

Article

Characterization and Analysis of the Mortars of the Church of Santo Domingo in Quito (Ecuador)

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Abstract: The religious art of the Dominican order is reflected in the church of Santo Domingo, built between 1541 and 1688. This work of heritage architecture, one of the first to be built in the colonized city, was affected by multiple earthquakes, interventions, and constructions that do not have a clear record. A total of 13 samples were taken from the mortar inside the cloister, central nave, and side chapel, following the minor destruction testing protocols and standards suggested by the research team. The analysis included mineral characterization studies and quantitative analysis by X-ray diffraction, petrographic, and scanning electron microscopy with microanalysis of the samples. The results showed the presence of volcanic aggregates and lime mortars, mortars of rustic composition and coarse manufacture. The results of mineralogical data and texture have allowed us to corroborate the historical information described by the chroniclers and to date relatively studied sites and to establish a hypothesis of constructive stages.

Keywords: Lime mortar; mortars with volcanic aggregate; mineralogy of historic mortars; Quito Cultural Heritage; Church of Santo Domingo of Quito.

1. Introduction

By December 1534, the original Quito would be occupied by Spaniards, and during the colonial period it would be the political and economic center of the new fief. The delimitation of the plots was made based on the central axis, which was the main square; this is where the buildings of the royal and religious authorities were implanted. At the limit of this node, a plot of land was given to the Dominican Order to spread the Christian faith and religion among polytheistic and pagan natives. This ancient center houses pre-Hispanic and Hispanic material and immaterial wealth in its 375,25 hectares with more than 4674 built properties, of which 130 are monumental properties. In the sixteenth century, there were 15 religious buildings, its central consolidated core estimated at 70,43 hectares [1]. Quito was recognized by UNESCO in 1978 [2,3], for having the best preserved and least altered historical center of Latin America (Figure 1). Here is the church, the convent and the square of Santo Domingo [4].

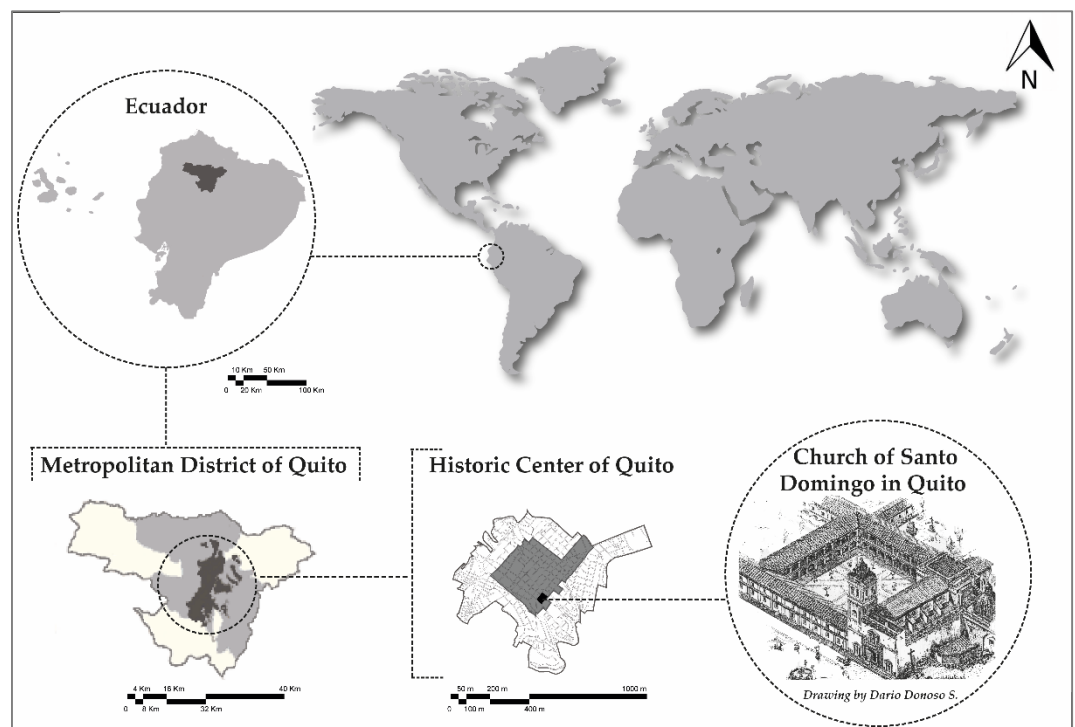


Figure 1. Location and context of the studied area. Drawing by Dario Donoso Samaniego, on page 139 [5]

The Dominicans were established in the Viceroyalty of Peru and Quito, by then considered a circumscription of Cusco. However, in the process of expansion of the faith, they were the first missionaries to travel the coasts of this territory to expand their Christian doctrine [6]. The royal decree of 1563 named the town of Quito a city [4,7], and the Dominicans obtained this land to settle on the border of the central nucleus and the Loma Grande.

1.1 Constructive historical chronology of the temple

The topographical conditions and accessibility to the property established that between 1541 and 1580 the Dominican order built a provisional convent made of cedar wood and carved coffered ceilings. It was located between the current courtyard of the main cloister and San Fernando College, according to studies by Josef Buys [8]. At the beginning of 1581, Francisco Becerra, who previously worked building temples in Mexico and Lima, began drawing the blueprints of the church and convent with serious modifications of the previous cloister with more generous dimensions for the faithful and religious, orienting it towards the south of the site [4,9].

The temple is developed with a single central nave, apse, and vaulted side chapels. On the right side of the transept was built the Chapel of the Rosary, which houses an original altarpiece from the sixteenth century of Baroque detail with samples of several artists. Among the artists that stand out are Father Pedro Bedón and Miguel de Santiago, as well as artists members of the native brotherhood of the Dominican church of the Rosary, Nicolás Javier Goríbar, Andrés Sánchez Galque, Alonso Chacha, Francisco Gocial, Jerónimo Vilcacho, Juan Diez Sánchez, Sebastián Gualoto, Francisco Guajal, Juan Greco Vásquez, among others [10].

After the completion of the work by Becerra it passed into the hands of Fray Rodrigo de Lara Manrique, who followed the guidelines previously left. Later, Fray Antonio Rodríguez took charge of the convent's work, while Fray Juan Mantilla was in charge of concluding the church's works on January 15, 1688 [7,11]. By 15 July 1688, an official report was issued by Antonio Rodríguez on the conditions of the convent. San Fernando College

was inaugurated on 6 August 1688, for poor children from Loma Grande, totally free of charge.

The Dominican complex has suffered several earthquakes that have affected its consolidation, among which we highlight the one in 1587 where part of the church collapsed and the tower was damaged. In 1736, the tower and roofs were damaged. In 1751, the bell tower and the bell itself were damaged. In 1755, due to what is known as the “Quito earthquake”, the church was severely damaged, causing the collapse of the walls and ceilings. In 1787, there was a collapse and sinking of the church and the novitiate. For 1797 there was a partial collapse of the tower, and there were damages to the novitiates. And in 1859, the tower was damaged and the support was destroyed, which is why the walls were raised to prevent further collapse [12,13].

Between 1869 and 1886, a group of Italian Dominicans made important reforms inside the temple and a new spatial conception of the convent, and its novitiate was projected. The sober façade of the church did not suffer changes by reformers, but it has contrasts between the Renaissance style of its exterior with the Baroque style of its interior, where the ornament and monochromatic prevail. In the twentieth century, between 1990 and 1996, restoration work was carried out on the altarpiece and the choir loft, and from 1998 to 2002, work was carried out on the frame (roof trusses) and ceiling [8].



Figure 2. Image of the five chronological phases of the construction of the Santo Domingo church in 345 years. (1541-1580) Earth construction; (1590-1620) Phase I; (1620-1781) Photography of the Chapel of the Rosary; (1781-1869) Photography of the mural in the convent corridor; and (1869-1886) Photography from the central nave to the main altar, with the location of the places where the mortar samples were extracted.

Information about previous research related to heritage mortars is limited. The bilateral project between Ecuabell and the National Institute of Cultural Heritage (INPC from its initials in Spanish), coordinated by Patrick de Sutter and Marcela Alemán, had as an objective the study of the mural painting in 1993. [14]. Later, the Rescue Fund of the Municipality of the Metropolitan District of Quito (FONSAL from its initials in Spanish) through a private consultancy by Paulina Moreno in 2006, again conducted studies on mural painting of the transept of Santo Domingo [15].

Regarding work related to building materials, we can highlight Moropoulou's, who conducted research on the San Francisco monastery in adobe and brick masonry [16], as well as research on the characterization of mortars of the Church of the Company of Jesus

[17]. This investigation focused on the types of mortar used, the dosage, compositions, and textures of heritage samples [18]. Given that the coatings used in this temple, due to their value and historical importance, require us to determine, in addition to those mentioned above, their chemical, physical, and mechanical structure [19,20]. The use of different microscopic techniques as a fundamental part of research processing allows us to visualize the precise characterization of binders, aggregates, additives, inorganic mixtures, etc. [21–23], which were used in these historical mortars and therefore were able to validate the sequential historical chronology described.

The progress of construction was limited by the economic resources restricted to tithes and alms of the religious order, which is so that historical documents show that the Real Audiencia of Quito decided that Dominicans obtained the material needed to build their properties from the lime quarries of the Panzaleo sector, on the southern border of the province [24]. This Andean region has the main mineral components of the volcanic rock used as aggregate in these mortars [25,26].

This work is part of a larger research project in which chemical-mineralogical properties will be determined. In this case, we wish to identify in a technical way the mineralogical composition of the mortars used in the construction of the church of Santo Domingo of Quito, and thus improve the level of future interventions in this building or in those that maintain the same material.

2. Materials and Methods

2.1. Materials

In this work, 13 mortar samples (according to Figure 3), extracted from the Santo Domingo church, considering the indications made by temple technicians about the places that presumably have not been altered in the rehabilitation stages. To carry out the sampling, three sectors were identified depending on the construction phase.



Figure 3. Blueprints of the church of Santo Domingo of Quito with the location of the analyzed samples; the figure describes the 13 samples with its location.

The church of Santo Domingo historically records a temporary construction of adobe (1541-1581), and later a phase I (1590-1620), of which we do not have samples.

Phase II (1620-1781), samples ISD-06, ISD-07, ISD-08, ISD-09, ISD-10, and ISD-11. Samples 6, 7, 8, 9 were extracted from the Chapel of the Virgin of the Rosary, while sample 11 was extracted from the south surface of the transept, and sample 10 is part of the nineteenth century reconstruction of the novitiate.

Phase III (1781-1869), samples ISD-04 and ISD-05. These samples were extracted from the surface of the wall of the convent cloister adjacent to the north wall of the temple.

Phase IV (1869-1886), samples ISD-01, ISD-02, ISD-03, ISD-12, and ISD-13. These samples are simultaneous to those of the Italian Reformation that intervened in the cloister of the convent, samples 1, 2, and 3; and the Central Nave of the Temple, samples 12 and 13.

It is to consider that previous historical studies records dated zones, as in 1631 the surface of the mural painting of the transept 'near to our sample 11' and in 1789 the surface of the mural painting of the cloister 'near to our samples 4 and 5' [10,15].

2.2. Methods

Combined methodology that gathers qualitative, quantitative, and analytical data was used in a systematic way that began with a historical and constructive analysis of the place where the samples were taken.

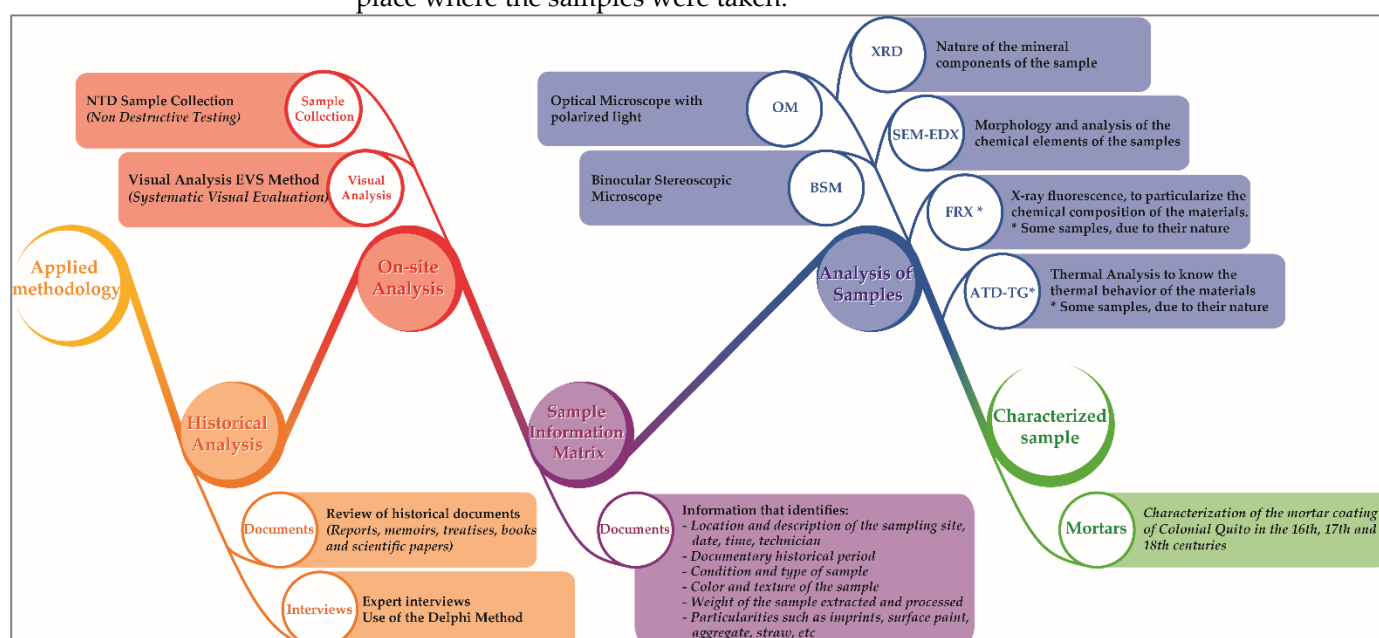


Figure 4. Description of the methodological process generated for the analysis of samples from general research. *Analyses performed for some of the samples due to their nature.

Historical research requires knowledge of the historical process from the time of construction to the moment of study. This analyzes its historical context, knowing its age, the construction system, the historical affectations in construction, and the main transformations it suffered due to earthquakes or anthropic effects [27,28].

We studied existing historical and graphic documents such as photographic images, planimetric drawings, and other treatises in which historical information is available on the construction systems, materials, and techniques used, with an emphasis on interviews with technicians or knowledgeable experts about the subject using the Delphi methodology.

Initially, once on site, the EVS method (Systematic Visual Evaluation from its initials in Spanish) method is used, which requires a dynamic protocol that starts with knowing the site, where the external conditions of implantation, orientation, sunlight, prevailing winds, precipitation, and rain that affect the building materials that are part of the study and affect the research are studied. In the interior part of the building, already with the existing tabulation of the historical analysis and the interview with experts, the type of

coating is visually identified and we locate the possible points of sample extraction, for which we use minor destruction tests. Therefore, we must avoid any kind of damage to the building and that the part of the study sample is contaminated using the methodology for the sampling of materials from cultural heritage UNE-EN 16085 [18].

At this point, an information matrix was generated to identify and locate the place where the sample was taken, the historical documentary period to which it belongs, the weight of the extracted sample, as well as the weight to be processed, its color, texture, and to identify the particularities or imprints left by external elements such as surface painting, aggregate, straw, etc. To later determine which and how many significant samples must undergo archaeometric analysis to identify and characterize them [19, 25, 26].

For characterization, we started with a binocular stereoscopic microscope that allows us to have a stereoscopic view of the sample, and a Zeiss Stemi 305 instrument was used, subsequently, both for identification by X-ray diffraction (XRD), and for mineralogical characterization of the 13 historical samples, which are part of the church, a 10 to 20 gr. portion was extracted and ground in an agate mortar and sieved using the polycrystalline powder method, which requires sample fractions with grains smaller than 53 μm . [30–32]. Mineralogical identification was carried out by XRD [29, 30], on a Bruker D8 ADVANCE diffractometer with Cu radiation, where disoriented powder diffraction patterns were obtained in an angular interval between 2 and 65°, in 1 s, with a step size of 0,02°. Where the relative proportions of each mineralogical phase were identified and determined following the Chung method (1975) [35], and using Bruker's EVA software, maintaining the experimental errors of the method plus - minus 5 %.

Thin sections of samples ISD-08, ISD-11 of phase II, ISD-05 of phase III, and ISD-12 of phase IV were prepared for Petrographic Microscopy (PM) using Zeiss Primotech model equipment and for morphological and chemical study using Scanning Electron Microscope (SEM-EDX) [23,36,37]. The equipment used was JEOL JSM-820, with a secondary and backscattered electron detector and microanalysis. The software used for the acquisition, treatment and evaluation of the analyzes was EDX Oxford ISIS-Link. The analysis was carried out by the Geological Techniques Unit of the Support Center for Research in Earth Sciences and Archaeometry of the Complutense University of Madrid (Spain).

3. Results

Table 1 allows us to identify the mineralogical composition and semi - quantification (+5%) resulting from the use of the XRD technique applied to identify the crystallographic structure in materials science. However, for this purpose, the samples have been grouped chronologically according to the historical information used in the investigation.

Table 1. XRD mineralogical identification and quantification. The symbols used for the mineralogical phases are according to [38]. Quartz = Qz, plagioclase = Pl, amphibol group = Amp, calcite = Cal, Illite group (ClayMinerals) = Illt, and larnite (belite) = Lrn.

Samples						
	Qz	Pl	Amp	Cal	Illt	Lrn
ISD – 06	3	87	6		4	
ISD – 07	<1	86	12		2	
ISD – 08		57	22	18	3	
ISD – 09	1	70	18	10	1	
ISD – 10	<1	88	6	5	1	
ISD – 11	3	84	9		4	
ISD – 04	2	64	12	6	4	11
ISD – 05	2	80	7	8	3	
ISD – 01	2	74	18	4	2	

ISD – 02		92	2	3	3
ISD – 03	3	54	7	30	6
ISD – 12	2	80	13		5
ISD – 13	2	83	9		6

The mineralogical identification carried out by XRD, petrographic microscopy (polished thin section), allows us to evidence the whole set of analytical qualitative data and the manufacture of mortars. For the study, it should be considered that the sample ISD-04 is contaminated with synthetic elements that do not belong to the temporality of the study, so it is discarded. Table 2 describes the types of mortars found in the three construction phases that are part of the chronology examined.

Table 2. Type of mortars found in the church of Santo Domingo.

Samples	Mortar
ISD – 06	Volcanic aggregate
ISD – 07	Volcanic aggregate
ISD – 08	Lime mortar with volcanic aggregates
ISD – 09	Lime mortar with volcanic aggregates
ISD – 10	Lime mortar with volcanic aggregates
ISD – 11	Volcanic aggregate
ISD – 04	Intervened area “cement mortar”
ISD – 05	Lime mortar with volcanic aggregates
ISD – 01	Lime mortar with volcanic aggregates
ISD – 02	Lime mortar with volcanic aggregates
ISD – 03	Lime mortar with volcanic aggregates
ISD – 12	Volcanic aggregate
ISD – 13	Volcanic aggregate

To identify the morphology, we used polarized optical microscopy (POM) and SEM to understand the different mineral phase textural relationship. XRD was used for the mineralogical identification. The samples ISD-08, ISD-11 from phase II (Figures 5 and 6), ISD-05 from phase III (Figure 7), and ISD-12 from phase IV (Figure 8) were chosen as representative samples of the use of volcanic aggregates in different ornamental situations. It is worth mentioning the use of these in stucco-type finishes [39,40].

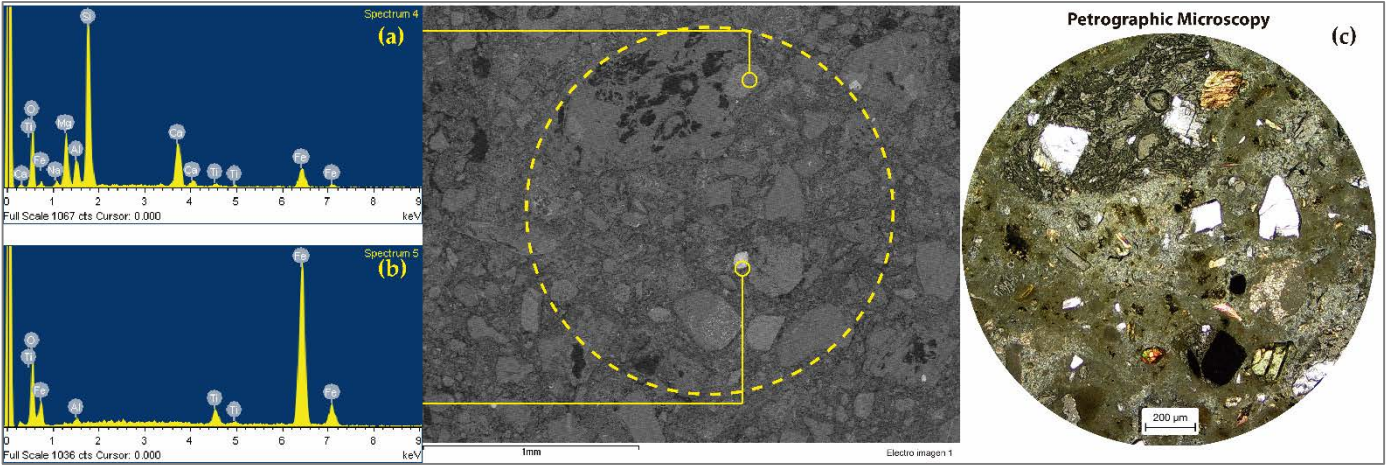


Figure 5. Sample ISD-08 (a) and (b) chemical analysis by EDX-SEM supported by a BSE image of lime mortar with volcanic aggregates; and (c) thin section image at 50x magnification under PM with X polarizer.

As shown in (Figure 5) of sample ISD-08, this EDX analysis was performed at nine different points of the main chemical elements; we have identified two relevant points, (a)

spectrum 4 with Si, Mg, Ti, Ca, Al, and Fe; (b) spectrum 5 with Fe, Ti, and Al; (c) image obtained at 200x magnification by the petrographic microscope that allows visualizing the properties of double refraction or crystallographic directions of the sample of the Chapel of the Rosary by controlling the contrast of the image and color variation.

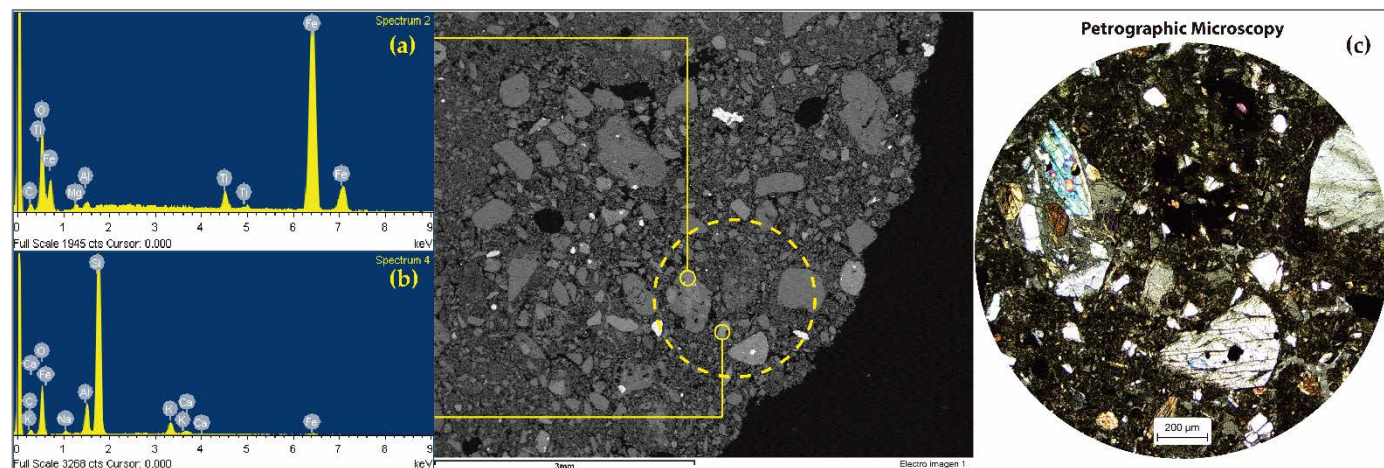


Figure 6. Sample ISD-11 (a) and (b) chemical analysis by EDX-SEM supported by a BSE image of lime mortar with volcanic aggregates; and (c) thin section image at 200x magnification under PM with X polarizer.

In the case of sample ISD-11 (Figure 6), this EDX analysis was performed at six different points of the main chemical elements, and we have pointed out two relevant points, (a) spectrum 2 with Fe, Ti, Al, and Mg; (b) spectrum 4 with Si, Al, Ca, K, and Na; (c) image obtained at 200x magnification by the petrographic microscope that allows visualizing the properties of double refraction or crystallographic directions of the sample from the lower part of the transept by controlling the contrast of the image and color variation.

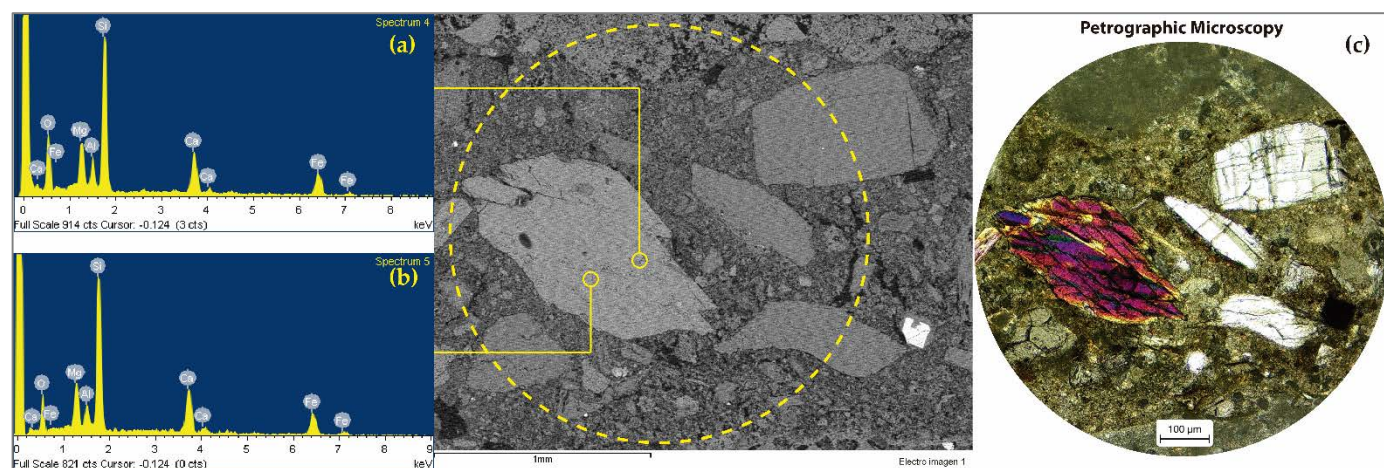


Figure 7. Sample ISD-05 (a) and (b) chemical analysis by EDX-SEM supported by a BSE image of lime mortar with volcanic aggregates; and (c) thin section image at 150x magnification under PM with X polarizer.

EDX analysis of sample ISD-05 (Figure 7), was performed at nine different points of the main chemical elements, we have pointed out two relevant points, (a) spectrum 4 with Si, Mg, Ca, Al, and Fe; (b) spectrum 5 with Si, Mg, Ca, Al, and Fe; (c) image obtained at 500x magnification by the petrographic microscope that allows visualizing the properties of double refraction or crystallographic directions of the sample of coating of mural painting by controlling the contrast of the image and color variation.

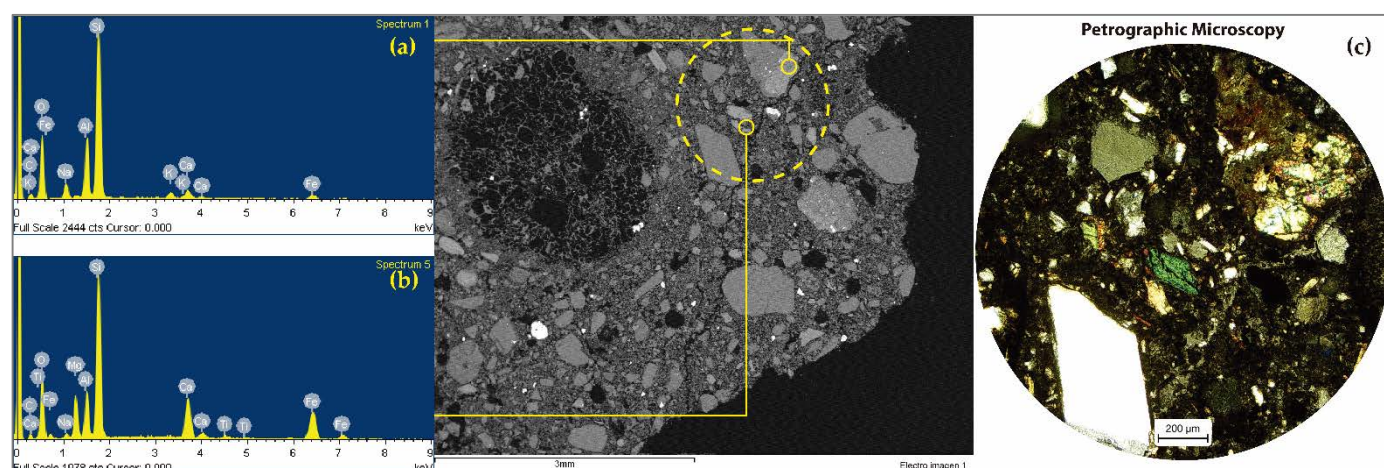


Figure 8. Sample ISD-12 (a) and (b) chemical analysis by EDX-SEM supported by a BSE image of lime mortar with volcanic aggregates; and (c) thin section image at 50x magnification under PM with X polarizer.

Finally, EDX analysis of sample ISD-12 (Figure 8), was performed at nine different points of the main chemical elements, we have pointed out two relevant points, (a) spectrum 1 with Si, Fe, Al, Ca, Na, and K; (b) spectrum 5 with Si, Mg, Ti, Al, Fe, Na, Ca, and Ti; (c) image obtained at 200x magnification by the petrographic microscope that allows visualizing the properties of double refraction or crystallographic directions of the sample of the central nave of the temple by controlling the contrast of the image and color variation.

4. Discussion

The identification, characterization, and structure of several of the elements studied in the Santo Domingo church allow us to determine its mineral composition of volcanic origin as lime mortar with volcanic aggregates. Here, a rustic and rudimentary manufacture of the aggregate is identified, allowing evidence of a vitreous texture of the same. This is evident in several of the samples that are part of the study, which supported the superficial whitewashing of the interior of the spaces as a feature of prestige in the architecture of the time, allowing the surface to ornament that area and the asepsis of the enclosure.

Analyses identified quartz with minimal proportions in all mortars, between 1% and 3%, and calcite in percentages between 3% and 30%, except in the samples ISD-06, ISD-07, ISD-11, ISD-12, and ISD-13, in which the calcite is not identified. It should also be noted that the presence of plagioclase and hornblende-type amphibole with significant values was observed in all samples. These are the main components of the volcanic aggregate found. The Andean valley has a dozen ancient andesitic volcanic centers, characterized by basaltic andesite (57 – 60% SiO₂ and 0.5 - 1.0% K₂O) as what happens in the territory where, according to historical data, the extraction quarry of the Dominican religious order was located [23, 37, 38].

The aphanitic or fine-grained texture is evident in the microscopic analysis of the samples where the vitreous crystals expose fragments of andesite and dacite manufacture. Materials are of widespread use in the civil and religious constructions of the Historic Center of Quito, which are evidenced in the studies of the Church of the Company of Jesus and the Church of San Francisco [16, 17]. In addition to the presence of anorthite in the triclinic section, a variety of plagioclase from the feldspar group and muscovite from the silicate group, phyllosilicate subgroup, were used as secondary minerals. According to SEM observations, the aggregates did not show any pozzolanic reaction ring in the interface zone.

In the sample ISD-04, larnite (belite) Ca₂SiO₄ was identified, granular with a transparent semivitreous structure with anhedral – subhedral crystals that unfold in the matrix

of the silicate family, which is a “natural analogue of the synthetic β modification of Ca_2SiO_4 , which is an important component of portland cement” [43]. It should be noted that the temple had some changes after the Italian Reformation that ended in 1886 and in the twentieth and twenty-first century with several administrations of the enclosure, this generated necessary maintenance interventions, but not well controlled, where the use of replacement materials lacking the original patterns of restoration is a gradual deterioration of our heritage.

The samples have different mineral compositions that allow us to identify different typologies, typical of the construction and chronological periods of the temple, generating a mortar based on volcanic aggregate identified in phase II and phase IV, while sample ISD-05 is a lime mortar with volcanic aggregates. Emphasizing that a rough manufacturing scheme of the volcanic compound is evidenced, which would allow us to discuss some aspects of the masonry technique in the construction of the temple.

The analysis obtained by the SEM interaction of the electron beam on the surface of the thin section allowed to evidence the volcanic slag and thus the validation of the origin of the materials used in the construction of the temple. Therefore, it confirms the hypothesis of the origin of the stone material extraction zone given to Dominicans in the south of the Pichincha province in the Panzaleo sector [24].

When viewing the characteristics of the aggregate, the question of the application of a widespread masonry technique in our region to buildings of historical value arises, which is the crushing of the disassembled mortar and its reintegration with the support of a conglomerating agent, which in this case is lime. That mortar that at first was a rustic monolayer with the addition of lime either in the mixture or on the surface of the finished coating, with time acquires greater durability, hardness, workability, and impermeability and improves the appearance of the final finish of this [25].

5. Conclusions

After their structure analysis in the binocular stereoscopic microscope, the samples can be identified by the crystalline contents of the mineral on the petrographic microscope to characterize it both by XRD and SEM-EDX. All of these analyzes determined the volcanic origin of the materials used in the construction of temple coatings. Confirming that the Panzaleo sector, in the equatorial Andean zone, destined for the Dominican order, was the site of extraction of stone aggregate for the manufacture of mortars [44].

The data obtained by XRD and SEM-EDX of the samples determined common patterns in the components, including calcite, plagioclase as anorthite, clay minerals, and quartz. All of these allowed to identify some characteristics of the construction period of the church associated with historical facts related by chroniclers that altered in several cases the original composition of the temple; previous studies dated some areas that were part of the research.

The samples have a relative presence of conglomerate, lime identified as calcite, except the ISD-04 sample, which contains larnite (belite). The presence of larnite indicates the use of a cement-based binder used in a subsequent intervention.

Finally, the mortar composition of the Santo Domingo church is due to the manufacture of volcanic aggregates and was part of all the construction phases investigated. It should be noted that despite the reforms of the temple, typical of the passing of time, and the seismic past that the church has survived, being several earthquakes highlighting those of 1755, 1797, 1859, and 1868, its state of conservation is relatively limited. In the visual analysis of the investigation, there were zones from which samples were not extracted due to capillary humidity, bulging, and erosion. Other areas adulterated with paint, resins, and varnishes that did not appear very well intervened; and altered areas with cement mixtures were not very permeable and visually detached from the original masonry due to its incompatibility with the setting.

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Data Availability Statement: The sources of historical books in this document are primary sources that have not been updated since the middle of the 20th century; some are considered '*gray literature*', but they serve as a fundamental basis within the qualitative investigation of the present manuscript.

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