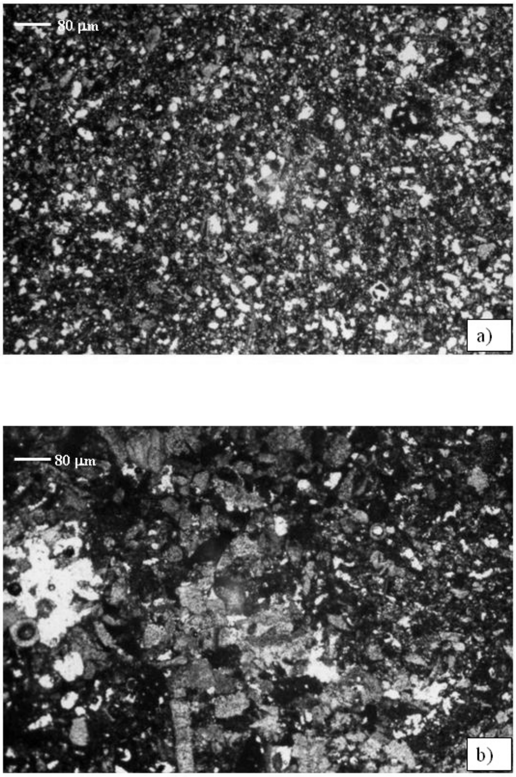

Fig. 5 – St. Oronzo obelisk. Optical microscopy, plane-polarised; a) Sample O8, intrabiomicrite, showing micritic matrix with mud- to grain-supported fabric; diffuse porosity is due to small cavities, sometimes filled with sparry calcite; b) Sample O7, intrabiomicrite, with mud-supported structure with micritic and organic intraclasts, extremely heterometric and morphologically poorly evolved.

particular, the "Calcare di Caranna" ones (locally better known as *Pietra Gentile.* The last name, which indicates easy workability of this material, is also used to identify the most famous "*Pietra Leccese*" from the city of Lecce near Brindisi).

Results and Discussion

All obelisk parts were built of almost pure limestone ($CaCO_3$ average value about 99.64 wt%; IR average value = 0.17 %wt; Tab. 2).

Chemically all analysed samples are very similar. As evidenced in previous studies (Tucci and Morbidelli, 2004; Tucci *et al.*, 1994) about limestones cropping out in south-eastern Murge, Sr amounts of all studied limestones are low (<270 ppm), if compared with marine analogs (average value = 510 ppm for Cretaceous carbonates from Italy, Fornaseri and Grandi, 1963; average value = 450 ppm for Cretaceous carbonates from world, Wedepohl, 1974) but similar to contents of other Apulian Cretaceous carbonate analised (average value = 134 ppm; Garavelli and Moresi, 1973).

Microscopically, two different lithotypes were identified (Fig. 5a,b).

Samples O1, O2, O3, O4, O8, O9, O12, O13, O14, O15 and O16 are intrabiomicrites (Folk, 1959, 1962) or wackestone/packstones (Dunham, 1962), characterised by a mud- or grain-supported fabric. In thin section (Fig. 5a), rock shows a micritic matrix containing peloid fragments and shell remains (*Sabinia*, radiolarians, rare miliolids). On the whole, micro/macrofossil contents are difficult to identify because of the considerable calcite recrystallisation (except gastropods in O4 and remains of *Cuneolina pavonia*, *Thaumatoporella parvovesiculifera* and *Stomiosphaera* sp. in O1).

Its diffuse porosity (observed by optical and scanning electron microscopy) is caused by small cavities (Fig. 6), sometimes filled with sparry

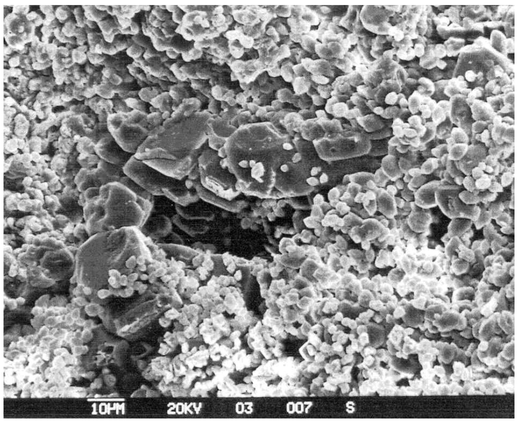

Fig. 6 – St. Oronzo obelisk. Scanning electron micrograph of sample O3, showing granular structure and porosities which are partially filled by calcite crystals.

TABLE 3
St. Oronzo obelisk (Ostuni, Brindisi). $^{87}Sr/^{86}Sr$ dating results on some selected samples

	$^{87}Sr/^{86}Sr$	Age
O1	0.707630±15	Upper Campanian
O3	0.707620±15	Upper Campanian
O6	0.707605±15	Upper Campanian-Late Maastrichtian
O8	0.707640±15	Upper Campanian
O9	0.707640±15	Upper Campanian
O10	0.707605±15	Upper Campanian-Late Maastrichtian
O16	0.707630±15	Upper Campanian

calcite. Some of them are subspherical (probably calcispherulid remains).

SEM and EDS analyses on insoluble residue indicate the occurrence, in order of decreasing abundance, of quartz grains, and, in some samples, rare plagioclase, Fe-oxides and phyllosilicates.

Samples O5, O6, O7, O10 and O11 are intrabiomicrites having mud-supported fabric (wackestone; Dunham, 1962), with micritic and biodetrital intraclasts (Fig. 5b). Voids, intercommunicating and variable in size, are much more abundant than in previous lithotype. The fossil component is represented by rudist fragments, *Stomiosphaera* sp. and other unidentifiable remains.

Mineralogical investigation, carried out with SEM and EDS on insoluble residue, is represented, in order of decreasing abundance, by quartz grains, Mg, Al, and Ca-silicates, and rare plagioclase crystals.

$^{87}Sr/^{86}Sr$ ratio datation, on 7 samples, ascribe first lithotypes to Upper Campanian and second to Upper Campanian-Late Maastrichtian (Tab. 3).

Above features and recognised dating, compared with Apulian Cretaceous formations (Fig. 4), allow us to attribute samples as follows (Fig. 7):

a) Samples O1, O2, O3, O4, O8, O9, O12, O13, O14, O15 and O16 (Fig. 3) belong to "Calcare di Caranna" formation (locally better known as "*Pietra Gentile*"), and in particular to lower portion of the "Membro ghiaioso a *Sabinia*" (Luperto Sinni and Borgomano, 1989) that is composed of whitish, chalky, compact intrabiomicrite with diffuse porosity and fossil component; it is dated to Upper Campanian and sedimented in a high-energy slope depositional with scarce terrigenous supply (Tucci and Morbidelli, 2004).

b) Samples O5, O6, O7, O10 and O11 (Fig. 3) show intermediate characters between "Calcare di Caranna" and "Calcare di Ostuni" formations (Luperto Sinni and Borgomano, 1989; Pieri and Laviano, 1989; Tucci *et al.*, 1994) on the basis of the evident peculiar characters: more soft rock, very abundant porosity (higher than in previous samples) and fossiliferous component deriving to the bioconstruction demolition ("Calcare di Ostuni" formation).

Its peculiar features, typical of a slope sedimentary environment (hemipelagites and resediments), compared with lithotypes cropping out at Ostuni and its surroundings (Luperto Sinni and Borgomano, 1989; Pieri and Laviano, 1989) allow to consider it like a transitional facies between "Calcare di Caranna" and "Calcare di Ostuni" heteropic formations (Fig. 4), but not comparable

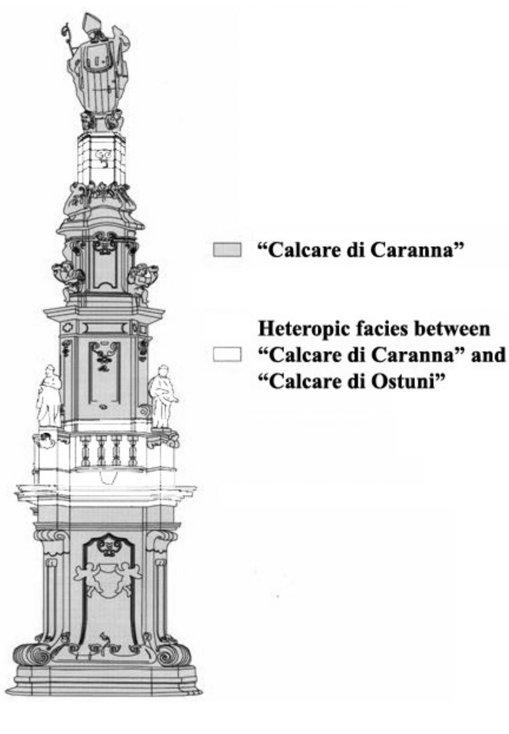

Fig. 7 Lithotypes utilised in St. Oronzo obelisk.

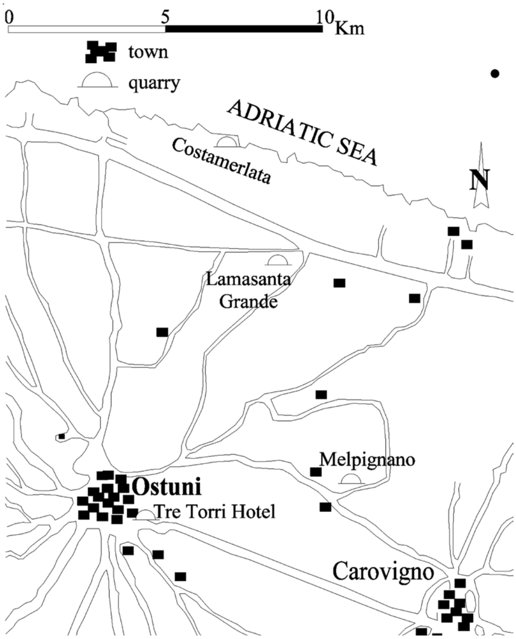

Fig. 8 – Ostuni district. Location of ancient quarries in which lithotypes used in the St. Oronzo obelisk crop out. 1) Lamasanta Grande; 2) Costamerlata; 3) Tre Torri Hotel; 4) Melpignano.

with "Calcare di Caranna" Ostuni variety (Tucci *et al.*, 1994; Tucci and Morbidelli, 2004).

As for the ancient quarries provenance (Fig. 8) of the study materials, the comparison between data of obelisk samples and those obtained by the Authors on 4 ancient quarries recognised in the Ostuni district (Tucci and Morbidelli, 2004) allow following considerations: samples belonging to "Calcare di Caranna" formation (lower part of "Membro ghiaioso a *Sabinia*", Luperto Sinni and Borgomano, 1989), may be attributed to ancient quarries still visible at Costamerlata, Lamasanta Grande and Melpignano (megabreccia blocks, Tucci and Morbidelli, 2004; Pieri and Laviano, 1989). Another little ancient quarry, with evident working traces, occurring at Ostuni (Corso V. Emanuele II, after Hotel Tre Torri; Tucci and Morbidelli, 2004) must be excluded because megabreccia blocks are too small and not compatible with those used in the obelisk.

As for the second used lithotype (heteropic facies between "Calcare di Caranna" and "Calcare di Ostuni" formations, but not comparable with "Calcare di Caranna" Ostuni variety) following considerations must be taken into account:

1. it has never been found in outcrops at Ostuni sector;
2. macroscopically, it is very similar to "Calcare di Caranna";
3. it was used only sparsely in the obelisk.

Thus, its provenance may be only referred to some megabreccia blocks outcropping at Melpignano.

Physical, mechanical and ageing tests

Tests were carried out on selected blocks from "Calcare di Caranna" formation (most utilised lithotype in the obelisk, Fig. 7) coming to the megabreccia crops out at Melpignano.

In order to provide a experimental and homogeneous data-base, useful for planning both consolidation and restoration of the obelisk, following physical and mechanical properties were determined: apparent specific gravity (ASTM C97); specific gravity (ASTM C97); total and apparent porosity (ASTM C97); water absorption (I_{24} and Q; ASTM C97); acoustic properties like elastic waves propagation (V_P; ASTM D2845-90), mechanical characteristics, elasticity modulus, compressive strength (ASTM D2938-86, ASTM D3148-86).

Results, in form of technical records, are listed in Tab. 4.

Specific gravity was measured with a helium picnometer. Average value, calculated on 10 measurements, was 26.54 kN/m^3. This value is slightly lower than pure calcite one (26.58 kN/m^3) due to weak argillaceous matrix occurrence.

Bulk density (Tab. 4) ranges from 21.54 to 23.66 kN/m^3. This variability, occurring both in normal and parallel samples, is mainly due to rock heterogeneity, to stressed porosity presence, to fractures, etc.

Study material appears very porous (Fig. 6, Fig. 9, Fig. 10; Tab. 4), but, at ordinary pressure, only a portion of pores is accessible by capillarity water penetrating. 25-30 vol% of total pores is closed or inaccessible as confirmed by thin section analyses,

Table 4
Summarising technical record on samples from megabreccia ("Calcare di Caranna") blocks showing physical and mechanical data

a-Bulk density		
orientation	**normal**	**parallel**
unit	(kN/m³)	(kN/m³)
mean	22.37	22.50
standard error	0.36	0.39
minimum value	21.54	21.13
value maximum	23.57	23.66
span	2.03	2.53

b–Elastic waves velocity (P)		
orientation	**normal**	**parallel**
unit	(m/s)	(m/s)
mean	4816	4870
standard error	161	167
minimum value	4394	4184
value maximum	5273	5241
span	879	1057

c-Porosity						
	normal			**parallel**		
	porosity (vol%)	**imbibition (vol%)**	**isolated pores (vol%)**	**porosity (vol%)**	**imbibition (vol%)**	**isolated pores (vol%)**
mean	15.8	4.9	71.0	15.2	4.2	71.1
standard error	1.1	0.4	1.3	1.5	0.5	0.7
minimum value	11.1	3.8	69.1	10.8	2.9	69.6
maximum value	18.8	5.8	73.4	20.3	5.5	73.1
span	7.7	2.0	4.3	9.5	2.6	3.5

d-Strength		
orientation	**normal**	**parallel**
unit	(MPa)	(MPa)
mean	70.0	77.16
standard error	4.5	12.3
minimum value	60.1	41.2
maximum value	82.6	109.2
span	22.5	68.0

e-Elastic modulus		
orientation	**normal**	**parallel**
unit	(GPa)	(GPa)
mean	37.2	40.2
standard error	2.7	5.3
minimum value	31.0	29.0
value maximum	45.0	58.0
span	14.0	29.0

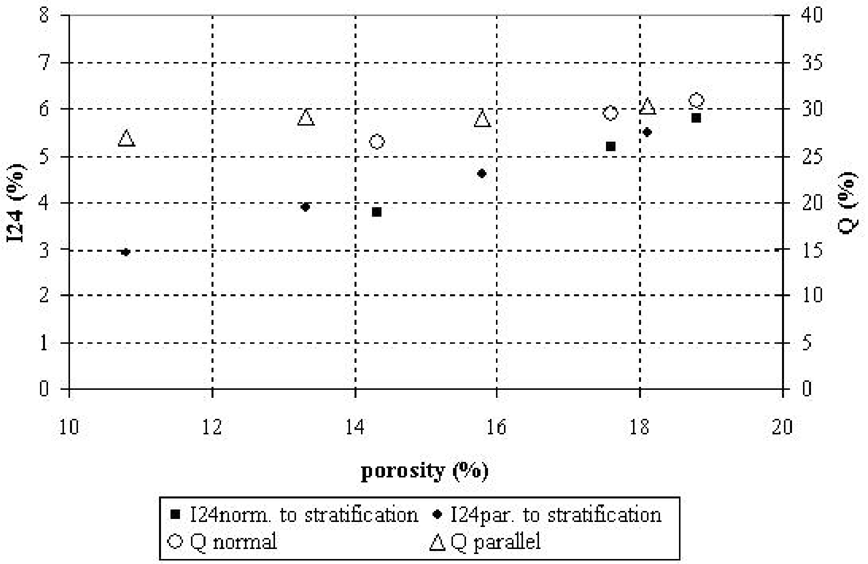

Fig. 9 – Diagram of I24 index (24-hour water absorption) versus Q (total absorbed water) relating to porosity of analysed samples. Results are expressed according to orientation of specimens

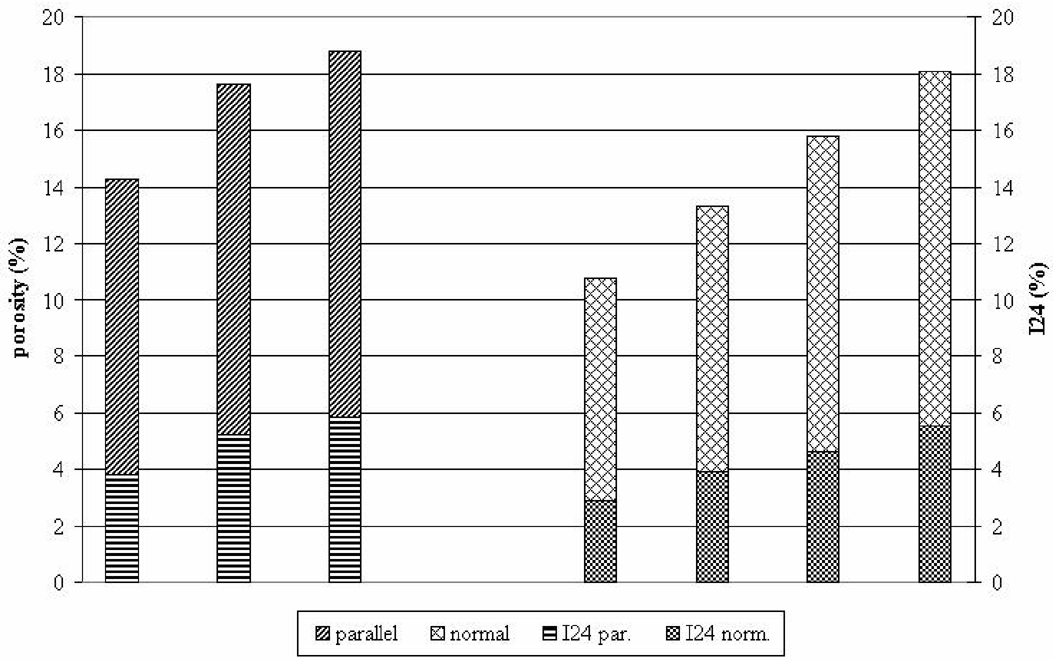

Fig. 10 – Water absorption and porosity histogram at ordinary pressure

where closed pores were identified in cellular structures of micro- and macrofossils or in most cemented portions.

As for mechanical features (Fig. 10, Tab. 4), strengths are lower in normal samples (60-80 Mpa) than in parallel (40-110 Mpa). Minimum value is due to discontinuities and pre-existent microfractures.

Elastic modulus mean values (Tab. 4), range from 37 (normal samples) to 40 GPa (parallel samples), confirm trend of strength. Classification values are reported in the Deere-Miller diagram (Fig. 11). They are characterised by low or very low stress (Deere, 1968), atypical in calcareous rocks with high modulus ratio. This mechanical behaviour is comparable to sandstone ones.

Measured values of elastic wave velocities (Tab. 4b) range from about 4300 to 5200 m/s. This variability, occurring in both normal and parallel samples, is due to rock strong heterogeneity, to marked porosity and to microfractures. As for mean values, velocities measured on parallel samples are slightly higher than on normal ones.

Ageing tests indicated a considerable samples degradation, with particles detachment generally along the edges, more or less accentuated after three cycles of immersion in $Na_2SO_4*10H_2O$ and thermal cycles; several cuttings in highly permeable samples were observed.

Conclusions

St. Oronzo obelisk is built of two different limestones (intrabiomicrites; Fig. 5a,b), almost pure ($CaCO_3 \cong 99.64$ wt%; IR average valure = 0.17 %wt) and chemically very similar, but showing different porosity degrees and paleontological contents. More frequently used lithotype (Fig. 7) is comparable to Apulian "Calcare di Caranna" formation and, in particular, to "Membro ghiaioso a *Sabinia*" bottom portion (Upper Campanian); the

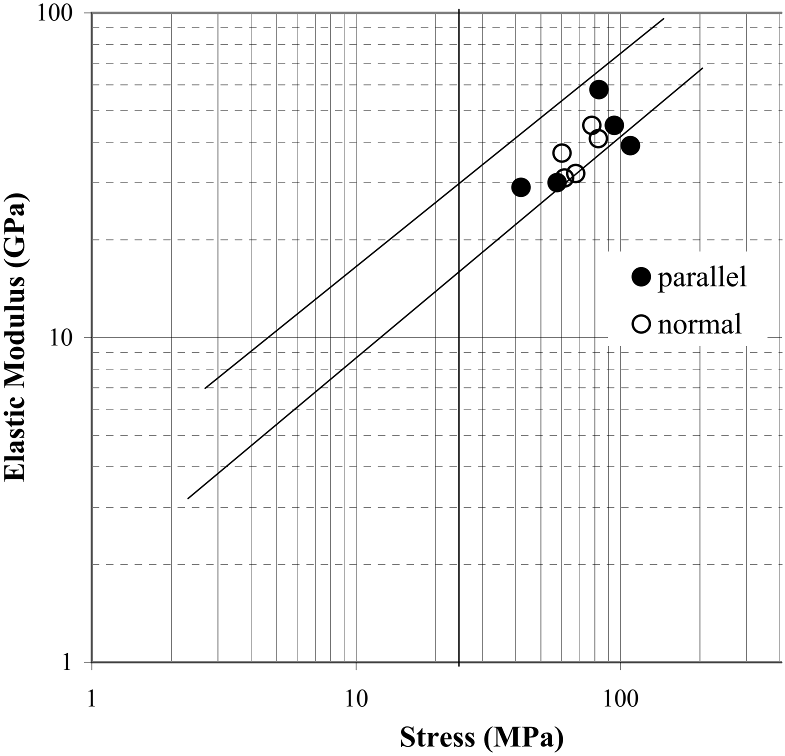

Fig. 11 – Deere-Miller diagram (Deere, 1968). Mechanical features of studied samples. Elastic modulus versus compressive strength in samples perpendicular and parallel to stratification.

other one is comparable to an intermediate term between heteropic facies of “Calcare di Caranna” and “Calcare di Ostuni” (Upper Campanian-Late Maastrichtian); it can not be compared to “Calcare di Caranna” Ostuni variety (Fig. 4) because of its macro- and microscopic features, porosity and fossil contents.

As regards the ancient quarries provenance of the two lithotypes: mineralogical, petrographic, chemical and palaeontological features compared with homologous samples from Ostuni ancient quarries (Tucci and Morbidelli 2004), samples datations, and also logic considerations, allow us to indicate both an origin from megabreccia megaclasts (Melpignano, Fig. 8), and to rule out, about “Calcare di Caranna” samples, Costamerlata and Lamasanta Grande quarries. Thus, being our 2 lithotypes macroscopically very similar, there wasn’t justification, for ancient workers, to take out one lithotype in the megabreccia and other one at Costamerlata and/or Lamasanta Grande quarries (6 km far).

At the end, physical-mechanical and ageing tests results on “Calcare di Caranna” quarry samples show following indications. The high to very high values of porosity coefficient indicate extensive water infiltration, with various types of water-related alterations. Thus, the use of such hygroscopic limestone in exposed places, where it would be in contact with water for long periods, is not recommended.

Coarse grain-size, favouring physical degradation, makes materials not very resistant about a mechanical point of view. It thus seems advisable to treat with water-repellent and reinforcing products these limestones if utilized for building purposes. For cleaning purposes, direct jets of pure fresh water, high-pressure water, water-saturated vapour, mechanical cleaning, and chemical products are strongly not recommended.

Acknowledgements

The authors thank the Fire Brigade of Brindisi for kindly making available resources and personnel.

REFERENCES

ASTM Designation C568-89 (1989) - *Standard Specification for Limestone Dimension Stone*, in “*Annual Book of ASTM Standards”*, **4**, 04.08, 534-536.

ASTM Designation C97 (1991) - *Test methods for Absorption and Bulk Specific Gravity of Dimension Stone,* in “*Annual Book of ASTM Standards”*, **4**, 04.08, 170-172.

ASTM Designation D653-90 (1991) - *Standard Terminology Relating to Soil, Rock, and contained Fluids*, in ”*Annual Book of ASTM Standards”*, **4**, 04.08, 260-263.

ASTM Designation D2845-90 (1991) - *Standard test method for laboratory determination of pulse velocities and ultrasonic elastic constant of rocks*, *Annual Book of ASTM Standards*, **4**, 04.08, 345-349.

ASTM Designation D2938-86 (1991) - *Standard test method for unconfined compressive strength of intact rock core specimens*, in “*Annual Book of ASTM Standards”*, **4**, 04.08, 375-376.

ASTM Designation D3148-86, (1991) - *Standard test method for elastic moduli of intact rock core specimens in uniaxial compression*, in “*Annual Book of ASTM Standards”*, **4**, 04.08, 411-414.

ASTM Designation D4583-85, (1991) - *Standard Practice for preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances*, in “*Annual Book of ASTM Standards”*, **4**, 04.08, 673-677.

Coppola D., Greco L., Sozzi F. (1990) - *Ostuni 1. Edizioni del Grifo, Lecce*, 117pp.

Craig H. (1957) - *Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analyses of carbon dioxide*. Geochim. Cosmochim. Acta 12, 133-149.

Deere D. U. (1968) - *Rock mechanics in engineering practice*, Stagg K. G., Zienkiewicz O. C. (Eds), *John Wiley and Sons, New York and London, International*, 442pp.

Dunham R. J. (1962) - *Classification of carbonate rocks according to depositional texture*, in: *Ham, W.E. (Ed.), Classification of carbonate rocks, A.A.P.G. Memoir*, **1**, 108-121.

Folk R.L. (1959) - *Practical petrographic classification of limestone*, A.A.P.G. Bulletin, **43**, 1-38.

Folk R.L. (1962) - *Spectral subdivision of limestone types* in: *Ham, W.E. (Ed.), Classification of carbonate rocks,* A.A.P.G. Memoir*,* **1**, 62-84.

Fornaseri M. and Grandi L. (1963) – *Contenuto in stronzio di serie calcaree italiane.* J. Geol., **31**, 171-198.

Franzini M., Leoni L. and Saitta M. (1972) – *Simple method to evaluate the matrix effects in X-ray* *fluorescence analysis*. X-ray Spectrom. **1**, 151-154.

Garavelli C. L. and Moresi M. (1973) – *Osservazioni sul contenuto in Sr di rocce carbonatiche pugliesi.* Per. Mineral., **42**, 69-111.

Greco L., Paiano E. and Peluso V. (2000) - *Guida di Ostuni: arte e storia nella Città Bianca. Congedo Editore, Taranto*, 162pp.

Guarnieri G., Laviano A. and Pieri P. (1990) - *Geology and Paleontology of Ostuni*, in: *Guide Book of the Second International Conference on Rudist*, Guarnieri G, Laviano A. and Pieri P. eds, Rome and Bari, 1/7 October, 8-13.

Leoni L. and Saitta M. (1976)- *X-ray fluorescence analysis of 29 trace elements in rock and mineral standards.* Rend. Soc. Ital. Mineral. Petrol., **32**, 497-510.

Ludwig K.R. (1994) - *A computer program for control of a thermal ionization single collector mass spectrometer*, US Geol. Survey, Open File Report, 92-543.

Luperto Sinni E. and Borgomano J. (1989) - *Le Crétace supérieur des Murges sud-orientales (Italie méridionale): stratigraphie et évolution des paléoenvironnements***.** Riv. It. Paleon. Strat., **95 2**, 95-136.

McCrea J. M. (1950) - *On the isotopic chemistry of carbonates and palaeotemperature scale*. J. Chem. Phys., **18**, 849-857.

Normal 3/80, 1980 - *Materiali lapidei: campionamento*. CNR-ICR, Roma..

Normal 13/83, 1983 - *Dosaggio dei sali solubili*, CNR-ICR, Roma.

Normal 1/88, 1988 - *Lessico per la descrizione macroscopica delle alterazioni sui manufatti in pietra*. CNR-ICR, 36-37, Roma.

Pieri P. and Laviano A. (1989) - *Tettonica e sedimentazione nei depositi Senoniani delle Murge sudorientali (Ostuni)*, Boll. Soc. Geol. It., **108**, 351-356.

Tucci P., Armiento G., Menichini P., Esposito R. (1994) - *I materiali lapidei della facciata de Le Monacelle di Ostuni e le loro antiche cave di provenienza*, in: "*La conservazione dei Monumenti nel bacino del Mediterraneo"*, Fassino V., Ott H., Zezza F. (Eds), Atti del III Simposio Internazionale, Venezia, 11-17.

Tucci P. and Morbidelli P. (2004) - *"Apulian marbles": recognition and characterisation of ancient quarries finalised to archaeometric aims. Ostuni District (South-Eastern Murge, Apulia, Italy)*, Per. Mineral., **73** special issue, 127-140.

Wedepohl J. H. (1974) – *Handbook of geochemistry*, Springer, Berlin.