INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 15, Issue 3, 2024: 1425-1434 www.ijcs.ro

DOI: 10.36868/IJCS.2024.03.17

FROM RAG TO WOOD GOING THROUGH CEREAL: TECHNOLOGICAL REVOLUTION AMONG THE SCHOOL MAPS IN THE ARCHIVES OF THE UNIVERSITY OF GRANADA (SPAIN)

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Abstract

School maps emerged as new type of document as a result of a series of technological and educational advances spanning the 18th to the 20th century. These maps originally played strictly functional and didactic roles. The passage of time has endowed them with an indisputable historical, documentary, scientific and even artistic character. Those currently housed in archives are generally poorly preserved due to issues related to their manufacture and general lack of concern for their safeguard after losing their original function. This study aims to characterise the materials serving to manufacture them by sampling a series housed in the Archives of the University of Granada, a task that is complicated by their multilayered nature (cloth, paper, printing inks and protective varnish). Preliminary identification of the fibrous elements reinforcing the papers and textiles by means of micro-invasive analytical techniques enables to subsequently define appropriate conservation and restoration protocols.

***Keywords**: Paper; Textile; Cellulose fibre; School map; Educational heritage; Microscopy*

Introduction

Cartographic documents are the oldest and best-known universal representations of space. Throughout their historical development, multiple materials and techniques have served for their manufacture. Examples are the Bedolina map (Italy) engraved in stone [1], the maps of Ga-Sur and the city of Nippur (Irak) on clay tablets [2] and the *Tabula Peutingeriana* [3] in the Austrian National Library, the Hereford Mappa Mundi (England) and the Map of Juan de la Cosa (Spain) [1] on parchment. Examples on paper include the different editions of the *Theatrum Orbis Terrarum* by Abraham Otelio [4]. The evolution of cartographic materials and systems of production was motivated by various causes including the search for cheaper procedures and greater efficiency yielding a greater number of maps for an increasingly broader and more diverse public. This interest was maintained centuries later when the innovations of Alois Senefelder, inventor of lithographic printing and Emil von Sydow, founder of methodical school cartography, gave rise to a new type: the school wall map [5].

The Archives of the University of Granada (Spain) currently houses 57 school wall maps mostly dating from the end of the 19th century to the beginning of the 20th century. All share similar characteristics, notably a large format (110-250cm in length and 74-227cm in width) and multilayers consisting of a textile medium adhering to paper, printing inks and a layer of protective varnish. The complexity of their structure has resulted in a current deplorable state of

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preservation complicating their preservation and restoration. Defining an adequate intervention protocol thus requires prior research to characterise the different strata of these documents [6].

The current study thus intends to define qualitative characterisations of their two cellulosic media: textile and paper. Based on the history of map manufacture, the starting hypothesis is that they resorted to cotton textiles to reinforce paper made from mechanical wood pulp. It must be borne in mind that the production of wall maps came at a moment of technological revolution when the use of rags to manufacture paper was almost exclusively replaced by wood fibre due to its low cost and great availability. However, the paper industry during this timeframe saw a great amount of research focusing on a variety of different raw materials [6]. Hence, in order to confirm or reject the starting hypothesis it is necessary to identify the fibrous composition of the media of various samples of maps housed in the University Archives, a task carried out through microscopic analyses.

Materials and methods

Paper and textile samples

The choice of the samples to analyse among the educational maps housed in the University Archives (Fig. 1) was governed by the following criteria. They must be school maps of a) large format, b) date between the end of the 19th and the beginning of the 20th century and c) be unrestored. This last aspect guaranteed the reliability of the results as no products were added *a posteriori* to their surfaces which could lead to errors in interpreting the data. Micro-samples of paper (≈1.0mm^2) and textiles (thread length <0.5cm) were thus collected from 17 documents. This number of samples, adhering to international regulations [7], rendered it possible to identify the fibres without jeopardising the documents themselves. Moreover, in most cases the samples were collected from detached fragments, in accordance with the lamentable state of preservation of the majority of the maps.

Fig. 1. Example of a school map housed in the Archives of the University of Granada (Map 13, *Mapa escolar de Europa*)

Each sample was labelled with a code identifying it either as textile (T) or paper (P) and its number (Table 1).

Table 1. List of the textile samples collected from school maps housed the Archives of the University of Granada

Paper sample	Textile sample	Title of document	Date
P-MAP1	T-MAP1	*América del Sur. Mapa Político*	1916
P-MAP2	T-MAP2	*África*	1959
P-MAP3	T-MAP3	*África. Mapa político*	195?
P-MAP5	T-MAP5	*Protectorado Español en Marruecos*	1924
P-MAP6	T-MAP6	*Britische Inseln (Großbritannien u. Irland.)*	1916
P-MAP7	T-MAP7	*Mapa político de Oceanía*	?
P-MAP8	T-MAP8	*Apenninen-Halbinsel*	1913
P-MAP12	T-MAP12	*Schwannsche Schul-Wandkarten Nº1 Deutschland*	1926
P-MAP13	T-MAP13	*Mapa escolar de Europa*	?
P-MAP14	T-MAP14	*Sur de Alemania y Norte de Italia Físico*	1915
P-MAP15	T-MAP15	*Spezial-karte von Afrika*	1892
P-MAP17	T-MAP17	*Australien und Polynesien*	1913
P-MAP19	T-MAP19	*Europa*	1916
P-MAP20	T-MAP20	*Mapa de España y Portugal*	?
P-MAP21	T-MAP21	*Mapa de Europa*	1905
P-MAP22	T-MAP22	*España y Portugal. Mapa Físico*	1942
P-MAP23	T-MAP23	*Das Zeitalter der Entdeckungen*	1916

Determining the fibre composition

The samples were prepared prior to the microscopic analyses (Fig. 2) following the guidelines of national regulations [8-10] which take into account the conditions of conservation of the papers and textiles and the difficulty of separating their fibres. The qualitative identification of their components was carried out based on the preparations' colors and theirn fibres' morphological characteristics [6, 11].

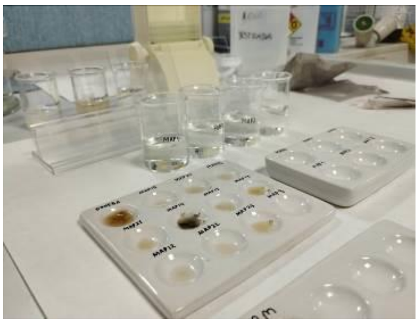

Fig. 2. Fibrous preparations of samples of school maps prior to the microscopic analyses

The papers were subjected to a pre-wash with distilled water prior to breaking up their fibres with pressurised water and dissecting needles. Textiles saw the same mechanical procedure serving for paper but preceded by boiling their threads in an aqueous solution of calcium hydroxide [15mL H_2O + 2mL NaOH (1M)] to disarm their framework.

Staining is carried out in both cases with the Herzberg stain [15], a solution consisting of a mixture of saturated zinc chloride ($ZnCl_2$), iodine (I) and potassium iodide (KI). The procedure consisted of adding 2-3 drops of the stain to the microscopic fibre preparation.

Optical microscopy

The Herzberg stain treatment makes it possible to determine the processes that yielded either the textile or paper media. A yellowish hue indicates the mechanical processing of fibres while red denotes the use of rags. A blue hue, in turn, corresponds to a chemical or semi-chemical pulp. After this treatment, a small portion of each fibre was placed on a slide where they were separated and disintegrated as much as possible (avoiding the formation of bubbles) to facilitate their identification. Immediately afterwards, a coverslip was superimposed to carry out the microscopic observations. Identification was undertaken with an Olympus Vanox

AHMT3 optical microscope equipped with objectives allowing four magnifications (5x, 10x, 20x and 50x) and an Olympus SZH10 binocular microscope (0.7x, 1x, 3x and 7x).

Fibre identification

As indicated above, qualitative characterisation of the fibrous components of paper and textiles is carried out through the identification of typical anatomical and morphological elements of forest and agricultural species. This task requires a certain skill, experience and prior knowledge in the field of paper and cellulose pulp microscopy [12]. Moreover, characterising the materials of school maps is complicated by the difficulties linked to their heterogeneity, their high degree of refinement and fibre deterioration. It is for this reason that this analysis, due to the historical framework of the manufacture of the school maps (known to have experimented with various raw materials), requires first consulting a series of atlases and reference standards and drawing up a descriptive guide of the most common fibres used at the time for the production of textiles and paper, from rag pulp to wood pulp.

Hence, before describing them, it is necessary to identify the different anatomical elements (cells) characteristic of each species [13]:

- *Cellulosic fibres* are long, narrow and hollow, with thick walls ending most often with sharp extremities. Their empty interior cavity is called the *lumen*.

- *Vessels* are short and wide. Their main difference with fibres is a greater width and their cell walls are not thickened as they are usually thinner and reveal perforations and blunt ends.

- *Parenchyma cells*, unlike vessels, are thin-walled and unperforated and are characterised by a similar length and width.

- *Epidermal cells* originate from the outer tissue of a leaf or stem. Their most distinctive feature is a wavy or jagged cell margin or perimeter. Hence their cells intertwine when they do not separate from each other.

Based on these elements, the following morphological traits and anatomical elements define the main species serving to manufacture the papers used to produce maps in the 18th to the beginning of the 20th century timeframe:

Nonwood plant species

- The ends of their long, cylindrical *flax* fibres are pointed and the cell walls are uniformly thick [1]. Worth highlighting is the presence of transversal faults or knots that divide the fibres (Figs. 3 and 4). *Hemp*, although very similar to flax fibre in size and scarcity of lumen [14], is identified by the rounded end of its fibres [13].

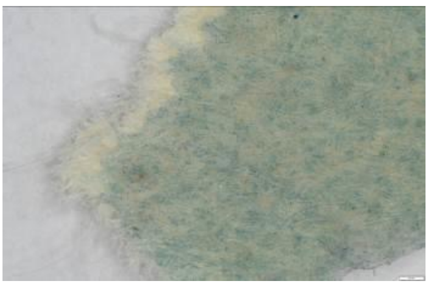

Fig. 3. Paper sample of P-MAP8. Olympus SZH10 (3x)

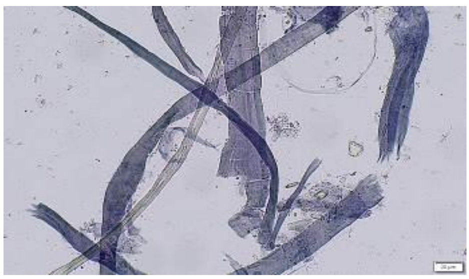

Fig. 4. Mixture of herbaceous flax and hemp fibres of P-MAP8. Olympus Vanox AHMTX (10x).

- *Cotton* is characterised by extremely long, cylindrical, hollow fibres with thin and irregular walls that undergo a typical phenomenon of torsion (Figs. 5 and 6) [14]. The twisting of its fibre is less pronounced at the points where the cell walls are thicker [13]. Epithelial or epidermal cells are visible (Figs. 7 and 8) among the cases of raw or minimally processed pulp such as those used to produce school maps [14].

- *Esparto* grass fibres (Figs. 9 and 10) are short with thick or thin walls and sharp extremities. Their parenchyma cells and vessels are small [13].

Fig. 5. Textile sample of T-MAP20. Olympus SZH10 (1x)

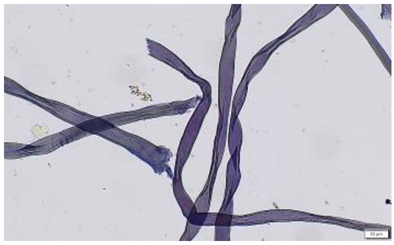

Fig. 6. Typical torsion of the cotton fibres of T-MAP10. Olympus Vanox AHMT3 (10x)

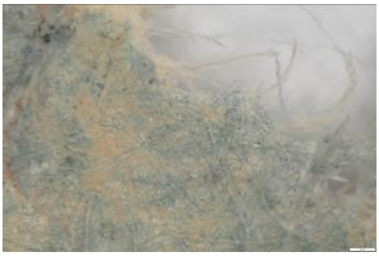

Fig. 7. Paper sample of P-MAP12. Olympus SZH10 (7x)

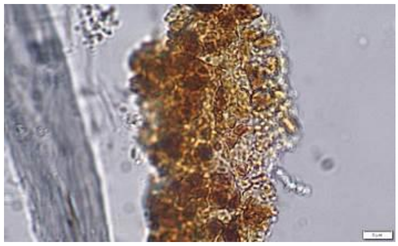

Fig. 8. Typical cotton epithelial cell of P-MAP12. Olympus Vanox AHMT3 v50x)

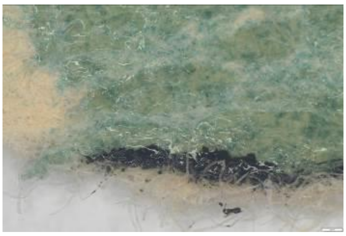

Fig. 9. Paper sample of P-MAP7. Olympus SZH10 (3x)

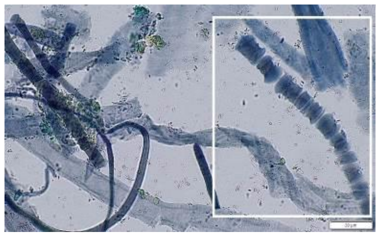

Fig. 10. Typical esparto fibre (highlighted in square to the right). Olympus Vanox AHMT3 (20x)

- *Cereal straw*, regardless of whether from wheat, rice or rye, is characterised by the same anatomical elements, notably fine, cylindrical fibres with a thick wall and a poorly developed lumen. This type also reveals knots, slightly marked folds and sharp and pointed extremities [14]. Cylindrical barrel-shaped parenchyma cells are typical and abundant (Figs. 11 and 12), as are proliferating epidermal cells with jagged margins and prominent notches (Figs. 13-16) [13].

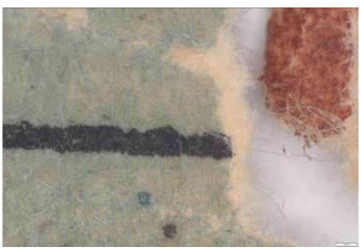

Fig. 11. Paper sample of P-MAP22. Olympus SZH10 (3x)

Fig. 12. Typical parenchyma cell of a cereal in P-MAP 22 (bottom). Olympus Vanox AHMT3 (10x)

Fig. 13. Paper sample of P-MAP14. Olympus SZH10 (7x)

Fig. 14. Typical cereal serrated epidermal cell of P-MAP14. Olympus Vanox AHMT3 (20x)

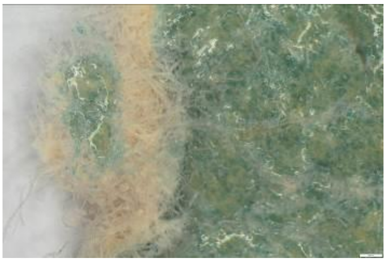

Fig. 15. Paper sample of P-MAP3. Olympus SZH10 (3x)

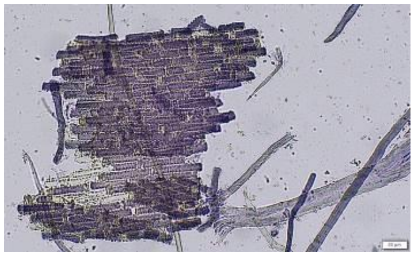

Fig. 16. Accumulation of epidermic cells typical of non-disintegrated cereal cells of P-MAP3. Olympus Vanox AHMT3 (10x)

Wood fibres:

- *Coniferous* wood consists of almost 90% of cellulosic fibres called tracheids, elongated and pointed cells bearing numerous areolated pits (Figs. 17 and 18) and pits in the crossing fields that appear at the intersection of longitudinal and transverse elements (Figs. 19 and 20). These pits are defined as the channels through which some fibres communicate with others, notably those of areolae nature with a vault shape. The parenchyma cells of conifers, on the other hand, are characterised by a rectangular shape and thin cell walls [15].

Fig. 17. Paper sample of P-MAP13. Olympus SZH10 (7x)

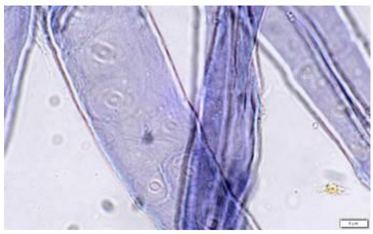

Fig. 18. Typical areolar pit of conifers of P-MAP13. Olympus Vanox AHMT3 (50x)

Fig. 19. Textile sample of T-MAP19. Olympus SZH10 (3x)

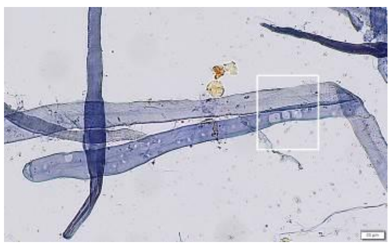

Fig. 20. Cross field areolar pit of T-MAP19. Olympus Vanox AHMT3 (10x)

Results and discussion

The result of the analyses of the fibrous composition of the papers serving to manufacture the maps are summarized in Table 2. They reveal that the paper that served to make the in maps in the Archives of the University of Granada is characteristic of the technological and innovative evolution of paper production introduced at the end of the 18th centurt and the beginning of the 20th centry.

Table 2. Results of the identification of the fibrous composition of the papers of the school wall maps housed in the Archives of the University of Granada

Paper sample	Results
P-MAP6 P-MAP8 P-MAP12 P-MAP20 P-MAP21	Semi-chemical pulp Mixture of herbaceous plants: flax, hemp, esparto grass and cotton epithelial cells.
P-MAP1 P-MAP17 P-MAP3 P-MAP19 P-MAP7 P-MAP22 P-MAP15 P-MAP23 P-MAP14	Semi-chemical pulp Mixture of herbaceous species: flax, hemp and esparto grass, cotton epithelial cells, serrated epidermic cells typical of cereal parenchyma
P-MAP2 P-MAP5 P-MAP13	Semi-chemical pulp Wood fibres from conifers, probably from the *pinaster* or *radiata* species

This study, based on the fibrous composition of the 17 samples and in accordance with the findings of the research of *L. Díaz* [16, 17], identified three different groups of maps:

- *Group 1*: Maps manufactured following the traditional composition of rag papers stemming from *flax, hemp and esparto* fibres (MAP6, MAP8, MAP12, MAP20, MAP21). The 18th century saw abundant research on the use of plant species, notably herbaceous fibres, for the manufacture of paper without the need for them to have previously gone through the state of cloth or rags. This process accelerated and reduced the costs of production. Worth highlighting in this sense is the research carried out by Jean Etienne Guettard, Christian Schäffer and that of Jérôme de la Lande penned in his work *Art de faire le papier* published in 1820 [16]. This type of paper, therefore, preserves the characteristics of rag papers in terms of quality and resistance while enhancing its preservation and long-term durability.

- *Group 2*: Maps produced mainly with *cereal straw* in combination with a lesser amount of other herbaceous species, notably flax, hemp or esparto grass (MAP1, MAP3, MAP7, MAP14, MAP15, MAP17, MAP19, MAP22 and MAP23). Research on the use of herbaceous plants pursued in the 18th century was materialised in the work of the English papermaker Matthias Koops who patented different techniques to produce paper pulp only from cereal straw [16]. These new raw materials stemming from agricultural waste were abundant, cheap and accessible [17]. They suffered nonetheless from signifiant colour instability and low resistance, which explains why they had to be mixed with other types of fibres to optimise their quality [16]. Although straw paper historically is considered somewhat specific and anecdotal, the findings regarding the school maps in the Archives of the University of Granada evidence that the technique persisted over time as evidenced by MAP15 dating from 1892 and MAP3 from to the middle of the 20th century.

- *Group 3*: Maps produced with coniferous-based *wood pulps* correspond to a procedure imposed by the industrial manufacture of paper that is even in use today (MAP2, MAP5 and MAP13). Practically simultaneous to the use of cereal straws, research began on wood pulp initially treated mechanically evidenced by the patents of Friedrich Gottlob Keller and Charles

Fenestry. It was customary to mix these materials, as in the case of the cereal straws, with wood fibres with rag pulp to improve their stability and long-term resistance [16].

However, the processing of pulps is independent of the type of fibre selected as a raw material for paper production. In all cases the Herzberg stain treatment yielded a heterogeneous bluish coloration stemming from a *differentiated semi-chemical treatment of the fibres* during their manufacture. Both straw and wood pulp comprise lignin, which was a new highly degradable compound of paper. Aware of this problem, research at the time attempted to eliminate it through chemical reagents notably both alkaline reagents (Anselme Payen, Hugh Burgess or Charles Watt) and acidic products (Benjamin Tilghman). The most successful was that of the German Karl Dahl, who in 1884 treated the fibres in a solution of calcium hydroxide and sodium sulphide at high temperature yielding the so-called kraft process [16]. This process was completed by bleaching the fibres with chlorinated products. It is also necessary to signal the key role of the machinery used with this chemical treatment. It was in fact not until the middle of the 19th century when M.A.C. Mellier together with T. Coupier developed new machines ensuring homogeneity during the treatment of the fibres [17]. The school maps of the current study thus represent a clear expression of the technological advances of the 19th century: chemical treatment of fibres, heterogeneous processing of the pulp and a deplorable state of conservation of the examples deriving from both alkaline reagents as well as bleaching with chlorinated products [6, 11].

The fibres identified in the textiles of the maps are listed in Table 3.

Table 3. Results of the fibers identified in the textile support of the maps

Textile sample		Results
T-MAP1	T-MAP13	Cotton fibres
T-MAP2	T-MAP15	
T-MAP3	T-MAP17	
T-MAP5	T-MAP20	
T-MAP6	T-MAP21	
T-MAP7	T-MAP22	
T-MAP8	T-MAP23	
T-MAP12		
T-MAP14		Coniferous wood fibres
T-MAP19		

The study of the textiles serving to reinforce the maps reveals two main types: cotton (Fig. 21) and fabrics containing wood fibres, specifically coniferous fibres (Fig. 22). The first group responds to the increase at the end of the 18th century of the supply of cotton rags [16]. This indicates, once again, that inexpensive and abundant materials were put to use to manufacture school maps. However, the fabrics of the second type open new lines of research as their textiles (MAP14 and MAP19) correspond to maps manufactured by the same person (Dr. Hermann Haack), the same publishing house (Justus Perthes) and the same timeframe (1915-1916). However, it is especially compelling that the wood fibres of these maps were compressed into the textile medium (Fig. 23), something unusual in this industry, while they do not form part of the paper despite the boom of the use of wood at the time of their production.

Fig. 21. Textile sample (cotton) of T-MAP1. Olympus SZH10 (3x)

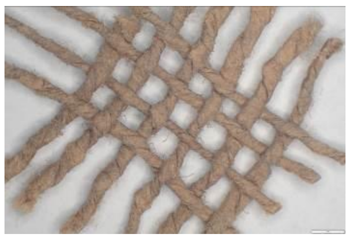

Fig. 22. Conifer fibre textiles of T-MAP 19. Olympus SZH10 (1x)

Fig. 23. Wood fibres compressed into the textile of T-MAP14.
Olympus SZH10 (3x)

Conclusions

The results of the identification of the fibrous composition of a series of samples representative of school maps housed in the Archives of the University of Granada rule out, at least regarding the question of the paper medium, the starting hypothesis. The chronological timeframe of the maps observed in this study suggests that most were made of wood fibres. The results of the analyses, on the other hand, point to materials corresponding to an earlier historical stage when most paper was manufactured from agricultural residues, that is, the straw of cereals.

The school maps housed in the Granada Archives are thus faithful historical witnesses of a period of research when the paper industry was in searching for new accessible and profitable raw materials. This lot of maps from Granada also reveal cases that respond to the period of transition in the processes of manufacture of paper ranging from rag-based papers to wood pulp papers, passing through cereal straw-based pulps. However, it must be noted that the interest in greater production efficiency did not rule out a concern to manufacture durable paper of a certain quality. This is reflected by the addition of flax and hemp fibres to wood pulp or fibres from agricultural waste to provide greater resistance in the same manner that the semi-chemical treatment of the fibres aimed to eliminate lignin, a product especially vulnerable to degradation. Yet both the highly lignified fibres and the effects of the alkaline and chlorinated products used during paper manufacture have aggravated their current state of conservation.

Once again, the fibrous composition of the textiles confirms the preference for inexpensive, abundantly available materials such as cotton fabrics. Despite this, the analysis‘ results of the analyses revealing the use of wood fibre cloths to reinforce two of the examples, open up new lines of research on textiles production techniques.

All these considerations related to the fibrous composition of the main and secondary media of wall maps are key aspects when determining and defining preservation and restoration protocols to apply to these types of objects. The choice of treatment types of must consider the initial nature of these cartographic documents and anticipate the alterations that can derive from circumstances related to their original nature and manufacture.

Acknowledgments

Our heartfelt thanks go to the Aid Program for the Training of University Professors (FPU) of the Ministry of Universities. Ana Reyes Pérez is a beneficiary of this program (FPU20/02198) at the University of Granada. We likewise express our gratitude to the personnel of the Archives of the University of Granada for access to the school maps, to the ICIFOR-INIA Pulp and Paper Group of the CSIC for their collaboration and active participation in the identification of their fibrous components, the Heritage Science and Culture Research Group (HUM-1057) of the University of Granada and the Precompetitive Research Project, 'Preservation of 19th and 20th-century Cartographic Documents through an Anthropological and Gender Perspective' funded by the Vice-Rectorate of Research and Knowledge Transfer of the University of Granada.

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Received: July 27, 2023
Accepted: July 4, 2024