UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias de la Tierra, Energía y Ambiente

TÍTULO: “Characterization of Haloclasty to reduce the deterioration of buildings in Urcuquí and near Villages, Ecuador.”

Trabajo de integración curricular presentado como requisito para la obtención del título de Geóloga.

Autor:

González Salazar Jenny Joselyn

Tutor:

PhD. Vázquez Taset Yaniel Misael

Co-Tutor:

PhD. Ávila Sosa Edward Ebner

Urcuquí, julio 2023

AUTORÍA

Yo, **GONZÁLEZ SALAZAR JENNY JOSELYN**, con cédula de identidad 1804912044, declaro que las ideas, juicios, valoraciones, interpretaciones, consultas bibliográficas, definiciones y conceptualizaciones expuestas en el presente trabajo; así cómo, los procedimientos y herramientas utilizadas en la investigación, son de absoluta responsabilidad de la autora del trabajo de integración curricular. Así mismo, me acojo a los reglamentos internos de la Universidad de Investigación de Tecnología Experimental Yachay.

Urcuquí, julio del 2023.

Firmado electrónicamente por:
JENNY JOSELYN
GONZALEZ SALAZAR

Jenny Joselyn González Salazar

Cl:1804912044

AUTORIZACIÓN DE PUBLICACIÓN

Yo, **GONZÁLEZ SALAZAR JENNY JOSELYN**, con cédula de identidad 1804912044, cedo a la Universidad de Investigación de Tecnología Experimental Yachay, los derechos de publicación de la presente obra, sin que deba haber un reconocimiento económico por este concepto. Declaro además que el texto del presente trabajo de titulación no podrá ser cedido a ninguna empresa editorial para su publicación u otros fines, sin contar previamente con la autorización escrita de la Universidad.

Asimismo, autorizo a la Universidad que realice la digitalización y publicación de este trabajo de integración curricular en el repositorio virtual, de conformidad a lo dispuesto en el Art. 144 de la Ley Orgánica de Educación Superior.

Urcuquí, julio del 2023

Firmado electrónicamente por:
JENNY JOSELYN
GONZALEZ SALAZAR

Jenny Joselyn González Salazar

Cl:1804912044

Dedicatoria

Quiero dedicarte este trabajo a toda mi familia. Especialmente a mis padres Williams José González y Jenny Susana Salazar, quienes me han brindado su confianza en todo momento y principalmente dándome su apoyo incondicional en todos mis estudios realizados. Además, por enseñarme a afrontar las dificultades que se han presentado al estar lejos de ellos.

A mis dos hermanas, por ser mis amigas, consejeras y compañeras de vida, por todo el apoyo que he recibido.

A mi familia en general por apoyarme y preocuparse por mi durante todo el tiempo que estuve lejos de mi ciudad natal.

Jenny Joselyn González Salazar

Agradecimientos

Quiero agradecer a toda mi familia por todo el cariño y preocupación. Principalmente, a mis padres por todo su esfuerzo, cariño, paciencia, y apoyo incondicional. Ambos me han demostrado su amor y confianza, corrigiendo mis faltas y celebrando mis triunfos durante todo el trayecto de mi vida. Sin ellos no hubiese sido posible llegar a este punto de mi vida.

Doy infinitamente gracias a Dios, por haberme dado fuerza y valor para culminar esta etapa de mi vida. Además, por permitirme conocer a todas las personas que puso en mi camino llenándome de alegría y felicidad en esos momentos que estuve lejos de mi familia. En especial a Evelyn Guiz, le agradezco mucho por ser mi amiga incondicional durante todos estos años. Hemos pasado juntas momentos felices y tristes, siendo como dos hermanas desde el primer día que llegamos al campus hasta el último. También quiero agradecer en general a todos mis amigos que conocí y que han formado parte de mi vida universitaria, brindándome todo su cariño y apoyo emocional.

Quiero agradecer a todos los profesores que brindaron todos sus conocimientos durante todos estos años. Ellos enseñaron que en un profesor también podemos encontrar un amigo. Especialmente a Germán, que durante toda la carrera me ha brindado su amistad y apoyo incondicional. Siempre estando presto para cualquier momento, dando todo de él para que nosotros como estudiantes aprendamos de la mejor manera posible. También quiero agradecer a mi tutor Yaniel y cotutor Edward por todo su apoyo, paciencia y tiempo brindado durante todo el proceso de elaboración de tesis.

Jenny Joselyn González Salazar

Summary

This research focuses on identifying the extent of damage caused by the crystallization of salt minerals in civil engineering in Urcuquí and nearby villages. This study examines the formation of salts and crystals in building materials that occur upon contact with water. The report details physical characteristics such as color, texture, degree of deterioration, and the environment where the crystals grow, whether natural or anthropogenic. Fieldwork was crucial in this research as it involved collecting samples and assessing the level of deterioration at each location. The growth of crystals is the leading cause of damage to walls, making it necessary to take samples to identify the most frequent types of damage, such as efflorescence or sub-efflorescence. Specific cracks are often observed at the base of walls, which can weaken the overall structure and potentially lead to collapse in the future. As the crystallization process starts, crystals form within the pores of building materials, causing them to expand and potentially damage the blocks and paint on the walls. X-Ray Diffraction analytical technique (XRD) analyzes, identifies, and presents the mineral phases. The Match program provides important mineral details, including their name, group classification, chemical formula, entry code, and unique characteristics. Based on the analysis, sulfates as the thenardite salt are a prevalent mineral in each sample. However, traces of carbonates, silicates, and nitrates are also present. According to the analysis results, sulfates seem responsible for the most significant deterioration, as they are present in all samples. It is essential to cover walls with impermeable material to prevent water infiltration. Additionally, during construction, the material should contain minimal amounts of sulfates in its composition.

Keywords: Salts, crystallization, deterioration, efflorescence, sub-efflorescence.

Resumen

Esta investigación se enfoca en identificar la magnitud de los daños causados por la cristalización de minerales de sal en la obra civil de Urcuquí y pueblos aledaños. Este estudio examina la formación de sales y cristales en los materiales de construcción que se producen al entrar en contacto con el agua. El informe detalla las características físicas como el color, la textura, el grado de deterioro y el entorno donde crecen los cristales, ya sea en un entorno natural o construido. El trabajo de campo fue crucial en esta investigación, ya que implicó la recolección de muestras y la evaluación del nivel de deterioro en cada lugar. El crecimiento de cristales es la principal causa de daño en las paredes, por lo que es necesario tomar muestras para identificar los tipos de daño más frecuentes, como la eflorescencia o sub-eflorescencia. A menudo se observan grietas específicas en la base de las paredes, lo que puede debilitar la estructura general y provocar un colapso potencial en el futuro. A medida que comienza el proceso de cristalización, se forman cristales dentro de los poros de los materiales de construcción, lo que hace que se expandan y dañen potencialmente los bloques y la pintura de las paredes. La técnica analítica de difracción de rayos X (XRD) analiza, identifica y presenta las fases minerales. El programa Match proporciona detalles minerales importantes, incluidos su nombre, clasificación de grupo, fórmula química, código de entrada y características únicas. Según el análisis, los sulfatos como la sal de thenardita son un mineral predominante en cada muestra. Sin embargo, también están presentes trazas de carbonatos, silicatos y nitratos. De acuerdo con los resultados del análisis, los sulfatos parecen ser los responsables del deterioro más significativo, ya que están presentes en todas las muestras. Es imprescindible recubrir las paredes con material impermeable para evitar la infiltración de agua. Además, durante la construcción, el material debe contener cantidades mínimas de sulfatos en su composición.

Palabras claves: Sales, cristalización, eflorescencia, sub-eflorescencia.

Index

Figures list

Tables List

Chapter 1. Introduction

The degradation of construction materials used in civil and architectural works is an issue that generates millions of dollars in losses and hazards linked with collapses. Salt crystallization causes physical damage to concrete through surface scaling that resembles the effects of freezing and thawing (Haynes & Mehta, 1996). The degradation of building materials is critical for civil engineers to comprehend physical, chemical, mechanical, or biological aggression (Furlani, 2016). In developed countries, there is a wealth of knowledge about the effects of sales, particularly about the preservation of cultural and heritage assets. Regrettably, such investigations are inadequate in Ecuador due to insufficient information on the subject matter.

Limestone, dolomite, and lime sand are commonly used in construction, and limestone can be heated to make cement (Hughes & Bargh, 1982). Sand has been a crucial component of civilization since it is abundantly available on Earth. Its unique properties enable particles ranging from 0.063 to 2 millimeters to be effectively compacted and used to reinforce various constructions (Rocha Álvarez et al., 2020). From the seventh through the nineteenth century, plaster mortars containing pure gypsum were used for joint repair and filling (Paula López-Arce, 2012). Rock and baked clay brick were two primary building materials used in ancient times (Rocha Álvarez et al., 2020). The composition and processing of raw materials can lead to short and long-term alterations. Common building materials include mortar, calcarenite, and bricks; mortar contains silicates and carbonates, calcarenite is made from shell-derived limestone, and bricks are based on silicates (Bates, 2010).

Bricks are tiny parallelepiped-shaped ceramic pieces created by molding, compressing, and burning clay-rich soils, being versatile because of their standard form and ease of handling (Barranzuela, 2014). Clay and sand comprise most of the bricks; clay is an aggregate of silica and aluminum hydrated, whereas sand is broken rock and is distinguished by its high grain size. Regarding hardness, these materials complement one another quite well. Crushing, adding water, baking, removing bubbles, molding, drying, and baking to combine clay and sand particles are some steps in manufacturing brick.

Concrete blocks are durable construction material that combines cement, sand, gravel, and water (Mishra, 2019). They are available in solid and hollow forms, with various shapes and sizes to suit different building requirements. These blocks are renowned for their strength, longevity, and resistance to extreme weather conditions, making them an excellent choice for various construction projects. The ratio of cement to aggregate in concrete blocks is 1:6. A blend of 60% acceptable and 40% coarse material is employed (Sereda, 1970). Both materials have a certain degree of porosity, which in one manner, helps reduce the weight of buildings. Due to exposure to demanding service conditions, concrete components may degrade before the planned service life. The production of harmful alkaline salts, frequently present in concrete, may result from using Portland cement as a substitute mortar for masonry constructions (Freedland, 1999).

Typically, dissolved salt and precipitated salt are the two possible states of salt in porous construction material (Koniorczyk & Gawin, 2008). It was shown that physical damage was much more prevalent than damage from chemical sulfate assault. Natural salts are involved in salt weathering, which physically disintegrates rock and construction materials. Salt may penetrate a building's exterior along with groundwater, rain, and dirty air or by leaching chemicals from cement-based components such as concrete, mortar, and cement paste (Koniorczyk & Gawin, 2008). Salt deterioration may have a considerable impact on the service life of many architectural structures, both ancient and modern (Delgado et al., 2016).

Understanding and reducing the harm caused by salts is critical for protecting material and cultural property. The quantity and intensity of weathering cycles that affect natural or artificial building stones in a particular region are influenced by various factors. Still, the most crucial is the climatic conditions, represented by air temperature and relative humidity (Kamh, 2007). Warmer climates encourage the proliferation of microbes. Unsuitable environments, regrettably, can lead to material degradation, health problems for residents, and, notably, the existence of (micro)biological activity (Balksten & Strandberg-de Bruijn, 2021). Sulfate, nitrate, or nitrite deposition on a building's surface may rise due to these growths (Freedland, 1999).

One of the erosion processes is freeze-thaw weathering, which occurs when ice crystals develop in cold locations. The mechanism is straightforward: when the temperature decreases, a fissure in a rock can fill with water, which then freezes. The ice expands, forcing apart and expanding the split (Balksten & Strandberg-de Bruijn, 2021). Similarly, salt crystals form when saline liquids enter rock fissures and crevices, allowing for evaporation and hydration. Heat causes these salt crystals to expand, putting pressure on the surrounding rock and causing it to disintegrate. The interaction between evaporation and supply rates can determine where crystallization occurs and the amount of damage. It is necessary to know that sub-florescence forms under the surface layer of concrete when the evaporation rate exceeds the rate of solution absorption (Benavente et al., 2003).

Rock decomposition has increased up to 40 times in some instances, causing erosion and fracturing of protected rocks due to gypsum crust development or calcite recrystallization (Hughes & Bargh, 1982). Weathering is how a rock´s chemical, mineral, and physical characteristics change in reaction to its surrounding environment (Furlani, 2016). Sulfate and nitrate pollution are particularly challenging due to the various methods through which SOx and NOx can be transported and deposited and the frequent occurrence of acid precipitation stemming from multiple pollution sources (Bates, 2010).

Many scientists from all around the world have studied the degradation brought on by salts. Some of the most significant publications used in this research, including articles and studies, came from foreign nations. The essay by Kristin Balksten and Paulien Strandberg (2021) explains that Historic Scandinavian brick masonry structures, particularly those from the neo-Gothic era, have significant durability issues, including weathering and decay; these are mainly the result of salts crystallizing and frost activity in the brick and mortar (Balksten & Strandberg-de Bruijn, 2021). Furthermore, Petra (Jordania), east of the Wadi Araba Valley, suffers from salt weathering, which affects Petra's monuments by causing laminations in the rocks and fluorescence on their surfaces (Paula López-Arce, 2012). Another research example is in the UAE city of Jazirat al Hamra, which is between two sabkhas on the coast and where salt weathering is causing the disintegration of surface materials, mainly in dryland regions (Bates, 2010). The complicated nature of these neo-Gothic brick walls means that salt and frost damage to medieval Scandinavian masonry structures is sometimes exceedingly significant and expensive (Balksten & Strandberg-de Bruijn, 2021).

Numerous methods have been devised to combat the harmful effects of salt growth. Desalination techniques that are actively applied can significantly reduce salt damage, particularly when the damage is caused by cyclic dissolution and crystallization of salts in response to changes in relative humidity (Delgado et al., 2016). For a long time, stone conservators have been using poulticing salts made from materials like clays or wood pulp that are highly absorbent to remove salts from significant wall paintings and carved stones

(Rodriguez-Navarro & Doehne, 1999). Another method for addressing salt damage on walls involves desalination. Desalination involves spraying a fine water mist onto the affected area, allowing it to dry naturally. However, it is essential to note that this approach may result in accelerated deterioration due to increased salt mobility during desalination (Freedland, 1999).

The purpose of the research is to convey knowledge about what salt degradation issues involve, including their origin, the factors that lead to their formation, and, if feasible, solutions to lessen their destructive impact on the long-term durability of the building materials. The sample structures of interest are found in Urcuquí and their surrounding communities. Results show the presence of the thenardite mineral in all the samples taken.

1.1 Conceptual Approach

The phrase "salt weathering" rather than "physical salt assault" is employed in this study since geologists use it to describe comparable salt damage to rocks.

Salt

Salt results from a chemical interaction between an acid and an alkali or an acid and a metal. Salt is a combination of ions that, in the solid state, are geometrically arranged in the form of crystals, but in an aqueous solution, the ions operate individually (Addleson, 1983).

Crystallization

Crystallization is the mechanism by which crystals develop inside a rock due to the passage of saline fluids through the material via capillary action. This process is triggered by changes in the concentration of solutions (through evaporation) or changes in the temperatures of solutions (Bates, 2010).

Efflorescence

Efflorescence is when salts crystallize on a material's surface because drying occurs more slowly than the pace at which salt solution is moving to the surface (Freedland, 1999). Efflorescence is linked to salt crystallization, and salts in solution cause various chemical attacks (Addleson, 1983). From the surface, a white spot made of salts spreads outward (Balksten & Strandberg-de Bruijn, 2021). Patches are more common in porosity rocks with a solid capillary flow. While certain salts are more likely to crystallize inside a pore, others are more likely to effloresce.

Sub-florescence

Salts crystallize just below the surface when the solution in a wall migrates more slowly than the pace at which it evaporates. Sub-florescence, a key source of harm, is in charge of porous construction materials' flaking, spalling, sugaring, and pitting (Freedland, 1999). Material loss occurs due to masonry salts that develop inside a porous medium and induce weathering from the inside out (Balksten & Strandberg-de Bruijn, 2021).

1.2 Study area description

San Miguel de Urcuquí has a land area of 757 km^2 in Imbabura province, Ecuador. Urcuquí is located 20 kilometers northwest of the provincial capital of Imbabura (Ibarra) (Figure 1). Urcuquí is the cantonal head of San Miguel de Urcuquí and encompasses a land area of 56.62 km^2. The average temperature in this region ranges from 14°C to 19°C throughout the year. It is located in the foothills of the Chachimbiro volcano, and it is situated at a height of 2,307 meters above sea level.

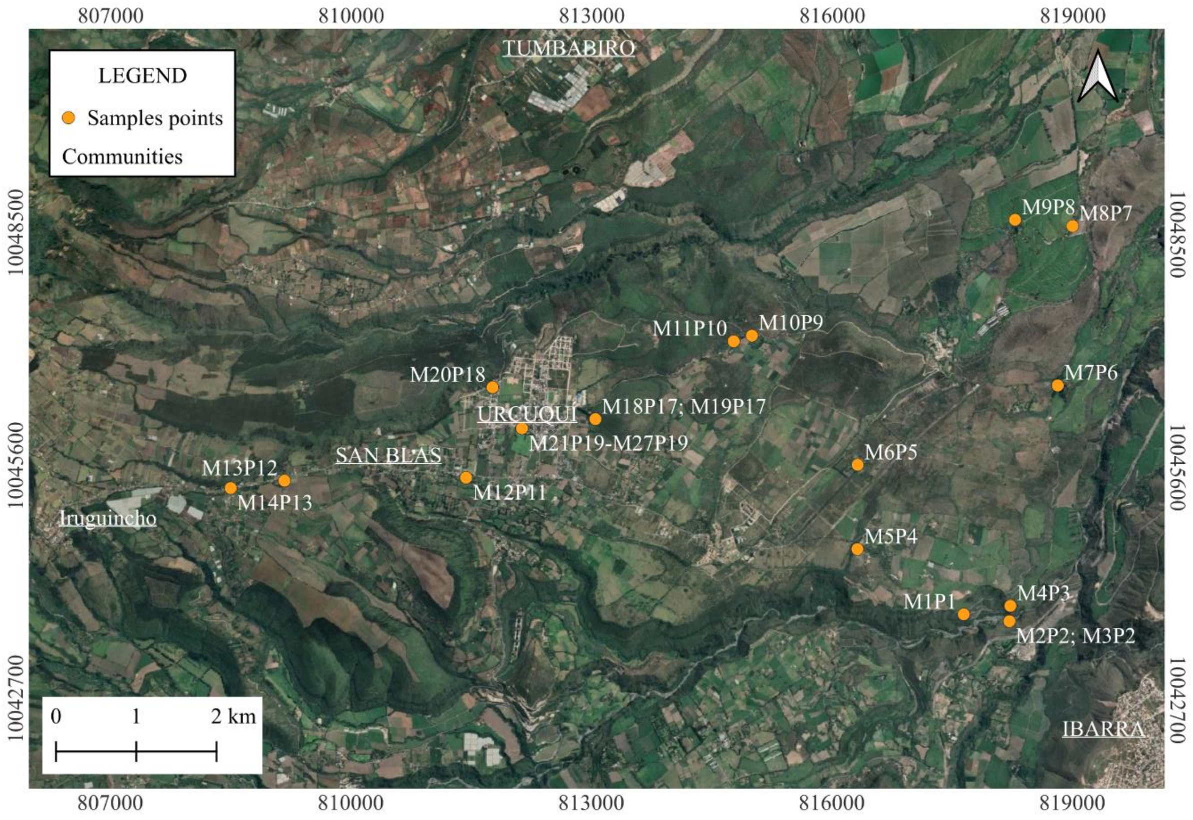

Figure 1. *Panoramic view from Google Earth of the study area. The orange dots on the map indicate the precise spots where the samples were collected.*

Urcuquí, San Blas, Tumbabiro, Pablo Arenas, Cahusqui, and Buenos Aires are the six parishes of this canton. To sample and assess their infrastructures and damages, particular communities, including El Puente, Tapiapamba, San Antonio, San Ignacio, San Juan, Iruguincho, Santa Cecilia, and Timbuyacu, were visited (Figure 1). The neighboring areas were selected because of the prevalence of deterioration problems. Some structures are deserted, with higher levels of deterioration and clear evidence of physical weathering.

1.3 Statement of the Problem

Urcuquí and nearby communities, including El Puente, Tapiapamba, San Antonio, San Ignacio, San Juan, Iruguincho, Santa Cecilia, and Timbuyacu, are being negatively impacted by salt weathering. This is causing harm to both historic and contemporary structures in the area. It is essential to understand the root cause of deterioration in walls fully. Unfortunately, many people fill and paint over holes without addressing the underlying issue, which wastes money on superficial fixes. Accurately characterizing the physical damage from salt weathering is vital in determining effective prevention or repair methods. Authorities must recognize the importance of addressing this issue, as proper maintenance, repair, and restoration of concrete structures can require significant economic resources.

1.4 Objectives

1.4.1 General Objective

The main objective of this work is to characterize and record the extent of damage to civil works in Urcuquí and the adjacent communities caused by salt growth.

1.4.2 Specific Objective

The specific objectives of this thesis are to:

- Characterize construction materials used.
- Study and identify the mineral phases within the structures causing their deterioration.

Chapter 2. Theoretical Background

The following chapter provides essential information regarding the deterioration of salt, the geological composition of the study area, different types of weathering, salt type descriptions, and the historical context of building materials.

2.1 Geological Settings

Volcanism and tectonism in Ecuador are primarily the results of the interaction of the Nazca, South American, and Cocos Plates; this event caused the Inter-Andean Valley depression to form in between the two mountain ranges of the Cordillera Real to the east and the Cordillera Occidental to the west, resulting in the formation of the Andean Cordillera (Ricardo & Ordóñez, 2021). Due to the region's intense volcanic activity, ashes, cangahuas, andesitic lavas, and other volcanic products are among the sediments deposited there, altering the landscape (Carrera et al., 2015).

The Chachimbiro Thermal is located 20 km southeast of Urcuquí. The geology of the Urcuquí parish is composed of volcanic deposits left by the Chachimbiro volcano. This volcano is located at the Interandino Valley's boundary and the Ecuadorian Andes's Western Cordillera on the eastern flank (Bernard et al., 2014). The lower regions were shaped by rivers carrying materials from higher areas, forming broad valleys.

The Holocene activity in the Chachimbiro region is marked by rare yet intense explosive eruptions of acid andesite to dacite, resulting in significant volcanic activity; following this explosion, a vast pyroclastic density current flowed toward the southeast, while a sub-Plinian eruptive column was carried westward by the wind (Bernard et al., 2014). Urcuquí Parish is located in a pyroclastic deposit formed by the Chachimbiro volcano (Bernard et al., 2011). Most of the geological landscape comprises avalanches and alluvial deposits from the nearby volcano, and the avalanche dump primarily consists of Andesitic rocks (Figure 2).

Dacite and andesite comprise the majority of the rocks in the study region. Dacites belong to igneous rock and are found in pyroclastic debris, lava flows, domes, dikes, and sills. This type of rock is commonly discovered on continental crusts above subduction zones, where an oceanic plate is melting beneath (Martín, 2010). Andesite is a fine-grained, extrusive igneous rock often found in lava flows across subduction zones. The type of minerals in a rock plays a significant role in determining its vulnerability to weathering and changes to its original shape (Kamh, 2011). This rock is primally composed of the feldspar subgroup, plagioclase, a solid solution between the minerals anorthite (CaAl2Si2O8) and albite (NaAlSi3O8).

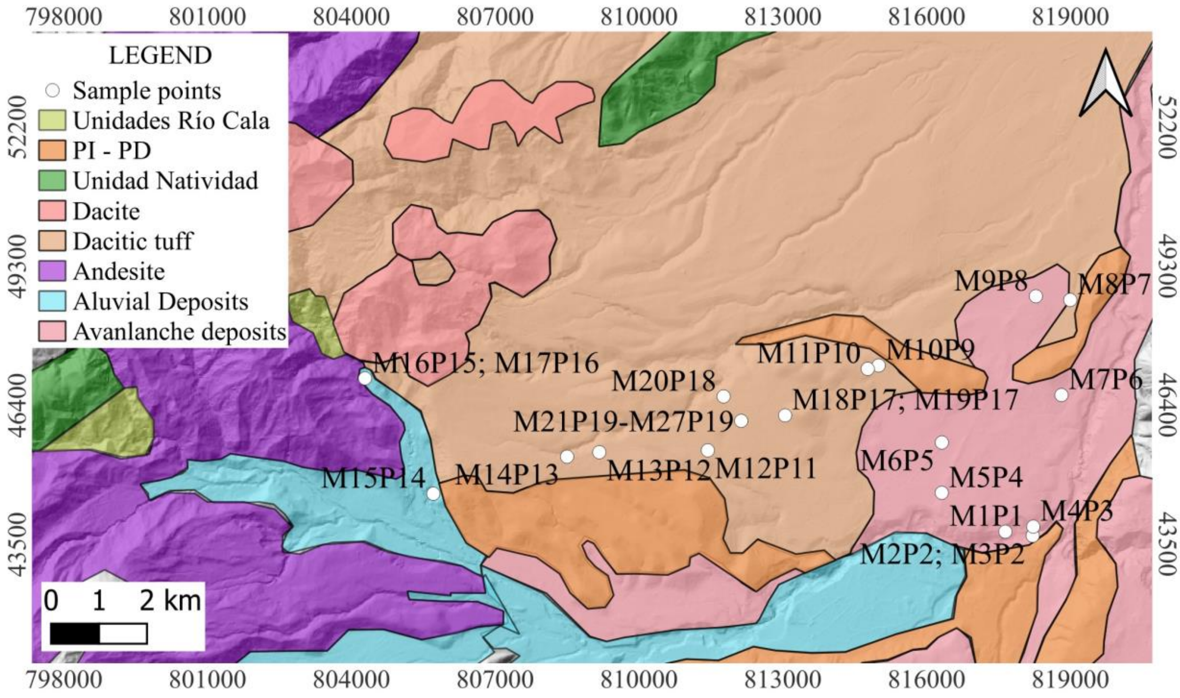

Figure 2. *Geological scheme of the study area. The area of interest where the sample was taken may include different kinds of sediment. Modified from Boland and Pilatasig et al. (1998)*

2.2 Types of Weathering

When rocks are stationary, they experience weathering, a natural process leading to deterioration. It is important to note that weathering differs from erosion, which is the movement of particles caused by water, wind, or ice (Furlani, 2016). In addition to other forms of deterioration like temperature changes, erosion caused by wind and water, or shifts in water phases, damage caused by salt can also have chemical or physical properties that worsen its effects (Delgado et al., 2016).

According to Atkinson (2004), in the case of salt weathering, the crystallization processes involving salt are chemical, but the forces included in raising the volume area are mainly physical. Weathering processes have three main divisions: physical, biological, and chemical weathering, even though chemical and physical processes in nature cannot be separated because they almost always happen at the same time (Furlani, 2016).

Physical weathering can cause the crushing of blocks. As a result, it increases the surface area exposed to chemical processes, while the chemical processes on crushed minerals can speed up mechanical processes (Furlani, 2016). The outer part of construction often shows physical deterioration, which can be caused by the expansion of salt crystals inside blocks in contact with water. As a result, the expansion of crystals causes damage to the building material, particularly at its base. Physical weathering occurs more rapidly in that area due to the materials being exposed to rainwater, moisture, and other weathering elements. Moisture transfer within walls containing porous materials significantly contributes to deterioration caused by salts. Both liquid and vaporized water can pass through a porous material. Water can move through different mechanisms depending on its state. Liquid water can be transported through capillarity and infiltration, while water vapor can be moved through condensation and absorption/adsorption (Delgado et al., 2016).

One of the most significant factors that contribute to the deterioration of the material is chemical weathering. This process involves decomposing blocks through chemical reactions, particularly in solutions like gypsum or carbonates. The temperature of the solvent, flow rate, and CO_2 concentration for carbonates all affect solution rates (Hughes & Bargh, 1982). During decomposition, rock cement agents are eliminated, and even chemical bonds are broken. This can result in the formation of new materials through chemical reactions (Kosmatka & Wilson, 2011).

Microorganisms can cause a range of bio-deterioration effects on rock surfaces. These effects can be seen at microscopic and macroscopic scales, including cracked or etched materials, flaking, spaling, and powdering (Kamh, 2011). When the temperature rises, it provides a favorable environment for the growth of microorganisms. This can lead to the accumulation of sulfate, nitrate, or nitrite on the surface of a structure. Furthermore, acidic rain can cause damage to calcareous building materials, resulting in the formation of black crusts, which are often made up of gypsum (Freedland, 1999).

The deterioration of strength and hardness caused by advanced physical weathering can eventually lead to the collapse of walls. Because physical weathering significantly impacts construction, it is essential to characterize the damage caused.

2.3 Salt types description

James Dwight Dana developed the categorization scheme, Dana’s System of Mineralogy, in the middle of the nineteenth century (Waage, 2017). Minerals are commonly categorized based on their chemical composition, which results in eight main mineral groups. These categories include mineraloids, silicates, oxides, sulfides, sulfates, halides, carbonates, and oxides (Mishra & Deshmukh, 2019). According to Dana's classification, this study will solely focus on salts known to cause deterioration. The objective is to identify and analyze various salts, including sulfates, carbonates, and silicates.

Sulfate ions can interact negatively with sodium ions in saltwater or other sources to create sodium sulfate (Freedland, 1999). Since sodium sulfate is recognized to be the worst of all the salts that are often employed, it is frequently utilized in accelerated durability testing (Tsui et al., 2003a). The brick may contain masonry salts if the clay includes pyrite. All sulfur in the sulfuric acid (FeS2) should be released after proper combustion. Still, occasionally the pyrite is only converted to iron sulfide (FeS), which may facilitate the adsorption and expansion of water (Balksten & Strandberg-de Bruijn, 2021).

Calcium and carbonate are commonly found in all sections of building lime mortar. Because of acid-base interactions, calcium carbonate becomes more soluble in acidic salts (Balksten & Strandberg-de Bruijn, 2021). Carbonates are less susceptible to SO2 attack. Silicate rocks weather at a pace that is typically slower than carbonate rocks (Hughes & Bargh, 1982).

The calcium nitrate solution had little efflorescence, although cracking and spalling occurred (Ramadan & Sakr, 2020). The ground may also contain nitrates due to organic matter decomposition (Freedland, 1999). Moreover, nitrates may damage urban structures and are frequently found in agricultural buildings. Nitric acid contributes to the breakdown of calcium carbonate and generates calcium nitrate on walls. It is produced by the oxidation of NOx from combustion processes or NH_3 found in the environment (Delgado et al., 2016).

Chlorides are a standard sea-site tracer that can enter structures due to increased moisture, salt spray, or floods. Another explanation is using saltwater in manufacturing mortars or deicing salts in road maintenance (Delgado et al., 2016). The presence of salt in the form of chlorides may also result from the building's previous usage as a food storage facility. Due to road salts, such as on stairways and pavements, sodium chloride and calcium chloride can also develop in masonry (Balksten & Strandberg-de Bruijn, 2021).

2.4 History of building materials

There are several types and origins for construction materials. One of the most prevalent and valuable elements on Earth is rock. Throughout history, rocks have been used for construction purposes without carving, and this practice has been commonplace in all stages of civilization (Rocha Álvarez et al., 2020). Due to their toughness and hardness, several rock materials are employed in the building. Sandstone, a cemented rock composed of many particles, is used for facade cladding and external and interior ornamentation. Granite, an igneous rock that was slowly solidified at deep depth and brought to the surface by the folding of the earth's crust, is a rock that is widely used in buildings. It is frequently used to pave roadways and cover the exterior of immense structures (Martín, 2010).

Limestone is one of the principal types of rock used in buildings since it is used to make bricks and is a critical ingredient in cement. This sedimentary rock consists mainly of calcite or dolomite, which are calcium and magnesium carbonates; it is common for limestone to have tiny fossils, shell fragments, and other remnants of fossils (Hughes & Bargh, 1982). Limestone typically occurs in marine environments, predominantly on shallow continental shelves, particularly in tropical regions with coral reefs (Panchuk, 2019).

Gypsum, or calcium sulfate, is employed as a cement ingredient, but it may also develop on lime-based surfaces when there is sulfur in the air, such as from automobile exhaust fumes (Balksten & Strandberg-de Bruijn, 2021). Gypsum offers better workability and a shorter setting time, which is one of its benefits for usage in construction; nevertheless, humidity, capillarity ascent of water, or run-off-induced descent dissolve this substance (Paula López-Arce, 2012).

Over the years, the most famous building material in the world has been concrete because of its adaptability, toughness, sustainability, and affordability. However, its drawbacks include being bulky and hefty. This material is known as concrete, a combination of aggregates, typically sand, gravel, or crushed stone, held together by a cementitious paste binder. Typically composed of Portland cement and water, the paste may include chemical admixtures and supplementary cementing materials (SCMs), such as fly ash or slag cement

(Kosmatka & Wilson, 2011). Crushing and grinding procedures decrease the size and homogenize raw materials to be fed into the clinker production process. The cement's primary ingredient, clinker, comprises tri and dicalcium silicates (alite and belite), tricalcium aluminate, and tetra calcium aluminoferrite. Clinker is produced by clinkerization, which involves synthesizing calcium oxide, aluminosilicates, and other ingredients. Combustion occurs at 1450 °C in combustion ovens (Petroche, 2021).

In Ecuador, brick and cement comprise the bulk of the dwellings; the remainder is built from more irregular materials, including bamboo cane, adobe, tapial (wooden formwork and clay soil), and bahareque (interwoven sticks or reeds with mud covering them). Sand from the sea is occasionally utilized in coastal locations; therefore, if coastal sand is used for mortar during early construction, salts may infiltrate the building (Freedland, 1999). Reinforced concrete accounts for 91.8% of the materials used in building construction, whereas wood, metal, and other elements account for less than 6%. Similarly, blocks (61.6%) and bricks (35.1%) are the most often utilized materials in the construction of walls (Reyes Quijije et al., 2022).

The most significant degradation cause for porous materials is often regarded as soluble salts (Freedland, 1999). In some cases, the presence of salt crystals causes the disintegration of the building materials. The harm is not just exterior because if crystals form inside porous materials, they will expand and shatter the blocks. Consequently, the infrastructure will also degrade since iron bars may become oxidized (Figure 3). Moreover, it causes physical harm as well as cosmetic damage in the form of efflorescence. Pour water in buildings frequently has one or more dissolved salts in it.

Figure 3. *The building's infrastructure appears to have a significant amount of corrosion. The concrete blocks are already breaking apart, and the iron bars are exposed, increasing the likelihood of a potential collapse in the future. The photo was captured in an abandoned building located in Tapiapamba (See location in Figure 1).*

Chapter 3. Methodology

This chapter describes the process, materials, and project completion techniques. Moreover, the method of collecting samples and determining where they belong is detailed.

3.1 Fieldwork and Sampling

The location for sampling was not hard to choose because there are abandoned buildings, new constructions, and external walls with varying degrees of decay everywhere around and in Urcuquí. Salt samples are pretty easy to gather since they appear everywhere at the base of the walls where blocks are bonded with a mortar. A total of 28 samples were collected, and all of them have been analyzed. The location, elevation (masl), name allocated, and sample coordinates are all included in Table 1.

Samples had to be taken at certain localities to gather the crystals of the minerals found in buildings during the fieldwork. The discovered minerals were collected by scraping the wall and removing the crystals with a spatula. The piece was then placed in a zip-top bag and given a code name that included the letters M for the number of samples and P for the number of places. From this process, the characterization is needed for deteriorated buildings assessing the level of degradation in constructions in Urcuquí and the other communities.

To ensure precise identification of mineral compositions and comprehensive sample analysis, X-ray diffraction (XRD) is deemed essential. Furthermore, a microscope is needed since it can recognize physical details, including color, structure, and brightness. Its configuration allows for a three-dimensional view of the material being studied. This visual appearance is made possible because each of its two eye lenses functions independently. Each sample was examined under a microscope to describe its external characteristics, such as texture, color, and other responses.

Table 1. *Sample points are taken in Urcuquí and near communities according to UTM coordinates*

X	Y	Elevation (masl)	Sample	Place of sample
817644	43764	1845	M1P1	Artificial channel
818213	43678	1840	M2P2	Tunnel (Hoja Blanca-Imbaya via)
			M3P2	
818225	43869	1873	M4P3	Hoja Blanca (Train station)
816316	44574	2053	M5P4	El Puente Community
816319	45624	2020	M6P5	Hacienda San Vicente
818814	46614	1855	M7P6	Hacienda La Merced Tapiapamba
818997	48599	1748	M8P7	Manantial
			M8.1P7	
818280	48676	1801	M9P8	Tapiapamba entrance
814990	47231	2120	M10P9	San Antonio Community
814772	47160	2139	M11P10	San Antonio Community
811435	45460	2339	M12P11	Near to San Ignacio Church
809172	45420	2454	M13P12	San Juan Church
808500	45328	2879	M14P13	Near to San Juan Church
805709	44556	2442	M15P14	Santa Cecilia Community
804284	46962	2700	M16P15	Outside Timbuyacu Resort
804284	46962	2700	M17P16	Inside Timbuyacu Resort
813048	46190	2295	M18P17	External Museum Wall
813050	46189	2295	M19P17	Internal Museum Wall
811765	46585	2299	M20P18	El Rosario neighborhood
812132	46075	2294	M21P19	A large brick wall
			M22P19	
			M23P19	
			M24P19	
			M25P19	
			M26P19	
			M27P19	
			M28P19	

3.2 Experimental Work

To remove contaminants like cement, clay, lithics, and other building materials, samples need to undergo mineral purification treatment. For a thorough and dependable analysis of a sample's composition and properties, it is recommended to conduct an X-ray diffraction analysis. This process examines the sample phases and crystalline structures to provide comprehensive insights into their intricate details, resulting in more accurate and insightful analysis.

3.2.1 Material Purification and Crushing Process.

A spatula was used to scrape the white patches from the wall to gather the twenty-eight samples. Consequently, this process caused fragments of construction materials, such as cement and clay, to fall into the sampling bag alongside the salt crystals (Figure 4A). To ensure the utmost accuracy, we meticulously used a tweezer to carefully separate the cement and clay pieces from the samples. Cleaning tools included a tweezer, a glass vessel to evenly scatter the sample, white paper to maintain the cleanliness of the workspace, and a sieve (Figure 4B). Subsequently, the salt crystals were crushed to obtain a fine grain for optimal results and distinguish between various salt types (Figure 4C). As the final step, the samples were sieved to create a refined material that could be utilized for the XRD process (Figure 4D).

Figure 4. *Crystal samples collected to be analyzed (A), Material used to separate pieces of building material (B), Crushing samples using a mortar (C), and sieving the samples (D).*

3.2.2 XRD analysis of mineral samples.

These samples were analyzed by the materials characterization laboratory at Yachay Tech University's School of Chemical Sciences and Engineering. A computer-controlled D/tex

Ultra2 detector equipped with a Rigaku Mini-flex-600 powder diffractometer, which can do qualitative and quantitative analysis on unidentified powder crystalline materials, was used for the analysis (Figure 5A). The XRD machine can analyze up to eight samples within an estimated 20 minutes (Figure 5B).

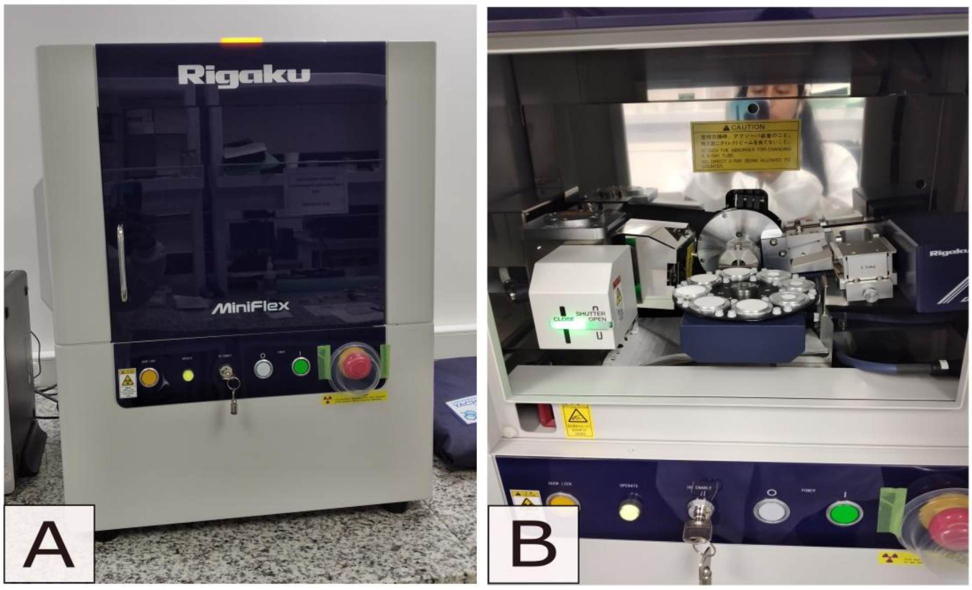

Figure 5. *The X-ray diffraction (XRD) machine and the space within it.*

The electromagnetic radiation known as X-ray diffraction (XRD) analysis gives qualitative and quantitative mineral or phase information in various geological materials investigated in a research laboratory or processed for industrial use. This flexible and nondestructive analytical method may swiftly gather comprehensive structural and phase data on materials. X-ray diffraction analysis is required to confirm damage by chemical sulfate attack (Dinnebier & Billinge, 2008). In materials characterization, X-ray diffraction is an essential technique for investigating the interior structure of things and obtaining details on an atomic level since it (Suryanrayana & Grant Norton, 1998).

To obtain accurate results, it is recommended to use a sample that contains a few tenths of a gram of material, preferably in its purest form. The material should be ground into a fine powder with a particle size of less than ~10 µm (or 200-mesh). The material must first be ground and evenly spread onto a glass slide to start the XRD process. It should then be placed in a sample holder, ensuring a flat surface. When packing the material into the sample container, it is essential to ensure that a flat upper surface is created. The XRD analysis started after placing the eight sample holders into the automatic sample changer (Figure 6).

Figure 6. *Crystal samples were prepared for the XRD analysis.*

The results are projected in a graphic when the machine processes the data gathered by the x-ray diffraction on the opposite side of a computer, yielding data of intensity and the second theta. All meaningful studies with crystalline stuff must include a fundamental identification using powder diffraction data as a fingerprint of the substance and search-and-match among hundreds of thousands of known powder diffraction patterns kept in different databases (Pecharsky & Zavalij, 2005). Halite ($NaCl$) and mirabilite ($Na_2SO_4.10H_2O$) are the predicted crystal phases to be discovered. The eventual result of mirabilite dehydration will be thenardite (Na_2SO_4), widely recognized for being present in various settings and habitats (Rodriguez-Navarro & Doehne, 1999).

Chapter 4. Results

This chapter presents findings from XRD analysis and microscopic examination of previously analyzed materials. Several tables list the different types of minerals, their names, concentration percentages, and chemical formulas. The information was collected by examining the analyzed data from the Match program. Search Match is a software that utilizes powder diffraction data to perform phase analysis. Its primary function is to automatically compare the diffraction pattern of the samples taken to a database of reference patterns to identify the phases present in the sample.

4.1 Characterization of physical weathering in Urcuquí and Near Communities

The following pages describe all the places visited where relevant information is shared to know the level of deterioration. Moreover, a collection of photos shows the damage caused by crystallization weathering. Natural outcrops and civil infrastructure were described, analyzed, and sampled during the fieldwork to identify the salts' potential source and determine whether they are present in the volcanic materials that comprise the region's geology and are subsequently used as construction materials.

Multiple areas were checked for growth salt crystallization causing the building components' degradation. Buildings that have been abandoned generally exhibit significant decay, making them one of the most often found structures for sampling. However, white spots in new buildings suggest that deterioration is also present in new buildings. The impression is that the white minerals are developing even while the block is being manufactured. In Urcuquí, several ongoing building projects are where bricks and concrete blocks are accumulating white crystals even though they have not yet been utilized.

4.1.1 Minerals in a Natural Environment

The outcrop (Figure 7A) is close to the Hoja Blanca station and adjacent to the ancient Urcuquí-Ibarra viaduct. The coordinates of the location where a natural mineral (sample M1P1) was sampled are shared in Figure 1 and Table 1. It depicts the displacement of volcanic material with expanded fractures (black lines) caused by the slope's instability. The height of this outcrop is approximately 70 meters. The clasts appear to have angular to subangular shapes, indicating that they were transported with medium-level energy and had a fine to coarse grain size. The initial sampling was made in an anthropogenic channel (Figure 7B). This channel was supposed to transport water but must be completed for unknown reasons. Possible natural salts are growing in the wet soil (Figure 7C). The minerals found in this location have an elongated and white fibrous structure (Figure 7D). On the other hand, it is well known that construction materials are extracted from mountains; hence, a salt sample at this location is required to identify what salt types are naturally crystallizing. The objective is to ascertain the specific kinds of salt that naturally develop into crystals.

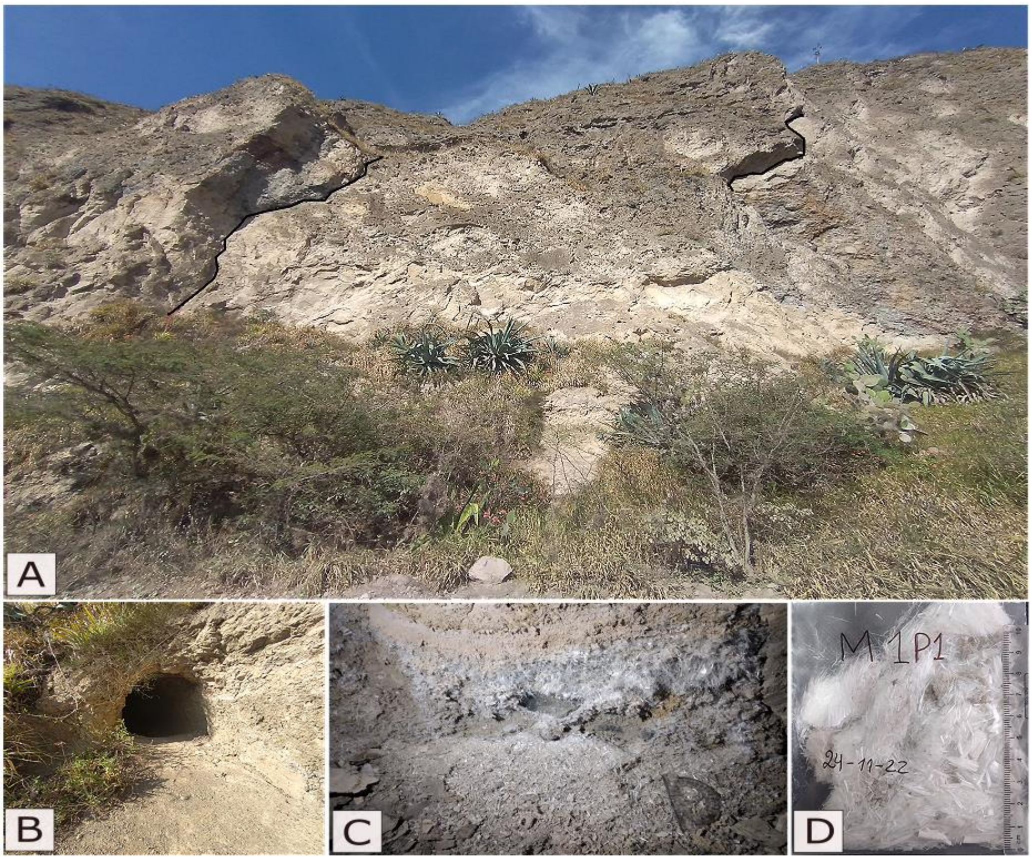

Figure 7. *Outcrop with cracks near the Ambí River (See location in Figure 1) (A). Artificial channel (B). Crystallized salts in the ground (C). M1P1 Sample taken in the channel(D)*

In this location (Figure 8A), two samples were collected in two different scenarios to know their composition. These outcrops are in an anthropogenic tunnel 100 meters from the first stand. Figure 1 and Table 1 show the site's location where two natural mineral samples (M2P2, M3P2) were taken. Sample M2P2 from the north wall (Figure 8B) and M3P2 from the south wall (Figure 8C). M2P2 presents minerals with a smooth texture and resembles fine dust (Figure 8D). Furthermore, it has white lamination layers in the outcrop's center but a conglomerate stratum with subangular clasts towards the base. M3P2 shows minerals growing as little green trees on the south side; however, due to their hardness, this sample was difficult to collect (Figure 8F). This wall contains a natural water source that keeps the wall moist. Aside from the two salt samples collected there, a piece of rock from this cave will be tested with HCl to determine how it reacts. The project's results section will include this piece's reaction to HCl.

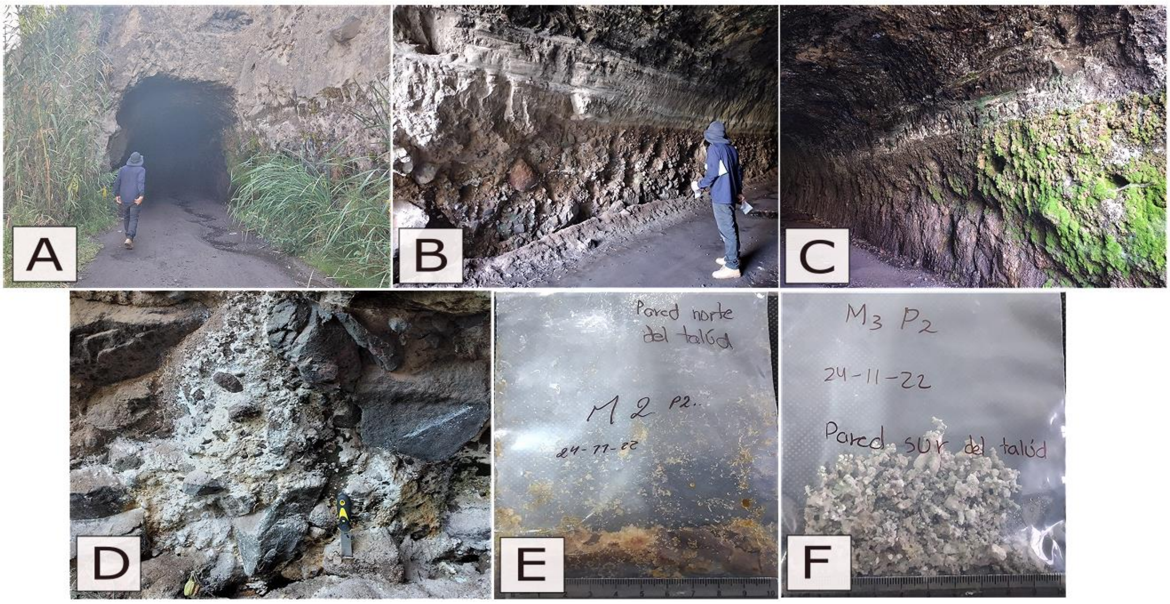

Figure 8. *Anthropogenic tunnel in Hoja Blanca – Imbaya via (See location on Figure 1) (A). North wall of the tunnel (B). South wall of the tunnel (C). Minerals in the north wall(D). Sample M2P2 from the north (E). Sample M3P3 from the south (F).*

The coordinates of the location where the natural mineral sample (M8P7) was collected are displayed in Figure 1 and Table 1. The following outcrop is several meters from the road (Figure 9A). In this place, possible salt crystals grow on the soil surface before reaching the spring water (Figure 9B). Sample M8P7 belongs to the outcrop near the spring water since the minerals are growing there (Figure 9C). The sample was extracted in pieces with 0.5 - 3 cm where the salt was growing in the rock (Figure 9D, 9E). This mineral's crystals are white to transparent in color and clump together to create an agglomeration. The outcrop has volcanic material known as pumice rock which is presented in a fence that surrounds the area to keep the water in (Figure 9F). Here is evidence of the implementation of volcanic material, such as pumice, in construction areas since it is found in concrete blocks. Due to pumice density, which makes it not heavy, it is well-recognized that this material is helpful for construction.

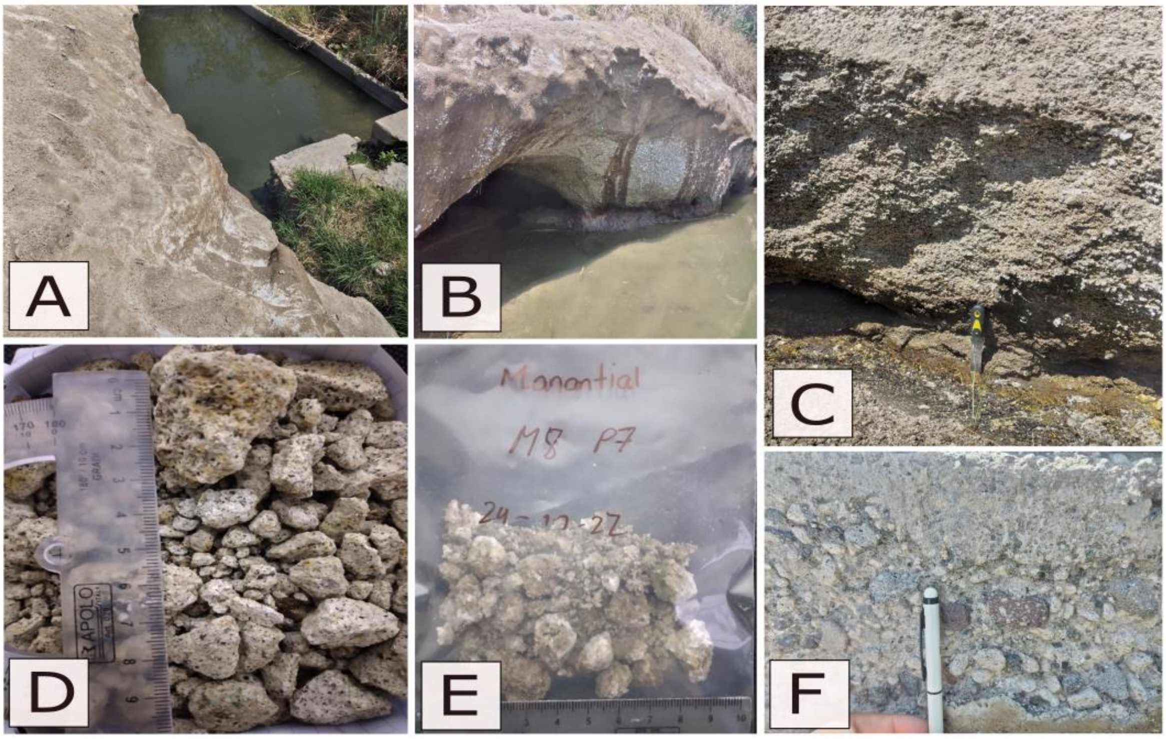

Figure 9. *Spring water with volcanic material (See location in Figure 1) (A). Possible salt in situ growing in the ground (B). Water flowing through volcanic material (C). Mineral sample collected (D). The volcanic material sample is taken M8.1P7 (E). Volcanic material is used with concrete to retain water (F).*

4.1.2 Minerals in Building Constructions

For many years, the Hoja Blanca Station has been abandoned (Figure 10A). As a result of the abandonment, the roof has crumbled through the years, resulting in ongoing damage from the sun and rain. The coordinates of the location where a mineral (sample M4P3) was sampled are shared in Figure 1 and Table 1. Possible salt crystals grow in the cement joints near the wall's bottom (Figure 10B). The inside wall has minor damage, but the external wall is deteriorating (Figure 10C). One of the principal construction materials is lava bricks at the base of the building bonded with a mortar mixture. The concrete block is a secondary construction material, which also presents deterioration. The sample M4P3 (Figure 10D) comes from the internal wall where the crystals are shown in the mortar mixture. All the physical conditions of the buildings are of great importance since they will help to study each case.

Figure 10. *Hoja Blanca Train Station (See location in Figure 1) (A). The internal wall presents salt crystallization (B). Abandoned and deteriorate building (C). M4P3 Sample taken from the inner wall (D).*

Take a sample from a house in El Puente Community. Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M5P4). On the left side of the house analyzed (Figure 11A), a white patch (possible salt crystals) is forming on the wall with considerable size (Figure 11B), which is where the M5P4 sample was obtained (Figure 11E). The second floor has no roof; thus, the soil is not protected from heat and rain. Consequently, the filtering of water likely is what is causing crystals to develop on the roof (Figure 11C). On the other hand, concrete blocks are one of the primary building materials used in this home. Additionally, the house’s walls are not covered with plaster but a sand mixture. The owner has noted the presence of several white spots on the walls, and rainwater is standing in several places on the second floor. He believes humidity causes those white spots created by the percolating water; nevertheless, he is unaware that the white areas are possibly salt crystals growing in buildings. On the other hand, salt crystals increase at the bottom of the wall (Figure 11D), indicating the soil's capillary absorption. Compared to the top of the wall, the degradation is more significant near the base. They are considering that the concrete blocks present a little detachment of material that covers the concrete blocks. Some homes in the small community of El Puente Community have varying degrees of deterioration.

Figure 11. *House in El Puente Community with possibly salt crystals (See location on Figure 1) (A). Identifying the existence of crystals in construction (B). Taking the mineral sample from the wall (C). Crystals at the base of the wall(D). Sample M5P4 taken (E).*

There are abandoned farms near Yachay Tech University with powerful indications of possible salt crystal damage. One is San Vicente Farm, which has several buildings with minerals growing on walls (Figure 12A). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M6P5). The sample comes from a house wall and a concrete bridge containing crystals (Figure 1B). Those crystals were removed from the wall with a spatula and a zip-top bag. Crystals of the minerals are white and have a lumpy texture. It is known that crystal growth causes the paint on the wall to expand because those minerals develop between the concrete block and the color (Figure 12C, 12D). Moreover, crystals may be seen in several pillars around the house (Figure 12D) because of the high level of weathering. Besides, another building on the property has cracks and cement patches, typical when deterioration begins (Figure 12F). The degradation level is high for paint conservation since it is one of the first materials to decay due to its expansion caused by crystals of minerals.

Figure 12. *Deterioration in a San Vicente Farmhouse wall (See location on Figure 1) (A). Concrete bridge with superficial salt deterioration (B). The place where the sample was taken (C). Concrete wall with the presence of salt crystals (D). Salt sample M6P5 (E). House with fractures in the wall and fixed with cement mixture (F).*

La Merced Tapiapamba Farm is another abandoned building near the Yachay University campus (Figure 13A). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M7P6). This farm was built in 1957, having been 65 years to this day. Dates are necessary to analyze the deterioration level throughout the years. Several structures around the sampling area belong to the farm, presenting a certain level of degradation too. Examining the constructions, all these are constantly deteriorating due to weathering and lack of maintenance. The primary building materials are concrete blocks (Figure 13B) and bricks. Most of the structures are exposed to the agents of erosion, such as rainwater, wind, and sun, causing material cracking. Furthermore, crystals grow primarily at the bottom of the wall (Figure 13C), where the sample M7P6 comes from (Figure 13F). Those crystals were taken by scraping the wall with a spatula and safe into a zip-top bag. Their physical appearance presents a smooth texture and white color. It is worth mentioning that crystallization occurs mainly in the mortar mixture that covers the concrete block giving some patterns to analyze (Figure 13D). In addition, iron bars are exposed to the environment, so they may start to oxidize and eventually cause the structure to collapse (Figure 13E).

Figure 13. *La Merced Farm construction from 1957 (See location in Figure 1) (A). The sample was taken in a porous material (B). White crystals were identified in the wall of an abandoned house (C). Concrete block pillars with salt crystals (D). Iron is revealed beneath a concrete table (E). Salt sample M7P6*

The state of this structure is one of abandonment and continuous decay (Figure 14A). The most affected areas are the lower part due to the soil humidity and the presence of minerals. The deterioration level here is increasing since it does not have constant maintenance (Figure 14B). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M9P8). Inside the house, one of the walls indicates a high level of degeneration since there is a big hole at the wall base. Similarly, the exterior side of the house presents damage to walls and pillars since the iron bars are already exposed (Figure 14C). The mineral sample M9P8 comes from the inside wall of the house (Figure 14D). These minerals have a smooth texture and white color (Figure 14E). This house's construction elements include concrete blocks with white paint and a damaged tile roof. The degree of deterioration in the building components puts this structure at risk of collapsing.

Figure 14. *Abandoned construction in Tapiapamba (See location in Figure 1) (A). Concrete block deteriorated (B). Iron exposed in concrete block construction (C). Sample-taking process (D). Salt sample M9P8(E).*

Around the San Antonio church, pillars have certain deterioration levels where the iron is already exposed; these pillars enclose a plot, and others are lamp posts (Figure 15-C). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M10P9). These pillars may crumble with time due to the degradation of the building materials. Touch-up paint was recently applied to the church walls, but since crystals are developing within, the color has expanded or inflated (Figure 15B). Additionally, a crack can be seen where they painted, and this paint expansion is worsening near the bottom of the wall. However, due to crystal accumulation, paving stones are also susceptible to degradation in front of walls (Figure 15D). To determine the type of mineral present, the sample M10P9 was obtained from a wall at this location (Figure 15E). These crystals have a smooth texture and white color. Those crystals were collected by scraping the wall with a spatula and putting them in a zip-top bag.

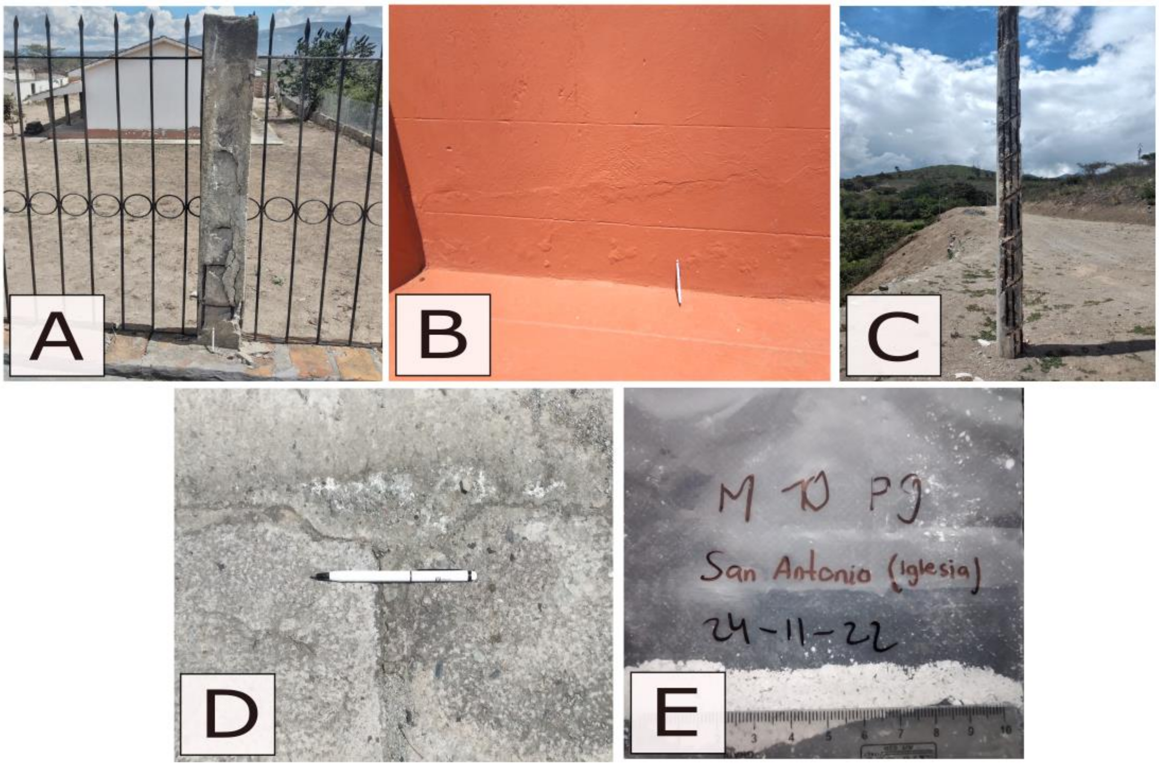

Figure 15. *In the San Antonio Community (See location in Figure 1), there is a concrete column that features exposed iron (A)(C). The paint on the wall has expanded due to crystal growth within the surface (B). Crystals of minerals growing on the floor (D). Sample M10P9 taken from church (E).*

Another common scenario around the villages is the next. Crystals are also present in walls and lampposts of the San Antonio neighborhood (Figure 16A-B). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M11P10). The iron bars in the lamppost are exposed to the environment, which is crucial to note since oxidation may occur in the future; consequently, it could collapse. The building materials used in the retaining wall analyzed appear to be made of concrete. Crystals or white zones, in this instance, are near the top of the wall, visible from the street. The presence of crystals descends to a drainage pipe, creating the impression that the water penetration is the leading cause of the crystal's formation (Figure 16C). To contrast the argument expressed, a sample must be taken here. The M11P10 sample will be examined to determine the mineral type found. These crystals are white and have a smooth texture (Figure 16D). To collect the crystals, one should scrape the wall using a spatula and store them in a zip-top bag for later use in the lab. Although the wall has some tiny crystals growing, the deterioration level is insignificant.

Figure 16. *House wall with crystals in the San Antonio community (See location in Figure 1) (A). A deteriorated light pole with exposed iron bars (B). Obtaining a mineral sample from the wall near the drainage (C). Sample M11P10 obtained (D).*

Both the newest and oldest buildings are being deteriorated due to the detachment of the building material caused by physical weathering. The San Ignacio village has a high level of deterioration in an ancient church structure. Figures 17A–B show the old church and the damage caused near the base of the wall. Similar to Figure 17B, Figure 17C depicts an ancient structure with comparable damage at the bottom of the wall. This building will be demolished since all that is left of it is one wall. Concrete blocks were used to construct those buildings, and compressed earth blocks were used to create these two buildings. Any porous material exposed to water over time may experience various forms of physical weathering. In another case, concrete blocks were installed in an old house, where the damage was found (Figure 17D), trying to mitigate the effects of the deterioration. However, the most recent materials used have experienced a detachment process that has resulted in almost 15% of lost material.

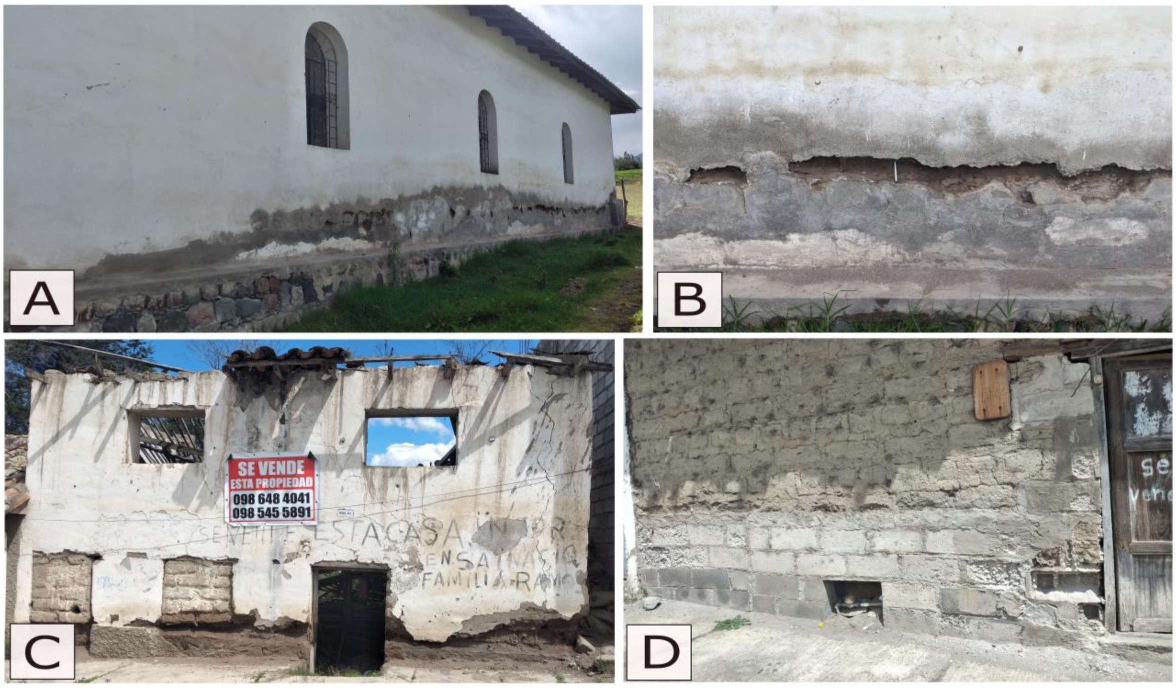

Figure 17. *Church wall with exterior degradation (A). The degree of degradation of the wall (B). Old house with significant degradation (C). The combination of construction materials and their degradation (D).*

The San Ignacio Plaza has damaged railings that are losing material due to deterioration processes (Figure 18A). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M12P11). The base of the walls also exhibits signs of building decay. In this location, the walls have moderate wall deterioration (Figures 18D-C). The M12P11 sample was taken from a brick wall (Figure 18B) where crystals cover part of the wall. The physical appearance of the minerals is white smooth (Figure 18E). These crystals were collected by scraping off the wall with a spatula and put in a zip-top bag. On the other hand, concrete and clay blocks are the most often used building materials in this zone, and both have certain degrees of degradation. Because public infrastructures represent most areas where weathering occurs, repairing them incurs significant expenditures. Having crystal samples in historic structures can help us determine what mineral types are presented.

Figure 18. *Deteriorated handrails in the San Ignacio Plaza (See location in Figure 1) (A). The sample was taken from a brick wall (B). Base wall with deterioration-caused fractures (C)(D). The sample was taken M12P11*

Public buildings in the San Juan neighborhood have crystals growing on external walls (Figure 19A). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M13P12). The base of a classroom wall has white minerals growing under the paint (Figure 19B). The color of the wall is one of the primary factors that are influenced in these deterioration cases. White crystals are forming along the freshly constructed water pipelines, as shown in Figure 19C. Humidity causes crystals to develop in the newly applied substance. To identify the mineral type, the sample M13P12 was collected from this public area (Figure 19D). These crystals were collected by scraping off the wall with a spatula and put in a zip-top bag. Consequently, the municipal authorities will need to spend more on building upkeep in these situations in the future.

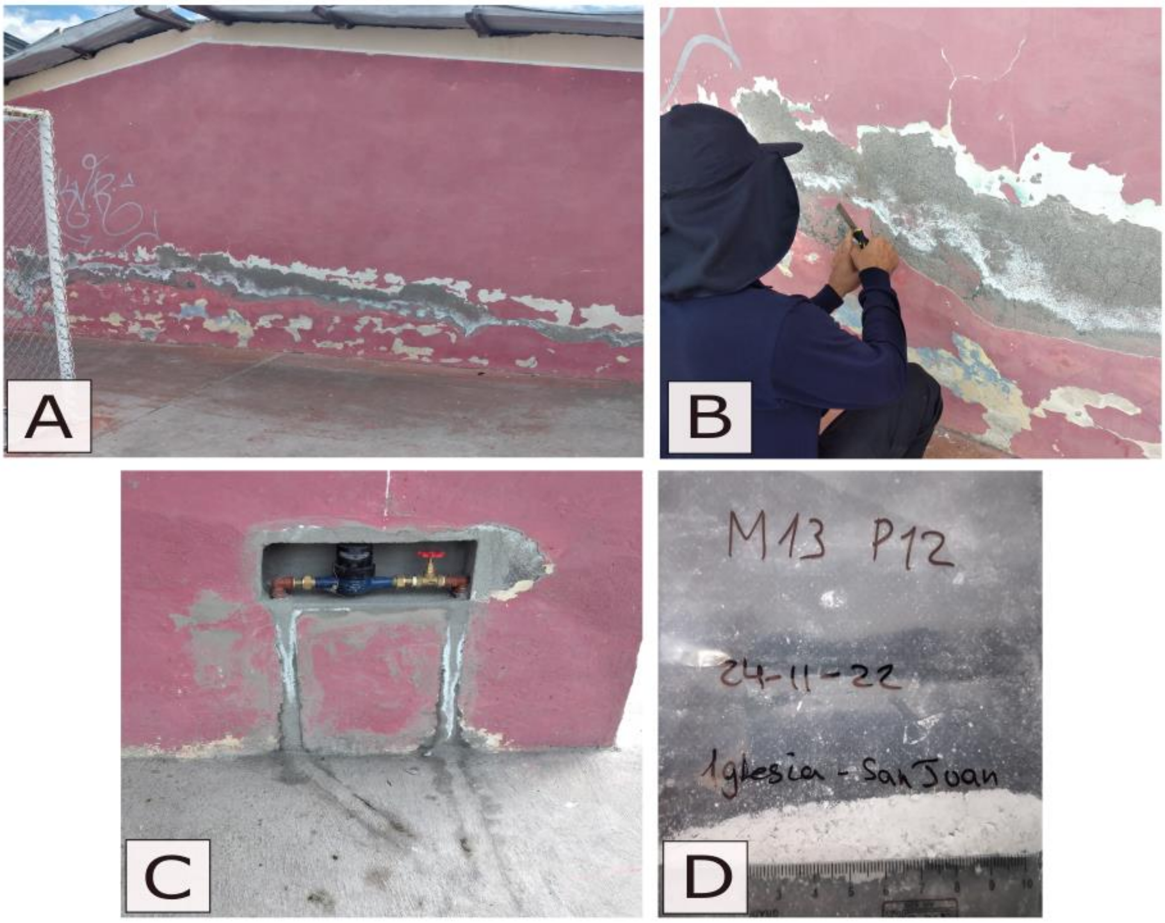

Figure 19. *San Juan church wall with salt crystals (See location in Figure 1) (A). The sample is taken from the wall base (B). Salt crystals are forming along the cement-covered pipe (C). Sample salt collected (D)*

According to Figure 20A, white crystals are developing between the ground and a height of one meter. Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M14P13). Concrete and rock blocks are used to construct retaining walls, but crystals are growing in both. Clay bricks are above the retaining wall; thus, they do not suffer from degradation. Using a spatula to scrape the crystals from the wall, they were placed in a zip-top bag for storage. The crystals collected have a smooth texture and white color (Figure 20B). On the other hand, Figure 20C demonstrates that those white crystals are developing at the base and in the concrete portion where the rock blocks are connecting between them. Curiously, mineral crystals also form in freshly constructed walls, proving that the date of construction does not have a part in the crystal's appearance; even those minerals grow in blocks recently made (Figure 20D).

Figure 20. *Taking crystals from a wall (A). The sample was taken M14P13 (B). White crystals are present at the base of a rock wall (C). Crystals are seen in a freshly built wall (D)*

Another town with possibly salt crystals on the walls is Santa Cecilia. The sample taken originates from a young-looking retaining wall (Figure 21A). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M15P14). The minerals that have been gathered have a smooth, white look. These crystals were collected by scraping them off the wall with a spatula and placing them in a zip-top bag (Figure 21D). The building materials employed are bricks at the top and on the base rock blocks with mortar (Figure 21B). Although white crystals can be seen in lava rocks, this does not necessarily mean that the minerals grow there; instead, they are displaced above the rock when it rains. Alternatively, those white minerals may be a part of the brick wall's upper portion. Similarly, a large white spot could be seen on the second floor, at the top of the wall in a nearby house. Given that the white patch is close to the roof, perhaps water has seeped in and caused it (Figure 21C).

Figure 21. *White minerals are present in lava brick walls in Santa Cecilia Community (See location in Figure 1) (A). Collecting crystals from the wall (B). A white splotch on a new house's second floor (C). Sample M15P14 taken (D).*

The Timbuyacu resort is covered in white crystals on the ceilings, walls, and flooring. Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M16P15). A white spot near the roof may be where water filters and condenses, creating dampness (Figure 22A). White patches also appear on the floor due to the grass on the ground being damp (Figure 22B). The soil comprises volcanic rocks (Figure 22C) and a cement mixture containing growing crystals. From the blue wall, a sample of those crystals was taken to determine the composition of those minerals (Figure 22D). These crystals were collected using a spatula to scrape them off the wall and put in a zip-top bag. Mineral crystals are white and have a smooth texture, but the scraping process took a part of the blue paint.

Figure 22. *Crystals grow in the upper part of the wall in Timbuyacu Community (See location in Figure 1) (A). White minerals are presented on the floor (B). Crystals develop around volcanic rocks in the soil (C). The sample taken from the walls was analyzed (D).*

Inside the Timbuyacu resort, crystals grow in walls, soils, and so on (Figure 23A). Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M17P16). The subsurface magma warms the groundwater of the Timbuyacu spring, creating steam and hot water. These minerals also appear in the soil around the pool due to the humidity produced by the hot water (Figure 23B). Because of the elements of the water that rises, the mineral crystals inside the resort appear green and smooth (Figure 23C). Ground fissures and fractures allow the heated, less dense water to ascend. It rises to the surface and creates features like hot springs. These crystals were collected using a spatula to scrape them off the wall and put in a zip-top bag. Deterioration of building materials is present in handrails and around the resort (Figure 23D). A crystal sample was obtained to determine the mineral type in this location (Figure 23E).

Figure 23. *Timbuyacu Resort walls with salt crystals (See location in Figure 1) (A), Salts are growing in the soil (B), Cement railing pillars deteriorated (C), and Sample (M17P16) was taken from this resort.*

Old buildings on the San Eloy farm have a certain level of deterioration in the exterior and interior wall base (Figure 2A, C). Figure 1 and Table 1 show the location of the site where the two mineral samples were taken (M18P17, M19P18). The flooring and walls show white and smooth minerals falling apart from the paint. The outer wall is the source for sample M18P17 (Figure 24C, D). These crystals were collected using a spatula to scrape them off the wall and put in a zip-top bag. These walls present big white spots and detachment of the paint coating. The archaeological museum daily has visitors such as teachers, students, school administrators, and schools. Authorities chose to repair all the fractures left by deterioration since the Museum is located there (Figures 24B and 25B). The existence of the crystal may be one of the effects of humidity; however, this problem cannot be resolved by simply painting the wall.

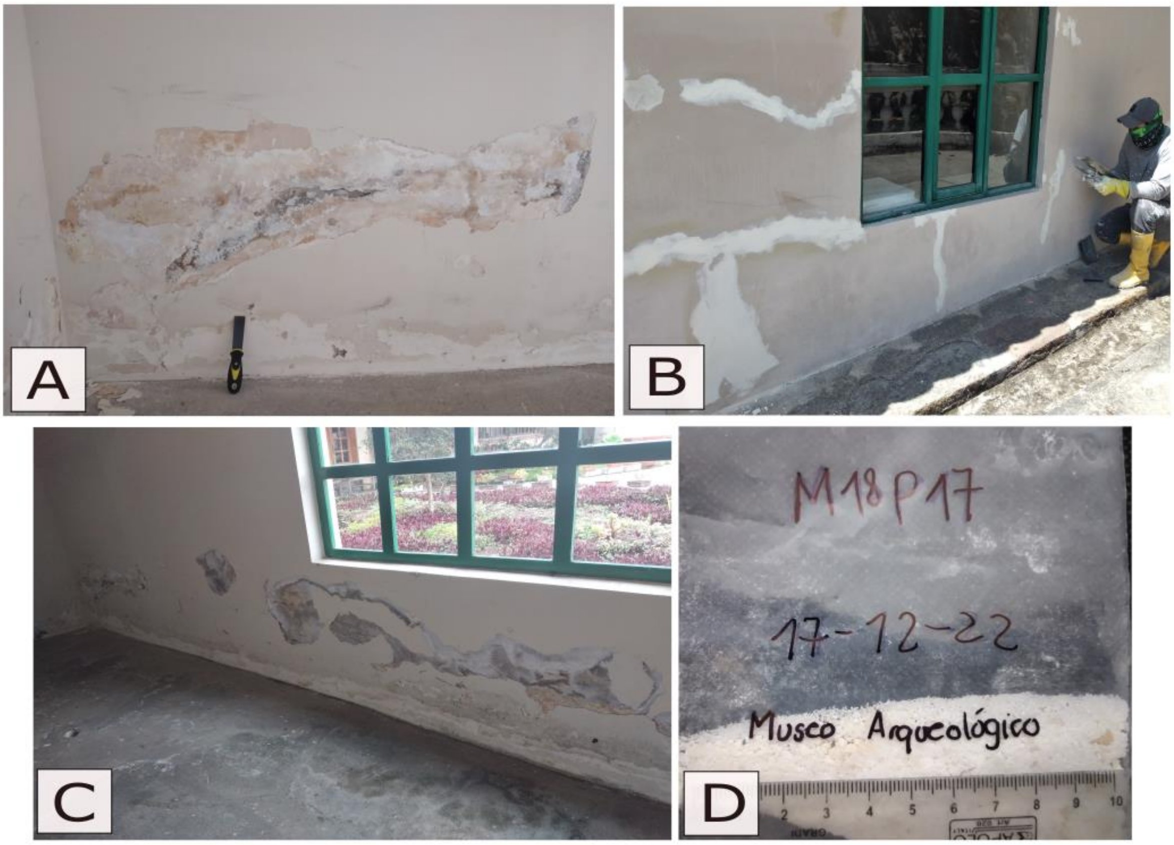

Figure 24. *Outer wall with white crystals in San Eloy (See location on Figure 1) (A). Reparation of the wall in the Archaeological Museum (B). Overview of the wall with deterioration (C). A sampleM18P17 taken from the external wall (D)*

From the internal wall, the sample M19P17 was taken (Figure 25A, D). These crystals present white color and smooth texture. The building materials used in these old constructions are lava, adobe, cement, and clay (Figure 25C). Most materials present mineral crystals growing under the paint, known as sub-florescence. Crystals appear when the color starts expanding and damaging the wall. On the other hand, there are no white spots on the place's interior; maybe the absence of decay can be related to the degree of humidity in the interior of the construction. The exterior of the infrastructure tends to deteriorate due to the exposition to the wind, sunlight, and rain.

Figure 25. *Inner wall with salt crystals in San Eloy (See location on Figure 1) (A). Reparation of the external wall in the Archaeological Museum (B). Clay blocks with salt crystals (C). Sample M19P17 was taken from the analyzed wall.*

Deterioration issues are also apparent in the El Rosario area, which is close to the Urcuquí town center. Figure 1 and Table 1 show the location of the site where the mineral sample was taken (M17P16). Building material is continually being destroyed by the growth of white crystals (Figure 26A). Those minerals were collected using a spatula to scrape them off the wall and put in a zip-top bag. The minerals are smooth in texture and white in color, although the sample has an orange tint because of the clay components included in the construction material (Figure 26B). When seen under a microscope, these clay particles will appear as a mixture of white-orange crystals. However, because the damage may result from the capillary absorption process, it is crucial to consider how far the damage is from the soil. In this location, the distance from the ground to the degradation is over 60 cm.

__Figure 26.__ Brick wall with degradation and white minerals growing in El Rosario neighborhood (See location on Figure 1) (A). Sample taken from the wall analyzed (B).

Near the Urcuquí´s cemetery is a considerable extension of a field where its external wall presents deterioration at certain levels (Figure 27A). Figure 1 and Table 1 show the location of the site where the two mineral samples were taken (M21P19- M28P19). The curiosity is why crystals grow at a given elevation and not in other sections (Figure 27B). Crystals are growing at the top of the wall due to a rainwater flow descending from the roof. That region is being hydrated by the water and dried by the sun, allowing the mineral crystallization process to occur. This is a crucial factor that must be characterized to identify the damage's origin since the white crystals that have been detected only appear at specific elevations. This wall is composed of clay blocks and a mixture of mortar to join them; moreover, the base of the wall is made of a cement mixture. Samples were taken from this wall every 20 cm to identify the types of minerals at each level. (Figures 27 C, D, E, and F). The possibility of obtaining the same mineral can be high, but knowing or understanding why the efflorescence appears at a persistent elevation is essential.

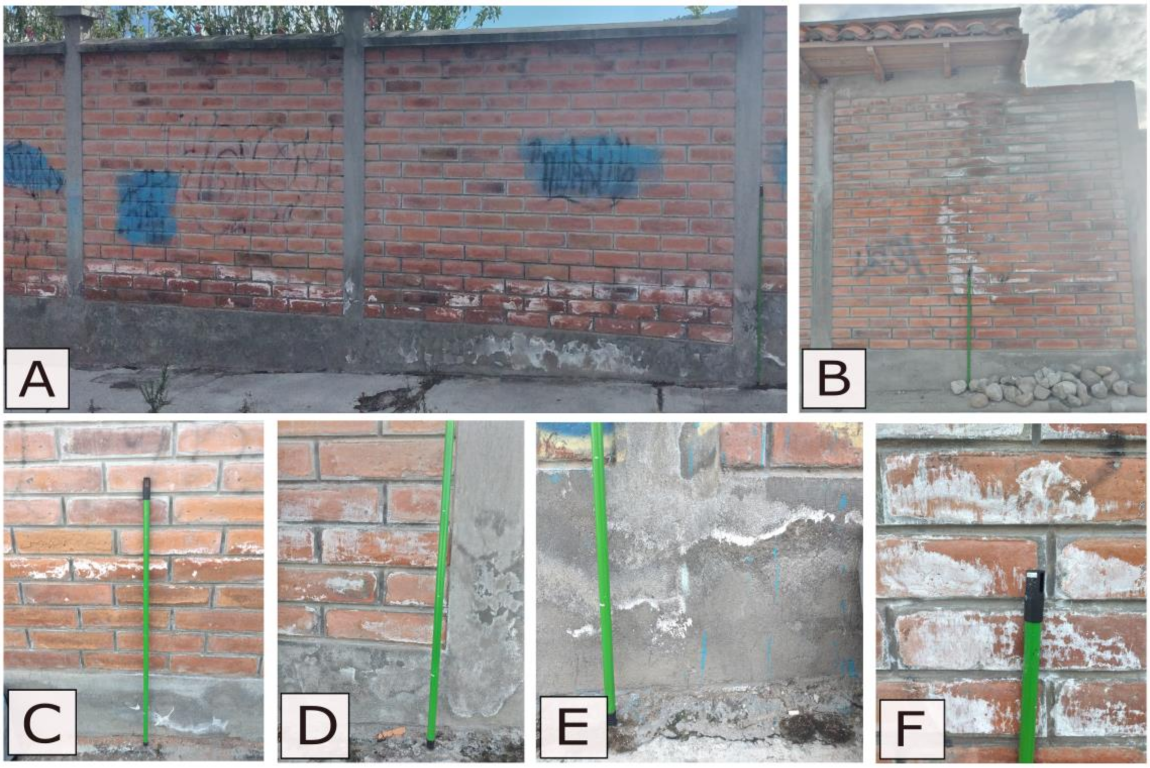

Figure 27. *Clay Wall with a low degree of deterioration in Urcuquí (See location in Figure 1) (A). Crystals grow at the top of the wall (B). White crystals develop at specific C, D, E, and F levels.*

4.1 Description of the mineral facies and environmental factors that support the quickly expanding

In the following pages, the findings will be divided into three categories: Natural salt samples, Salt samples obtained from building sites, and Salt samples obtained from a particular brick wall. This is only to improve the development of this chapter.

The Match program provides information about the mineral's properties in the samples, including details such as the mineral phase, chemistry formula, and chemical composition in percentages. In addition, two diffractograms are shared - one from a natural environment and another from a construction site - to illustrate the processing data method with Match software. The aim is to understand the process without any confusion clearly.

The information gathered through XRD has been organized and displayed in Table 2. The table contains essential details such as sample number, location, mineral phase, formula, and chemical composition percentages. It is necessary to provide instructions for evaluating the salt using these aspects. The name of a mineral is determined by its mineral phase, while the chemical composition of the mineral is revealed by its formula. The sample's chemical composition is quantified as a percentage, indicating the presence of each mineral.

Table 2. *Mineral phases detected in the salt samples with their quantitative.*

Sample	**Location**	**Mineral Phase**	**Formula**	**Chemical Composition (%)**
M1P1	Artificial channel	Epsomite	$MgSO4*7H2O$	100
M2P2	Hoja Blanca (Tunnel-Imbaya via)	Mirabilite	$Na2SO4 * 10 H2O$	88.3
M3P2		Sodium Calcium Silicate	$Na15.6Ca3.84(Si12O36)$	16.3
		Aragonite	$CaCO3$	83.7
M4P3	Hoja Blanca (Train station)	Thenardite	$Na2SO4$	66.8
		Gypsum	$Ca(SO)_4(H2O)_2$	33.2
M5P4	El Puente	Thenardite	$Na2SO4$	44.8

	Community	Andesine	Na0.5Ca0.49Al1.4Si2.5O8	40.2
		Calcite	Ca(CO3)	15
M6P5	Hacienda San Vicente	Thenardite	Na2SO4	83.9
		Calcite	Ca(CO3)	7.1
		Albite low	Na(AlSi3O8)	9
M7P6	Hacienda La Merced Tapiapamba	Thenardite	Na2SO4	63
		Labradorite	Na0.4Ca0.5Al1.5Si2.4O8	30.2
		Quartz	SiO2	6.9
M8P7	Manantial	Trona	$Na3H(CO3)_2(H2O)_2$	62.1
		Albite high	Na(AlSi3O8)	27.8
		Dolomite	$CaMg(CO3)_2$	10.1
M8.1P7		Amphibole	$Al3.2Ca3.4Fe4.0K.6Mg6.0Na1.0Si12.8O44(OH)_4$	36.8
		Labradorite	Na0.4Ca0.5Al1.5Si2.4O8	61.9
		Quartz	SiO2	1.3
M9P8	Tapiapamba entrance	Thenardite	Na2SO4	45.8
		Nitratine	NaNO3	4.1
		Labradorite	Na0.4Ca0.5Al1.5Si2.4O8	50.1
M10P9	San Antonio Community (Church)	Thenardite	Na2SO4	70.2
		Labradorite	Na0.4Ca0.5Al1.5Si2.4O8	29.8
M11P10	San Antonio Community	Thenardite	Na2SO4	31.6
		Calcite	Ca(CO3)	6.6
		Trona	$Na3H(CO3)_2(H2O)_2$	8.4
		Anorthite	Ca(Al2Si2O8)	53.1
M12P11	Near San	Thenardite	Na2SO4	70.3

	Ignacio Church	Labradorite	Na0.4Ca0.5Al1.5Si2.4O8	29.7
M13P12	San Juan Church	Thenardite	Na2SO4	45.8
		Nitratine	NaNO3	44.2
		Calcite	Ca(CO3)	4.8
		Anorthite	Ca(Al2Si2O8)	5.2
M14P13	Near San Juan Church	Thenardite	Na2SO4	39.7
		Anorthite	Ca(Al2Si2O8)	47.1
M15P14	Santa Cecilia Community	Thenardite	Na2SO4	14.7
		Trona	$Na3H(CO3)_2(H2O)_2$	73.2
		Anorthite	Ca(Al2Si2O8)	12.1
M16P15	Outside Timbuyacu Resort	Thenardite	Na2SO4	74.4
		Quartz	SiO2	1.7
		Dolomite	$CaMg(CO3)_2$	12.9
		Calcite	Ca(CO3)	11
M17P16	Inside Timbuyacu Resort	Thenardite	Na2SO4	19.7
		Labradorite	Na0.4Ca0.5Al1.5Si2.4O8	80.3
M18P17	External Museum Wall	Mirabilite	Na2SO4 * 10 H2O	100
M19P17	Internal Museum Wall	Thenardite	Na2SO4	63.6
		Calcite	Ca(CO3)	21.1
		Anorthite (Na-exchanged)	(Na0.4Ca0.5)(Al1.5Si2.4O8)	15.3
M20P18	El Rosario	Thenardite	Na2SO4	63.9
		Anorthite Sodian	(Na0.4Ca0.5)(Al1.5Si2.4O8)	25

		Trona	$Na3H(CO3)_{2}(H2O)_{2}$	11.1
M21P19	A large brick wall	Talc	$Mg3(OH)_{2Si4O10}$	47.2
		Eitelite	$Na2Mg(CO3)_{2}$	32.4
		Magnesite	$Mg(CO3)$	20.4
M22P19		Nitratine hight	$NaNO3$	14.4
		Serandine	$Ca0.3Mn1.6NaH(SiO)_{3}$	44.2
		Magnesian	$Mg0.1Ca0.9CO3$	15.8
		Gowerite	$CaB5O8(OH)B(OH)_{3}(H2O)_{3}$	22.2
		Hydrocalumite	$Ca8Al4(OH)_{24}(CO3)Cl2(H2O)_{1.6}(H2O)8$	5
M23P19		Thenardite	$Na2SO4$	6.9
		Labradorite	$Na0.4Ca0.5Al1.5Si2.4O8$	17.5
		Covellite	CuS	74.1
		Sodium Alum	$NaAl(SO4)_{2}(H2O)_{12}$	1.5
M24P19		Anorthite	$Ca(Al2Si2O8)$	9.2
		Euchlorine	$NaKCu3O(SO4)$	16
		Albite high	$Na(AlSi3O8)$	65.1
		Hydrocalumite	$Ca8Al4(OH)_{24}(CO3)Cl2(H2O)_{1.6}(H2O)8$	9.8
M25P19		Thenardite	$Na2SO4$	21.9
		Albite low	$Na(AlSi3O8)$	70.2
		Euchlorine	$NaKCu3O(SO4)$	8
		Quartz	$SiO2$	6
M26P19		Euchlorine	$NaKCu3O(SO4)$	7.6
		Trona	$Na3H(CO3)_{2}(H2O)_{2}$	14.9
		Albite high	$Na(AlSi3O8)$	56

		Quartz	SiO2	21.5
M27P19		Thenardite	Na2SO4	70.1
		Albite high	Na(AlSi3O8)	25.6
		Gypsum	Ca(SO)$_4$(H2O)$_2$	1.3
		Quartz	SiO2	3
M28P19		Thenardite	Na2SO4	11.8
		Anorthite (Na-exchanged)	(Na0.4Ca0.5)(Al1.5Si2.4O8)	73.3
		Quartz	SiO2	14.9

The diffraction profile reflects the outcomes achieved through X-ray diffraction (XRD). It can provide details about the diffraction peaks, the 2-theta interval utilized, and the intensity of each peak. The diffractogram shows the makeup of the construction of the sample M7P6 (Figure 28). The analysis shows the significant existence of sodium sulfate, commonly referred to as Thenardite.

After analyzing the data, it has been observed that the samples contain minerals like labradorite and quartz. These minerals are commonly found in volcanic rocks and are not responsible for deterioration. The cause of damage should be attributed to the salts present in the samples, such as thenardite and mirabilite.

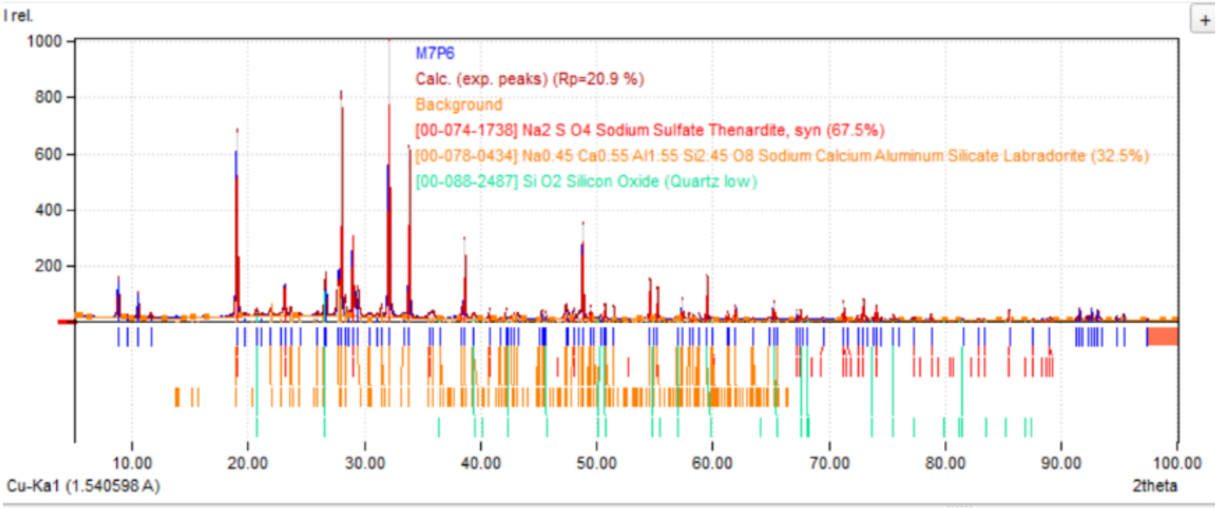

Figure 28. *X-ray diffractogram of the sample M7P6 taken from a wall.*

The mineral sample M8P7 is composed of 60% Trona, which is a hydrate of sodium hydrogen carbonate ($Na_3H(CO_3)_2(H_2O)_2$), and 30% albite, a mineral made up of sodium aluminum silicate ($Na(AlSi_3O_8)$) (Figure 29). According to Dana's classification, Trona mineral is categorized under the carbonate group. On the other hand, Albite is a prominent component of felsic rocks and belongs to the silicates group.

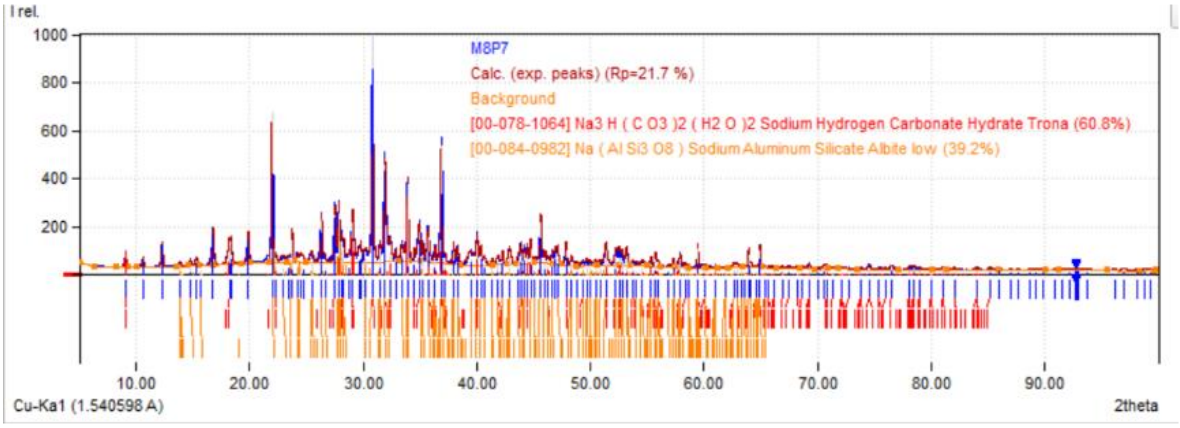

Figure 29. *X-ray diffractogram of the sample M8P7 taken from a natural environment.*

According to X-ray diffraction studies, the primary mineral constituents are sodium sulfate minerals like thenardite and gypsum. During the examination, it was discovered that additional minerals were present, specifically silicates, carbonates, and nitrates.

4.1.1 Natural Salt Samples

This section indicates the five samples collected from a natural environment (Table 3). These samples were taken from the avalanche deposits' outcrop containing natural salt. The localities are abundant in volcanic materials, which have their source from the Chachimbiro volcano. The three natural environments where the samples were collected share similar features. These areas have a moderate to high humidity level at the base of the outcrops, water flows through the rocks, and they are exposed to erosion.

The XRD analysis revealed the presence of sulfates, silicates, and carbonates in the natural salt samples. The sulfate group is commonly found in many cases, with thenardite being the most prevalent mineral. The severe damage is because when water gets into the thenardite-containing material, this mineral's breakdown produces a highly supersaturated solution in terms of mirabilite. Mirabilite can cause harm in certain circumstances. Additionally, if there is enough salt for the mirabilite to fill all pores, the severity of the damage can increase significantly (Tsui et al., 2003b).

***Table 3**. Minerals associated with sulfur, silicate, carbonate-based, their entry number, and quantitative value.*

Sample	Mineral Phase	Formula	Quant (%)	Entry #	Functional chemical group
M1P1	Epsomite	$MgSO_4{*}_7H_2O$	100	96-900-7484	Sulfate
M2P2	Mirabilite	$Na_2SO_4 * 10\ H_2O$	88,3	00-074-0937	Sulfate
M3P2	Sodium Calcium Silicate	$Na_{15.6}Ca_{3.84}(Si_{12}O_{36})$	16,3	00-075-1332	Silicate
	Aragonite	$CaCO_3$	83,7	00-071-2396	Carbonate
M8P7	Trona	$Na_3H(CO_3)_2(H_2O)_2$	62,1	00-078-1064	Carbonate
	Albite high	$Na(AlSi_3O_8)$	27,8	00-083-1607	Silicate
	Dolomite	$CaMg(CO_3)_2$	10,1	00-073-2324	Carbonate
M8.1P7	Amphibole	$Al_{3.2}Ca_{3.4}Fe_{4.0}K_{.6}Mg_{6.0}Na_{1.0}Si_{12.8}O_{44}(OH)_4$	36,8	00-073-1135	Silicate
	Labradorite	$Na_{0.45}Ca_{0.55}Al_{1.55}Si_{2.45}O_8$	61,9	00-078-0434	Silicate
	Quartz	SiO_2	1,3	00-085-0504	Silicate

Water molecules have a negative oxygen side and a positive hydrogen side, which causes them to break the ionic connections that hold sodium and chlorine in salt together. When the water evaporates, the two substances can reunite and form crystals. An example is limestone, composed of calcite (CaCO3), which can develop inorganically or due to biological reactions. Limestone is porous and allows liquids to pass through, which can lead to the formation of large salt concentrations. As water passes through the pores of the limestone, the salt dissolves, creating voids and weakening the stone. As the water evaporates, the salt crystallizes, causing further damage.

4.1.2 Salt in Buildings

An analysis was conducted on minerals extracted from a building to identify their phases. Moisture facilitates the rapid infiltration of soluble salts into buildings, which can be transported further (Delgado et al., 2016). The majority of the mineral phases found were sulfates and silicates. Among the most prevalent sulfates present in all samples was thenardite, classified as a member of the sulfate group according to Dana's classification.

Sulfates

Sodium sulfate is more prevalent in this category than sodium sulfate hydroxide and hydrated calcium sulfate (gypsum) (Table 4). Thenardite also outweighs epsomite, gypsum, and mirabilite when it comes to minerals. Additionally, thenardite has a quantitative value of more than 50% compared to most minerals in all the samples.

Table 4. *Minerals associated with sulfur-based, their entry number, and quantitative value.*

Sample	Mineral Phase	Formula	Quant (%)	Entry #
M4P3	Thenardite	Na2SO4	66.8	00-074-2036
	Gypsum	$Ca(SO)_4(H2O)_2$	33.2	00-074-1433
M5P4	Thenardite	Na2SO4	44.8	96-900-7484
M6P5	Thenardite	Na2SO4	83.9	00-074-2036
M7P6	Thenardite	Na2SO4	63	00-074-2036
M9P8	Thenardite	Na2SO4	45.8	00-074-2036
M10P9	Thenardite	Na2SO4	70.2	00-074-2036
M11P10	Thenardite	Na2SO4	31.6	00-074-2036
M12P11	Thenardite	Na2SO4	70.3	00-074-2036

M13P12	Thenardite	Na2SO4	45.8	00-074-2036
M14P13	Thenardite	Na2SO4	39.7	00-074-2036
M15P14	Thenardite	Na2SO4	14.7	00-074-2036
M16P15	Thenardite	Na2SO4	74.4	00-074-2036
M17P16	Thenardite	Na2SO4	19.7	00-074-2036
M18P17	Mirabilite	Na2SO4 * 10 H2O	100	00-074-0937
M19P17	Thenardite	Na2SO4	63.6	00-074-2036
M20P18	Thenardite	Na2SO4	63.9	00-074-2036

Silicates

The Silicate mineral group is the largest and most abundant in the Earth's crust, surpassing the total quantity of all other mineral groups combined. Silica (SiO2) is only present as a mineral in crystallizing magma when the abundance of SiO2 exceeds that of all other cations available to create silicates. Silicates are mineral compounds of oxygen (O) and silicon (Si) atoms; they are widely considered the most prevalent elements combined with other factors. Silicates play a significant role in forming rocks, and they are responsible for creating critical rock-forming minerals such as feldspar, quartz, olivine, pyroxene, amphibole, garnet, and mica (Mishra & Deshmukh, 2019).

Sodium Calcium Aluminum Silicates, such as Labradorite and Anorthite, are more prevalent in this category than silicon dioxide (Quartz) (Table 5). These minerals are known as the Feldspar group, a collection of aluminum silicate minerals. In the Feldspar group, albite, anorthite, orthoclase, and microcline are the principal rock-forming minerals.

Table 5. *Minerals associated with silicate-based, their entry number, and quantitative value.*

Sample	**Mineral Phase**	**Formula**	**Quant (%)**	**Entry #**
M5P4	Andesine	$Na_{.499}Ca_{.491}Al_{1.488}Si_{2.506}O_8$	40.2	00-079-1148

M6P5	Albite low	$Na(AlSi_3O_8)$	9	00-076-0897
M7P6	Labradorite	$Na_{0.45}Ca_{0.55}Al_{1.55}Si_{2.45}O_8$	30.2	00-078-0434
	Quartz	SiO_2	6.9	00-085-0504
M9P8	Labradorite	$Na_{0.45}Ca_{0.55}Al_{1.55}Si_{2.45}O_8$	50.1	00-078-0434
M10P9	Labradorite	$Na_{0.45}Ca_{0.55}Al_{1.55}Si_{2.45}O_8$	29.8	00-078-0434
M11P10	Anorthite	$Ca(Al_2Si_2O_8)$	53.1	00-086-1706
M12P11	Labradorite	$Na_{0.45}Ca_{0.55}Al_{1.55}Si_{2.45}O_8$	29.7	00-078-0434
M13P12	Anorthite	$Ca(Al_2Si_2O_8)$	5.2	00-086-1706
M14P13	Anorthite	$Ca(Al_2Si_2O_8)$	47.1	00-086-1706
M15P14	Anorthite	$Ca(Al_2Si_2O_8)$	12.1	00-086-1706
M16P15	Quartz	SiO_2	1.7	00-085-0504
M17P16	Labradorite	$Na_{0.45}Ca_{0.55}Al_{1.55}Si_{2.45}O_8$	80.3	00-078-0434
M19P17	Anorthite (Na-exchanged)	$(Na_{.45}Ca_{.55})(Al_{1.55}Si_{2.45}O_8)$	15.3	00-085-1415
M20P18	Anorthite Sodian	$(Na_{0.45}Ca_{0.55})(Al_{1.55}Si_{2.45}O_8)$	25	00-078-1064

Carbonates

Minerals containing carbonate are frequently produced in marine environments, where shells gather and build up on the ocean floor, as well as in evaporative areas and karst regions (Grossp & Esbert, 1994). The minerals known as carbonates comprise metallic elements, carbon, and oxygen. These minerals feature $(CO3)^{2-}$ anions and include popular options like aragonite and calcite (both composed of calcium carbonate), dolomite (made up of magnesium and calcium carbonate), and siderite (consisting of iron carbonate). This group also encompasses borate and nitrate minerals(Mishra & Deshmukh, 2019). This group contains more calcium carbonate, such as calcite, than sodium hydrogen carbonate (Trona) and calcium magnesium carbonate (Dolomite) (Table 6). These samples were all taken at the bases of the walls. The Annexes section provides the XRD-derived visuals.

Table 6. *Minerals associated with carbonate-based, their entry number, and quantitative value.*

Sample	Mineral Phase	Formula	Quant (%)	Entry #
M5P4	Calcite	$Ca(CO3)$	15	00-086-2339
M6P5	Calcite	$Ca(CO3)$	7.1	00-086-2339
M11P10	Calcite	$Ca(CO3)$	6.6	00-086-2339
	Trona	$Na3H(CO3)_2(H2O)_2$	8.4	00-078-1064
M13P12	Calcite	$Ca(CO3)$	4.8	00-086-2339
M15P14	Trona	$Na3H(CO3)_2(H2O)_2$	73.2	00-078-1064
M16P15	Dolomite	$CaMg(CO3)_2$	12.9	00-073-2324
	Calcite	$Ca(CO3)$	11	00-086-2339
M19P17	Calcite	$Ca(CO3)$	21.1	00-086-2339
M20P18	Trona	$Na3H(CO3)_2(H2O)_2$	11.1	00-078-1064

Nitrates

In contrast to the other groups in Table 7, this group exhibits a relatively small size. Notably, the nitrate samples M9P8 and M13P12 demonstrate different percentages of sodium nitrate, also known as nitratine.

Table 7. *Minerals associated with nitrate-based, their entry number, and quantitative value.*

Sample	Mineral Phase	Formula	Quant (%)	Entry #
M9P8	Nitratine	$NaNO3$	4.1	00-085-1462
M13P12	Nitratine	$NaNO3$	44.2	00-085-1462

4.1.3 Mineral samples obtained from a particular wall

The analysis of a specific brick wall aims to identify the minerals responsible for its deterioration, as the decay levels differ from one level to another. This particular wall contains sulfates, silicates, carbonates, and nitrates.

After an analysis, it was discovered that most samples contained a mineral component called thenardite (Na_2SO_4). The most commonly detected element was sodium sulfate, followed by hydrated calcium sulfate (gypsum) and sodium-potassium copper oxide sulfate (Euchlorine). Although most of the samples examined had thenardite, it was found in low amounts. Silicates were also present in most samples, with a higher percentage than sulfates. The silicate group detected in the XRD analysis showed that sodium aluminum silicate was the most prevalent type. It is important to note that silicates such as quartz and labradorites are not causing any damage to the walls. Additionally, structural changes were observed with ordered and disordered Al-Si distributions at low and high temperatures, referred to as "low albite" and "high albite," respectively. Other substances in this category included magnesium carbonate, calcium aluminum hydroxide carbonate, chloride aqua hydrate (hydrocalumite), and sodium magnesium carbonate (Eitelite), all obtained from near the wall's base. It was also discovered that borates were involved in the brick manufacturing process (Figure 30).

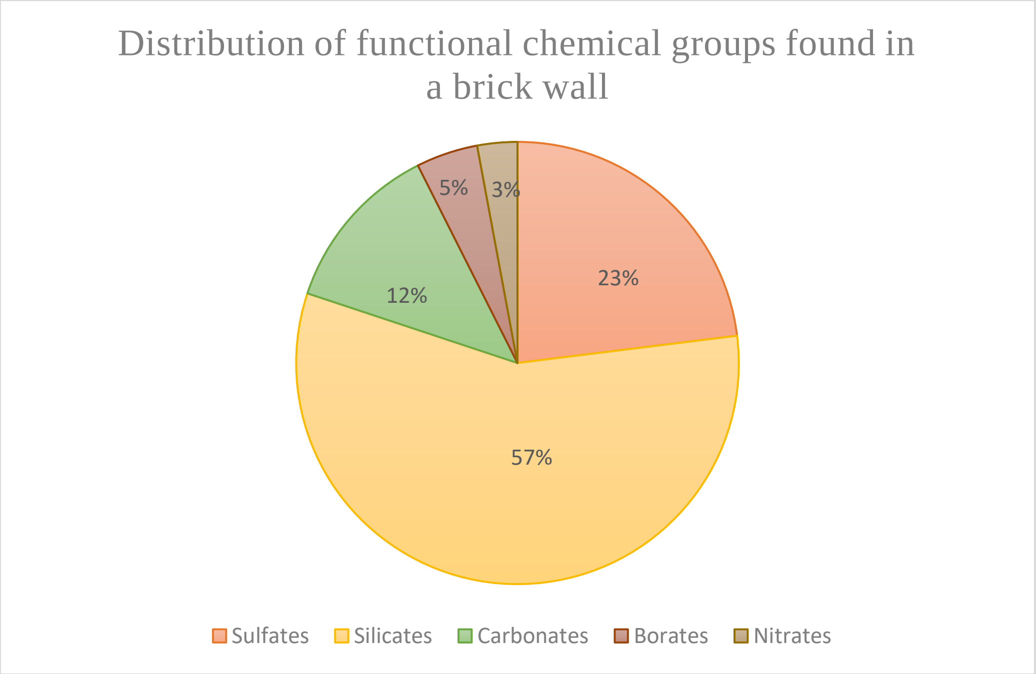

Figure 30. *Percentage of each functional chemical group found in a brick wall from Urcuquí.*

4.2 Analyze the rate of growth.

The ground's wetness, the deterioration of rocks, or airborne pollution are only a few sources of salt. The physical structure description is an effective means of getting an overview of the building. It is sometimes possible to determine whether the bricks were formed by extrusion or molds and to choose the approximate grade of the brick. If signs of deterioration are present, the distribution of sound and altered brick is vital in determining the cause. Features such as cracks, organic growths, and fluorescence should also be described in terms of their structural location (Hughes & Bargh, 1982). Variations in relative humidity can lead to salt dehydration and hydration, dissolution, and crystallization. These events can result in the expansion and contraction of the porous material and stress or fatigue (Paula López-Arce, 2012).

The relative humidity (RH) of the environment must be lower than the relative humidity at equilibrium (HReq) for a mineral precipitate to form (Paula López-Arce, 2012). Mirabilite's HReq at 20°C is 95%; if the humidity is higher than this level, the salt will be in solution; if humidity is lower than the percentage as mentioned above, the salt will precipitate. The material's pore structure and the external factors that cause cycles in relative humidity and temperature determine how long moisture stays in porous materials (Benavente et al., 2003).

Carlos Rodrigo and Eric Doehne (1999) proved that mirabilite ($Na_2SO_4 * 10\ H_2O$) could occasionally form dendritic aggregates outside the solution droplet when the relative humidity is high. This might suggest that mirabilite and thenardite (Na_2SO_4) are more likely to develop sub-florescence, whereas halite is more likely to form efflorescence (air-solution contact) within the solution.

Moisture transport causes salts deposited on internal wall surfaces to move into the masonry. As the masonry can absorb a significant amount of moisture, the salts dissolve and migrate with the drying water toward a surface. Due to temperature fluctuations in the masonry and surrounding air, coupled with high relative humidity, the salts in the masonry often surpass their crystallization thresholds, resulting in repeated damage. It is not possible to prevent salt crystallization entirely in the case of salts like sodium sulfate by controlling the indoor climate. Instead, when renovating the affected walls, using appropriate and compatible materials can reduce the damage caused by salt crystallization (Balksten & Strandberg-de Bruijn, 2021).

Over time, the brick may degrade and exhibit efflorescence caused by salt crystallization in its capillary pores, leading to internal pressure buildup. To prevent damage to structural and masonry components, it is necessary to carefully choose the building materials because Ecuador is a country with significant seismic risk (Reyes Quijije et al., 2022). To ensure a long-lasting renovation, it is crucial to determine the specific type of salt damage and the type of salt present in the masonry.

4.3 Description Stereomicroscope.

Physical characteristics of the minerals collected

The initial illustration showcases Epsomite, which belongs to the sulfate category and has a chemical formula of $MgSO_4*7H_2O$. Its structure is characterized by elongated and white crystalline shapes, as depicted in Figure 30A. Only M1P1 was identifiable under the microscope during the sample collection process due to its distinct dry crystal formation and transparent look. Nonetheless, to confirm its real identity, it is necessary to conduct XRD processing.

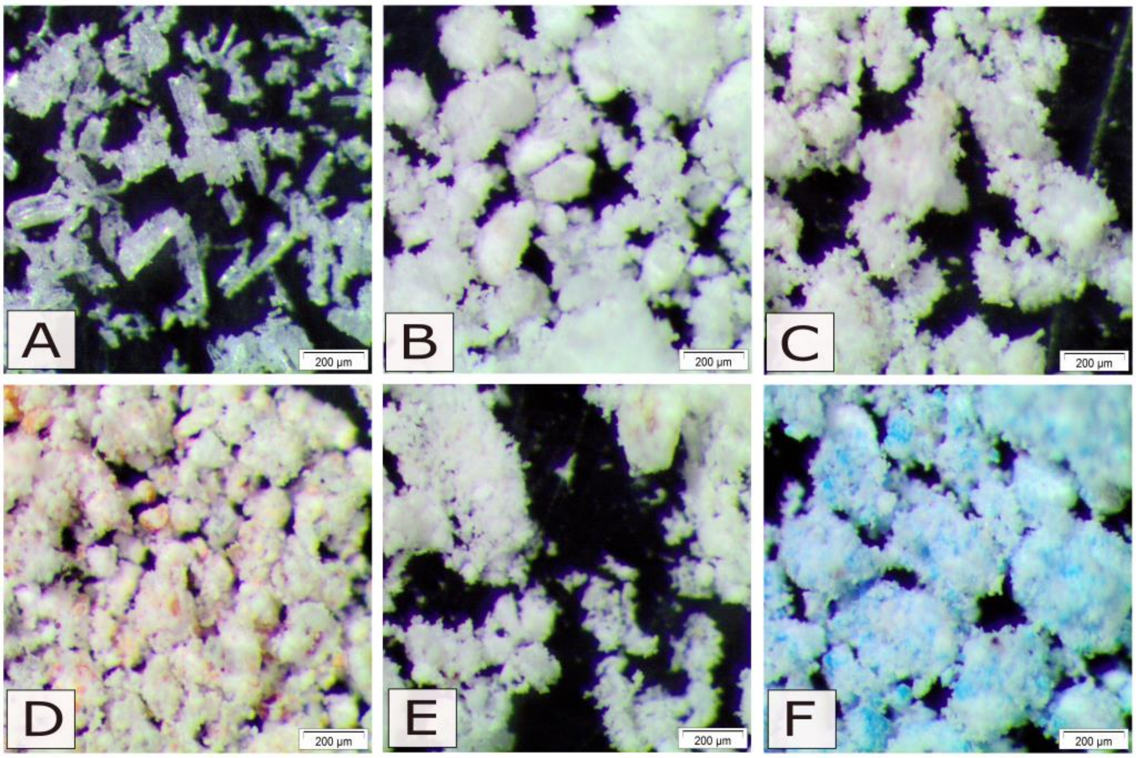

Figure 31. *Mineral samples under stereomicroscopic view. Sample M1P1(A). Sample M6P5(B). Sample M7P6(C). Sample M12P11(D). Sample M2P2(E). Sample M16P15(F).*

The remaining pictures showcase different examples with similar physical attributes, as depicted in Figures 30B, C, and E. These samples are all white, and their crystalline structure is not readily visible. Identifying the specific crystalline structure of each mineral sample can be pretty challenging since most minerals are interconnected. Although the majority of samples are white, some of them exhibited traces of building materials. This was particularly noticeable in the orange color in the image, which was identified as clay. Additionally, the blue substance observed in the picture is the painting on the wall during sampling, as shown in Figures 30D and F.

Chapter 5. Discussion and Conclusion

Twenty-eight samples were collected from the external walls of constructions in Urcuquí and near communities. Most of the samples were collected from the low part of the walls since the crystals are growing there due to moisture and capillary rise. Salts may enter buildings through several channels, including air pollution, sea spray, chemical reactions, decompositions, construction work, deicing chemicals, and rising humidity (Delgado et al., 2016). Upon analysis, it appears that salt crystals have been observed growing on both the surface and within the pores of the building material of most of the buildings examined. The degradation of the structures observed is a constant process, as they are subject to erosive agents such as wind, sun, and rainwater.

The structures observed exhibit damage mainly at the base, which may be attributed to capillary absorption and other cases, water trapping since most of the houses are not protected from rainwater and other weathering factors. Due to the lack of maintenance and care, abandoned buildings experience significant deterioration. This can manifest in various forms, such as structural damage, decay, and degradation of interior and exterior surfaces. The absence of regular upkeep can accelerate the deterioration process, leading to potentially hazardous conditions for those who may come into contact with the building.

The XRD data analysis determined that all samples contain sulfates, including thenardite, typically found in dry evaporite environments. This particular salt is known for causing structural damage due to its crystallization. The samples also contain functional chemical groups such as nitrates, chlorides, carbonates, and silicates (Figure 31). Typically, cement repairs and urban atmospheric deposition are the sources of sulfates, sulfites, nitrates, and nitrites. Aside from being present in bird droppings, which can contaminate urban structures, nitrates are frequently found in agricultural structures (Delgado et al., 2016).

According to the results, sulfates ($(SO_4)^{2-}$) are among the most plentiful substances in the study samples. Salts usually cause problems if they can reach water, move around a building, and crystallize. According to bibliographic research, most of the experiments conducted by several researchers in this field used sulfates. As the reason for the deterioration of the walls, they cite sulfates.

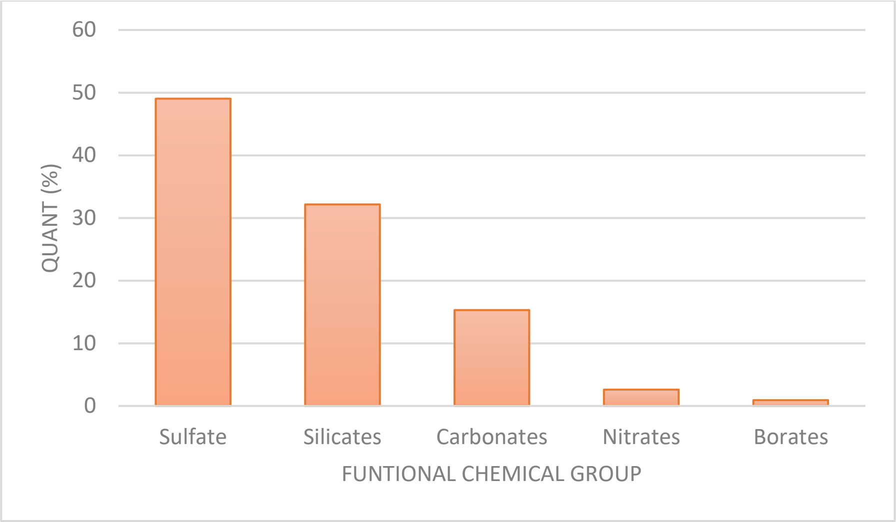

Figure 32. *The specimens gathered encompass a range of functional chemical groups with distinct functional properties.*

Geology deals with the development and presence of essential resources, the preservation of their stocks, and their exploitation and usage effects on the environment (Carrera et al., 2015). Slight fractures between bricks and mortar, particularly brick walls, increase the wall's permeability to air and water (Tsui et al., 2003b). Building material tensile strength, pore size distribution, and degree of supersaturation are more significant predictors of crystallization damage than the chemistry or mineralogy of the host. Porous building materials have four water phases: chemically bonded, physically bonded, capillary, and nominally free. Rain or ground moisture through capillary action is more effective than condensation. A layer of water molecules must cover the entire surface for rainwater to enter. Wind can help, but if the surface is dry, water cannot penetrate. (Delgado et al., 2016).

The results obtained by Tsui (2003) show that harm only happens when mirabilite is allowed to crystallize, regardless of how thenardite was created. Moreover, they discovered that mirabilite precipitation might produce stresses significant enough to destroy most rocks and concrete. More damaging than sodium chloride are sodium sulfates, nitrates, and calcium carbonates and sulfates (Bates, 2010). Damage from sodium sulfate may be caused by the precipitation of thenardite rather than mirabilite, especially in settings of persistent capillary rise (Tsui et al., 2003b).

Conclusions

The degradation of building materials used in construction in Urcuqui and nearby communities has been studied. In addition, a mineral phase analysis was conducted by compiling minerals, field observations, photos, and the X-ray diffraction method. Twenty-eight samples were gathered from natural settings (four) and construction sites (twenty-four). The characterization process is of utmost importance when ascertaining the overall structural stability of buildings.

After analyzing the data, it was found that sulfates were the predominant functional group. Among the minerals in all the samples, thenardite was the most frequently occurring. This mineral is notorious for causing damage to buildings since it is presented in all the cases analyzed. Additionally, it can lead to the development of mirabilite, another salt type. Based on our analysis of the samples, it has been confirmed that sulfates are the leading cause of the decay of building materials. Silicates and carbonates follow as secondary causes. The significance of mirabilite precipitation as the root cause of injury was deduced from the findings.

Many of the structures surveyed were built using concrete blocks and bricks. Unfortunately, both materials showed signs of deterioration in the form of cracks and lost parts of the material (Figure 33). This issue is predominantly caused by weathering, which is common among many buildings observed. Abandoned structures demonstrate how weathering factors can damage a building if maintenance is lacking, and the root cause of the problem needs to be addressed (Figure 33A, B).

In certain instances, the walls presented moderate to significant deterioration. It has been observed that some level of damage is present at the base of recently built and previously constructed structures. (Figure 33C). Many individuals attempted to address the issue by patching with cement any holes and painting the impacted walls (Figure 33D). Any potential risk factor that could pose a threat to the structural integrity of the building should be identified and addressed at the earliest possible stage to prevent any future collapses or damages.

Figure 33. *Constructions with deterioration at the base of the walls. Concrete blocks exposed to weathering with high levels of damage (A) (B). There are some missing blocks on a house wall in Urcuquí town, which was damaged by weathering (B)(C). The wall underwent recent repairs, with cement patches applied to cover holes that resulted from deterioration (D).*

Additionally, it is essential to assess the factors that contribute to salt occurrence, including salt transport, crystallization patterns, and cycles based on the microclimate where the damage originated. An effective way to address the problem of salt crystallization could be to explore various potential solutions. It is essential to consider the most suitable option to mitigate and prevent recurring issues.

To reduce the impact of physical weathering associated with the growth of salt, local construction materials, and building practices, it is necessary to use suitable materials to avoid problems in the future. The benefits of using rocks in construction include their resistance to bending, sliding, water absorption, bulk density, abrasion, open porosity, non-conductor of fire, thermal shock, compression, vapor permeability, and, most importantly, avoid physical damage because rocks have the resistance to salt crystallization, frost, and salts.

Suggestions

To ensure the long-term preservation of structures, it is essential to use blocks with high durability and low levels of carbonate and clay. In addition, the mortar used should have low or no carbonate content to prevent the creation of salts caused by chemical reactions with air pollutants, mainly if these pollutants cannot be controlled (Kamh, 2011).

At the beginning of construction, it is recommended to utilize mortars low in sulfate and tricalcium aluminate and bricks with low sulfate content; all these are effective ways to prevent thenardite production (Hughes & Bargh, 1982). To prevent damage, the most critical approach is physically separating building materials from soil moisture and salts. This is typically achieved through the traditional method of using a "damp-proof course" (Rodriguez-Navarro & Doehne, 1999).

Installing barriers that waterproof the impacted regions and refraining from using gypsum mortar are the best ways to slow down the degradation of construction components. On the other hand, environmental control of the area is advised if degradation is found in interior portions of the construction. To prevent the precipitation of the salts, it is required to determine the types of salts and study the best temperatures for the location(Paula López-Arce, 2012).

References

Balksten, K., & Strandberg-de Bruijn, P. (2021). Understanding deterioration due to salt and ice crystallization in Scandinavian massive brick masonry. *Heritage*, *4*(1), 349–370. https://doi.org/10.3390/heritage4010022

Barranzuela, J. (2014). *Proceso productivo de los ladrillos de arcilla producidos en la Región Piura*.

Bates, S. J. (2010). A Critical Evaluation of Salt Weathering Impacts on Building Materials at Jazirat al Hamra, UAE. *Geo-Verse, Oxford Brookes University, Oxford, UK*.

Benavente, D., Garcıa, M. A., Cura, D., & Ordonez, S. (2003). Salt influence on evaporation from porous building rocks. In *Construction and Building Materials* (Vol. 17).

Bernard, B., Hidalgo, S., Robin, C., Beate, B., & Quijozaca, J. (2014). The 3640–3510 BC rhyodacite eruption of Chachimbiro compound volcano, Ecuador: a violent directed blast produced by a satellite dome. *Bulletin of Volcanology*, *76*(9), 1–20. https://doi.org/10.1007/s00445-014-0849-z

Bernard, B., Robin, C., & Hidalgo, S. (2011). *Nuevo modelo evolutivo y actividad reciente del volcán Chachimbiro*. https://www.researchgate.net/publication/259283375

Carrera, D., Guevara, P., Tamayo, L., & Guallichico, E. (2015). Análisis multivariado de las aguas de la Subcuenca del Río Ambi en época de estiaje y su relación con la calidad desde el punto de vista agrícola. *CONGRESO DE CIENCIA Y TECNOLOGÍA ESPE*, *10*.

Delgado, J. M. P. Q., Guimarães, A. S., De Freitas, V. P., Antepara, I., Kočí, V., & Černý, R. (2016). Salt Damage and Rising Damp Treatment in Building Structures. In *Advances in Materials Science and Engineering* (Vol. 2016). Hindawi Limited. https://doi.org/10.1155/2016/1280894

Dinnebier, R. E., & Billinge, S. J. (2008). *Powder Diffraction Theory and Practice* (R. Dinnebier & J. L. Billinge, Eds.). Royal Society of Chemistry.

Freedland, J. (1999). Soluble Salts in Porous Materials: Evaluating Effectiveness of Their Removal. In *Theses*. https://repository.upenn.edu/hp_theses

Furlani, S. (2016). *Weathering and erosion*.

Grossp, CM., & Esbert, R. M. (1994). *Las sales solubles en el deterioro de rocas monumentales. Revisión bibliográfica*. http://materconstrucc.revistas.csic.es

Haynes, H. H., & Mehta, P. K. (1996). *Concrete deterioration from physical attack by salts*. https://www.researchgate.net/publication/291365632

Hughes, R. E., & Bargh, B. L. (1982). *The Weathering of Brick: Causes, Assessment, and Measurement*.

Kamh, G. M. E. (2007). Environmental impact on construction limestone at humid regions with an emphasis on salt weathering, Alhambra Islamic archaeological site, Granada City, Spain: Case study. *Environmental Geology*, *52*(8), 1539–1547. https://doi.org/10.1007/s00254-006-0598-1

Kamh, G. M. E. (2011). Salt weathering, bio-deterioration and rate of weathering of dimensional sandstone in ancient buildings of Aachen City, Germany. In *International Journal of Water Resources and Environmental Engineering* (Vol. 3, Issue 5). http://www.academicjournals.org/ijwree

Koniorczyk, M., & Gawin, D. (2008). Heat and moisture transport in porous building materials containing salt. *Journal of Building Physics*, *31*(4), 279–300. https://doi.org/10.1177/1744259107088003

Kosmatka, S. H., & Wilson, M. L. (Architectural engineer). (2011). *Design and control of concrete mixtures : the guide to applications, methods, and materials*. Portland Cement Association.

Martín, G. F. (2010). *Las rocas y los materiales de construcción* (pp. 25–29). L'esprit Ingénieux. http://geografiamungia.files.wordpress.com/2009/09/casa-rocas.jpg

Mishra, M. (2019). *MINERALS : THE BUILDING BLOCKS OF ROCKS*. http://egyankosh.ac.in//handle/123456789/58935

Mishra, M., & Deshmukh, B. (2019). *Classification of minerals*. http://egyankosh.ac.in//handle/123456789/58937

Panchuk, K. (2019). *Chapter 9. Sedimentary Rocks*. http://openpress.usask.ca/physicalgeology/

Paula López-Arce, D. (2012). *DAÑOS POR CRISTALIZACIÓN DE SALES*.

Pecharsky, V. K., & Zavalij, P. Y. (2005). *FUNDAMENTALS OF POWDER DIFFRACTION AND STRUCTURAL CHARACTERIZATION OF MATERIALS*. Springer Science+Business Media, Inc.

Petroche, D. (2021). *Desempeño Ambiental del Cemento y del Concreto en el Ecuador: Una puerta a la Construcción Sostenible*.

Ramadan, M., & Sakr, Y. (2020). *Physical Salt Attack on Concrete: Mechanisms, Influential Factors, and Mitigation*.

Reyes Quijije, M., Rocha Tamayo, A., García Troncoso, N., Baykara, H., & Cornejo, M. H. (2022). Preparation, Characterization, and Life Cycle Assessment of Aerated Concrete Blocks: A Case Study in Guayaquil City, Ecuador. *Applied Sciences (Switzerland)*, *12*(4). https://doi.org/10.3390/app12041913

Ricardo, J., & Ordóñez, P. (2021). *MAGNETOMETRY SURVEY APPLIED TO GEOTHERMAL EXPLORATION IN CHACHIMBIRO, NORTHERN OF ECUADOR*.

Rocha Álvarez, D. E., Pérez, C., & Villanueva, J. (2020). Material ecológico para construcción en vidrio, arena y poliplásticos (VAPoli). *Ciencia e Ingeniería Neogranadina*, *30*(2), 49–66. https://doi.org/10.18359/rcin.4643

Rodriguez-Navarro, C., & Doehne, E. (1999). Salt weathering: Influence of evaporation rate, supersaturation, and crystallization pattern. *Earth Surface Processes and Landforms*, *24*(2–3), 191–209. https://doi.org/10.1002/(sici)1096-9837(199903)24:3<191::aid-esp942>3.0.co;2-g

Sereda, P. J. (1970). The structure of porous building materials. *Canadian Building Digest*. https://doi.org/10.4224/40000790

Suryanrayana, C., & Grant Norton, M. (1998). *X-Rays and Diffraction*. Plenum Press, New York.

Tsui, N., Flatt, R. J., & Scherer, G. W. (2003a). Crystallization damage by sodium sulfate. *Journal of Cultural Heritage*, *4*(2), 109–115. https://doi.org/10.1016/S1296-2074(03)00022-0

Tsui, N., Flatt, R. J., & Scherer, G. W. (2003b). Crystallization damage by sodium sulfate. *Journal of Cultural Heritage*, *4*(2), 109–115. https://doi.org/10.1016/S1296-2074(03)00022-0

Annexes

During fieldwork, several photos were taken where the gradual growth of salts shows the detrimental effects it causes from salt crystallization. Depending on the circumstances, the persistence of salt growth may lead to a collapse or a less severe form of deterioration.

Image 1. Salt crystals are growing in an anthropogenic cave. Sample M1P1

Image 2. It has been observed that the base of the wall in La Merced Hacienda is experiencing some form of deterioration.

Image 3. Building under weathering agents shows the degradation of building materials.

Image 4. Rock blocks are surrounded by white crystals growing in the mortar.

Image 5. The wetness at the wall base allows salt growth (white spots).

Image 6. The concrete roof presents white spots; the water filtration would cause this.

Image 7. The wall has significant deterioration at the base and a moderate level higher up. It has been patched with brick and concrete to cover large holes. The blocks have shrunk by half due to their significant deterioration.

Image 8. Filtration of water could lead to the degradation of paint, forming salt crystals at the bottom of the wall.

Image 9. The white and black spots on the wall indicate the presence of water filtration, wetness, and CO2.