

THE SPANISH APSE FROM SAN MARTIN DE FUENTIDUENA AT THE CLOISTERS, METROPOLITAN MUSEUM OF ART, NEW YORK

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1 INTRODUCTION

1.1 Historical background

Near the small town of San Martin de Fuentiduena, in the province of Segovia, Spain, lay the ruins of a small church. These ruins, of which the apse was the main part, had been used as a cemetery for many years, all the space enclosed within its walls having been filled with dirt to make the burials possible.

There are no records that deal with the construction of any churches in Fuentiduena and it is unlikely that any religious buildings were begun in this area until the bishopric of Segovia was restored in 1123. It is also unlikely that any were started in Fuentiduena after the town lost its importance early in the thirteenth century [1]. It would seem reasonable therefore to assume that this church was built in the later part of the twelfth century.

In November 1956 an agreement was reached between the Spanish authorities and the Metropolitan Museum of Art to allow the moving of the apse to American soil as part of an Iberian-American exchange [2]. The apse was dismantled in 1957 and the 3300 stones which make up the 'Fuentiduena Apse' were transported to New York City where they arrived in February 1958.

When the 'dry run' of several courses of both the outer and inner walls was made, decisions were also made as to whether to use the badly disintegrated old stones at the base level or the new stones cut in Spain for replacement. New stones were also cut and put in place to complete the gable wall that joined the apse to the existing nave at The Cloisters and to take the place of several missing stones in the cornice under the roof. The billet motif that decorates this cornice was carved in the new stones by the same workmen who did the rest of the work. Wherever possible the old stones were chosen though they sometimes had to be squared off at the corners with small patches of stone called 'dutchmen'.

Casts were made of one of the finest large exterior capitals and of the exterior pier sculpture with caryatid figures. The casts replace the originals in the outside structure and the originals themselves are displayed inside.

In May 1958, the work of setting the stones in mortar finally began. Since in the original construction the stones were laid with very little mortar, the joints in the reconstruction were kept to a minimum, averaging about 0.3mm in thickness [3]. Except for the pointing of the exterior and interior, the reconstruction of the old apse was virtually finished by January 1960 (Fig. 1).

1.2 Previous treatments

Recent analyses indicate that the surface of all the stones, both wall and sculptures, had been coated in the past with a thin, yellow layer of polychromy as evidenced by the presence of limonitic iron oxides and calcium oxalate (Whewellite $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$). The latter can also be related (and possibly the yellow ochre too) to an old treatment and may correspond to the final deterioration product of an organic medium [4].

During the summer of 1958, all the stones that make up the apse were treated by alternate immersion in solutions of MgF_6Si and $\text{Ba}(\text{OH})_2$. In spite of this treatment, by 1966 it was obvious that the stones were suffering from extensive flaking, and soluble salts were efflorescing on their surface [5].

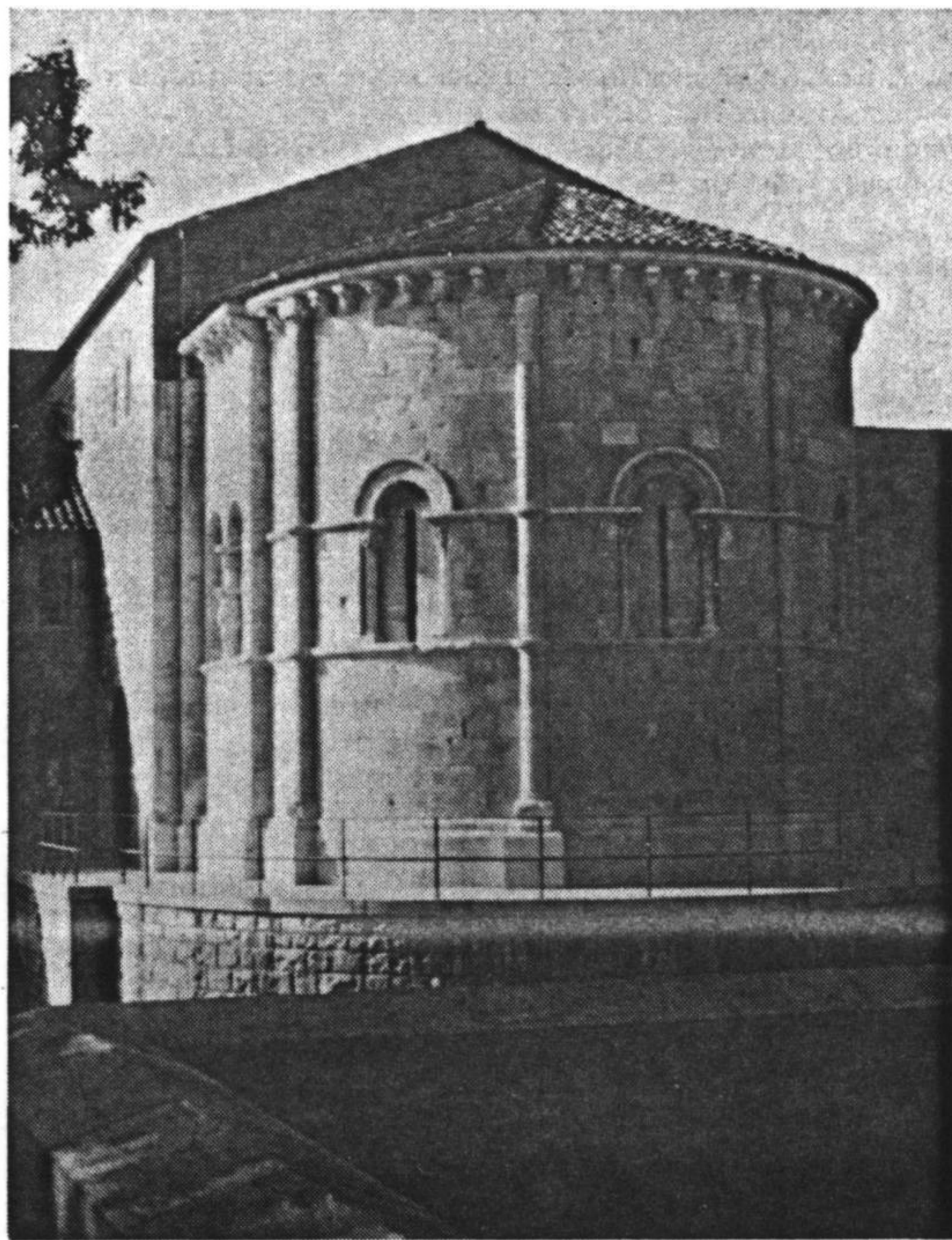


Fig. 1 The 'Spanish Apse' reconstructed at The Cloisters.

In 1969 the yellow dolomitic limestone blocks making up the walls were treated with an ethyl-silicate-based preservative, while the white limestone sculptures were treated with a $\text{Ba}(\text{OH})_2$ -urea solution [6]. These treatments followed an extensive study and *in situ* testing [7].

In spite of this second treatment, the stones from the walls appeared to continue to deteriorate. Whether the rate of deterioration was less than before could not be established. To avoid any further damage a provisional shelter was built around the apse in 1971 (Fig. 2).

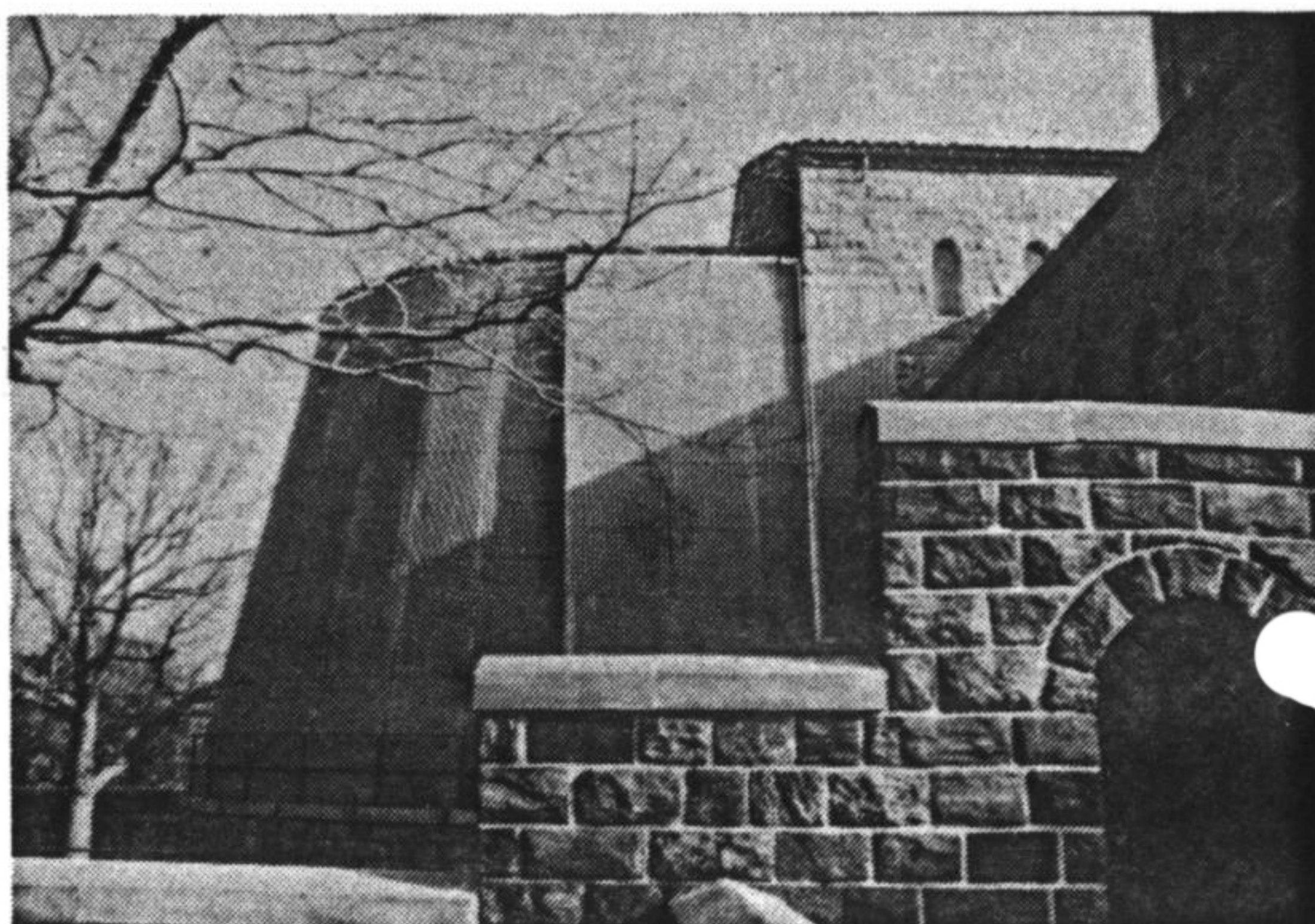


Fig. 2 The provisional shelter built around the apse.

1.3 Present state of preservation

At the present time the white limestone of the sculptures is in a good and apparently stable condition. Some of the yellow dolostone blocks making up the wall are deteriorating. This deterioration can be attributed to the crystallization of soluble salts which are concentrated in areas where water seepage through the protective shelter occurs, mainly at the end piers of the apse. In these areas, extensive growth of microorganisms can also be observed. The deterioration is apparent as an extensive pulverization and some flaking of the surface (Fig. 3).

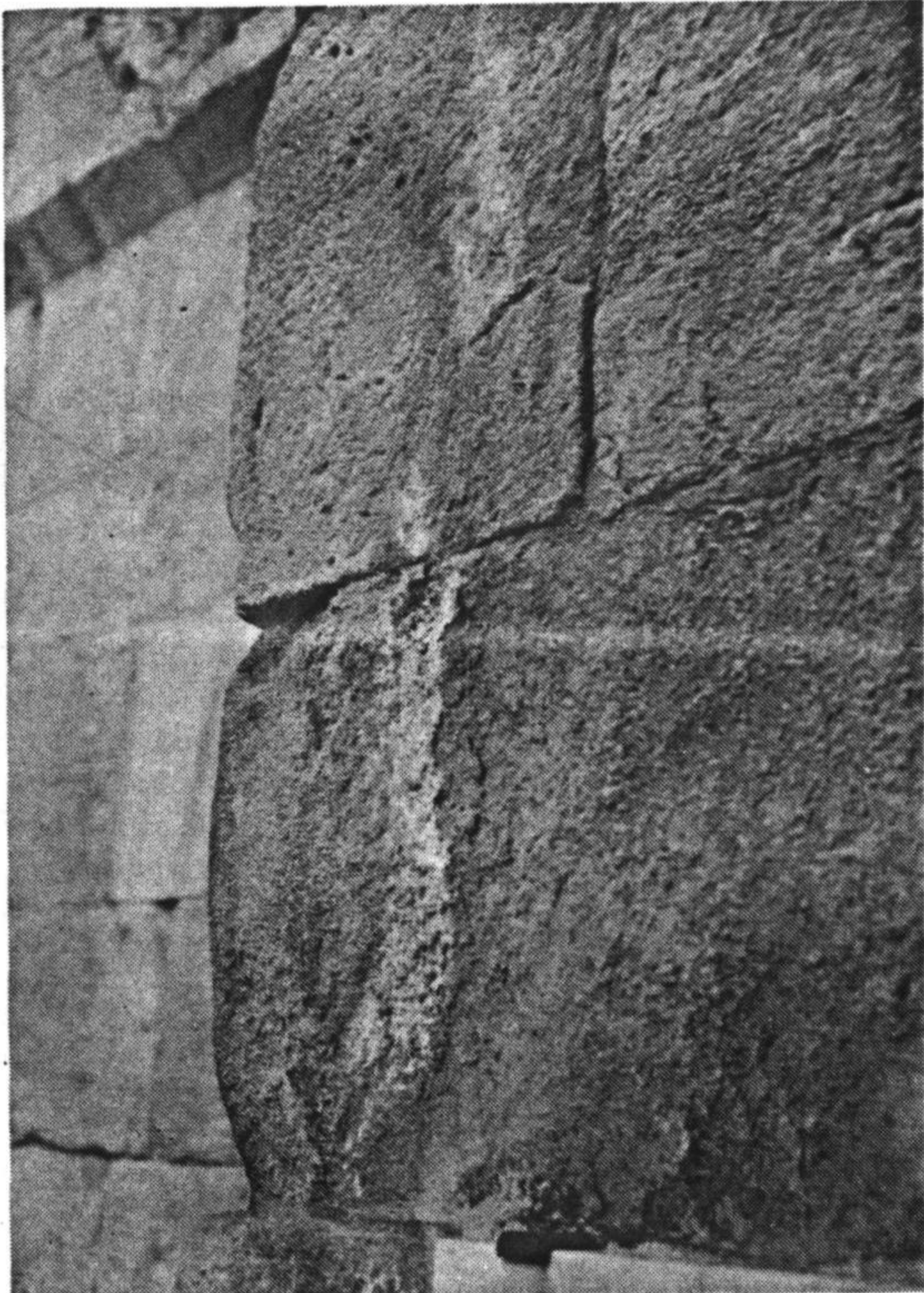


Fig. 3 Typical damage to the stones of the apse.

2 EXPERIMENTAL

2.1 Geological and petrographic characteristics of the stones

The petrographic examination of the white limestone classifies it as a pure, microcrystalline limestone characterized by the presence of a small amount of microfossils. These fossils belong to the gastropods and miliolids groups and are in general not well preserved, possibly due to postgenetic recrystallization phenomena. Similar rocks of the calc-dolomitic formation of the Upper Cretaceous are found in the province of Segovia and outcrop near San Martin de Fuentiduena in the basal areas of Sur de Pradales and north of Sepulveda, between Hontalbilla and Navalmanzano [8, pp.571-572].

The yellow stone varies in composition from block to block.

It can range in classification from a dolomite, to a calcitic dolomite (the most frequent) and finally to a dolomitic limestone [9, p.360]. This variation appears to be genetically connected to an original incomplete dolomitization sometimes resulting in a mottled stone characterized by a patchy distribution of dolomite easily evidenced in polished rock

fragments by staining with Alizarin Red S. This mottled pattern has been interpreted for most rocks of this type as a product of arrested dolomitization produced by migration of magnesium solutions. The control of this phenomenon has been attributed to magnesium-containing algal organisms [9, pp.363,370].

The calcite versus dolomite distribution in this yellow stone is better studied in stained thin-sections, where most of the fossils present, coralline algae and bryozoans, appear to be calcitic, while the rest of the stone is dolomitic. The microfossils always appear corroded and/or etched by the dolomitic metasomatism, which has sometimes left unaltered areas of microcrystalline or micritic calcite pertaining to the original biogenic sediment.

The dolomite shows a variable structure, passing from areas with large euhedral rhombic crystals to a fine micrite. The euhedral rhombic form of crystallization is always observed in correspondence with pores which in this rock assume the shape of vugs* and, subordinately, of channels and fenestrae. On dolomitic rhombs, evidence has also been observed for a weak dedolomitization process that occurred after the main genetic formation of the rock.

Accessory minerals, visible under the microscope, are small quartz clasts, probably detritic in origin, and limonitic masses of brown-yellow color (ochres) irregularly dispersed in the stone, but often concentrated in thin strips or small areas. Chalcedony has also been found filling small pores.

The yellow stone of the apse belongs to the same geological formation as the white stone used in the sculptures. Dolostones of this type, very variable in grain size and degree of dolomitization, outcrop in large areas to the north-east of the province of Segovia [8, map p.577] and it is very likely that the old quarries were opened near the south-east of San Martin de Fuentiduena.

2.2 Chemical and mineralogical analysis

The chemical analysis of several samples of the yellow stone has confirmed the great variability in dolomite/calcite content. An average analysis would be:

Dolomite	94-90%
Calcite	1-5%
Insoluble residue + iron oxides	5%

X-ray diffraction of powder samples of the residues have always shown the presence of quartz (either detritic, in small angular clasts or as chalcedony in some cases) and clay minerals. These last have been identified mainly as kaolinite with a small fraction of illite. This composition is consistent with the petrography of the rocks from the area specified above [10]. Most of the iron oxides present are soluble in dilute HCl, but a small quantity of earthy limonite remains in the residue and together with quartz may account for 10-20% of this residue. The iron oxides are responsible for the yellow color of the rock.

2.3 Physical properties

The yellow dolostone has an apparent density of about 2.46g/cm³. The total porosity of the stone, as determined by the mercury intrusion method, can vary by as much as 8% (19%-27%) within a single block, or as little as 2% (21%-23%). The pore size distribution was uni-modal in the first case, with a pore radius range of 4-10 μ m, and bi-modal in the second case; the peaks corresponded to a pore radius of 0.4-1.0 μ m and 2-12 μ m.

* Small unfilled cavities in rock.

The capillary water absorption coefficient, as determined by the RILEM 25 PEM method [11], was correspondingly variable: 1.3×10^{-2} to $8.6 \times 10^{-2} \text{kg m}^{-1} \text{sec}^{-1/2}$, depending on the particular part of the block used in the test. The stones absorb more than 95% of water in the first four hours. If the stones are totally immersed in water, it only takes two hours to reach the 95% water absorption level.

2.4 Analysis of efflorescences and soluble salts

The white efflorescences on the stones were analyzed several times during the course of the history of the apse in New York City. The first analysis showed the presence of epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) the presence of which was attributed to the action of the polluted atmosphere on the stone. The efflorescence found on the granite blocks which constitute the facing of the building to which the apse is joined was found to be composed of a mixture of thenardite (Na_2SO_4), apththitalite ($(\text{Na},\text{K})_2\text{SO}_4$) and niter (KNO_3). These substances could not have come from the granite itself under any weathering conditions and must have migrated into it from the mortar used.

After the enclosure was put up in 1971, the environment in that enclosure was dried by means of dehumidifiers. The drying and the simultaneous increase in temperature caused by the shelter produced an even more abundant efflorescing of salts. The efflorescences were now found to be composed of humberstonite ($\text{K}_3\text{Na}_7\text{Mg}_2(\text{SO}_4)_6(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$), thenardite, epsomite and gypsum. The first salt occurs naturally only in the Atacama desert in Chile.

On the mortar joints, the efflorescences proved to be trona ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$) and apththitalite, indicating that the cement used in the mortar was rich in alkalis.

The soluble salt content in the walls of the apse, measured in core samples, varies from 0.03% in the interior of the wall to 0.9% at the exterior part. The salts are essentially composed of nitrates, sulfates and chlorides of sodium, potassium and magnesium.

2.5 Analysis of biological growths

Samples of microorganisms, growing primarily in the areas where water seepage through the protective shelter occurs, were obtained and cultured in the laboratory. They were then identified as a *Trichothecium* sp. fungus, a Chlorococcales alga, and a cyanobacterium.

From laboratory testing, it was found that the *Trichothecium* sp. fungus could severely etch dolomite and calcite crystals [12]. This etching can contribute significantly to the overall deterioration of the stone. Testing carried out on thin-sections prepared from the stone of the apse has shown that both calcite and dolomite deteriorate as indicated by an opacification of these components.

2.6 Testing of water-repellent treatments

Four commercially available water-repellent treatments have been tested in the laboratory for possible application to the walls of the apse. The resins tested were: Wacker-H, Keim-H, catalyzed methyl trimethoxy silane and DriFilm 104. The first three products were applied as provided; the DriFilm was applied in a 30% v/v solution in toluene.

The products were tested on cut cubes ($5 \times 5 \times 5 \text{cm}$) from original stones of the apse (when replacements were made). The resins were applied through capillary rise, leaving each side of the cube in contact with the resin for one hour.

The amount of resin that was taken up by the stones is given in Table 1. The variability in the stones can be seen, as all of the cubes were cut from one block.

Table 1 Resin uptake of the stone from Fuentiduena

% Wacker-H	% Keim-H	% Cat.MTMOS	% DriFilm
2.7 ± 1.8	1.8 ± 0.2	1.1 ± 0.3	1.6 ± 0.1

The water-repellent action was tested by water capillary absorption measurements [13]. Water absorption was decreased significantly, so that even after a fortnight in contact with water, the water uptake was about 0.3-0.5% for the first three products and about 3% for the DriFilm.

On this basis, and considering that this last product also darkens the color of the stone slightly, it was discarded as a possible treatment.

The treated blocks were then subjected to salt crystallization tests to compare the resistance of these treatments when mechanical damage occurs in the stone. The test was carried out using a saturated solution of sodium sulfate with 24-hour cycles of immersion and oven-drying at 60°C. The stones were left to cool for half-an-hour after the oven cycle and before immersion in the solution to avoid thermal shock to the stone.

Mechanical damage is the most likely to occur, both on account of any salts present or that will be produced when the walls of the apse are exposed to the polluted atmosphere, and in the case of freeze-thaw cycles. The water-repellent treatment should improve resistance to this damage by diminishing the amount of water penetrating the stone.

The control blocks deteriorated continuously between the seventh and the twenty-fifth cycles (average weight loss 32%), while the treated blocks were largely unaffected. (Two of the samples treated with Wacker H exhibited a 3% weight loss in 25 cycles.)

3 DISCUSSION

The main causes of the present deterioration can be attributed to a combination of the effect of soluble salts crystallizing and the presence of clays in the stone.

The sources of soluble salts are many:

- salts accumulated in the past centuries while the apse was in Spain (most likely source for the presence of nitrates);
- the treatment applied when it arrived at The Cloisters (MgF_6Si);
- the high-alkali cement mortar used in the setting of the stones;
- the attack of the stone by acid air pollutants present in the atmosphere in its New York location.

The erection of the enclosure and drying out of the walls intensified the crystallization of the salts and increased the damage. The leaks through the enclosure have produced localized areas of heavy deterioration.

The intrinsic presence of clays (kaolinite and illite) in this stone, which can absorb and retain water for long periods of time, make this stone particularly susceptible to freeze-thaw damage, which could have occurred prior to the erection of the enclosure.

In the areas where the leaks occur the stone tends to be permanently moist and biological growth is active, contributing to the overall decay by increasing the surface area exposed to water.

4 CONCLUSIONS

The following recommendations are made for the conservation of the apse:

- The shelter should be removed as it is not totally effective

and does not allow for the aesthetic appreciation of the apse.

- 2 Structural repairs to the apse, such as addition of a gutter around the roof, and sealing of the cracks that have opened in the walkway around the apse, should be carried out.
- 3 Consolidation should be carried out only in those blocks of stone that present heavy deterioration. The consolidant to be used could be of the tetra-alkyl silicate type. (Care should be taken to test these consolidants on samples of the stone to be treated. Some stones react unfavorably to these treatments).
- 4 In the eventuality that the deterioration of the stones approaches a degree to endanger the structural integrity of the apse, these stones should be replaced by new stones from the same quarry, as utilized in the lower course during the reconstruction.
- 5 After partial consolidation, soluble salts should be removed by poulticing. This again is a local treatment to be applied on those blocks that are under active deterioration.
- 6 All of the apse should receive a water-repellent treatment, which should be reapplied as necessary, when the water-repellency is lost after some years.
- 7 Any sculptures, capitals or caryatids of significant historic or artistic value should be replaced by copies, the originals to be kept in the interior of The Cloisters.
- 8 Monitoring for biological growth should be carried out. If biological growth expands to the whole surface of the apse, a biocidal treatment might be necessary.

The practical work will begin during the spring of 1986 and results up to the time of the Congress will be reported there.

MATERIALS

Methyl trimethoxy silane: Dow Corning Z-6070 or T-4-0140 (the numbers refer to the same chemical compound but with different marketing purposes). Dow Chemical, Midland, MI 48640, USA. The

catalyst used was lead naphthenate.

Wacker-H and Wacker-OH: ProSoCo, Kansas City, KS 66117, USA.

Keim-H: Mineros, New York, NY 10034, USA.

DriFilm 104: General Electric, Waterford, NY 12188, USA.

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