Per. Mineral. (2000), ***69*****, 2, 89-105** 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*

«Caroselli»: building elements typical of historic buildings in Calabria (southern Italy). Chemical-physical and mineralogical-petrographic characterisation and attribution of origin

CATERINA GATTUSO[1*], STEFANIA LANZA[2], GIUSEPPE PANZERA[3], GIUSEPPE REPACI[3], GIUSEPPE SABATINO[4] and MAURIZIO TRISCARI[4*]

[1] Dipartimento di Architettura e Analisi della Città Mediterranea, Università di Reggio Calabria, Salita Melissari-Feo di Vito, I-89124 Reggio Calabria, Italy
[2] CNR-IRTEC, Via Granarolo, 64, I-48018 Faenza (RA), Italy
[3] Dipartimento di Chimica, Università di Reggio Calabria, Feo di Vito, I-89124 Reggio Calabria, Italy
[4] Dipartimento di Scienze della Terra, Università di Messina, Salita Sperone 31, I-98166 Messina-Sant'Agata (ME), Italy

Submitted, October 1999 - Accepted, April 2000

ABSTRACT. — Mineralogical and chemical analyses were performed in order to characterize the so-called «caroselli» a peculiar clay building material dating back to Byzantine period in Calabria (southern Italy). INAA and ICP chemical data, interpreted by means of cluster analyses and normalization were used, to recognize, amongst others, Ba, Cr, Cu, Ni, Pb, Rb, Sr, V, Zn and Zr, which may be usefully employed as discriminants. Petrographic observations identified the mineralogical composition of samples, showing that only specimens from Monterosso (Vibo Valentia area) can easily be distinguished from the others.

RIASSUNTO. — Sono state condotte analisi mineralogiche e chimiche volte alla caratterizzazione dei cosiddetti «caroselli», peculiari elementi costruttivi in cotto utilizzati sin dal periodo bizantino in Calabria (Italia meridionale). Analisi effettuate mediante tecniche INAA ed ICP e la successiva loro elaborazione statistica hanno permesso di riconoscere, tra gli altri, elementi quali Ba, Cr, Cu, Ni, Pb, Rb, Sr, V, Zn e Zr che possono essere validamente utilizzati come discriminanti per l'attribuzione di provenienza. Le osservazioni petrografiche hanno fornito la composizione mineralogica dei campioni tra i quali solo quelli dell'areale di Monterosso (Vibo Valentia) mostrano nette differenze con gli altri.

* Corresponding authors, E-mail: caterina.gattuso@unirc.it, maurizio@labcart.unime.it

KEY WORDS: *Archaeometry, INAA, ICP, major and trace elements, caroselli, Calabria, ceramics.*

INTRODUCTION AND PREVIOUS RESEARCH

In the historic centres of many small towns in Calabria (southern Italy), it is still possible to find examples of traditional buildings, constructed with unusual building materials and techniques, characterised by means of an artisan's way of working with clay and known as «caroselli». According to information locally collected, the use of these elements dates back to very distant times (Byzantine period) and continued right up to the last century.

The use of hollow bricks in the history of building has already been noted and studied by a number of experts. Thanks to their characteristics, lightness, homogeneity, nonconductivity, adaptability and variety of uses, hollow bricks were used, although with different specific characteristics, in distant times to roofs buildings of great monumental value, as well as for more modest dwellings. Floors, ceilings and domes constructed by means of the regular and ordered juxtaposition of hollow bricks have been noted prevalently in territories facing the Mediterranean.

Arslan (1965a) concentrates in a number of his works on the spread of buildings characterised by fictile elements. Referring to studies by Bovini (1959), Crema (1952), Lézine (1954), Monneret de Villard (1924), Verzone (1936) and others, he notes a particular abundance of these structures in North Africa, dating back prevalently to the period between the II and VI centuries; in Sicily (III-VII centuries), in Northern Italy (Adriatic Riviera, Val Padana and Istria, belonging to the Paleochristian and Longobard periods). Arslan (1965b) advances the hypothesis that the particular distribution of these remains in part of the Mediterranean area is to be attributed to the availability of supplies of gypsum, suitable for the production of quick-setting mortar, the indispensable for fictile elements. The areas mentioned have in common an abundance of gypsum.

In literature mention is made of vases and hollow pipes, the latter more simply known as «tubules», of various dimensions, shape, grouping and purpose. In the history of building the use of hollow open «tubules» is well known: linked to one another they were used to create domes of considerable size. The use, of Byzantine origin, of amphorae and vases is also known: they were placed in the side supports of vaults in order to ensure lightening of weight on load-bearing structures. Among others are:

– Amphorae of a bulging shape, generally placed at random in the side supports of vaults and over the extrados, but sometimes also positioned and ordered in a more structural manner;

– Fictile vases, fitted into one another, connected by means of a more or less pronounced protuberance, and cemented together with quick-setting mortar;

– Tubules, of an elongated cylindrical form, terminating with a conical shape or in any case so as to permit them to fit together in rows or to be positioned as single elements, again cemented with chalk plaster mortar.

The «carosello» may be considered to belong to the family of fictile elements, yet it is different because of the different conception of aggregation, strongly linked to its particular shape.

Recent studies, Gattuso and Menozzi (1995), have awakened interest which has led to more detailed research into fictile elements and the building techniques used.

TYPES OF BUILDINGS

Research based on written documents and information collected from various sources, supported by subsequent field surveys, has made it possible to outline a preliminary map illustrating «caroselli» sites in Calabria. Although this map needs updating as new and more extensive data arrive, «caroselli» were mainly used in towns along the Ionian coast of Calabria, with a penetration in the mountain areas of the region as far as Vibo Valentia; a number of examples have also recently been discovered in the Cosenza area.

These discoveries were made in the original centres of towns which, as a result of development towards the coast, or towards larger towns, were gradually abandoned. This tendency, while on the one hand leading to a decline in the original centres, on the other favoured the preservation of older buildings and the cultural identity of those areas in which it is now possible to carry out research and studies of buildings unspoiled by subsequent human intervention.

The «carosello» has a number of peculiar aspects closely connected with the aggregation system used. Single elements are juxtaposed across lateral facades, and are held together only by the mortar which fills the gaps between

Fig. 1 – Various types of «caroselli» studied.

Fig. 2 – Arrangement of «caroselli» in a house in Crotone.

them. The resulting structure, therefore, proves somewhat lighter than that consisting of vases or tubules placed in series. Given the limited dimensions of these elements, they are very suitable for aggregation in such a way as to form thin vaults even of considerable width.

The «carosello» is like a closed box, empty, with a truncated conical shape; there is quite a variety of dimensions, so that it is possible to find squat, flattened examples or longer slim ones, as can be seen in fig. 1. The upper face has a slightly convex shape and has a hole, which may sometimes be found along one of the sides; these are not very thick, usually about 0.5 cm.

On inner and outer surfaces it is often possible to note traces of manual shaping in the grooves resulting from the pressure of the artisans' fingers: this was their way of making their labour recognisable. The slight irregularities in size and shape is due to the fact that the «caroselli» were made one by one, by artisans. Chromatically, these artifacts are similar to those of other terra cotta elements: from pale yellow to brick red (fig. 2).

They are positioned with the concave part facing the inside of the structure to be built; the flat part was left visible facing the intrados of the vault so that a particular effect was obtained from the view of series of circles embedded in mortar.

At first sight the «caroselli» appear to have been placed randomly without a specific order, but a closer study defines some simple but precise criteria of aggregation: in the case of the vault at Crotone, they are arranged in long alternately staggered parallel rows (fig. 2).

In the cross-vaulting of the «episcopio» in Gerace, the «caroselli» were placed starting from below at the impost of the arch, corresponding to the corners of the opening, with the base towards the intrados. This was done a little at a time: the first three «caroselli» were placed on a square base, situated at the corners of the opening and embedded in abundant plaster mortar, which can still be seen today overflowing round the base. On these were placed a second row of «caroselli», and so on, concentrically, following the curving line of the arch and widening as the number of elements increased in each row (fig. 3).

In this way, the lower part of the vault was given a self-supporting structure; in order to complete the upper part scaffolding was probably used.

In the «Chiesa del Mastro», the now completely destroyed dome appears to have been built by juxtaposing the «caroselli» in a concentric manner according to a hierarchised criterion of positioning: the longer and slimmer elements were placed at the base of the dome and, as the keystone was reached the elements of smaller size but wider diameter were used, probably in order to confer on the dome a more solid support and a lighter apex.

The floors of the houses built at the beginning of the twentieth century, made use of steel girders placed approximately 80 cm apart; between these the «caroselli» were placed horizontally, connected together and embedded in mortar.

SAMPLES

For the present study fragments were taken from «caroselli» used in the buildings listed in Table 1, in which the initials used to identify the samples are also recorded.

In many of the buildings indicated it was not possible to give a precise estimate of the period in which the «caroselli» were made, because of a local custom which led to frequent re-use of building elements in different constructions and different periods.

The geographical distribution of the sites and towns in Calabria where «caroselli» were found are shown in fig. 4.

GEOLOGICAL CONTEXT

Reference is made to the attached bibliography of Amodio Morelli *et al.* (1976) and IGCP (1993), for a complete picture of the complex structure of the Calabro-Peloritan arc. In southern Calabria there are three main flat areas, the plains of Lamezia, Gioia Tauro and the area inland from Crotone.

Fig. 3 – Arrangement of «caroselli» at arch impost of «Episcopio» in Gerace (circa 1700).

TABLE 1

Provenance of samples.

Location	Samples	Building type
Lattarico (CS)	LAT1 – LAT2 – LAT3	«Madonna del Pettoruto» Church
Locri (RC)	LOC1	Old building in historical city center
Ardore (RC)	ARD1 – ARD2 – ARD3 – ARD4	Building belonging to a «caruselli» maker
Isca (CZ)	ISC1	Old building in historical city center
Mammola (RC)	MAM1	Old building in historical city center
Siderno (RC)	SID1 – SID2 – SID3	Old building in historical city center
Guardavalle (CZ)	GUA1	Old building in historical city center
Sant'Andrea (KR)	AND1	Old building in historical city center
Monterosso (VV)	MONl – MON2 – MON3	Old building in historical city center
Crotone (KR)	KR1 – KR2 – KR3 – KR4 – KR5 – KR6	Old farms near archaeological site
Crotone (anphora)	KRANF	Old farms near archaeological site
Gerace	GER1 – GER2 – GER3 – GER4	«Episcopio» Cathedral

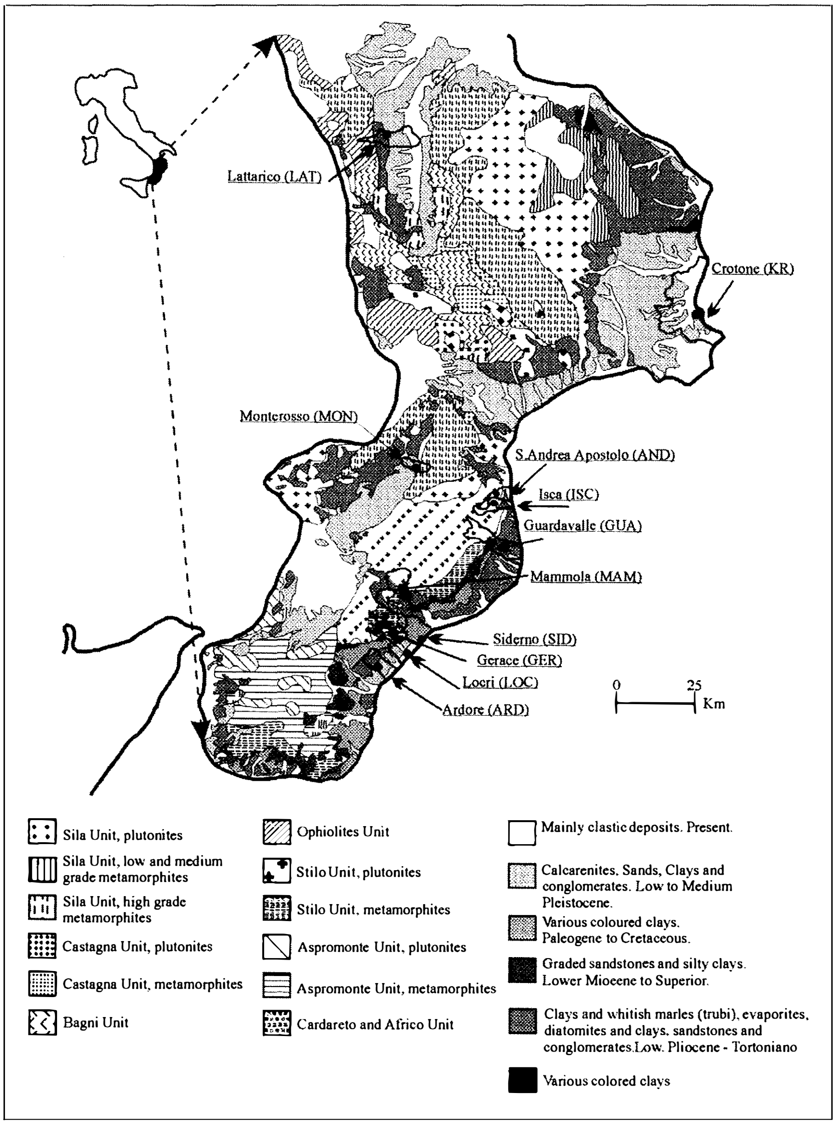

Fig. 4 – Geographical and geological distribution of the Calabrian «caroselli».

In all these areas, as also on the Ionian coast, Miocene and the Plio-Pleistocene clay formations outcrop. It is therefore possible that the quarry sites in the Crotone area refer exclusively to Pleistocene clays, while for all the other areas of the lower Ionic side the clays may have included both Pleistocene and Pliocene. There is still a doubt remaining about the possible use of Miocene clays for some sites, such as Gerace and Mammola.

METHODS

Mineralogical and petrographic analysis was performed by means of thin sections. The main aim of this type of analysis was to examine individual mineralogical phases which could be used as distinguishing traces.

Description of assemblages was performed following NORMAL (Italian C.N.R. and Istituto Centrale del Restauro) recommendations 12/83 and 15/84, as well as descriptive schemes following Peacock (1977), Whitbread (1989) and Amadori and Fabbri (1998).

Chemical analyses were carried out on the same samples by means of ICP-MS for major elements and INAA for minor and trace elements for a total of 60 analysed elements.

The resulting analytical values were treated in order to establish the main statistical parameters and possible co-relations. On the basis of previous analytical experience with similar materials (tiles), given the high degree of compositional homogeneity of the type of material, the data were treated statistically and normalised to their aluminium content.

This procedure makes it possible to refer all values to a common element (Al) which is widely present, since it is the principal constituent of the alumo-silicates of clay minerals, and at the same time has a high degree of stability in the exogenous environment of residual clay product formation. Normalisation to this element allows homogenisation of data for all other elements analysed. Further mineralogical definition of the phases, was carried out by XRD analysis. Porosimetric analysis was also carried out with a Carlo Erba Mod. 2000 porosimeter.

DISCUSSION

Microscopic determinations on thin sections defined five groups on the basis of different mixtures (Table 2), almost all characterized by significant variations in bulk mass (isotropy, colour, porosity) and fewer variations in the mineralogical compositions of fragments (C1, C2, C3, C4) except the Monterosso samples (C5) with inclusions of various types.

The only discriminating criteria for mixtures seems to be restricted to the total bulk composition and to distribution of inclusions in the various granulometric classes. Some samples were defined «standing alone», as it was difficult to relate them with others. In all samples, except the Monterosso ones, bioclasts and thermally altered carbonatic fragments (calcite ghosts) are present.

Groups C1 (samples GER1, GER2, GER3, GER4, SID1, SID2, SID3), C2 (samples ARD1, ARD2, ARD3, ARD4) and C3 (samples KR1, KR2, KR3, KR4, KR5, KR6, KRANF) have a variable groundmass from isotropic to anisotropic, orange-yellow to brick-red to grey-green in colour. Rare argillaceous sub-rounded rock fragments in shape (Whitbread, 1989) are present, more than 500 μm in size. Porosity varies from 5% to 20%, with rounded to elongated pores, and seldom filled with secondary calcite and intergranular bridges. Several pores showing a dark reaction rim point to carbonatic fragments which melted, due to high firing temperatures.

Coarsening of textures is mainly low, from < 5% to 10%; only group C3 shows values of 10% to 15%. Grain sizes is restricted mainly to very fine sandy fraction (63-125 μm) and at lower values to silty and fine sandy fractions. Medium sandy grain size (250-500 μm) and coarse (> 500 μm) are only found rarely or as traces. Grain shapes varies from angular to sub-rounded, with low-medium sphericity.

Mineral composition is monocrystalline quartz, sometimes fractured, rarely polycrystalline; altered plagiocase (sericitized); carbonatic rock fragments (micrites and biomicrites); micas, commonly biotite; bioclasts (planctonic foraminifera, *Globigerina spp.* and *Orbulina spp.*); feldspars; opaques; haematite. In some samples rare pyroxenes and amphiboles crystals were observed; in others, metamorphic and magmatic rock fragments with myrmekitic structure were found. In groups C2 and C3 micas show clear isoorientation effects parallel to the external surface.

Samples from group C4 (LAT1, LAT2,

TABLE 2

Microscopic determinations on thin sections.

Group	Samples	I/M/P	Relative abundance of inclusions					Main mineralogical composition of inlcusions				Ground mass
			<63 μm	63-125 μm	125-250 μm	250-500 μm	>500 μm	<125 μm	125-250 μm	250-500 μm	>500 μm	
C1	GER1	5/85/10	xx	xxx	xx	x	tr	Q,Pl,Fc, Mi,F,Mo	Q,Pl,Mi, Fc	Fe,Q,Pl, Mi	Q	S
	GER2	10/80/10	xx	xxx	xx	x		Q,Bi,Pl,Mi F,Mo,Em	Fc,Bi,Q, Pl,Mi	FcBi,Mi		S
	GER3	5/75/20	xx	xxx	x	+-	tr	Q,Mi,Fc, Pl,Mo,F	Q,Mi,Pl, Mo,F	Q,Pl,Fc, Mi,Mo	Q,Frm	S
	GER4	10/80/10	xx	xxx	x	+-		Q,Fc,Pl,Mi Mo,F,Em	Fc,Q,Pl Mi,Mo	Fc, Mi		S
	SID1	10/80/10	xx	xxx	x	+-	+-	Q,Pl,Fc,Mi, Mo,F,Em,An	Fc,Q,Pl Mi,Mo	Fc,Q,Pl, Mi,Frv	Q,Frc, Mi	S
	SID2	10/80/10	xx	xxx	x	+-	+-	Q,Bi,Pl,Mi Mo,Em,Px	Bi,Pl,Q Mi,Frc,Mo	Bi,Q,Pl Mi	Q,Pl Bi	A
	SID3	10/80/10	xx	xxx	x	+-	+-	Q,Bi,Mi,Pl Mo,An,Px	Bi,Q,Pl, Mi,Frc,Mo	Bi,Q Pl,Mi	Frc,Bi Q,Mi	A
C2	ARD1	10/85/5	xx	xxx	+-	+-		Bi,Q,Pl,Frc Mi,Mo,Em	Bi,Frc Q,Pl,Mi	Bi,Frc,Mi Mo		A
	ARD2	5/90/5	xx	xxx	+-	+-		Q,Mi,Pl,Mo,Px	Q,Mi,Pl,Mo	Q,Pl,Fc,Mi		I
	ARD3	10/80/10	xx	xxx	x	+-		Bi,Q,Pl,Mi, Mo,Em	Bi,Q,Mi Pl,Frc,F	Bi,Q,Mi Mo,		A
	ARD4	5/90/5	xx	xxx	+-	+-		Q,Mi,Pl,Mo Frb,Em	Q,Pl,Fc Mi	Fc,Mi		S
C3	KR1	10/80/10	xx	xxx	xx	x	x	Q,Mi,Bi,Frc, Pl,F,Mo,Em	Q,Bi,Pl,Mi, Frc,Mo,Em	Q,Mi,Bi Pl,F	Q,Mi Frc	A
	KR2	15/80/5	xx	xxx	xx	x	x	Q,Bi,Pl,Frc, Mi,Mo,Em,	Bi,Pl,Mi Frc,Mo,	Q,Bi,Frc Pl,Frm,	Q,Bi,Mi Frc,Frv	A
	KR3	10/75/15	xx	xxx	xx	+-		Q,Pl,Mi, Em,Mo	Q,Pl,Mi,Mo Fc	Mi,Q,Mo		S
	KR4	10/85/5	xx	xxx	xx	x	x	Q,Mi,Pl,Bi Mo,F	Q,Bi,Pl Mo,Frc,Mi	Q,Bi,Mi Mo,Frm	Fc,Q Frm,Frv	A
	KR5	10/80/10	xx	xxx	xx	x	x-	Q,Frc,Mi,Fe, Pl,F,Mo,Em	Q,Fc,Pl Mi,Mo	Q,Fc,Mi	Q,Frv Fc	AS
	KR6	15/75/10	xx	xxx	xx	x	x	Q,Fc,Mi,Pl F,Mo	Q,Mi,Fc, Mo,Pl,F	Q,Pl,Mi Fc,Mo	Q,Mi	AS
	KRANF	10/80/10	xx	xxx	xx	x		Q,Bi,Mi, Pl,Mo,Em	Bi,Q,Mi,	Q,Bi,Pl,Mi		A
C4	LAT1	5/85/10	xx	xxx	tr	tr	tr	Q,Frc,Mi Bi,Mo,Pl,F	Q,Bi,Mo Mi,Frv	Q,Mo	Q	A
	LAT2	<5/75/20	xx	xxx	tr	tr		Q,Mi,Fc,Pl,Mo	Mi,Fc	Fc		SI
	LAT3	<5/80/15	xx	xxx	tr	tr		Q,Fc,Pl,Mo	Fc,Q,	Q,Fc		I
C5	MON1	20/65/10	xx	xxx	xxx	x	x	Q,Mi,Pl,F, Mo,Em,Px	Q,Pl,Mi Mo,Em,Gr	Q,Mi,Pl	Q	A
	MON2	25/70/5	xx	xxx	xxx	xx	x	Q,Mi,Pl,F Px,Gr,Mo	Q,Pl,Mi,F Gr,Px,An	Q,Mi,Pl, Gr,F	Q,Frc	A
	MON3	20/75/10	xx	xxx	xxx	x	+-	Q,Pl,Mi,Px F,Gr,Em	Q,Pl,F Px,GrEm	Q,Pl,Mi Gr,Em	Q,F Gr	A
Stand alone	ISC	<5/80/15	xx	xx	x	+-		Q,Fc,Mo Mi,Pl,Em	Fc,Q,Mi	Q,Fc,Mi		S
	GUA	5/87/8	xx	xxx	x	+-	+-	Q,Bi, Pl,Mi,Mo	Bi,Q,Mi Frm,F	Bi,Q,F	F,Erm Q	A
	AND	10/85/5	xx	xxx	x	x	+-	Q,Bi Mi,Pl,Mo	Q,Bi,Mi Pl,Frm,Mo	Bi,Q, Mi,	Q,Bi Frm,Frc	A
	MAM	25/65/10	x	xx	xxx	xx	xx	Q,Bi,Mi, Pl,Px,Mo,	Bi,Q,Mi, F,Mo,Em	Bi,Q,Mi Pl,Frv,Frm	Q,Mi,Frm Frv,Bi	A
	LOC	10/80/10	xx	xxx	x	+-	+-	Bi,Q,Mi Pl,F,Mo,Em	Bi,Q,Mi Frm	Bi,Mi,Q, Fr	Q,Frm	A

I/M/P = ratio inclusions (I)/groundmass (M)/pores (P), A = anisotropic, S = semisotropic, I = isotropic, An = amphiboles, Bi = bioclast, E = haematite, F = feldspars, Frc = carbonatic rock fragments, Frm = metamorphic rock fragments, Frv = volcanic rock fragments, Fc = calcite ghosts, Gr = garnets, Mo = opaques, Mi = micas, Px = pyroxenes, P1 = plagioclases, Q = quartz. Semiquantitative determinations: xxx = very abundant, xx = abundant, x = less abundant, +- = scarce, tr = traces.

LAT3), similar to the above-mentioned samples, are discernible on the basis of very low bulk thickening (< 5%) and the absence of inclusions in grain size fractions > 125 µm. In group C5 (MON1, MON2, MON3) groundmass is orange-yellow to brick-red in colour and is always anisotropic. Several argillaceous aggregates are present between 300 to 500 µm in size, rounded in shape. Porosity varies between 15% to 10%. Main granulometric fractions represented, are very fine sandy and fine sandy; the silty fraction is abundant, and the sandy one varies from scarce to low abundant. Clast morphology varies from sub-rounded to angular. Mineral composition is monocrystalline quartz, rarely polycrystalline, altered plagioclase, biotite, haematite, feldspar, opaques, garnet, pyroxene and amphibole.

The «standing alone» samples (LOC, GUA, AND, MAM, ISC) show slightly different micro-structural, compositional and granulometric characters. LOC and GUA, with mineralogical and granulometric composition similar to that of group C1, were not inserted in this group because the former contains clear metamorphic rock fragments (schists) and the latter a lesser percentages of micas. ISC, with mineralogical and granulometric composition similar to that of group C2, was not considered due to the absence of micas. AND shows a different grain size distribution in the groundmass mainly fine sandy. MAM, like the mineralogical composition of group C3, differs for grain size distribution in the various classes. The fine sandy fraction is heavily represented and metamorphic and volcanic

TABLE 3

Major element composition (wt%) of studied samples.

SAMPLES	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
LAT1	55.74	16.5	6.31	0.07	2.69	9.62	1.08	2.96	0.73	0.17
LAT2	53.58	15.76	12.24	0.11	2.52	10.33	1.06	2.83	0.7	0.16
LAT3	57.41	17.03	6.39	0.07	2.76	11.62	1.16	3.02	0.76	0.17
LOC1	45.83	13.78	5.61	0.1	2.75	14.63	1.21	2.58	0.59	0.15
ARD1	47.32	15.21	5.62	0.08	2.9	17	1.27	2.77	0.65	0.19
ARD2	52.59	16.4	8.03	0.09	3.05	13.58	1.49	2.91	0.7	0.17
ARD3	46.85	14.55	5.35	0.07	2.73	15.19	1.34	2.56	0.62	0.17
ARD4	50.63	15.91	6.38	0.08	3.16	16.46	1.45	2.81	0.68	0.18
GER1	46.54	13.07	4.72	0.06	6.04	19.49	1.18	2.32	0.56	0.16
GER2	44.31	12.31	4.82	0.05	2.9	19.58	0.94	2.43	0.52	0.16
GER3	41.78	11.76	4.43	0.05	3.65	21.89	1.04	2.21	0.49	0.01
GER4	45.17	12.99	4.68	0.06	5.96	18.17	1.18	2.63	0.54	0.17
ISC1	41.22	12.86	4.8	0.09	2.71	24.1	1.26	1.45	0.55	0.16
MAM1	46.36	12.4	4.56	0.07	1.97	16.51	1.27	2.77	0.53	0.22
SID1	50.11	15.78	5.92	0.11	2.87	14.69	1.27	2.44	0.68	0.18
SID2	46.08	14.27	5.51	0.1	2.44	14.97	1.04	2.45	0.61	0.15
SID3	48.64	14.48	5.74	0.09	1.9	15.65	1.24	2.69	0.65	0.02
GUA1	39.5	11.2	4.37	0.06	1.58	18.85	0.87	2.18	0.5	0.02
AND1	41.26	12.57	4.51	0.08	2.42	21.22	0.85	2.1	0.53	0.15
MON1	59.55	18.74	6.81	0.04	2.06	2.04	1.68	2.64	0.77	0.12
MON2	59.2	19.62	8.8	0.06	1.99	2.09	1.38	1.95	0.89	0.1
MON3	62.17	20.73	7.85	0.06	2.08	1.79	1.65	2.46	0.95	0.09
KR1	52.42	14.61	5.75	0.07	2.63	10.8	1.74	3.28	0.63	0.18
KR2	53.93	15.14	5.34	0.08	2.4	11.18	1.05	2.81	0.65	0.18
KR3	57.22	15	5.82	0.09	2.59	11.54	1.53	2.84	0.65	0.2
KR4	53.58	15.37	5.47	0.07	2.44	12.1	1	2.79	0.67	0.15
KR5	51.8	14.84	5.32	0.07	2.43	11.74	0.96	2.83	0.64	0.16
KR6	51.72	14.75	5.45	0.07	2.66	11.21	1.72	3.34	0.64	0.17
KRANF	52.92	14.54	5.51	0.08	2.75	11.53	1.64	2.74	0.64	0.17

TABLE 4

Selected trace element composition (ppm) of studied samples.

SAMPLES	Ba	Cr	Cu	Ni	Pb	Rb	Sr	V	Zn	Zr	Ce
LAT1	360	99	30	53	19	116	694	123	110	164	85
LAT2	432	132	96	69	17	129	466	120	141	183	85
LAT3	462	106	28	54	7	123	425	132	109	166	88
LOC1	461	86.8	31	54	187	109	571	109	90	146	79
ARD1	476	92.3	26	64	53	108	739	111	100	155	86
ARD2	524	111	38	69	101	123	569	103	109	172	96
ARD3	380	79.2	24	59	166	105	802	109	92	148	80
ARD4	515	93.7	29	65	202	103	734	106	106	161	95
GER1	411	73.7	23	37	36	106	1055	79	92	138	76
GER2	410	69.4	24	33	48	101	1046	86	80	132	73
GER3	334	68.2	22	30	59	100	1979	88	81	120	66
GER4	346	74.6	24	34	34	104	2014	94	86	133	71
ISCI	316	92.4	30	45	93	104	921	97	87	99	71
MAM1	396	69.5	33	34	117	87	1073	95	81	137	69
SID1	448	114	32	62	268	131	861	124	100	134	94
SID2	386	96.6	35	57	48	123	855	118	96	137	80
SID3	395	105	33	61	285	130	877	109	96	153	87
GUA1	254	76.7	26	38	150	98	692	96	72	111	60
AND1	347	85.9	26	40	216	113	766	109	79	102	69
MON1	595	79.3	26	28	65	109	160	104	82	236	115
MON2	539	111	38	43	34	101	161	128	87	245	137
MON3	707	92.7	25	31	22	122	156	128	100	303	145
KR1	329	104	28	41	139	138	342	113	317	155	77
KR2	329	103	26	45	23	129	333	126	103	137	77
KR3	341	113	27	49	16	126	339	104	126	155	77
KR4	358	108	26	43	21	140	360	115	92	142	79
KR5	333	96.7	26	44	27	113	330	114	99	140	76
KR6	342	105	28	44	154	137	360	114	413	151	81
KRANF	339	106	27	49	30	125	393	108	192	153	78

rock fragments are more abundant and larger. Argillaceous aggregates are present, ranging in size from 300 μm to 1 mm, sub-rounded in shape.

Results of chemical analyses of major elements are listed in Table 3, and those of chemical analyses for minor elements in Table 4. For statistical processing of data only those with significant variability were used.

Comparing the chemical compositions of major elements for all samples, there appears to be a good possibility of co-relation, particular with reference to Ca and Si contents, except for the samples from the Monterosso area which appear quite distinct (fig. 5).

On the basis of these results, it appears important to restrict the search for specific discriminating elements to those present in traces only. Normalised cluster analysis was therefore performed on these values, the results of which are shown in fig. 6. These data show how the samples may easily be grouped in «families» with different degrees of compositional affinity. From this type of analytical elaboration a number of groups already begin to appear clearly defined.

An example of this is given by the samples from the Crotone area, (samples KR), Monterosso (samples MON) and Gerace, which show a clear distinction between samples GER1 and GER2, more similar to the others, and samples GER3 and GER4, completely different from all the other samples of «caroselli» examined.

The statistical parameters for major elements (Table 5) show less variability

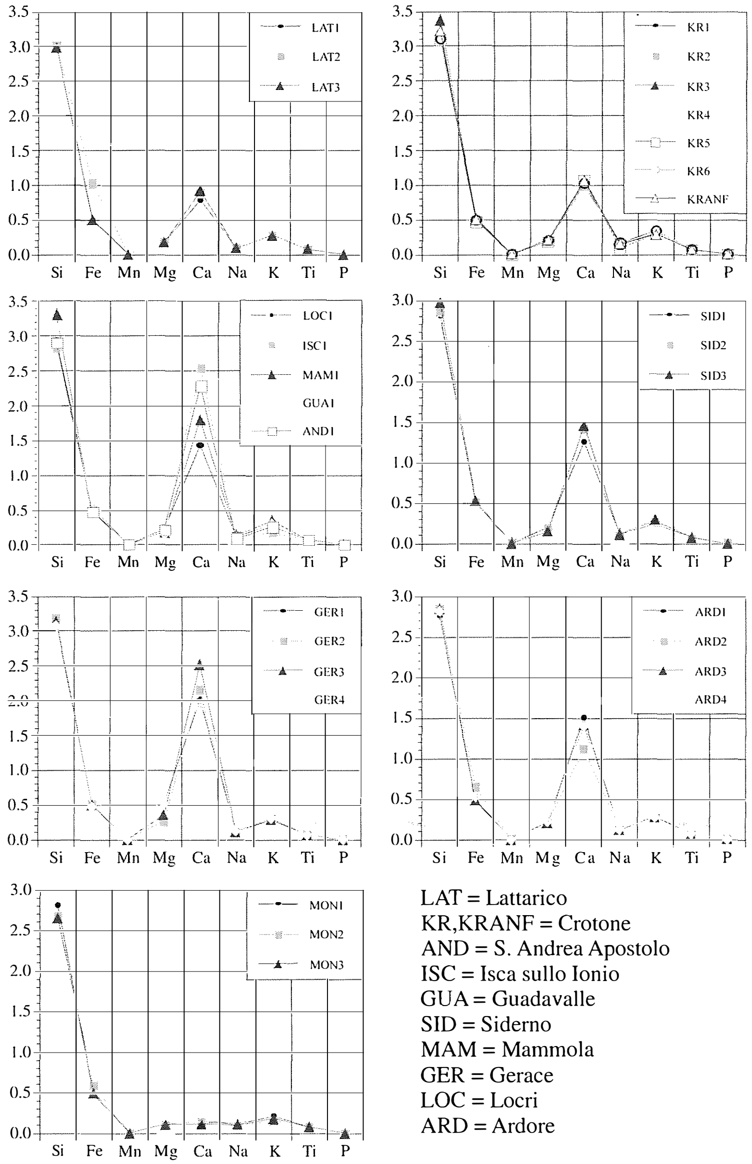

Fig. 5 – Chemical composition (major elements) of samples examined, normalised to aluminium.

compared with that of minor and trace elements (Table 6). The latter show greater variability for the following elements: Ba, Cr, Cu, Ni, Pb, Rb, Sr, V, Zn and Zr. It was therefore decided to use these more widely «variable» elements, to verify the agreement of results of cluster analysis.

Among the various major chemical elements constituting the clays used for construction the «caroselli», aluminium is the least mobile

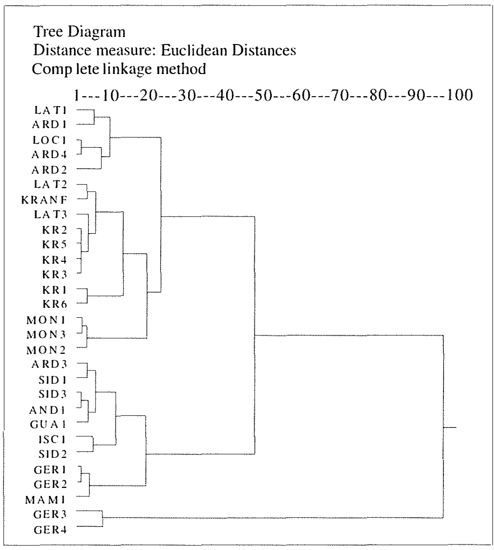

Fig. 6 - Multivariated cluster analysis on minor elements content, normalised to aluminium. Samples from various sites are grouped according to chemical composition affinities.

during chemical alteration, since it forms insoluble hydroxides. It was therefore considered opportune to use it as a reference element (fig. 7) normalising to it – one at a time – some significant elements. This was the case of the strontium used in fig. 8: a number of populations may already be divided into groups, e.g. the Monterosso (MON) Crotone (KR) and Siderno (SID) which have analogous Sr/Al% ratio.

Plotting the Sr/Al% *vs.* Pb/Al% ratio, (fig. 9) it is possible to make further distinctions of areas within which single populations of samples fall, and this also appears to be in agreement with the original results of the cluster analyses shown in fig. 6. Proof that these groupings correspond to real homogeneity of composition may be inferred from analogous diagrams made with other variables, for example the Sr/Al% *vs.* Ce/Al% ratio (fig. 10).

Analysis of porosimetric data, although it cannot be used as a chemical discriminator, certainly offers valid indications of the structure and homogeneity of the materials employed, and may therefore be used as an indication of manufacturing and firing processes. As shown in Table 4, almost all samples reveal a high degree of homogeneity of material, with a single series of mesopores in the range from 0.1 to 1 μ. The sole exception was for the samples of «caroselli» from the areas of Monterosso and Gerace. In addition, data for a Greek amphora, found in Crotone, are given as similar to those reported for some of the investigated «caroselli».

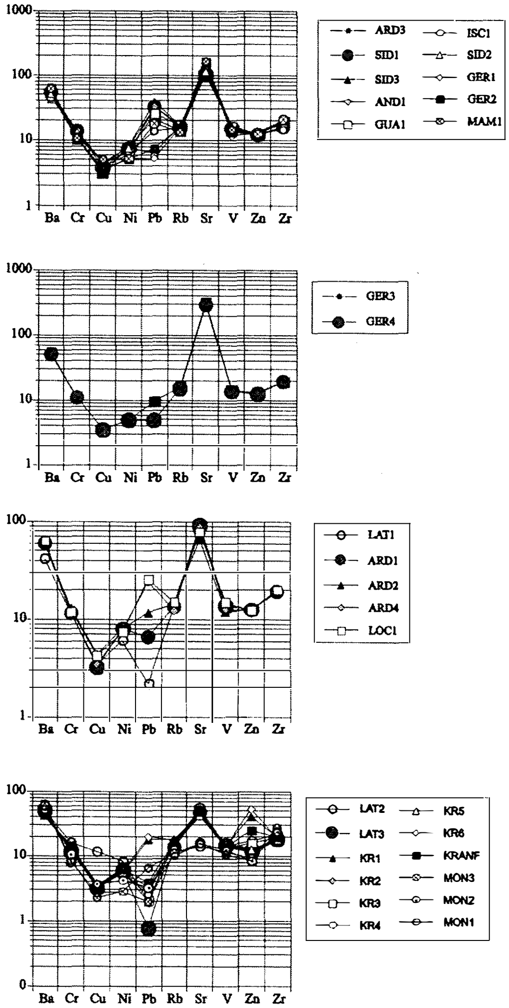

Fig. 7 – Chemical composition (trace elements) of samples examined, normalised to aluminium.

TABLE 5

Statistical parameters for major elements.

Major elem. (wt.%)	Min.	Max.	Range	Mean	Mode	Std. Dev.	Kurtosis	Skewness	Count
SiO_2	39.5	62.2	22.7	50.2	53.6	6.0	-0.8	0.1	29
Al_2O_3	11.2	20.7	9.5	14.9	—	2.2	0.5	0.8	29
Fe_2O_3	4.4	12.2	7.9	5.9	5.5	1.6	6.1	2.3	29
MnO	0.0	0.1	0.1	0.1	0.7	0.02	-0.4	0.2	29
MgO	1.6	6.0	4.5	2.8	—	1.0	5.6	2.4	29
CaO	1.8	24.1	22.3	13.8	—	5.6	0.2	-0.5	29
Na_2O	0.9	1.7	0.9	1.3	1.3	0.3	-0.9	0.4	29
K_2O	1.5	3.3	1.9	2.6	—	0.4	1.3	-0.8	29
TiO_2	0.5	1.0	0.5	0.7	0.6	0.1	1.2	1.0	29
P_2O_5	0.0	0.2	0.2	0.2	0.2	0.1	1.8	-1.6	29

TABLE 6

Statistical parameters for trace elements.

Trace elem. (ppm)	Min.	Max.	Range	Mean	Mode	Std. Dev.	Kurtosis	Skewness	Count
Au	1	18	17	3.83	1	4.05	4.86	2.23	29
As	3	14	11	7.24	8	3.08	-0.62	0.43	29
Ba	254	707	453	409.1	329	96.78	1.47	1.21	29
Be	2	3	1	2.31	2	0.47	-1.33	0.82	29
Co	10.5	22.8	12.3	15.13	16.1	2.75	0.63	0.59	29
Cr	68.2	132	63.8	94.64	—	16.08	-0.61	0.01	29
Cs	3.5	6.7	3.2	5.67	—	0.91	-0.28	-0.76	29
Cu	22	96	74	30.59	26	13.24	19.05	4.35	29
Hf	3.3	8.3	5	4.53	4.3	1.1	3.92	2.01	29
Ni	28	69	41	47.41	—	12.17	-1.05	0.23	29
Pb	7	285	278	90.93	—	81.09	-0.24	0.96	29
Rb	87	140	53	115.6	123	13.82	-0.96	0.04	29
Sb	0.4	1.6	1.2	0.78	0.7	0.25	2.66	1.55	29
Sc	10.4	23.4	13	14.37	—	2.92	3.69	1.78	29
Sr	156	2014	1858	692.2	360	454.77	2.36	1.49	29
Ta	0.6	1.9	1.3	1.02	0.8	0.31	1	1.2	29
Th	8.5	19.9	11.4	11.31	10.6	2.59	3.53	1.98	29
U	2	4	2	2.81	2.5	0.52	-0.38	0.4	29
V	79	132	53	109	109	13.32	-0.46	-0.31	29
Y	18	43	25	24.1	24	5.29	5.5	2.34	29
Zn	72	413	341	117.9	—	73.31	8.8	3.09	29
Zr	99	303	204	155.5	—	42.36	3.96	1.89	29

CONCLUSIONS

In order to carry out this research a single construction element was examined, known as «carosello», used for parts of structures in historic buildings. In particular, the buildings belonging to eleven towns in Calabria were studied. To perform the necessary analyses, about thirty samples were taken, which may be considered representative of almost the whole

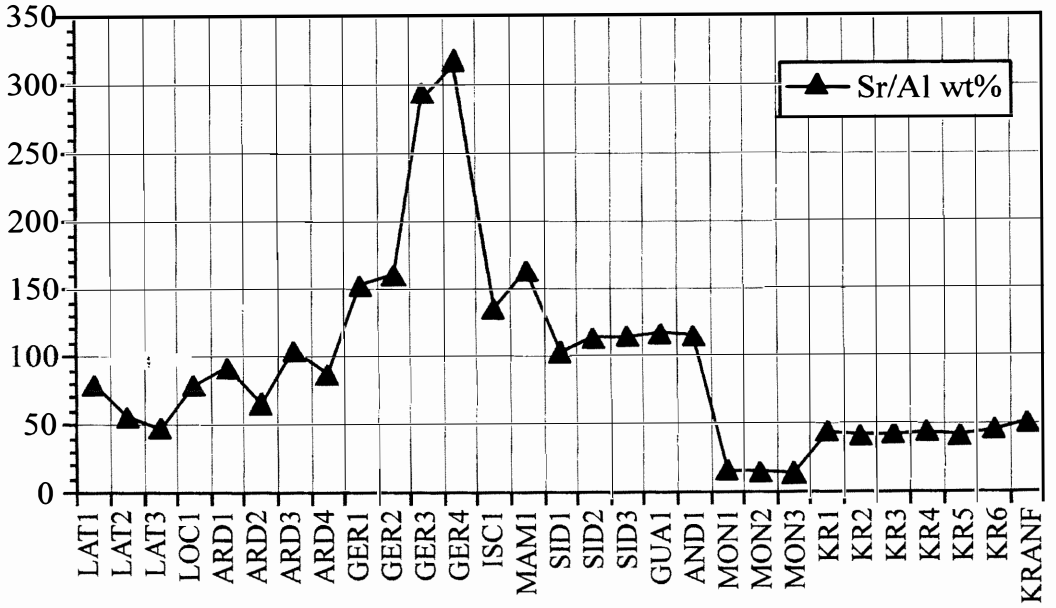

Fig. 8 – Strontium contents in samples examined, normalised to aluminium.

range of cases studied. Further comparisons may be found in the works of Gattuso and Menozzi (1995), Gattuso (1996, 1997).

Minero-petrographic investigations revealed five types of mixtures. Samples from Gerace, Siderno, Ardore and Crotone, show similarities which may be found in geologically similar rocks in nearby of villages where «caroselli» were used. In the Calabrian-Peloritan Arc, metamorphites, plutonites and calcarenites outcrop from Crotone to the north to Ardore in the south, and it is impossible to distinguish

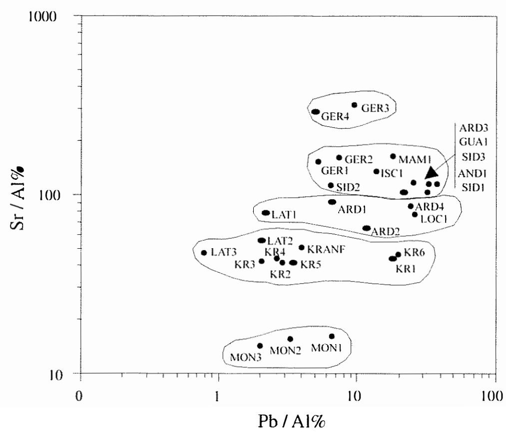

Fig. 9 – Scatter diagram of Sr/Al *vs* Pb/Al ratios showing possible groupings of samples into areas.

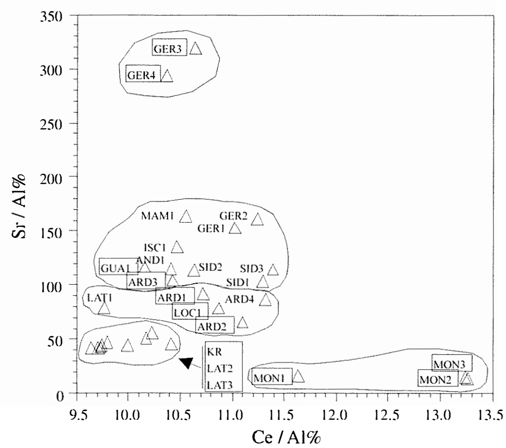

Fig. 10 – Scatter diagram of Sr/Al *vs* Ce/Al ratios showing possible groupings of samples into areas.

TABLE 7

Porosimetric data.

Camp.	$V_c$max mm³/g	P_{tot} %	ρa g/m³	(d<0.1)	(0.1<-0.2)	(0.2<0.4)	(0.4<0.8)	(0.8<1.2)	(1.2<1.6)	(d>1.6)
				V% (pores volume in % and diameter in μ)						
LAT2	128.57	22.5	1.75	51.7	26	17.94	20.02	75.92	7.28	1.04
LOC1	232.47	39.75	1.71	24.32	33.66	125.36	4.98	–	3.12	8.52
ARD3	257.19	42.95	1.67	33.14	36.46	125.14	–	3.04	–	2.2
GER1	282.93	43.28	1.53	10.22	7.94	10.1	25.14	63.36	81.72	1.48
GER3	216.06	35.86	1.66	16.62	7.92	9.02	24.52	28.48	60.6	52.84
ISC1	265.76	43.85	1.65	23.18	4.34	7.74	55.32	97.08	3.26	9.1
MAM1	242.63	39.54	1.63	34.08	37.4	101.44	16	–	3.22	7.82
SID2	226.68	37.17	1.64	40.1	40.56	101.78	–	–	–	1.8
GUA1	97.28	22.66	2.33	94.84	102.72	1.8	–	–	–	0.60
AND1	178.41	32.82	1.84	20.52	17.8	81.96	80	–	–	0.48
MON3	133.56	25.51	1.91	14.88	3.96	–	10.12	4.96	6.16	159.92
KR5	163.34	30.87	1.89	90.36	36.44	45.18	8.02	–	–	20.02

$V_c$max: maximum cumulative volume; ρa: apparent volumic mass; P_{tot}: percentage open integral porosity; V%: percentage volume as a function of the diameter.

ceramics only on the basis of rock fragments in the mixture. Moreover, all along the Ionian several Lower Pleistocene to Miocene clay and sand formations occur.

Group C4 differs due to the lack of bulk and of scarcity of grain size larger than 125 μm. Samples from the C5 are quite different from the others in grain size, for the presence of garnet and the lack of carbonate rock fragments. Some of the «standing alone» samples do not show great differences from some of the other investigated specimens, indicating areal variations in these clay deposits which need to be compared with the original clay materials used.

From all the analytical results collected it appears possible to group together the various samples of «caroselli» in homogeneous families from the point of view of chemical composition.

Minero-petrographic analysis gives substantial homogeneous characteristics for samples belonging to classes C, C2, C3 and C4 (Table 2), whereas samples from Monterosso are easily discernible for the presence of garnet and the lack of calcite.

Chemical discrimination based on minor and trace elements contents, is once again confirmed. In particular, it was seen that the elements which are more widely variable in content, such as Ba, Cr, Cu, Ni, Pb, Rb, Sr, V, Zn and Zr, may be usefully employed as discriminants. Samples are divided into homogeneous «families» according to fig. 8.

In particular, the samples from the Monterosso area, Crotone and, to a lesser degree Gerace 1 and Gerace 2 reveal peculiar characteristics. GER3 and GER4 are strikingly different from these.

The grouping in a single family of the samples from Crotone (KR) is linked to the large basin of Pleistocene clays inland, such as to guarantee uniformity of composition in supplies over time. The clays used in the Monterosso area (MON) are also of Pleistocene age but reveal a different type of inert added, referred to the high-grade metamorphites from the Sila range, which are totally absent from the basin of Crotone.

Similarly, the samples from Lattarico (LAT) fall into two different «families», since in the neighbourhood of that site both Pliocene and Pleistocene clays are found. The different quarrying areas therefore characterise the materials which, although used in the same architectural structure, may derive from quarries situated in different areas.

All the other populations of samples come from both Pliocene and Pleistocene clay outcrops; there are also quantities of Miocene clays in samples taken from the lower Ionian coast. Unfortunately, the extremely heterogeneous nature of the contents of inert used in the mixture made it impossible to distinguish individual families.

The above is stressed in the results by the different significance of processing of chemical analysis data, since cluster analysis (fig. 6) takes into account the whole general compositional sequence of chemical elements, while subsequent processing by scatter diagrams discriminate better between the affinities noted previously by means of multivariate analysis.

Further and more detailed reference values for the «families» of uncertain origin may be evaluated only after a suitable *in loco* selection of samples of materials from the original clay quarries on the various sites.

The presence of similar geological formations near sampling localities and the lack of direct comparisons to them do not allow precise attributions to be made.

On the basis of the data collected it was therefore possible to define the chemical composition of this particular family of building elements. They constitute a *unicum* in the construction field, with similar findings in the Campania area and sporadic use in other areas of Southern Italy.

The present data may therefore be considered a point of reference for the characterisation and definition of finds in the future. The discriminants, both minero-petrographic and chemical, used for this research appear therefore substantially valid and effective.

Acknowledgements

Thanks are due to Profs. B. Fabbri and M. L. Amadori of CNR-IRTEC of Faenza for useful suggestions and discussions. Thanks are also due to the anonymous reviewers who helped in improving the manuscript.

REFERENCES

Amodio-Morelli L., Bonardi G., Colonna V., Dietrich D., Giunta G., Ippolito F., Liguori V., Lorenzoni S., Paglionico A., Perrone V., Piccarreta G., Russo M., Scandone P., Zanettin-Lorenzoni E. and Zupetta A. (1976) — *L'arco Calabro-Peloritano nell'orogene Apenninico-Maghrebide.* Mem. Soc. Geol. It., **17**, 1-60.

Amadori M.L. and Fabbri B. (1998) — *Indagini archeometriche su ceramica fenicia da mensa proveniente da Cartagine (VIII-VI sec. A.C.).* In Atti 2° Giornata di archeometria della ceramica. Ravenna.

Arslan E.A. (1965a) — *Osservazioni sull'impiego e la diffusione delle volte sottili in tubi fittili.* Boll. d'Arte, ser. **V**., 45-52.

Arslan E.A. (1965b) — *Il significato spaziale delle volte sottili romane e paleocristiane.* Boll. D'Arte, ser. **V**, anno L.

Bovini (1959) — *L'impiego dei tubi fittili nelle volte degli antichi edifici di culto ravennati.* In «Corsi di cultura sull'arte ravennate e bizantina», Ravenna, pp. 27-43.

Consiglio Nazionale delle Ricerche, Istituto Centrale del Restauro (1983) — *Aggregati artificiali a matrice legante non argillosa: schema di descrizione.* Raccomandazione NORMAL 12/83. CNR-ICR, Roma.

Consiglio Nazionale delle Ricerche, Istituto Centrale del Restauro (1985) — *Manufatti ed aggregati a matrice argillosa impiegati come materiale da costruzione.* Raccomandazione NORMAL 15/834. CNR-ICR, Roma.

Crema L. (1952) — *Origine e impiego di fittili cavi nell'architettura romana.* In «Bollettino del Centro di Studi per la storia dell'architettura romana», **6**, Roma, pp. 6-8.

Gattuso C. (1996) — *Il carusello: una tecnica costruttiva come costante del versante ionico calabrese.* Forum Internazionale di Studi, La Città del Mediterraneo, Reggio Calabria

Gattuso C. (1997) — *Some characteristics of a singular constructive ceramic element in Magna Greece.* IV Intern. Symp. Conserv. Monum. In the Medit. Basin., Rodi, 183-193.

Gattuso C. and Menozzi L. (1995) — *Ceramic facing in the architecture of some southern italian centers.* IV European ceramic conference, Riccione.

I.G.C.P. PROJECT n. 276 (1993) — *The Calabria-Peloritani arc and its correlations with northern Africa and southern Europe*. Messina A. and Russo S. Edt., Newsletter, **6,** Messina, pp. 144.

LÉZINE A. (1954) — *Les voutes romaines à tubes emboités et les croisées d'ogives de Bulla Regia.* In «Kartago», **V**, 168-181.

LUGLI G. (1972) — *La tecnica edilizia romana*, Roma, pp. 671-672.

MANACORDA D. (1986) — *Nuovi dati sulle volte costruite con vasi fittili, in ceramica medievale nel Mediterraneo occidentale.* Atti III Congr. Intr., Firenze, 511-541.

MONNERET DE VILLARD U. (1924) — *Sull'impiego di vasi e tubi fittili nella costruzione delle volte in Sant'Agata dei Goti.* Roma, 149-155.

OLCESE G. (1994) — *Ceramica romana e archeometria: lo stato degli studi.* Firenze, Ed. All'insegna del Giglio, 319 pp.

PEACOCK D.P.S. (1977) — Pottery and early commerce. London.

VERZONE P. (1936) — *Le cupole a tubi fittili nel V-VI secolo in Italia.* In Atti del I Cong. Naz. di Storia dell'Architettura, Firenze, 7-11.

WHITBREAD I.K. (1989) — *A proposal for the systematic description of thin section of ancient ceramic technology.* In Archeometry Proceeding of the 25th International Symposium, Tokyo, 127-138.