The Art of Ceramics
The Blend of Art and Science in Technology
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COLOURS AND STORIES OF THE ITALIAN MOSAICS

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1. INTRODUCTION

The art of mosaic dates back four thousand years. The findings in Mesopotamia, in the rich temples and palaces on the Euphrates river, clearly indicate its use on the most ancient masonry. Subsequently, all the countries on the Mediterranean began producing different types of mosaics with variations in designs and materials used[1-3].

The Mediterranean was the cradle of this art: Italy and its islands, by virtue of their geographical position, acquired nearly every type of floor and wall mosaic, with figural and geometric decorative motifs of historical, political and religious origin.

The first examples of Phoenician mosaics of white marble tesserae which decorated cocciopesto floors (*opus signinum*) are dated to the end of the 2nd millennium B.C. At Solunto and Selinunte, Greek cities in Sicily, there are remains of the "sign of Tanit" in marble tesserae on cocciopesto floors (Figure 1). The sign of Tanit, a female divinity, is associated with the symbol of the male divinity – a bull's head surrounded by rays.

In the island of Mozia, near Sicily, there are mosaics made from river pebbles (Figure 2). This technique, associated with an iconography of oriental origin, and with a preference for hunting scenes or animal fighting scenes, was very probably introduced by Greek mosaicists.

In the southern part of Italy, which took the name *Magna Grecia* due to its numerous and powerful Greek colonies, there are countless brick floors, still preserved outdoors, with pleasing and inventive geometric decorations.

The productive Alexandrian period, from 300 B.C., saw a flourishing of Hellenistic mosaic and the technique of *opus tessellatum (using tesserae obtained by cutting stone, and subsequently also ceramics and glass)*, a precious marriage of Greek skill and Egyptian workmanship. In Italy, these works adorned the homes of the wealthy Samnites, and later those of the Romans. In Pompeii they decorated the floors of public and private buildings; one famous example is the *House of the Faun*. Many of the so-called *"Nilotic"* mosaics found in Pompeii are now kept in the National Museum in Naples (Figure 3); among

these, there is the mosaic depicting the Alexander the Great's victorious battle against Darius (Figure 4).

Even the Nile Mosaic, an extraordinary floor mosaic which we shall describe in detail later on, constructed by Silla in the 1st century B.C. in an Iseum in the Temple of Fortuna Primigenia at Palestrina (temple and large lighthouse 50 km from Rome), is of Hellenistic origin.

The mosaics of the Roman imperial period, particularly those kept in the museums of Rome and in the Vatican Museum, testify to the Eternal City's wealth in the days of the Caesars, the richness of the precious marbles, the careful mortar-work, the sophisticated techniques for composing refined and admirable designs. But they also illustrate how, in becoming Roman, mosaic art began to reflect the characteristics of a nation that was still divided into castes – an enduring Hellenistic legacy.

The most patent example is Villa Adriana at Tivoli, where the type of decoration, the types and colours of the marble on the walls and floors, and the singular use of Luni marble, all differentiate the parts of the villa intended for the emperor's use (Figure 5a) from those inhabited by domestics, soldiers and servants (Figure 5b).

The great villas of Sicily had other functions. Villa di Patti, Villa di Piazza Armerina (3rd-4th century A.D.) and the others still being designed were built when the imperial capital was far away, at Constantinople, and their mosaics had the political purpose of displaying the wealth of the owner.

The floor mosaics depict the great hunts (Figure 6), and the transport from India, Egypt, Mauritania and many other parts of Africa – at the *dominus'* expense – of wild animals (Figure 7) that were shown in the circus to entertain the populace; the same populace which was subsequently called upon to elect the regent of the city.

Theodoric, king of Italy by will of the Byzantine Emperor, in the 6th cent. A.D. enriched his capital city, Ravenna, with Arian churches decorated with magnificent mosaics (Figure 8). These works reveal the Gothic king's love of this art, with their exquisite designs admirably executed by master mosaicists, using marble, coloured glass and tesserae with gold and silver leaf. Before him Galla Placidia, (Figure 9) and after him Justinian, (Figure 10) also gave Ravenna mosaics which embody the rich legacy of the Byzantine school of mosaic and glass-making art.

Unfortunately, we cannot describe all the mosaics that are kept in Italy, but neither can we neglect to mention at least a few great examples which exist in our country and bear witness to its history. Among these are the works adorning Saint Mark's Cathedral in Venice, which is decorated with marble and sculptures brought after the last Crusade, but with mosaics designed in

Venice itself, whose iconography and technique mark the transition from the typical Byzantine style to the more descriptive Venetian style, inspired by the most famous painters.

We must also mention the works of that same period, which in southern Italy adorned the floors of the basilicas at Otranto, Trani, Trapani and Rossano Calabro. These are the *"books in stone"*, which describe characters drawn from passages of history and religion, among the branches of the symbolic tree of life.

It is clear that priest Pantaleone, author of the floor mosaic design in the Basilica of Otranto, was able to consult the well-supplied library of the Basilian monks in their monastery not far from his native city in Puglia. Biblical characters from the Pagan and Christian periods are mixed with images from oriental religions and folk scenes inspired by the seasons (Figure 11). The tesserae used in this mosaic were cut from local stones – the same stones which make up the loose layers placed under the mosaic floor to improve its conservation.

The medieval mosaics which stand out, by virtue of their exquisite beauty, are the 12th century works in the Palatine Chapel and in King Roger's Room (with an Arab-influenced mosaic design) at Palermo, and those in the great church at Monreale (Figure 12), near the Sicilian capital city. In this church, the mosaics cover nearly the entire surface of the walls and vaults, depicting stories from the Old and New Testaments, over an area of 6430 m^2 (it is the church with the second-largest extension of mosaic decorations in the world, after S. Sophia in Istanbul and before St. Mark's in Venice).

In Rome, Giotto also measured himself with this art, and there are extant fragments of a large mosaic composed by him, which decorated the old Roman Basilica of St. Peter. However, after the sixteenth century, mosaic art was abandoned, and mosaic techniques were used only to imitate the major well-known works of famous painters. Examples of these can be seen in the new Basilica of St. Peter.

In the 20th century, mosaic art flourished again, and Ravenna has been one of the most important international hubs of this revival[4]. Among the modern mosaic artists who have already made their mark in history, we can cite Severini (a significant example is the Via Crucis, Figure 13) and Signorini.

2. THE MOSAICS TELL A STORY

From the countless stories narrated by Italian mosaics, we have chosen three which represent three significant aspects of human existence: the religious symbolism of the city of God descending from the heavens; the political power underlined by the splendid robes of an imperial court and the scenes[5] of everyday life around a great river[6].

FIGURE 1 - The "sign of Tanit" in marble tesserae on a cocciopesto floor at Selinunte (Sicily, Italy).

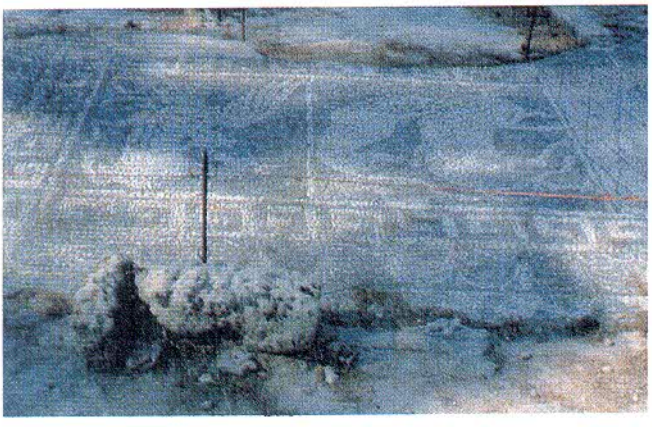

FIGURE 2 - Mosaic made of river pebbles in Mozia (Sicily, Italy).

FIGURE 3 - Mosaic from the "House of Faun", Pompeii (National Museum of Naples, Italy).

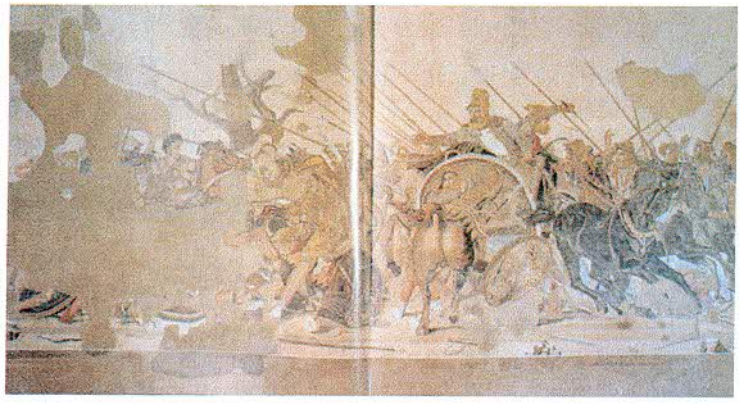

FIGURE 4 - Mosaic of Alexander the Great's victorious battle against Darius, from the "House of Faun", Pompeii (National Museum of Naples, Italy).

FIGURE 5a - Mosaics of Villa Adriana, Tivoli (Latium, Italy): from the emperor's rooms (Vatican Museum - Rome, Italy).

FIGURE 5b - Mosaics of Villa Adriana, Tivoli (Latium, Italy): mosaic of the imperial guard's rooms.

2.1. The heavenly city

The apse mosaics of San Vitale and S. Apollinare in Classe, dating back to the 6th century, attest to the presence of master artists of the Byzantine School at Ravenna, to the utmost care in the selection and use of mosaic materials, particularly glass tesserae, and to a high degree of erudition in interpreting the words of the "Apocalypse".

According to tradition, the words of the Apocalypse, written by John the Evangelist while on a mountain on Patmos island, were dictated by God himself who, after the destruction of Babylon (a city which represented the cause of all suffering, a city where the desire to do evil triumphed, hypocrisy dominated and deceit and seduction prevailed), wished to reconcile himself with mankind by bestowing a new, holy city in which nobody could desire evil, practice corruption, or act falsely. The City of God was caused to descend from the heavens; it had the greatest splendour, and shone like a precious stone – like a gem.

In the apse of San Vitale, the new Jerusalem and Bethlehem (Figure 14) are radiant images, magnificent presences and forceful realities, shown in their full splendour, while still near the heavens during their voyage towards the earth. It is the holy city which an angel shows to John, and which the apostle meticulously describes in the Apocalypse. Jerusalem, entirely bathed in light, seeks to set itself apart from the storms which buffet mankind. Alternating inside the gold, which forms the entire background and gives the overall colour, are bejewelled areas of brilliant blues and greens, set off by the luminous white of the marble.

The mosaic representation of the city is identical to the vision described in the Apocalypse and, element after element, it illustrates the Biblical passage. The city which the angel showed to John had tall sturdy walls, with three doors facing each of the four points of the compass. Each of the twelve doors is depicted in the mosaic with a tessera made from a single pearl. The city was square in shape, its length equal to its width, and also to its height. The angel used a gold reed to measure the walls of the city in John's presence.

The Bible lists the names of the semi-precious stones and gems that were used. In the mosaic, these stones are imitated using "enamel" tesserae of the corresponding colour and of equal brilliance. Below is the list of the gems, in the same order as they appear in the biblical passage: jasper, sapphire, chalcedony, emerald, sardonyx, tourmaline, chrysotile, beryl, topaz, chrysoprase, hyacinth, amethyst. In nature, some of these stones are banded, others exhibit a starburst effect, while others still are clear varieties, coloured green or blue, or with golden highlights. The refinement of the mosaic decoration lies in the fact that these highlights were taken into consideration during its composition, and enhanced by the effect of the golden background.

The Basilica of S. Apollinare in Classe, built almost at the same time as San Vitale, is decorated with mosaics representing several verses from the Apocalypse (Figure 15), and more specifically: the open heavens with the image of Christ resplendent among precious stones and surrounded by four living creatures: the first living creature is like a lion, the second creature like a calf, the third has a face like a man, and the fourth is like a flying eagle. All have wings and are full of eyes within, and a voice continually repeats, day and night: Holy, holy, holy is the Lord God Almighty. In the apsidal arch the words are written on the labara of the heavenly militia, and of the Archangels Michael and Gabriel.

In the Basilica of S. Apollinare in Classe we again see the two heavenly cities, Jerusalem and Bethlehem, from whose doors emerge the twelve tribes of Israel; alongside is the tree of life. In this arch, too, we note the extraordinary splendour of the gold, which enhances the colours of the gems, precious stones and ornamental stones, resplendent with green and blue light; they shine like crystals, appearing to capture the reflections of the gold leaf. A superb harmony, impossible to achieve without knowledge of the description and characteristics of the gems, which the angel so clearly indicates in the biblical passage, and which the apostle reiterates with the words "I, John have heard and seen these things".

2.2. The silken robes of imperial court of Byzantium

The "secret of silk" was for many centuries the exclusive property of China. By indirect means, empress Theodora of Byzantium managed to discover the exact method for raising silkworms, processing the cocoons and obtaining their precious filament: from two Nestorian monks – heretics therefore – who brought from China, hidden in the hollow of a bamboo cane, the small larvae and the mulberry leaves on which they feed. Theodora had them promoted to abbots and regents of their monastery in Lebanon. Emperor Justinian later made the manufacture of silk, whose method was kept secret, a state monopoly.

This preamble helps us to examine and recognise the colours and designs of the silks worn by the Byzantine emperors and ladies-in-waiting in the wall mosaics of the Basilica of San Vitale in Ravenna. It should be noted that, at the time when this mosaic was composed, the empress Theodora was very probably already dead.

The colours and patterns of the silken robes were specially designed for the rich Byzantine court by the already-thriving state manufacture, and personalized to reflect the status of the high office which each personage held at the time.

Especially striking is the complex pattern on the dress of Antonina (the

FIGURE 6 - Mosaic depicting the great hunts, Villa of Piazza Armerina (Sicily, Italy).

FIGURE 7 - Mosaic depicting wild animal transport, Villa of Piazza Armerina (Sicily, Italy).

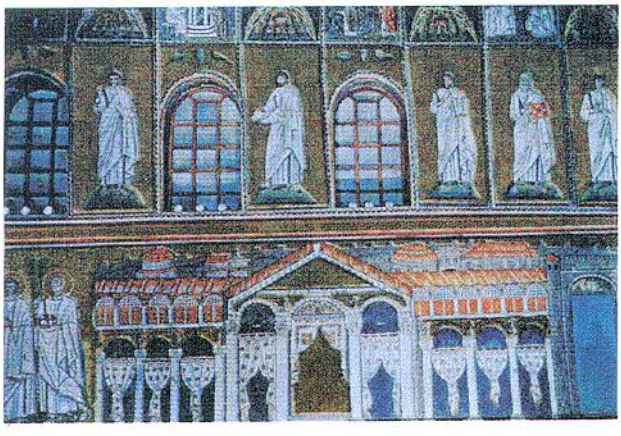

FIGURE 8 - Wall mosaics in S. Apollinare Nuovo (Ravenna, Italy).

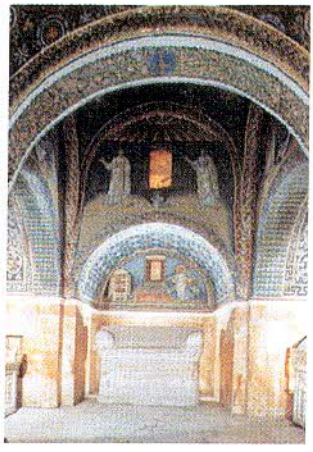

FIGURE 9 - The mausoleum of Galla Placidia (Ravenna, Italy).

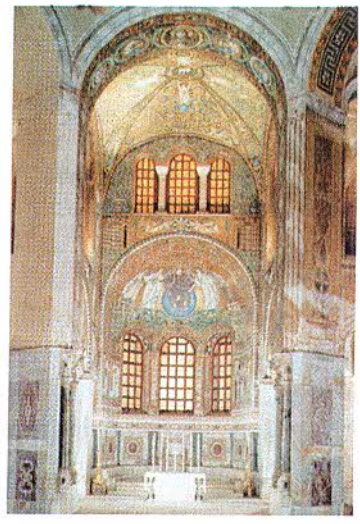

FIGURE 10 - The apse of S. Vitale (Ravenna, Italy).

FIGURE 11 - Detail of the floor mosaic in the Basilica of Otranto (Puglia, Italy).

FIGURE 12 - Mosaics of the Monreale Cathedral (Sicily, Italy).

inseparable friend of Theodora, who was called to court as lady-in-waiting to the empress) embellished by sumptuous decorations up until the border, giving emphasis to the whole. Nearby is the graceful and delicate figure of Giovannina, daughter of Antonina and the General Belisario. The amiable character of this young woman is underlined by the harmonious hues of her dress (Figure 16), with a pattern of flowers and birds. The contrast between this personality and the jaded Byzantine court ultimately led her to enter a convent.

Without a doubt, some of the other female figures shown in the mosaic were better integrated at court. One of these is dressed in sumptuous silks and jewels, and another in silks of contrasting colours: red and green (Figure 16). The latter was probably particularly close to the emperor at that time. In fact the figures of birds on her green dress are strikingly similar to those on the golden banner draped over Justinian's shoulders (Figure 17).

These observations aside, it is important to remember that the silks, and hence the dresses themselves, were manufactured by the state and court, rather than in Persia or China. The materials of the glass mosaic tesserae, highlighting the designs and colours of the silks, help create a harmonious yet opulent effect, and the brilliance of the jewels adds the finishing touch to this magnificence.

2.3. Life and nature on the Nile River and its banks

The "Nile Mosaic" is a floor decoration in the Temple of Fortuna at Praeneste, near Rome. The mosaic was commissioned by Silla, in 82 B.C., to celebrate his victory in the war against Marius. It is situated in the oracle hall that was possibly an Iseum, i.e. a Sanctuary of Isis.

The mosaic shows the course of the River Nile from source to delta. It depicts the sluice-gates, and the tumultuous passage of the water through the rugged mountain terrain, with the river growing calmer as it approaches the delta (Figure 18).

The religiousness of Egypt, its science, natural beauty, the colours of its sky from dawn to dusk, are portrayed in all their glory. Hunting scenes take place along the course of the river – with bows and arrows in the region of Upper Egypt, and with spears in the marshy delta region (Figure 19). There is the breeding of various types of land and aquatic animals, and the characteristic dovecotes. The mosaic also depicts the population's most productive activity: agriculture.

The colour and transparency of the glass mosaic tesserae have been preserved intact, despite the restorations they have undergone. From the principal historical sources, we know that the mosaic was composed by Alexandrian workers, and that the materials for the tesserae also came from

that city. In fact, there is documentary evidence of entire families of mosaic artisans leaving the Egyptian capital and setting ashore at the port of Puteolis (Pozzuoli, near Naples), supplied with considerable quantities of glass, and later settling in the Roman territories. The port of Puteolis had links with the port of Alexandria, especially for the importing of grain. The Alexandrian glass materials are attributable to workshops of exceptionally high technological standard, and the skill of the mosaicists is ascribable to experience acquired in specialist schools and workshops. Alexandria was the point of reference for the most advanced artistic workshops of the day. Even the design of the Nile mosaic itself is attributed to an Alexandrian artist.

The area supporting the mosaic was originally at a slightly lower level than the other floors of the Iseum, making it possible to fill this singular basin with water, creating the illusion of images in movement. In this way the lotus - divine flower which germinates beneath the waters of the Nile before opening - seemed to sway underneath the water surface. The flowers of the acacia tree acquired greater vividness, as did the reed leaves and the pinnate fronds of the date palms. The real and imaginary fauna is depicted with Greek names. We recognise, among others, the cheetah, the lion and the hippopotamus, which disappeared from Egypt around 1000 B.C., and crocodiles, gazelles, cattle, jackals, hyenas, monkeys, wild boars and donkeys used for transport. The infinite colour gradations of the mosaic glass enable us to recognise many birds, including: pigeons, ducks and geese.

The composer of this work must have been particularly skilled in multiple disciplines, and able to consult the precious books of the celebrated library of Alexandria, which collected texts on all the sciences known at the time.

The buildings and architectural elements display the artist's perfect knowledge of Egyptian constructions. The human elements are handled with especial care. The priests wear white linen robes and are shown intent on sacred functions, or in procession. One priestess is making an announcement to the soldiers (Figure 20). Men and women, gladdened by musicians, are gathered underneath a pergola during a nocturnal feast. Black hunters armed with bows and arrows hunt birds in the rough rocky terrain, while the hunters of the delta throw their spears at the hippopotamuses submerged underwater. On the ships, the men are engaged in line fishing and, near the huts, others are taking the oxen to pasture, tending the dovecotes or cultivating the fields and vegetable gardens. The warships, with multiple ranks of rowers, are laden with soldiers and arms, spears and shields, and the sails of the merchant ships are being pulled by the seamen.

The well of Syene recalls (Figure 21) the custom of measuring the level of the Nile, in order to set equitable taxes as a function of the abundance of the harvest. But it also reminds us that the scientists were able to measure the

FIGURE 13 - Contemporary mosaic: the "Via Crucis" by Severini (Cortona, Italy).

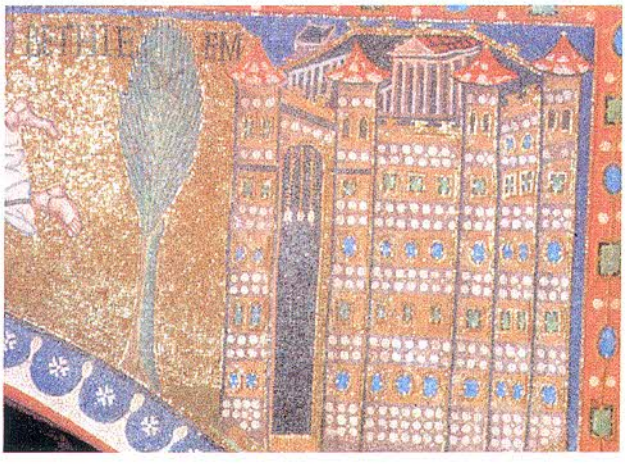

FIGURE 14 - The "heavenly city" of Bethlehem, mosaic of the apse of S. Vitale (Ravenna, Italy).

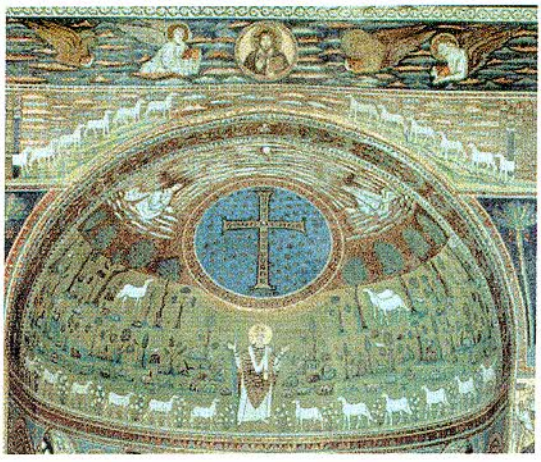

FIGURE 15 - Mosaic decoration of the apse of S. Apollinare in Classe (Ravenna, Italy).

FIGURE 16 - Mosaic of Antonina and other ladies-in-waiting of the empress Theodora, mosaic of the apse of S. Vitale (Ravenna, Italy).

FIGURE 17 - Mosaic of Justinian, apse of S. Vitale (Ravenna, Italy).

earth's diameter, based on the angle of the sun's rays upon the surface of the water in these wells.

The colours and arrangements of the tiles confer life and animation to these representations, and to the waters of the Nile which form the backdrop. The design of this mosaic, and the richness of the mosaic glass used to compose it, encompasses the history of scientific knowledge, arts and craftsmanship up until the first century B.C. in this region of the Mediterranean. Its capital Alexandria promoted artistic craftsmanship which produced admirably designed and executed works, and exported glass materials, finished works and specialised labour. The Roman villas constructed in the African Mediterranean regions bear witness to this.

In addition, Alexandria was a merchant centre with a very wide sphere of influence. From here, the techniques of glass mosaic spread toward the Roman west. Epigraphic evidence testifies to the extraordinary mobility of the workers, who established glass-making and mosaic workshops in Rome and other parts of Italy, but also in central Europe. At Trier and Cologne we find works of vitreous enamel, artistic glass, and a glass-making technology that continues to this day. Alexandria held the supremacy in the field of glass and mosaic technology up until the 3rd century A.D.

It is likely that King Theodoric, for the wall decorations of his important 6th century Arian basilicas, did not rely on the experience of the Byzantine glass-makers, and on the glass produced in that city, but instead imported from Ravenna the Roman glass-makers who produced classic glass in the ancient tradition.

3. STRUCTURE AND PROPERTIES OF COLOURED GLASS

For many centuries, up to the Roman epoch, mosaics were almost exclusively employed in floor decorations. The materials used were stones and ceramics and, rarely, glass.

The range of colours of these mosaics, although often reaching a surprising variety and a valuable aesthetic effect, was considerably limited by the materials employed. Besides, elegance and austerity criteria diffused in Roman epoch, made the "simplified" mosaic typologies to be prevalent, to end up with the predominating black and white mosaic.

With the advent of the Christianity, the mosaic decorations got to the walls and vaults of the religious sites, probably with the aim to elevate the sacred icons to higher positions, in spiritual sense, too. The decorations were then realised with materials destined to last "forever", to become "eternal painting".

The position of the wall mosaics, untouched by the wear and the mechanical stress, allowed the use of glass. At that time, this material had already undergone an intense technological development of production and manufacturing and was available with a vast range of colours. The glass played a fundamental role in the evolution of the mosaic technique of the walls covering and decoration, towards an art that reached sublime forms.

The colouring of ancient mosaic glass is one of its most striking aesthetic characteristics; in fact the special beauty of a glass mosaic depends in part on how the material is cut and shaped, but most importantly on the various colours and tints of glass which are available.

It has been suggested that the coloration of the glass and the resulting tints were not always an intentional result, but rather obtained through the empirical addition of colouring agents to the base. The colouring elements could either occur as impurities in the principal materials and in raw materials designated "special ingredients", whose composition was not known.

The coloration of the ancient mosaic glass is determined by the presence of four colouring elements (iron, copper, manganese and cobalt), which combined in opportune proportions and included in different glass matrices make it possible to obtain a vast range of colours and shades. Sometimes even tiny quantities can make an important contribution: for example cobalt, in the form of cobalt oxide percentages even less than 0.1%, imparts a very intense colouration to the glass, and covers the colouring produced by other ions.

Another way in which chemical elements can become part of the glass structure as colorants is through the formation of aggregates or particles of colloidal or microcrystalline dimensions, which takes place under special conditions during the melt; in this case the metal is not dissolved in the glass, but rather dispersed in the form of minute particles.

The physical origins of the glass coloration result from a complex interaction of structural and chemical effects[7-8]. The absorption process in coloured glass is determined by the presence in the glass base of 3d elements known as chromofores (Fe, Mn, Cu, Co, Cr, etc.), and is analogous to the effect of salts of those same elements in aqueous solution.

Whether they occur as impurities in the raw materials or as the result of deliberate additions, their absorption of electromagnetic energy in the visible spectrum (450 – 700 nm) is due to an electron transition from a lower-energy orbital d to a higher-energy orbital d.

In addition to being influenced by their own nuclei, these excitation electrons also undergo other interactions with ions or groups of ions known as binders, which in combination with the 3d elements give rise to coordination compounds within the glass matrix. Often, a small change in the field of the

FIGURE 18 - Mosaic of the River Nile, Praeneste (Latium, Italy).

FIGURE 19 - Hunting scene in the delta region, a detail of "Nile Mosaic", Palestrina (Latium, Italy).

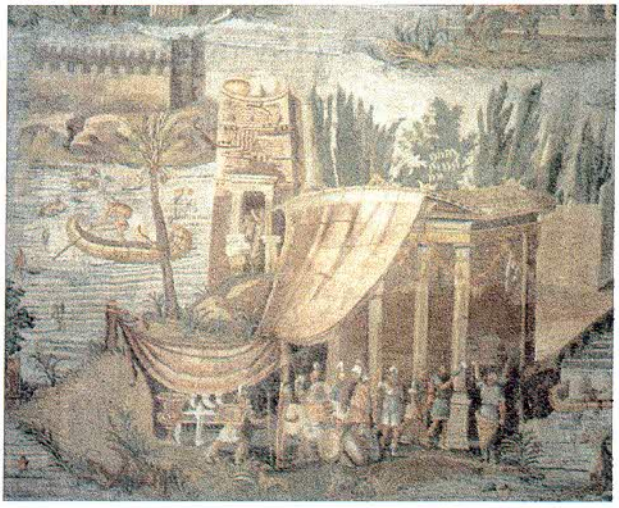

FIGURE 20 - Sacred function, a detail of "Nile Mosaic", Palestrina (Latium, Italy).

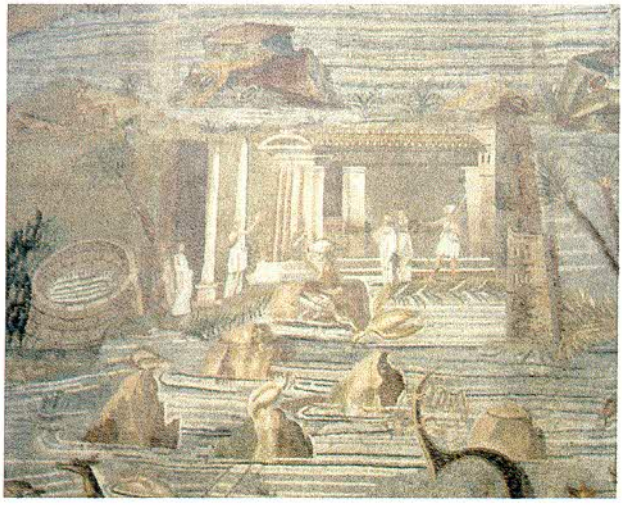

FIGURE 21 - The well of Syene, a detail of "Nile Mosaic", Palestrina (Latium, Italy).

binders can produce enormous changes in the absorption behaviour, with consequent effects on the colouring.

The visible-spectrum absorption bands of the coordination compounds are thus affected both by d→d type transitions, and by the transfer of charge from the binder to the metal or vice versa, which is increasingly facilitated the more the metallic cation is oxidising, and the more the binder is reducing.

The colouring effects of metal ions are very complicated: they depend on the equilibrium between the various valence forms as well as on the coordination state. In the latter case, absorption often depends on the equilibrium between two or more differently coordinated colour centres, as in the case of iron (III).

The modification of the base mixture of a coloured glass, without any alteration of the colorants, plays a fundamental role in determining the absorption behaviour of the glass. The effect of the base composition of the glass is so important that soda-lime and leaded glass must often be considered separately.

The polarization effect between nearby ion pairs considerably influences the absorption behaviour: this can be seen in coloured glass containing alkaline ions, which exhibit stronger absorption due to their low field force. The effect of the surrounding electromagnetic fields can facilitate or hinder electron orbital jumps, thereby shifting the absorption band.

4. TYPES OF GLASS

Our study about composition and colour of mosaic glasses belonging to a long period of time (5^{th}–13^{th} century), is not limited to the analyses of samples coming from Italian sites, but is extended to materials from other regions of the Mediterranean area: Greece, Jordan and Syria (Table I). After identifying the various types of glass through observation of the data obtained[9-10] (soda-lime glass, lead glass, etc.) distributed in various locations and belonging to different periods, it was interesting to compare the characteristic tesserae of each sample group, with a view to their systematic classification, differentiating ancient glass on the basis of region or chronology (from the 5^{th} to the 13^{th} century A.D.) and attempting to identify the trends in the development of glass-making technology.

4.1. Fundamental components

The first comparison can be drawn from Table II, which summarises the concentration intervals of the glass from each sample group, with regard to the most commonly occurring oxides, in soda-lime and lead matrices.

TABLE I - Provenance and period of the examined samples.

SITE OF FINDING	LOCALITY	PERIOD
Archaeological excavation	Bosra - Syria	5th –6th century
Archaeological excavation	Petra - Jordan	5th –6th century
Archaeological excavation	Nebo Mountain - Jordan	5th –6th century
Neoniano Baptistery	Ravenna - Italy	6th century
S. Vitale Church	Ravenna - Italy	6th century
Archaeological excavation	S.Giusto-Faragola (Puglia, Italy)	6th century
S. Ambrogio Church	Milan - Italy	9th century
Dafni monastery	Athens - Greece	11th century
S. Maria in Aracoeli Church	Rome - Italy	13th century

TABLE II - Approximate concentration intervals of the glasses main components in soda-lime and soda-lime plus lead matrices (weight %).

SODA-LIME GLASSES						
Provenance	**SiO_2**	**Na_2O**	**CaO**	**K_2O**	**MgO**	**Al_2O_3**
Bosra	69-71.5	13-15	6-6.5	0.5-1	0.5-1	2-2.5
Petra	66-71	9.5-15	7-10.5	1-2	0.5-1	2.5-4
Nebo mountain	68.5-72	10.5-17	7-9.5	0.5-1	0.5-1	2.5-3.5
Neoniano	61-65.5	15.5-21	4-8	0.5-1	0.5-1.5	1.5-2.5
S. Vitale	60.5-70.5	15-20	6-13	0.5-1.5	0.5-1.5	1.5-3
S. Giusto	66.5-68.5	15.5-19.5	5.5-9	0.5-1	0.5-1	1.5-3
Faragola	65-68.5	17.5-19	6-13	0.5-1.5	0.5-1.5	1.5-3
S. Ambrogio	60.5-66	14-21.5	5.5-11.5	0.5-1	0.5-1.5	2-3.5
Dafni	64.5-79.5	7.5-13.5	5-11.5	1-3	1-2.5	0.5-3
Roma	62.5-64.5	12.5-15	8-9	3-4.5	2.5-3	1.5-2

SODA-LIME + LEAD GLASSES							
	PbO	**SiO_2**	**Na_2O**	**CaO**	**K_2O**	**MgO**	**Al_2O_3**
Bosra	~ 30	45.5-46	7.5-8	6-6.5	0.5-1	0.5-1	1.5-2
Petra	3-19	58.5-67.5	10-12	6-10	1-3	0.5-1	2-3
S. Vitale	4-13	56-61.5	15-22.5	5-8	0.5-1	0.5-1.5	1.5-2.5
S. Ambrogio	2-20	57.5-64	15-17	5.5-8.5	0.5-1	0.5-1	2-3.5
Dafni	3-9	61.5-65.5	11.5-14	5-8.5	1.5-3	1-2	0.5-3.5
Roma	3-13	58-60.5	9-11.5	6.5-8.5	2-2.5	2-2.5	0.5-1

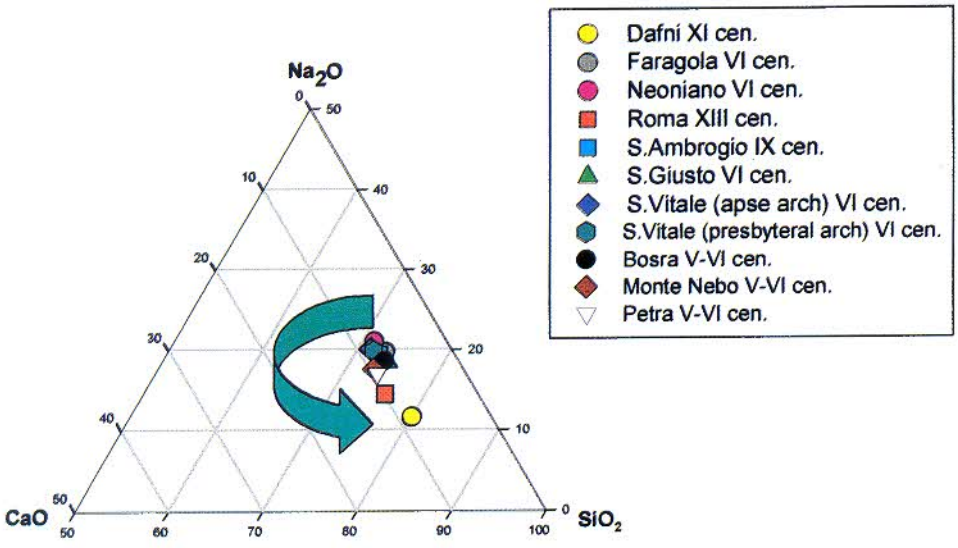

FIGURE 22 - Ternary diagram SiO_2-Na_2O-CaO of Byzantine mosaic glasses.

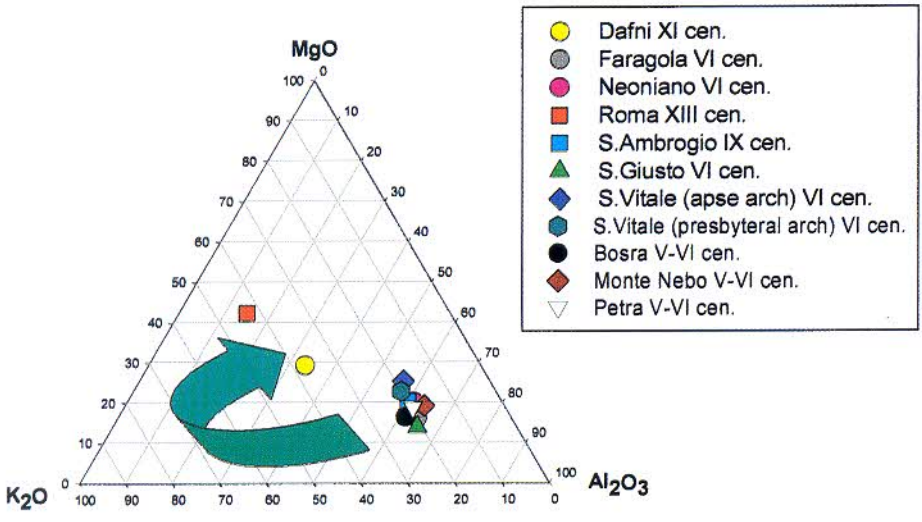

FIGURE 23 - Ternary diagram K_2O-MgO-Al_2O_3 of Byzantine mosaic glasses.

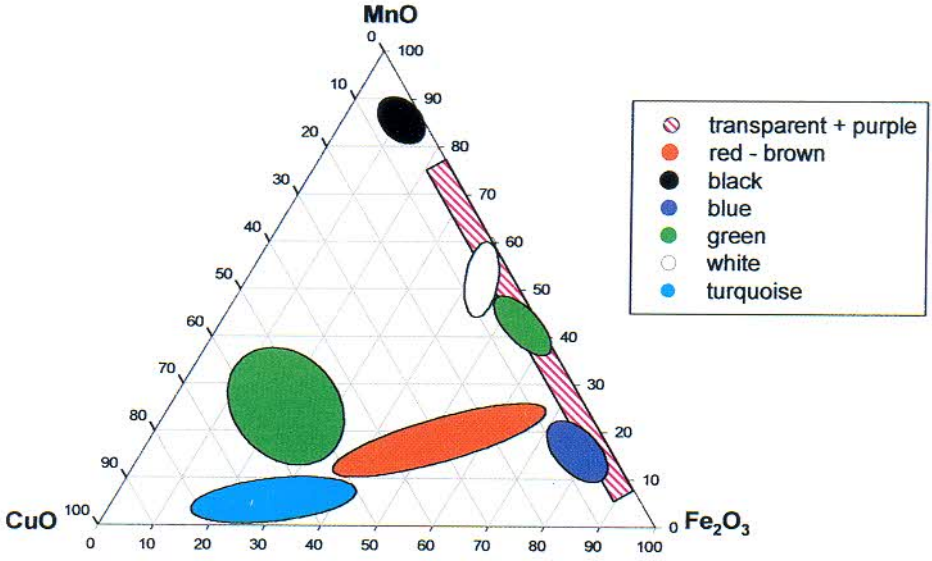

FIGURE 24 - Ternary diagram Fe_2O_3-MnO-CuO of unleaded Byzantine mosaic glasses.

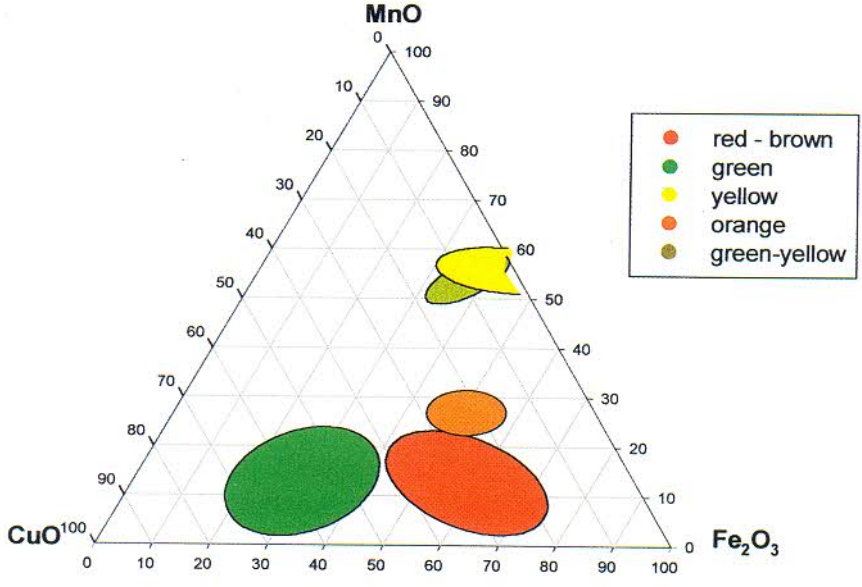

FIGURE 25 - Ternary diagram Fe_2O_3-MnO-CuO of leaded Byzantine mosaic glasses.

The SiO_2-Na_2O-CaO ternary* diagram (Figure 22) shows the proportions of the three principal oxides in the original mixture. The positioning of the Rome (13th century) and Dafni (11th century) samples is clear, and probably not attributable to a different basic recipe, but rather to the use of fluxing agents with a lower content of Na_2O, and a greater amount of K_2O. As a matter of fact, the principal oxides have very similar intervals in the various sample groups, and, in this first analysis, are not completely useful for the proposed objective; more information are obtained by analysing the concentrations of minor oxides: K_2O, MgO and Al_2O_3. These oxides characterise three different categories of glass: the tesserae from the mosaics at S.Giusto, Faragola, S.Vitale, Battistero Neoniano, S.Ambrogio, Petra, Monte Nebo, Bosra (covering a period of time from the 5th to the 9th century) have fairly similar chemical compositions, with low concentrations of both K_2O and MgO; the concentrations of both oxides are slightly higher in the "Dafni" samples, whereas the "Rome" samples exhibit markedly higher concentrations.

The K_2O-MgO-Al_2O_3 ternary diagram (Figure 23) enables us to discriminate the various samples as a function of the aforesaid oxides present in the raw materials, as secondary components in the siliceous sands, or as modifier agents of the glass network. The 5th to 9th century glass samples are of the "low-magnesium" and "low-potassium" type, whereas the Rome and Dafni samples are differentiated by a higher content of K_2O in both, and of MgO in the case of the Rome samples.

The analysed tessera samples essentially conform to the typical compositions of the glass produced during the various periods: starting from the 5th century A.D. we find glass with a typically Byzantine composition, in which Na_2O and CaO based fluxing and stabilizing agents were used; in glass samples from the 11th century A.D. ("Dafni" samples) and subsequently from the 13th century A.D. ("Roma" sample) the composition of the glass suggests an evolution towards medieval glass-making technology, in which K_2O and MgO based fluxing agents and stabilizers were used. It is possible that this development started from northern Europe, where the use of K_2O and MgO rich fluxing agents is supposed to have originated, and then spread to the Mediterranean regions.

4.2. Analysis of the colours

The results of the analyses about the origin of the various colours of the mosaic glass are reported in two distinct ternary diagrams which show the

** The sum of the three contents is relative to 100; the data are calculated for each sample group, taking the mean values for the mosaic samples considered to be original for each location.*

relative concentrations of the three oxides of iron, manganese and copper (Fe_2O_3-MnO-CuO) in glass with unleaded (figure) and leaded (figure) matrices, making it possible to group and analyse the different colours of the glass tesserae. Data are expressed in terms of element oxides, as usually reported for chemical analyses results. In the case of polyvalent elements, preference is given to the more stable state, even if this could not always correspond to the real valence of the element in the glass matrix. Cobalt is not included in the following discussion because its presence was revealed only in blue glasses, where moreover, it is the main cause of this tint.

A series of colours can be observed in the diagram of the soda-lime unleaded glasses (Figure 24): different concentrations and varying proportions between iron and manganese oxides, give rise to colours like transparent, purple, black, white and some hues of green, some other colours, like turquoise and some tones of green are obtained with relatively high concentrations of copper and finally, red glasses spread over a quite extended area in the intermediate region of the diagram, since they contain each of the three chromophore oxides.

The colours present in the lead glasses diagram (Figure 25) cover the range from yellow to yellowish green, to green and from orange to red. High concentrations of copper and iron concerns the green, red and orange glasses, whereas high contents of iron and manganese (copper is nearly absent), give rise to the yellow and yellowish green tesserae.

5. CONCLUSIONS

For what concerns the colours of the tesserae, it should be underlined that the origin of colours in glass is a vast and complex problem: to obtain a large number of gradations it was necessary to combine the principal colorants in different proportions, with the addition of elements which acted as opaquing or colouring agents (for example antimony and tin) depending on the matrix to which they were added. Although four main colouring agents were used (iron, manganese, copper and cobalt), the presence of cobalt is only decisive in blue glass.

The colouring of glass is determined by a multitude of complex factors, to the point that it is difficult to predict which ones influence the end result. Among these, we can cite the concentration of chromofores, their interaction with the binders, the base composition of the glass, the equilibrium between the various valence forms, all determined by special procedures and contrivances during the preparation of the glass material: the quantity of the colorant added, the presence of other colouring agents, the presence of opaquing agents, the temperature reached, the duration of the melted state,

the reducing or oxidising atmosphere of the furnace, the type of fluxing agent (whether alkaline or lead-alkaline), the rate of cooling, etc.

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