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Evidence for the provenance of building stone of igneous origin in the Roman Theatre in Catania

ROSA ANNA CORSARO, RENATO CRISTOFOLINI, ANTONINO PEZZINO* and ANNA SERGI

Dipartimento di Scienze Geologiche and Centro di Ricerche sulle Cause di Degrado per il Recupero dei Beni Culturali e Monumentali - Università di Catania, Corso Italia 55, I-95129 Catania, Italy

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ABSTRACT. — The Roman Theatre in Catania was built using basically both local lithotypes such as lava blocks from quarries in Etnean flows, and granite and marble from various regions of the Mediterranean basin.

In the *cavea,* the tiers were made of lava blocks, originally covered by large limestone slabs, and of calcareous blocks, probably derived from an earlier Greek theatre which had existed on the same site. The tiers were subdivided into sectors by steps in lava, a material resistant to the constant passage of the public and whose colour, contrasting with that of the white limestone seats, created a pleasing chromatic effect. Granite slabs were used to pave part of the *orchestra* and for the columns. Some of these columns still remain within the theatre, where they lie, fallen in the *orchestra*; however, most of them were removed from the area and used to ornament the facade of the Cathedral and other monuments in Catania. At present, one of them may also be admired at Largo della Marina (the Marine Parade) where it supports the statue of St. Agatha, the patron saint of Catania.

This paper examines the petrographic and chemical characters of some types of lava used for the construction of the tiers, and of the granitoid rocks used in the flooring and columns of the Theatre. The resulting data made it possible to define the probable areas of origin of the building stone, by comparing it with reference sources concerning ancient Roman quarries.

It is hypothesized that the lava blocks forming the tiers of the *cavea* in the Roman Theatre, despite their heterogeneous appearance, were all quarried from prehistoric lava flows of the Recent Mongibello, near the monument itself, outside the Roman city walls.

Petrographic and petrochemical studies on the granitoid rocks used to pave the *orchestra* and for the columns reveal their mineralogical and compositional heterogeneity. It is assumed that all but three of these samples came from Western Turkey («Mysian marble» from Kozak). It is not yet possible to define the provenance of these three samples on the grounds of their petrographic and geochemical characters.

RIASSUNTO. — Nel Teatro Romano di Catania sono stati utilizzati come materiali da costruzione sia litotipi locali come lave provenienti dalle cave etnee che rocce come graniti e marmi provenienti da differenti regioni del bacino del Mediterraneo.

Nella cavea le gradinate, costituite in gran parte da blocchi di lava, originariamente ricoperti di lastre calcaree e da grandi blocchi di pietra calcarea, probabilmente ricavati da un preesistente teatro Greco, erano suddivise in settori da scale con gradini di pietra lavica, che più difficilmente veniva logorata dal transito degli spettatori e il cui colore,

* Corresponding author, E-mail: pezzino@mbox.unict.it

contrastando con quello dei bianchi sedili calcarei, creava un gradevole effetto cromatico. I graniti vennero invece utilizzati per la pavimentazione dell'orchestra e per le colonne. Diverse di queste colonne rimasero all'interno del Teatro, e ora si ritrovano accantonate in varie parti dell'orchestra, mentre la maggior parte è stata, tuttavia, rimossa dal Teatro ed utilizzata nella costruzione di vari edifici a Catania; in particolare attualmente alcune di queste colonne si possono ammirare nella facciata della Cattedrale e al Largo della Marina dove una di esse sostiene una statua di S. Agata, Patrona della città.

In questo lavoro sono stati studiati i caratteri petrografici e chimici di alcuni campioni di lave utilizzate per la costruzione delle gradinate, e di rocce granitoidi usate per la pavimentazione e le colonne del Teatro. Questi dati hanno permesso di individuare le probabili aree di provenienza dei materiali litici, operando un confronto con i dati di letteratura inerenti le antiche cave romane.

Si è quindi proposto che i blocchi lavici delle gradinate nella cavea del Teatro Romano di Catania, pur nella loro eterogeneità, siano stati prelevati da cave aperte in colate preistoriche del Mongibello recente ubicate in prossimità del teatro stesso, fuori della cinta muraria della città Romana.

Per quanto riguarda le rocce granitoidi utilizzate per il pavimento dell'orchestra e per le colonne, le indagini petrografiche e petrochimiche condotte su questi campioni hanno messo in luce una eterogeneità mineralogica e composizionale. Si ipotizza che la maggior parte di questi campioni provengano dalla Turchia occidentale (marmo misio, Kozak), mentre per tre restanti campioni non è stato possibile individuare un probabile sito di estrazione sulla base delle loro caratteristiche petrografiche e geochimiche.

KEY WORDS: *Archaeometry, granites, Etnean lavas, provenance.*

INTRODUCTION

Granitic stone for the construction of monuments in Italy was already used in Roman times. Trade in ornamental stone extracted from quarries in the Mediterranean basin was widespread in all the Roman provinces, and permitted monuments to be built in which local rocks alternated with exotic lithotypes, to create pleasing chromatic effects.

The Roman Theatre in Catania is a combination of various building materials differing in both composition and origin, and is a perfect example of the aesthetic possibilities offered by polychromatic marble, glistening granite, white Iblean limestone and dark Etnean lava. Some of its materials (granite and lava) were analysed for more detailed information on their provenance, for the benefit of archaeologists.

Samples of lava taken from the tiers of the *cavea* were analysed and classified from the petrographic and chemical points of view. They were then compared with samples of lava flows (Corsaro, 1990; Corsaro and Cristofolini, 1993) outcropping near the Roman Theatre, in order to define the probable quarrying area. The same procedure was applied to the granitoid samples taken from the paving and columns of the Theatre. Their petrographic and chemical data were compared with those of granitoid rocks occurring in the Mediterranean area, used as building material in the past.

A BRIEF HISTORY OF THE ROMAN THEATRE IN CATANIA

The great theatre in Catania, built on the southern slope of the *akropolis* of the Greek town, belongs to the Roman period, as revealed by the vaulted corridors and the construction «*ad opus incertum*», a building technique widely used by the Romans from the end of the 2nd century B.C. until the beginning of the Empire (De Roberto, 1907). The walls consist of small, trapezoidal stone blocks, with only one smooth face, designed to form the *paramentum*: once the external blocks had been laid, closely fitted to each other on both sides of the wall, the inner part was completed with smaller stone chips of various sizes, the whole being held together with lime mortar. Along the walls and also in the vaulted arches, horizontal rows of terracotta bricks frequently occur, arranged in single or double lines, in order to confer greater stability to the building.

At the time of the Normans in the 10th century A.D., at the wish of Count Roger de

Hauteville, many of the ornamental elements of the Theatre, consisting of columns and marble facings, were used to build the Cathedral of Catania. Before the 1693 earthquake, in fact, it was possible to observe eight granite columns taken from the Theatre, capitals decorated with ancient reliefs, frames and other fragments of decorative elements, some of which were used in the staircase leading to the choir. Private houses were later built on the site of the Theatre, which was thus despoiled.

Many remains belonging to the Theatre were to be found in the collections of the Palace of the Princes of Biscari, as one of them first began excavations, and in the Benedictine Abbey, where there is an inscription which was originally emplaced between the stage and the tiers on the western side. Of the eight columns initially in the Cathedral, six now adorn the lower order of its facade, one is preserved in the Biscari Palace, and the remaining one supports the statue of St. Agatha, on the Marine Parade (Largo della Marina, now Piazza dei Martiri).

In the Theatre, the tiers for the public, separated by horizontal aisles called *precinctiones*, were subdivided into sectors by means of stairs. A seat of honour was placed on a platform in the centre of each sector (De Roberto, 1907). The seats were chiefly made of limestone and partly also of lava blocks, probably originally covered by limestone slabs; the steps of the stairs subdividing the sectors were made of lava because of the higher resistance of this rock to wear caused by passing spectators. The floor of the *orchestra* and the *cavea* were faced with white marble.

What now remains of the Theatre consists of some of the steps leading from below to the first aisle; the lower order of seats contains twenty-one tiers, divided by eight flights of steps into nine sectors. The second-order tiers no longer exist, but it is estimated that there were twelve of them. There were vaulted corridors below the lower and higher aisles. At the top of the *cavea*, behind the second aisle, there was an arcade, the columns of which are now scattered in various parts of the city. A further corridor ran all round the base of the building. These internal passages were connected by flights of steps leading to the aisles (De Roberto, 1907).

The Theatre of Catania, with its capacity of about 7,000, was smaller than the Greek Theatre in Syracuse, which could accommodate 8,000 spectators, and even smaller than that of Taormina, which had seating for 10,000 (De Roberto, 1907).

Sampling and analytical techniques

The samples taken from the Theatre consist of small fragments detached from the monument as a result of natural degradation and of fragments of material already catalogued and deposited, under the permission of the Cultural and Environmental Authorities in Catania (*Soprintendenza dei Beni Culturali ed Ambientali di Catania*).

Fourteen samples were taken from lava blocks forming the tiers of the two easternmost sectors (nos. 1A, 2A, 2B, 4D, 6E, 2F, 3F, 3G, 1L, 1M, 3N) and of the seventh sector to the west (samples IIA, IIO, IIID). Ten samples of granitoid rock were taken from the paving of the *orchestra* (TR2, TR8, TR9, TR12, TR13) and from the columns originally supporting the arcade at the top of the *cavea* (TR1, TR3, TR4, TR6, TR7).

Major element contents were determined at the Department of Geological Sciences of the University of Catania, using various procedures: XRF spectrometry on rock powder pellets (SiO_2, TiO_2, Al_2O_3, Fe_{tot}, MnO, CaO, Na_2O, K_2O, P_2O_5) with matrix effect correction (Franzini *et al.*, 1972); $KMnO_4$ titration (FeO); AAS (MgO); and weighing (LOI).

Minor element contents were determined at the ACTLABS laboratories, Ancaster, Ontario, Canada, by INAA (Instrumental Neutron Activation Analysis; Rb, Th) and ICP-MS (Inductively Coupled Plasma and Mass Spectrometry; Sr, Ba, Zr, Y). Analytical uncertainty is lower than 5%.

THE MOST FAMOUS GRANITES OF THE PAST

Of all rocks, the various types of granite have always occupied a significant place in the construction of important buildings, probably because man has always associated this rock with great solidity and durability, considering it best qualified to make his works «immortal».

The Romans, who called granite *marmor*, i.e., marble, because it was so easy to polish, quarried it throughout the Mediterranean basin. The most famous granites in ancient times were:

– **Red Egyptian granite**, also known as syenite, quarried in ancient Egypt at Syene, now called Aswan. It is a coarse-grained alkali granite, from red to pink in colour, with large K-feldspar crystals. Its paragenesis is made up of microcline, quartz, biotite, scarce plagioclase and hornblende; titanite, apatite, allanite, magnetite and zircon are the main accessory phases (Lazzarini, 1987; Ragab *et al.*, 1978). Radiometric dating gives an age of about 586 Ma for the Aswan granitic rocks (whole rock Rb/Sr; Ragab *et al.*, 1978).

– **Claudian marble**, also known as 'Forum granite' from the Trajan Forum in Rome, in which it was widely used. It was quarried from the eastern Egyptian desert on Gebel Fatireh, once known as *Mons Claudianus*. It is a medium-grained granodiorite, light grey in colour, with microgranular mafic enclaves. Its mineral association is given by plagioclase, quartz, K-feldspar, biotite and hornblende; common accessories are titanite, apatite, opaque minerals and zircon (Lazzarini, 1987).

– **Granite** from **Wadi Fawakhir**, for which there is no defined name, either ancient or modern. Quarries were located near the village of that name in Egypt. It is a fine- to medium-grained granite, pinkish-grey in colour, often deepening to a more definite grey. The main minerals constituting this rock are quartz, plagioclase, K-feldspar, biotite and muscovite; apatite, titanite, opaque oxides, epidote and zircon occur as accessories (Lazzarini, 1987).

– **Mysian marble** came from a small ancient quarry near Kozak in Turkey. The pluton emplaced in this area is apparently Miocenic in age and consists of prevailing grey, medium-grained granodiorite containing abundant mafic microgranular enclaves (Bingol *et al.*, 1982). The dominant mineral assemblage is plagioclase, quartz, K-feldspar, biotite and hornblende. Apatite, titanite, opaque minerals and zircon are accessories (Bingol *et al.*, 1982; Galetti *et al.*, 1992).

– **Troadensian marble**, also called «violet granite», was quarried in the Troades area (Turkey), at the foot of the mountain range now known as Cigri Dag, near the town of Ezine. The granitoid intrusion emplaced in this area (Kestanbol Intrusion) consists of a homogeneous quartz-monzonitic body about 21 Ma in age (Birkle and Satir, 1994). This fine- to medium-grained rock is violet-grey with large reddish-violet K-feldspar crystals (up to 1.5 cm in diameter) and abundant mafic microgranular enclaves. The main minerals are plagioclase, K-feldspar, hornblende, biotite and quartz; magnetite, titanite, apatite and zircon are accessories (Birkle and Satir, 1994).

– **Elba granite,** also called 'Old Granitello', was extracted on a vast scale, in both Roman and Medieval times, from the foot of Monte Capanne on the island of Elba. The average K/Ar and Rb/Sr ages for the Monte Capanne pluton are 6.7 Ma (Ferrara and Tonarini, 1985). The main facies (MF) of this pluton consists of light-grey, medium- to coarse-grained monzogranite, with K-feldspar megacrysts and mafic microgranular enclaves. Besides K-feldspar, the minerals making up this facies are plagioclase, quartz and biotite. Apatite, zircon, titanite, opaque oxides and rare monazite occur as accessory minerals. A leucocratic facies (LF) is randomly distributed within the MF of the pluton, with no evidence of tectonic or intrusive relationships: it consists of rocks whose composition varies from monzogranite to syenogranite, medium- to fine-grained and pale in colour. The mineral assemblage, similar to that of the MF, consists of K-feldspar, plagioclase, quartz, biotite and primary muscovite. Accessory minerals are opaque oxides, apatite, zircon and titanite (Poli *et al.*, 1989).

– **Giglio Island granite**. This was quarried from Cala delle Cannelle on the eastern coast of the island, which consists almost entirely of a 5-Ma-old granitic intrusion (Ferrara and Tonarini, 1985). Here too, as on Elba, there are a main facies (MF), light-grey, medium- to fine-grained monzogranite with microgranular mafic enclaves, and a leucocratic facies (LF), irregularly distributed within the intrusive body, consisting of pale, medium- to fine-grained syenogranite. The minerals in both facies are plagioclase, quartz, K-feldspar, biotite and primary muscovite with titanite, apatite, zircon, tourmaline and monazite as accessories (Poli *et al.*, 1989).

– **Sardinian granite**, like Elba granite, was exploited in considerable quantities in both Roman and Medieval times along the north-eastern coastline of Sardinia. Nowadays, remains of Roman quarries are found in various sites near Capo Testa, e.g., Cala Spinosa, Punta Acuta and Santa Reparata (Lazzarini, 1987). Poli and Tommasini (1991) studied the granitic stocks outcropping in this area. These intrusive rocks, which belong to the Sardinia-Corsica batholith, were emplaced during the late tectonic phase of the Hercynian orogeny (from 320 to about 280 Ma BP). Detailed field observations and petrographical and geochemical studies have revealed four distinct granitic intrusions, separated by clearcut contacts (Tommasini, 1987). The intrusive sequence ranges in composition from gabbroic to leucogranitic plutons, with monzogranitic and granodioritic masses largely prevailing.

The granodioritic rocks display an equigranular medium-grained texture, and are light-grey with mafic microgranular enclaves. The dominant mineral assemblage is plagioclase (An_{51-34}, cores; An_{28-20}, rims), quartz, orthoclase, hornblende and biotite; common accessories are apatite, opaque minerals, zircon, titanite and allanite. The monzogranite is greyish-pink and shows both an inequigranular, medium- to coarse-grained texture, with pink poikilitic K-feldspar crystals, and an equigranular medium- to coarse-grained texture. The main minerals are K-feldspar, quartz, plagioclase (An_{34-13}, cores; An_{29-11}, rims) and biotite; apatite, zircon, allanite, titanite and opaque minerals are accessories (Poli and Tommasini, 1991).

The chemical compositions of these granites, widely known as having been used in ancient times, are listed in Table 1.

PETROGRAPHIC CHARACTERS OF SAMPLES

Granitoids

The analysed samples were subdivided into three groups on the basis of their macroscopic and microscopic characters.

On the hand specimen scale, the group I samples - TR1 and TR3 (columns) and TR2, TR8, TR9, TR12 and TR13 (pavement of the *orchestra*) - are medium- to fine-grained, generally grey in colour, and with microgranular mafic enclaves (MME). They are holocrystalline, with a hypidiomorphic and homeogranular texture. The main minerals are plagioclase, quartz, K-feldspar, biotite and amphibole, with apatite, zircon, titanite and opaque oxides as accessories.

Euhedral to subhedral plagioclase always shows oscillatory and normal zoning. Crystal sizes are generally less than 4 mm, with core composition of about An_{45}; rim compositions range from An_{27} to An_{20}. Plagioclase frequently encloses small, rounded biotite flakes, zircon, apatite and opaque oxides, and is often altered into sericite and clay minerals.

Amphibole is the most abundant mafic mineral, occurring here as euhedral to subhedral crystals, or associated with biotite, titanite and opaque oxides. Its optical characters (pleochroism: α = yellow-beige; β = light green; γ = apple green; $C^\wedge\gamma = 20°$) are typical of hornblende; it is sometimes twinned and encloses tiny biotite laths.

Biotite occurs as polycrystalline aggregates, discrete hexagonal crystals, and euhedral to subhedral flakes with ragged outlines, its dimensions never exceeding 2-3 mm. It is pleochroic from straw-yellow (α) to dark brown (β,γ) and often altered into chlorite. The

TABLE 1

Major and minor elements of marbles (granitoid rocks) used in the past.

	SARDINIA								ASWAN
Sample	LG2	SP 60	SP 59	SP 41	SP 146	SP 42	SP 88	SP49	LG10
SiO_2	72.98	65.04	66.59	67.48	67.64	67.94	68.18	69.77	71.65
TiO_2	0.31	0.72	0.62	0.58	0.63	0.56	0.56	0.56	0.49
Al_2O_3	13.7	16.32	15.98	15.52	15.35	15.46	15.6	15.61	13.63
$FeO_{(tot)}$	2.73	4.38	3.86	3.86	4.19	3.72	3.6	3.51	3.33
MnO	0.06	0.06	0.08	0.08	0.09	0.08	0.07	0.08	0.05
MgO	0.6	1.64	1.33	1.33	1.15	1.27	1.18	1	0.49
CaO	1.94	3.78	3.51	3.23	3.39	3.12	2.99	3.17	1.48
Na_2O	3.31	3.37	3.19	3.37	3.44	3.15	3.2	3.79	3.05
K_2O	4.31	3.26	3.7	3.49	3.25	3.59	3.7	2.9	5.87
P_2O_5	0.1	0.17	0.14	0.15	0.11	0.1	0.15	0.16	0.05
L.O.I.	0.26	1.12	0.86	0.80	0.52	0.87	0.63	0.83	0.29
Total	100.07	99.86	99.86	99.89	99.76	99.86	99.86	101.38	100.26
Th	3	-	7.7	-	-	11.6	-	14.2	7
Zr	148	260	254	229	242	221	237	246	339
Y	28	49	65	42	25	44	37	70	34
Rb	157	124	115	131	123	138	133	118	104
Sr	134	259	258	227	194	216	219	232	184
Ba	602	882	1322	828	634	834	1065	969	1152

LG2, LG10 (Galetti *et al.*, 1992); SP60, SP59, SP41, SP146, SP42, SP88, SP49 (Poli and Tommasini, 1991).

	WADI FAWAKHIR		CLAUDIAN MARBLE		ELBA GRANITE		GIGLIO GRANITE	
Sample	LG4	GRIII	LG3	GRIV	LF (mean)	MF (mean)	LF 1	LF 2
SiO_2	70.46	70.14	65.68	68.59	70.64	67.66	73.5	71.3
TiO_2	0.38	0.47	0.57	0.48	0.41	0.56	0.2	0.4
Al_2O_3	14.88	14.1	16.21	15.2	15.20	15.85	13.9	14.5
$FeO_{(tot)}$	2.67	2.84	4.09	2.92	2.34	3.16	0.89	2.75
MnO	0.05	0.06	0.07	0.08	0.04	0.07	0.04	0.05
MgO	0.62	0.63	2.07	1.16	0.80	1.39	0.4	0.7
CaO	1.19	1.71	4.79	2.92	1.82	2.76	0.8	1.9
Na_2O	4.41	4.57	4.39	4.51	3.15	3.17	3.1	2.4
K_2O	3.88	3.64	1.65	2.77	4.71	4.42	6.3	5.3
P_2O_5	0.12	0.15	0.19	0.13	0.18	0.16	0.11	0.15
L.O.I.	0.57	0.75	0.59	0.83	0.66	0.80	1.2	0.5
Total	99.75	99.06	100.03	99.59	99.29	100.01	100.44	99.95
Th	4	-	1	-	-	24	-	-
Zr	196	231	144	148	135	154	53	153
Y	18	31	12	27	22	24	19	29
Rb	102	99	23	56	314	298	372	318
Sr	373	240	620	392	161	222	65	100
Ba	852	618	431	495	265	374	74	354

TABLE 1: *Continued*

TROADENSIAN MARBLE

Sample	LG12	PL1	PL2	PL3	PL4	PL5	PL6	TK1
SiO_2	63.54	64.81	63.56	62.29	62.21	64.79	63.57	64.05
TiO_2	0.61	0.48	0.52	0.63	0.66	0.51	0.56	0.57
Al_2O_3	15.95	15.48	15.63	16.01	15.72	15.67	16.04	16.04
$FeO_{(tot)}$	2.25	3.87	3.93	4.74	4.9	3.95	4.14	3.24
MnO	0.09	0.1	0.08	0.09	0.09	0.08	0.07	0.09
MgO	2.25	1.91	2.02	2.27	2.31	2.31	2.14	1.93
CaO	4.29	3.59	3.79	4.5	4.52	3.65	3.96	4.15
Na_2O	3.77	3.41	3.83	3.46	3.45	3.45	3.53	3.47
K_2O	4.69	5.1	4.74	4.61	4.29	4.48	4.69	4.97
P_2O_5	0.34	0.23	0.28	0.28	0.28	0.22	0.26	0.31
L.O.I.	0.31	0.47	0.49	0.48	0.34	0.7	0.44	0.85
Total	100.29	99.71	99.13	99.64	99.01	100.04	99.66	99.67
Th	65	-	-	-	-	-	-	23
Zr	192	249	233	237	240	206	213	317
Y	24	29	32	32	33	24	27	46
Rb	206	209	186	160	158	187	189	133
Sr	843	761	845	853	819	648	769	758
Ba	1019	1202	1088	1229	1070	1071	1189	1025

LG3, LG4, LG12 (Galetti et al., 1992); GRIII, GRIV (Greenberg, 1981); LF, MF, LF1, LF2 (Poli et al., 1989); PL1, PL2, PL3, PL4, PL5, PL6 (Birkle and Satir, 1994); TK1 (new original data).

MYSIAN MARBLE

Sample	B105	B106	S138	S3	S119
SiO_2	63.38	65.05	64.06	64.60	64.57
TiO_2	0.51	0.54	0.58	0.60	0.53
Al_2O_3	16.12	16.16	15.25	15.28	16.24
$FeO_{(tot)}$	3.86	3.96	4.36	4.21	4.10
MnO	0.08	0.08	0.11	0.10	0.07
MgO	2.23	2.42	3.10	3.20	2.12
CaO	4.32	4.30	3.60	3.70	3.86
Na_2O	4.01	3.32	3.50	2.90	3.56
K_2O	3.33	3.41	3.40	3.57	3.56
P_2O_5	0.21	0.22	0.15	0.08	0.25
L.O.I.	0.85	0.88	1.15	0.60	0.63
Total	98.90	100.2	99.41	99.00	99.49
Th	-	-	23	25	23
Zr	166	150	161	177	175
Y	19	24	23	21	23
Rb	116	108	102	95	115
Sr	643	624	609	596	665
Ba	-	-	1206	1163	1373

B105, B106, S138, S3, S119 (Altunkaynak and Yilmaz, 1998) most frequent inclusions are plagioclase, apatite, titanite, zircon and opaque oxides.

Anhedral quartz and K-feldspar are restricted to interstitial patches.

Group II contains only sample TR7 (column), pale grey and medium- to fine-grained. K-feldspar, quartz, plagioclase and biotite are the most abundant minerals; apatite, zircon, opaques and titanite are accessories. The analysed fragment is too small to reveal the possible presence of K-feldspar megacrysts or mafic microgranular enclaves.

K-feldspar occurs as both interstitial patches and large euhedral cristals.

Plagioclase is found as euhedral or subhedral crystals, between 2 and 4 mm, with normal or oscillatory zoning and compositions of about An_{32} (cores) and An_{20-18} (rims). Inclusions are most frequently small, rounded biotite crystals, zircon, apatite and opaque oxides. The plagioclase grains are often altered into sericite and clay products.

Biotite occurs as discrete euhedral to subhedral crystals (1-2 mm), pleochroic from yellowish-brown (α) to reddish-brown (β,γ). Most of the crystals are altered into chlorite; their inclusions are plagioclase and accessories.

The two samples of group III, TR4 and TR6 (columns), are fine-grained and pinkish-white in colour. Their texture is hypidiomorphic homeogranular, and paragenesis is given by K-feldspar, plagioclase, biotite, quartz and primary muscovite. Apatite, zircon and opaque minerals are the main accessories.

Plagioclase, varying in size from 1 to 3 mm, is mainly twinned according to albite and albite-Carlsbad laws, and shows either direct or oscillatory zoning with An_{34-28} (cores) and An_{20-11} (rims). It mostly encloses accessory minerals and biotite, and is often altered into sericite and clay products.

Biotite is present as discrete euhedral and subhedral crystals (<2mm), with commonly ragged outlines, surrounded by muscovite. It is pleochroic from yellowish-brown (α) to reddish-brown (β,γ) and is frequently transformed into chlorite. Zircon and apatite are the most common inclusions.

Muscovite shows the following textural features: *a)* in late-magmatic patches, with reaction rims to quartz, resulting in K-feldspar and fibrolithic sillimanite; *b)* grown over biotite crystals; *c)* enclosed as thin flakes in plagioclase, quartz and K-feldspar.

The macroscopic and microscopic characters of the samples may be compared with those reported in the literature on granitoid rocks used in Roman times and extracted from quarries throughout the Mediterranean basin.

On the hand-specimen and microscopic scales, the group I samples are similar to granitoids from quarries in Eastern Egypt (Claudian marble; Lazzarini, 1987) and Western Turkey (Mysian marble, Bingol *et al.*, 1982). The Sardinian granites, although macro- and microscopically similar to the analysed samples, are excluded because of their accessory allanite, which is not found in the examined granitoid rocks.

The single group II sample appears similar to rocks from quarries on Elba (MF; Poli *et al.*, 1989).

Lastly, the group III samples may be compared with the granitoid rocks of Elba (LF; Poli *et al.*, 1989). They are also similar to the Giglio Island granite: the absence of monazite and tourmaline in them does not in fact exclude this provenance, because these accessory minerals are not ubiquitous in the Giglio granite.

Lavas

The lava blocks forming the tiers in some of the sectors, as previously stated, are generally roughly squared and have a maximum size of 40 cm. They vary in colour from light to dark grey and occasionally have a thin reddish patina. Some of the blocks are massive; others appear vesicular because of degassing cavities, often elongated and iso-oriented.

The lava blocks, from oligophyric to porphyritic in structure, show different kinds and abundances of phenocrysts: large plagioclase phenocrysts are common in many of them, although plagioclase is also associated with pyroxene and olivine in some samples. In a few, the plagioclase phenocrysts (elongated and tabular) tend to be iso-oriented due to laminar flow, and give rise to clear anisotropic structures. Such lava blocks are randomly distributed among the tiers of various sectors.

According to their Porphyricity Index (PI), these lavas were subdivided into three groups:

1) Lavas with PI <10 (samples: 6E, 2F, 3F, IIA, IIO, 1L)

These are the most common; their scarce phenocrysts essentially consist of plagioclase (1 to 5-6 mm) and less abundant pyroxene and olivine. In all samples except 3F, the microlites and larger phenocrysts are iso-oriented.

2) Lavas with PI = 25 (samples 1A, 2B, 4D, 1M, IIID)

These rocks also mainly contain phenocrysts of plagioclase, fairly homogeneous in size (0.5-1mm); only in sample IIID are isolated crystals larger, up to 5-6 mm.

3) Lavas with PI = 35 (samples 2A, 3G, 3N)

These are the most porphyritic, and their dominant phenocrysts are plagioclase (sample 2A) or mafic minerals (pyroxene and olivine in order of decreasing abundance; samples 3G, 3N).

In all the above samples, the groundmass is generally intersertal and consists of plagioclase, pyroxene, olivine and opaque oxides.

The characters common to the minerals of the samples are described below:

Plagioclase: crystals, always fresh, are prevailingly euhedral and only rarely sub-rounded in shape (sample 3M). They are commonly twinned and frequently show direct zoning. *Sieve textures* are frequent in the larger crystals, arranged in rows parallel to the major axis or, less frequently, forming envelopes concentric to their cores. The largest crystals frequently contain inclusions of mafic minerals. According to the optical characters, plagioclase is labradoritic to bytownitic in cores and andesinic in rims.

Clinoyroxene: most of the phenocrysts are euhedral and show no traces of alteration. Crystals, brownish in colour and frequently twinned, show an augite composition ($C\wedge\gamma$ = 42°) and often enclose opaque oxides (magnetite) and scarce olivine.

Olivine: sub-rounded and frequently enclosing opaque minerals (magnetite). No alterations were observed except in sample 4D, in which iddingsite occurs along fractures.

These macroscopic and microscopic characters are consistent with those of recent lavas outcropping in areas close to the Theatre (Corsaro, 1990; Corsaro and Cristofolini, 1993; unpublished data). The Theatre, like most of the city of Catania and its outskirts (Sciuto Patti, 1872; VV.AA., 1979; Cristofolini and Romano, 1982; Monaco and Tortorici, 1999), was built on lava flows of Greek and Roman age, with fairly homogeneous surface morphologies (*aa*). In detail, the blocks enriched in plagioclase phenocrysts probably came from quarries near the «*Fratelli Pii*» flow (Sciuto Patti, 1872; dated at 698 B.C. according to VV. AA., 1979).

Chemical data

Granitoids

Table 2 lists the chemical data for granitoid samples.

The analysed rocks fall approximately on the boundary between calc-alkaline and alkaline types, with a pronounced medium- to high-K nature. According to the normative diagram of Streckeisen and Le Maitre (1979), they plot in the fields of granodiorites (group I) and monzogranites (groups II and III) (fig. 1).

Group I samples have the lowest SiO_2 contents (65-67 wt%) and relatively high amounts of P_2O_5 (0.3-0.4 wt%), TiO_2 (0.6 wt%), Th (15-29 ppm), Sr (569-664 ppm) and Ba (1126-1285 ppm).

These geochemical characters are very similar to those of the granodiorites from Western Turkey (Mysian marble), as deduced from the Harker diagrams of figs. 2 and 3, in which the compositional field defined on the grounds of reference data for this marble is also

TABLE 2

Major and minor elements of granitoid samples.

Sample	TR1	TR2	TR3	TR4	TR6	TR7	TR8	TR9	TR12	TR13
SiO_2	66.72	66.36	64.80	73.44	73.77	68.79	67.10	65.35	66.77	66.89
TiO_2	0.62	0.61	0.71	0.15	0.13	0.52	0.57	0.58	0.59	0.54
Al_2O_3	14.87	14.84	15.22	14.39	14.72	15.42	14.93	15.73	15.02	14.84
$FeO_{(tot)}$	3.42	3.58	3.82	1.24	0.97	2.61	3.31	3.55	3.68	3.37
MnO	0.08	0.08	0.09	0.05	0.04	0.06	0.08	0.09	0.08	0.08
MgO	1.82	1.97	2.04	0.4	0.39	0.81	1.62	1.81	1.58	1.73
CaO	4.09	4.18	4.65	1.85	1.63	2.62	3.96	4.15	3.77	4.08
Na_2O	2.97	3.01	3.09	3.97	4.28	3.05	3.16	3.29	3.12	3.15
K_2O	4.11	3.97	3.90	3.23	2.94	4.47	3.59	3.53	3.79	3.36
P_2O_5	0.28	0.35	0.32	0.22	0.10	0.21	0.35	0.29	0.31	0.40
L.O.I.	0.85	0.87	1.16	1.00	0.96	1.34	1.15	1.46	1.09	1.38
Total	99.83	99.82	99.8	99.94	99.93	99.9	99.82	99.83	99.8	99.82
Th	22	15	20.9	4.06	4.17	20.5	26.8	18.6	24	29.4
Zr	159	234	147	68	70	147	170	193	179	213
Y	19.4	21.1	19.4	9.7	7.3	18.3	20.9	22.1	24.8	22.7
Rb	125	116	123	105	100	259	117	116	116	117
Sr	626	617	664	487	487	204	608	641	569	625
Ba	1246	1196	1285	1433	1379	527	1211	1259	1126	1212

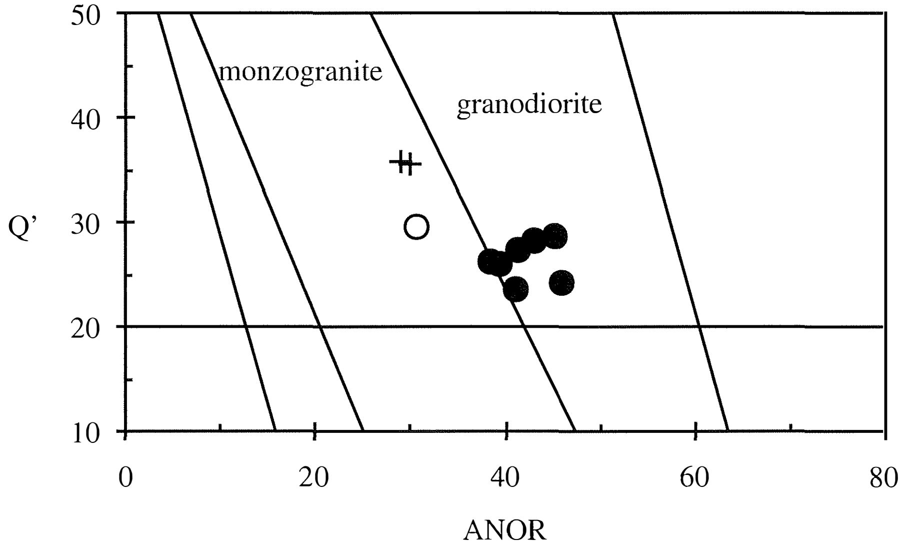

Fig. 1 – Classifying diagram for granitoid samples (Streckeisen and Le Maitre, 1979). Filled circles: TR1, TR2, TR3, TR8, TR9, TR12, TR13 (Group I); open circle: TR7 (Group II); crosses: TR4, TR6 (Group III).

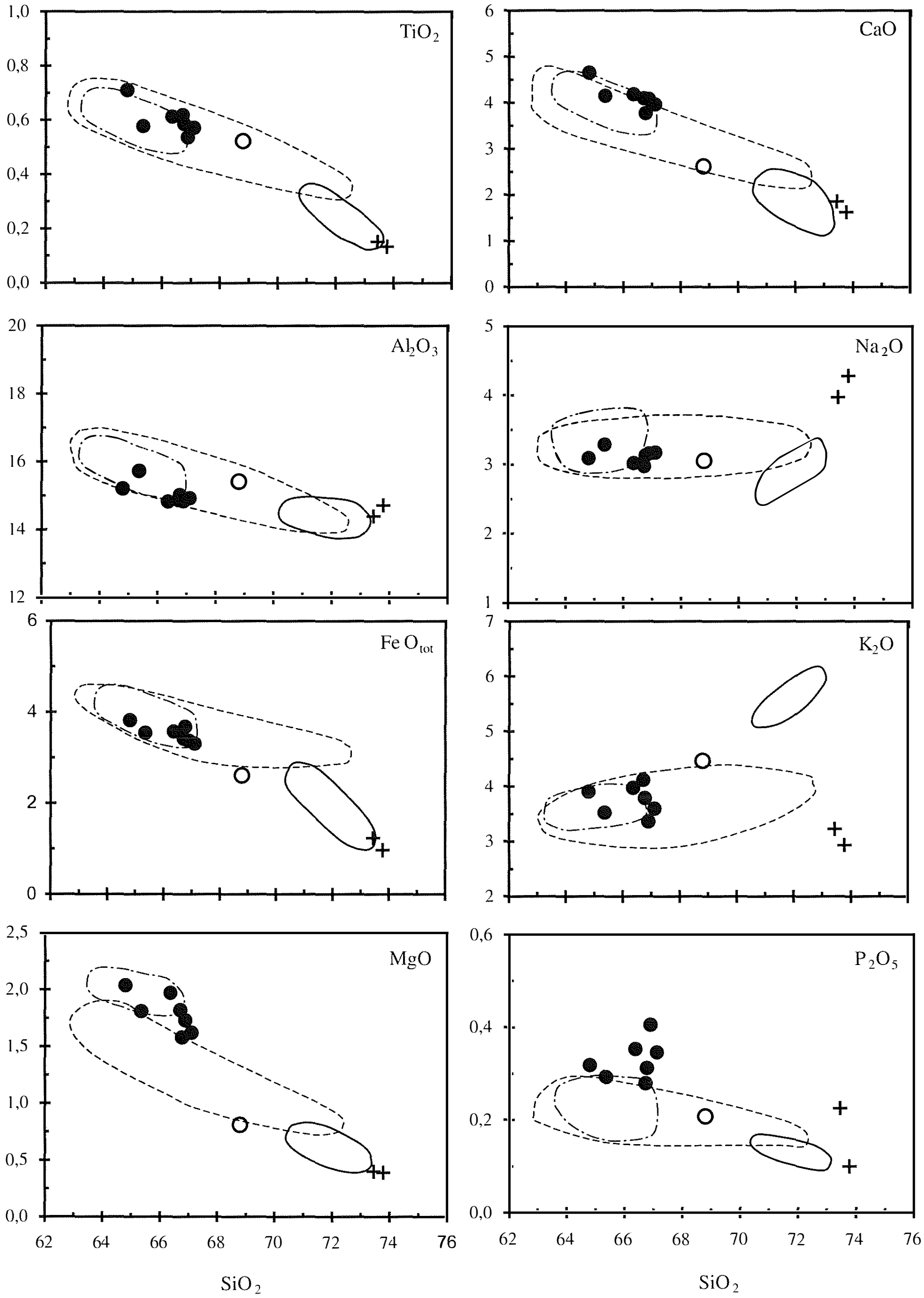

Fig. 2 – Harker variation diagrams of major element oxides in granitoid samples. Dash and dot line: compositional field of Mysian marble (Altunkaynak and Yilmaz, 1998); dashed line: field of the Sardinian granites (Galetti *et al.*, 1992; Poli and Tommasini, 1991); continuos line: field of the Giglio island granites (Poli *et al.*, 1989). Symbols as in fig. 1.

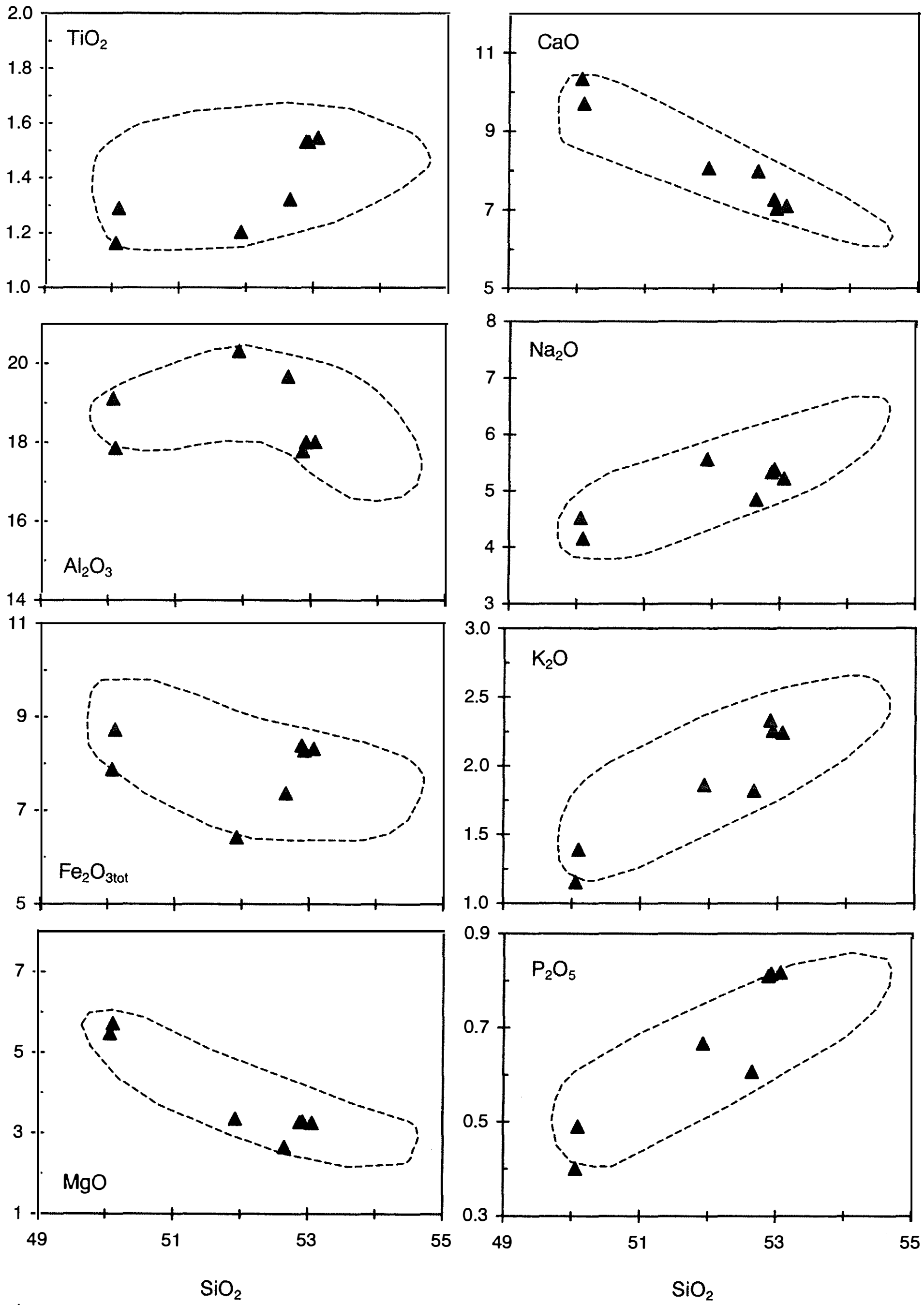

Fig. 5 – Harker variation diagrams of major element oxides in lava samples. Dotted line: compositional field of lavas of Roman and prehistoric periods near Catania (Corsaro, 1990; Corsaro and Cristofolini, 1993).

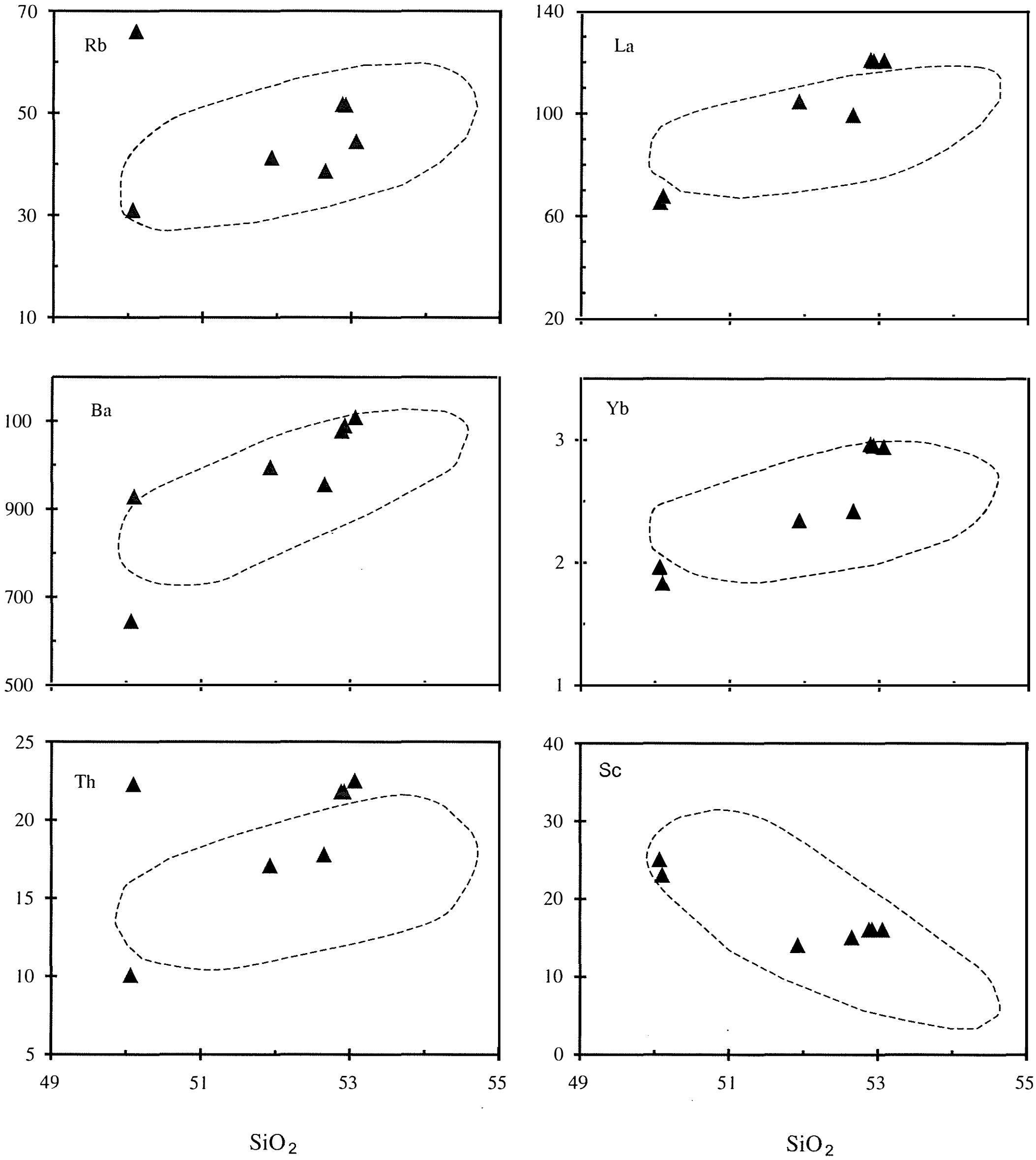

Fig. 6 – Variation diagrams of SiO_2 versus analysed minor elements in lava samples. Dotted line: compositional field of lavas of Roman and prehistoric periods near Catania (Corsaro, 1990; Corsaro and Cristofolini, 1993).

lithotypes identified by microscopic observation. The average and standard deviation values (σ) of prehistoric Etnean lavas outcropping in the vicinity of Catania (Corsaro, 1990; Corsaro and Cristofolini, 1993) are reported for comparison.

All the rocks belong to the Na-alkaline series and mostly plot in the mugearite and subordinately hawaiite fields of the TAS diagram (Le Maitre, 1989) (fig. 4). In both TAS and Harker variation diagrams (fig. 5) and in those showing the distribution of some minor elements versus SiO_2 (fig. 6), the analysed samples plot in or near the compositional field of prehistoric lavas outcropping in the vicinity of Catania (Corsaro, 1990; Corsaro and Cristofolini, 1993).

CONCLUSIONS

Granitoid and volcanic rocks used as building materials for the Roman Theatre in Catania were analysed in order to establish their probable provenance.

The granitoid samples were subdivided into three groups with homogeneous characteristics on the basis of their combined petrographic and chemical data.

Group I includes the rocks used for paving the *orchestra* and for many of the columns which originally supported an arcade at the top of the *cavea*. At present some of these columns are placed to one side in the *orchestra* of the Theatre; others were used in other monuments in the city, specifically the Cathedral. The group I samples show petrographic and geochemical characters wholly consistent with those of granodiorites once extracted from a quarry in Western Turkey («Mysian marble» from Kozak). The group II sample, consisting of only one fragment of a column, is hypothesized to come from the island of Elba.

For the remaining samples, taken from columns, no certain indication of provenance can yet be made.

The petrographic and geochemical data on the volcanic rocks and comparisons with data from the literature (Cristofolini and Romano, 1982; Corsaro, 1990; Corsaro and Cristofolini, 1991) indicate that the blocks forming the tiers in the *cavea* of the Roman theatre in Catania, despite their relative heterogeneity, all undoubtedly came from the Etnean area, and were probably excavated from quarries opened up in Recent Mongibello lava flows of pre-Roman to prehistoric times, located in the vicinity of the ancient Roman city.

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