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Advanced Imaging Techniques for the Material Analysis and Documentation of Rigas Velestinlis' *Charta of Greece* in the Onassis Foundation Collections.

Keywords: Cultural Heritage, Rigas' Charta of Greece, non-destructive methodology, spectral imaging techniques, RTI, Photogrammetry

Summary: The *Charta of Rigas Velestinlis* stands as a landmark artifact of the Neo-Hellenic Enlightenment and a seminal example of pre-revolutionary Greek cartography. While its ideological and historical importance has been widely studied, its material and technical dimensions have received comparatively limited scholarly attention. This study addresses that gap through a comprehensive investigation of one surviving copy from the Onassis Library, using non-destructive analytical techniques to explore the Charta's physical structure and condition.

A multimodal approach was applied, combining Reflectance Transformation Imaging (RTI), close-range photogrammetry, and hyperspectral imaging (HSI). RTI enabled high-resolution visualization of surface morphology and mechanical deformations; close-range photogrammetry provided accurate digital reconstructions for geometric analysis and documentation; while HSI, supported by visible-light imaging and digital microscopy, contributed to the identification of materials, printing techniques, and degradation products. The results revealed key information regarding the handmade laid paper substrate, the use of intaglio and offset lithographic printing methods, and the Charta's physical alterations over time. The study highlights the value of these imaging techniques in the technical examination of historical cartographic documents and proposes a transferable methodology for the digital documentation and authentication of similar cultural heritage objects.

1. Introduction

The *Charta of Greece* (Χάρτα της Ελλάδος) by Rigas Velestinlis (hereinafter referred to as the *Charta*) stands as one of the most emblematic cartographic productions of the Neo-Hellenic Enlightenment and a key milestone in the pre-revolutionary Greek intellectual movement. Created between 1796–1797, this monumental work transcends its function as a geographical map: it is a complex visual and ideological document that synthesizes Enlightenment values, historical memory, and political vision. Combining geographical knowledge with classical historiography, iconographic references, and didactic intent, the *Charta* emerges as a hybrid medium—simultaneously cartographic, educational, and symbolic—designed to cultivate a sense of national consciousness and cultural unity among Greek-speaking populations under Ottoman rule.

Recognized for its innovative structure and composite content, the *Charta* served not only as a tool for navigation or education but also as a political artifact—a printed call to identity and liberation.

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It reflects the aspirations of a subjugated people and a vision for an independent nation founded on shared history, culture, and knowledge. In that sense, it can be seen as a "multimedia" creation avant la letter (Livieratos 2008), merging map, chronicle, emblem, and manifesto into a single visual language.

While considerable scholarship has been devoted to the historical, ideological, and philological dimensions of the *Charta*, significantly less attention has been paid to its physical structure, materiality, and condition. These aspects, however, are crucial for both the long-term preservation of the artefact and for deepening our understanding of its production, both technologically and socio-economically as well as its original function.

This study responds to that gap by focusing on one of the surviving copies of the *Charta* housed in the collections of the Onassis Library. Employing a suite of non-destructive imaging techniques—namely **Reflectance Transformation Imaging (RTI)**, **close-range photogrammetry (CRP)**, and **spectral imaging (MSI/HSI)**—the research aims to uncover detailed information about the artefact's materials, the production processes, and the current conservation state. Such data not only provide new insight into the *Charta's* technical and material profile but also contribute to a more comprehensive and scientifically grounded framework for the management and conservation of similar historical documents.

By integrating these advanced imaging methodologies into the field of cartographic heritage studies, the present paper proposes a model of interdisciplinary analysis that bridges humanities-driven inquiry with state-of-the-art technological practices. While the research is firmly grounded in the context of historical cartography, its methodological core is inherently technical and analytical, underscoring the potential of non-invasive imaging to transform our engagement with fragile and culturally significant artifacts.

2. The *Charta of Greece* by Rigas Velestinlis

2.1 Content, Structure, and Iconographic Features

Engraved in Vienna between 1796–1797, the *Charta of Greece* by Rigas Velestinlis represents one of the most ambitious cartographic and ideological projects of the Neo-Hellenic Enlightenment. Comprising twelve intaglio-printed folios on Dutch handmade paper (Livieratos 1999), the full map measures approximately 203 × 207 cm. It spans a territory from the Danube to Crete and western Asia Minor, blending Ptolemaic frameworks with Enlightenment geopolitical vision.

The Charta's content is both topographically dense and symbolically charged. It features over 5,800 toponyms, ancient city plans, mythological scenes, archaeological monuments, and coin illustrations (Penna 1998)—often drawn from classical sources like Barbié du Bocage's atlas (Barbié du Bocage 1788). Iconographic elements such as topographical plans of Constantinople and Velestino, views of the Sultans palace and various symbolic depictions, coins and comments, further support its ideological and educational mission.

2.2 Production, Historical Context, and Cartographic Techniques

Created during Rigas' second stay in Vienna with technical assistance from engraver François Müller and funding from Efstratios Argentis, the Charta likely drew on earlier conceptual work from Wallachia. The production involved upscaling existing cartographic sources—mainly of the

Delisle–Seutter typology (Mihailou 2021)—using drafting tools like the pantograph (Amantos 1997) to enlarge conventional European map formats.

Despite limited archival documentation, comparative analysis of extant copies suggests the existence of two main editions (Type-A and Type-B) (Pazarli 2014), with minor topographic and orthographic variations indicative of post-printing interventions. Some surviving examples show hand-coloration, pointing to limited but personalized enhancements.

Spelling inconsistencies, likely due to the engraver's limited knowledge of Greek, further attest to the technical and linguistic challenges of the project. Each folio was sold separately, at a relatively high cost, limiting distribution, though the estimated total print run of ~1,220 copies reveal Rigas' ambitious vision.

2.3 The Onassis Foundation Copy: Significance and Research Relevance

The Onassis Library holds a complete twelve-folio copy of the *Charta*, which offers an invaluable opportunity for in-depth technical study. The fragile character of the artefact and the specific characteristics of this exemplar—including paper texture, printing quality, coloration, and evidence of mounting techniques—make it particularly suitable for scientific investigation using non-destructive methods.

Given the lack of bibliographic references focused on the technical, material, and conservation-related aspects of the *Charta*, the study presented here aims to produce scientifically based data, and a methodological model for future investigations of similar artefacts, through a systematic and interdisciplinary analysis that combines heritage science with historical cartography.

3. Aim of the Research

A detailed and comprehensive study was carried out based on non-destructive testing and analytical techniques such as **Reflectance Transformation Imaging (RTI)** and **close-range photogrammetry (CRP), Multi** and **Hyperspectral Imaging (MSI/HIS)** as well as **portable XRF** and **FTIR-ATR analysis.**

The preliminary results of this research have been published in Alexopoulou et al. (2024) while in the present publication the focus is given to the imaging techniques primarily that enables high-resolution, contactless documentation and analysis of the Charta's material and structural features. The present paper specifically shows how advanced non-destructive imaging helps us gather crucial information. This information is key to understanding and engaging with cultural assets like this from various points of view—technically, materially, and historically—and to guide their future management and conservation.

The main objectives of this research are to:

- visualize surface morphology, capturing micro-reliefs, tool marks, and deformations indicative of both the original printing process and later handling or damage
- generate accurate 2.5D surface models of each folio, serving as geometrically precise digital surrogates for analysis, conservation, and scholarly access
- assess geometric inconsistencies, misalignments, and deformation patterns potentially caused by environmental exposure, mounting, or aging
- detect pigment alteration, media degradation, and enhance interpretation of characteristic features

- distinguish any repairs and interventions that are inconsistent with the Charta's historical period and production methods.

This coordinated approach demonstrates how advanced imaging techniques can form a scalable, reproducible strategy for documenting large-format cartographic heritage. It allows for the detection of subtle material clues not visible through conventional imaging, enhancing both scholarly understanding and conservation planning.

Ultimately, the project contributes not only a detailed digital archive of the Charta but also a transferable model for the technical analysis of fragile historical documents. The resulting data support broader interdisciplinary goals—advancing the study of Enlightenment-era cartography while promoting sustainable digital preservation practices in heritage collections.

4. Materials and Methods

4.1. The Onassis Library Copy of Rigas' Charta

The object of the present study is the copy of Rigas Velestinlis' *Charta of Greece* (Type B), currently housed in the Onassis Library in Athens. This specific exemplar originates from the Konstantinos Staikos Hellenic Library Book Collection, acquired by the Onassis Foundation in 2009. Prior to this, the map belonged to the private collection of Athanasios D. Chatzidimos.

For the past fifteen years, the *Charta* has been displayed in the Onassis Library within a custom-made wooden frame, covered with uncoated glass. The twelve individual folios comprising the *Charta* have been directly adhered onto two large plywood panels, each measuring 103 × 207 cm. These two panels are connected via small square wooden blocks and screws to form a unified structure.

The folios are arranged in a 4 × 3 grid: four horizontal rows labeled A to D (top to bottom) and three vertical columns labeled 1 to 3 (left to right), resulting in an overall dimension of approximately 203 × 207 cm (Fig. 1). The individual dimensions of the folios vary slightly, with average measurements of approximately 50 × 70 cm. In certain areas, marginal overlaps between adjacent sheets are observed (Fig. 2).

Figure 1. Labelling the folios of The Charta using letters and numbers.

Figure. 2. VIS, detail of the overlapping areas. Self-adhesive tapes have been used along the joints.

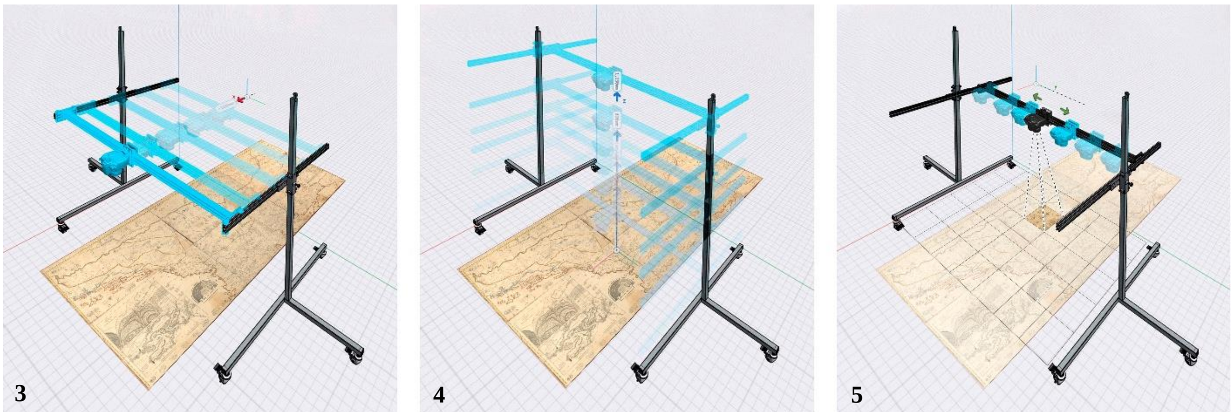
4.2. Research Methodology and Instrumentation

Aligned with conservation science’s best practices, the study employed a suite of non-destructive, multi-modal imaging techniques to investigate the Charta’s material structure and condition:

- Spectral imaging (visible, ultraviolet luminescence, infrared reflectance false color, hyperspectral cubes)
- Topographic analysis using Reflectance Transformation Imaging (RTI)
- Geometric reconstruction through Close-Range Photogrammetry (CRP)
- Supplementary digital microscopy (Dino Lite microscope)

These methods were selected for their high spatial resolution, material sensitivity, and ability to capture degradation features non-destructively.

Given the fragile nature of the *Charta* and its value as a paper-based cultural heritage object, the entire documentation process was carried out with the artefact placed in a strictly horizontal position. This approach minimized the risk of mechanical stress and was crucial for preserving its current physical integrity throughout the study. To accommodate this requirement, the RTI methodology employed a ceiling-mounted custom camera rig, ensuring a perfectly perpendicular alignment to the folio plane. Likewise, the CRP acquisition utilized a custom-engineered horizontal scanning frame (Tsairis 2024), enabling controlled stepwise movement along the x, y, and z axes while maintaining constant focus and geometric alignment (Fig. 3-5).



Figures 3–5. Sequential documentation of the scanning process using controlled camera movement. Figure 3 illustrates lateral displacement of the camera along the x-axis, parallel to the surface of the Charta. Figure 4 shows vertical movement along the z-axis, perpendicular to the plane of the object. Figure 5 depicts the segmented photographic capture of the surface, achieved through linear motion of the camera along the y-axis

4.2.1. Imaging Techniques

The imaging protocol adopted in this study integrated a range of modalities to document both macro- and micro-level visual information. Visible light photography (VIS) was performed under normal, raking, and transmitted illumination conditions, while ultraviolet-induced luminescence (UVL) (Kaminari et al. 2022), multispectral and hyperspectral imaging (MSI/HSI), as well as infrared reflectance and false color imaging (IRRFC) (Alexopoulou et al. 2024), were also employed. Comprehensive imaging was carried out on both the recto and selected verso areas of the folios.

UVL imaging proved effective in revealing features imperceptible to the naked eye, including organic residues, overpainting, and surface inconsistencies. Hyperspectral imaging within the visible and near-infrared range (VNIR, 400–1000 nm) offered critical insights into pigment composition, signs of oxidation, and the stratigraphy of applied materials.

To support the above methods, an array of advanced imaging instruments and accessories was utilized. These included a Nikon D800 DSLR (FX-format, 36 MP CMOS sensor) equipped with both macro and wide-angle NIKKOR lenses, and a Sinar p3 view camera coupled with a Sinar eVolution 75H digital back (33 MP).

A modern MUSES9-HS 1700 hyperspectral camera, 6 MP CMOS, covering a 400–1000 nm spectral range by 5 nm spectral step and alternatively a MuSIS HS multispectral CCD camera (1600 × 1200 px) were used to provide insight into pigment composition, oxidation phenomena, and layering structure. The techniques enabled both the mapping of material heterogeneities and the visualization of previously undocumented features.

Microscopic examinations were conducted using a DinoLite digital microscope with capabilities in the visible, ultraviolet, and infrared spectra. Lighting was provided by a Hensel flash system (4000–500 J) with UV-filtered bulbs. The ultraviolet source delivered 14,250 mW at 365 nm and was paired with optical filters and a Kodak 2E filter on the camera lens to optimize spectral purity.

Color accuracy and spectral fidelity were maintained through the use of X-Rite ColorChecker SG calibration targets, an Eizo CS2730 monitor, and the Color Navigator 7 software. Image acquisition and processing workflows were managed with Sinar Capture Flow and BasiCColor Input 5.

Hyperspectral scanning was selectively applied to specific folios. These included full-surface imaging of folios A1, B3, and C3, as well as macro-imaging of folio B1, providing detailed spectral data to support subsequent analytical interpretation.

4.2.2. Reflectance Transformation Imaging (RTI)

Reflectance Transformation Imaging (RTI) is a computational photographic method designed to record and analyze microrelief features and subtle surface variations. It has been extensively applied in cultural heritage research for its ability to visualize material textures, engraved line structures, ink deposits, and physical deformations such as creases, abrasions, and planar distortions (Woodham, 1980; Malzbender et al., 2000, 2001; Earl et al., 2010; Frey et al., 2017). RTI operates by capturing a series of images from a fixed camera position, each illuminated from a different angle. These are then synthesized into a single interactive dataset that enables dynamic relighting and mathematical enhancements, including specular and diffuse enhancement, normal vector visualization, and surface curvature analysis.

In the context of this study, RTI was systematically applied across all twelve folios of the *Charta*, allowing for detailed documentation of both surface morphology and conservation-related features. The folios were grouped into two main sections:

- Upper section: A1, A2, A3, B1, B2, B3
- Lower section: C1, C2, C3, D1, D2, D3

This segmentation enabled optimized workflow management and ensured consistent imaging parameters across the entire object.

The RTI capture setup was carefully designed to maximize data fidelity. A Nikon D800 DSLR (36 MP, full-frame CMOS) paired with a Tokina AT-X PRO 16–28 mm f/2.8 lens (used at 28 mm) was mounted on a custom ceiling rig to ensure precise perpendicular alignment to the folio plane, effectively eliminating parallax distortion. Illumination was provided by a Nikon Speedlight flash, manually repositioned across 47 to 48 unique lighting angles per section. Each session produced a high-resolution dataset capable of revealing textural nuances imperceptible under standard illumination.

Post-capture processing and interactive rendering were conducted using the open-source software tools RTIBuilder and RTIViewer, developed and maintained by Cultural Heritage Imaging (2002–2021). These platforms enabled the generation of PTM and HSH-based RTI files, offering advanced tools for interpretive visualization and measurement.

4.2.3. Close-Range Photogrammetry (CRP)

Close-range photogrammetry (CRP) employs a structure-from-motion (SfM) methodology to reconstruct the three-dimensional geometry of objects from overlapping two-dimensional photographs. Widely adopted in the documentation of cultural heritage (Remondino & El-Hakim, 2006; Kraus, 2007; Westoby et al., 2012; Remondino & Campana, 2014; Kelley & Wood, 2018; Luhmann et al., 2023), CRP allows for metrically accurate analysis of surface geometry, deformation patterns, and structural evolution over time.

In the case of the *Charta of Greece*, CRP was utilized to produce high-resolution orthophotos, 2.5D surface models, and Digital Elevation Models (DEMs), contributing valuable spatial datasets for the analysis of physical distortions and conservation state.

Image acquisition was performed using a Nikon D800 DSLR (36 MP), equipped with an AF Nikkor 50 mm f/1.8D lens. The process yielded a total of 419 photographs for the upper group (folios A1–B3) and 468 for the lower group (folios C1–D3), maintaining a minimum overlap of 75% between successive frames. A custom-engineered horizontal scanning frame facilitated stepwise movement along the x, y, and z axes, ensuring consistent focus and alignment. Diffused daylight-simulating illumination was employed throughout to minimize shadows and reflective artifacts on the paper surface.

The photogrammetric datasets were processed using Agisoft Metashape Professional v2.0.1, which allowed for high-precision reconstruction of textured surface models. Coded targets and scale bars enabled georeferencing and 1:1 scale model generation, ensuring full metric accuracy across the resulting datasets.

The principal outputs included:

- Orthophotos:
  - Group A–B: 23,804 × 11,926 px
  - Group C–D: 23,357 × 11,700 px
  - Merged full map: 27,447 × 26,989 px at 300 dpi
- Digital Elevation Models (DEMs): Provided quantifiable elevation data for detecting surface warping, folding evidence, and structural irregularities.
- 2.5D models: Offered shaded relief and color-coded depth visualizations to support morphological interpretation.

Together with RTI, the CRP data contributed to a multidimensional understanding of the *Charta*'s current structural condition. The applied methodologies adhere closely to the standardized protocols described in detail by Tsairis et al. (2025), including mounting strategies, acquisition parameters, calibration methods, and post-processing workflows.

5. Results and Discussion

5.1. Display Methodology and Mounting Materials

The current mounting system of the *Charta* involves the use of multiple pressure-sensitive adhesives (PSAs), primarily double-sided tape, along with the paper edges, packaging, and pressure sensitive tapes (e.g., 3M Magic Tape), applied inconsistently along folio edges and junctions. These materials exhibit visible signs of ageing, including oxidation, embrittlement, and tack loss. Consequently, the folios present uneven tension, edge lifting, and, in parts, detachment from the plywood backing support.

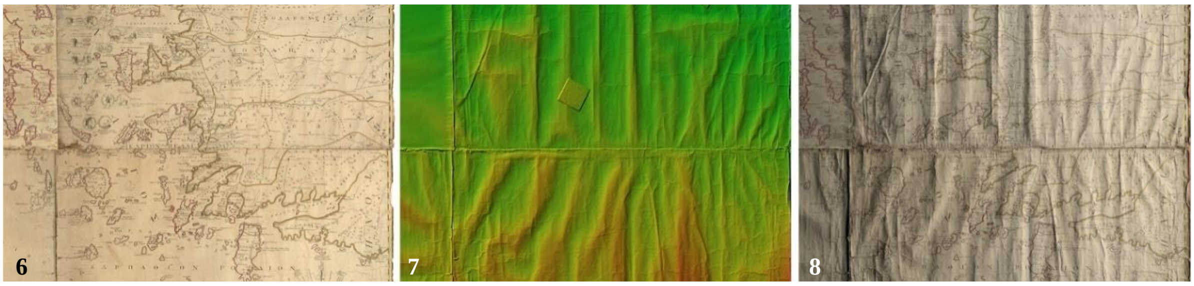


Figure 6, 7, 8. Combined orthomosaic, Digital Elevation Model, and Reflectance Transformation Imaging of folios C3 and D3 visualize traces of attempted reinforcement or rejoining. The irregular positioning and limited efficacy of these interventions underscore structural inconsistencies between the two adjoining sheets.

The presence of textile strips on the verso indicate earlier reinforcement or rejoining attempts, likely adhered using starch- or protein-based adhesives.

CRP, DEM and RTI confirmed geometric inconsistencies between adjacent folios, notably between A2/B2 and C3/D3. The resulting orthomosaic captured three-dimensional misalignments and shadowing beneath lifted sheet corners, illustrating the effects of adhesive fatigue and pointing to areas at heightened mechanical risk (Fig. 6-8).

5.2. Materials and Technical Characteristics

Paper Support

According to Alexopoulou et al. (2025), the substrate was identified as a handmade, rag-based laid paper, typical of late 18th-century European papermaking. A partial watermark reading "..& I Honig" (Fig. 9) links it to a renowned Dutch paper mill. The original size corresponds to that so-called "Double Elephant" size (approximately 67.8 × 101.6 cm), which was subsequently trimmed prior to assembly.

Figure 9: Transmitted light photography. The watermark "...& I Honig" is revealed through transmitted light imaging, clearly visible due to the structural transparency of the laid handmade paper.

RTI imaging revealed fine papermaking features—chain and laid lines, a slightly rough surface with undulations, and textural differences between the mould and felt sides on verso and recto side respectively. Printing occurs on the felt side, consistent with intaglio printing practices.

In addition to papermaking features, RTI proved essential in detecting surface-level microrelief characteristics imperceptible through standard imaging methods. These included localized paper deformations, planar distortions, and embedded creases, as well as differences between lightly and heavily inked areas (Fig. 10-13). RTI also visualized areas of abrasion, pigment accretion, and signs of earlier restoration interventions. Such diagnostic capabilities enhanced the understanding of mechanical stress patterns associated with historical folding, handling, and mounting practices.

The CRP survey further revealed geometric irregularities such as folio misalignment, sagging due to mounting on the backing substrate, and structural warping caused by prolonged mechanical stress. DEM analysis confirmed earlier hypotheses regarding folding patterns (Alexopoulou et al. 2025: 19).

Together, RTI and close-range photogrammetry enabled a comprehensive structural mapping of the artifact's current condition, significantly enriching the holistic assessment of its physical integrity.

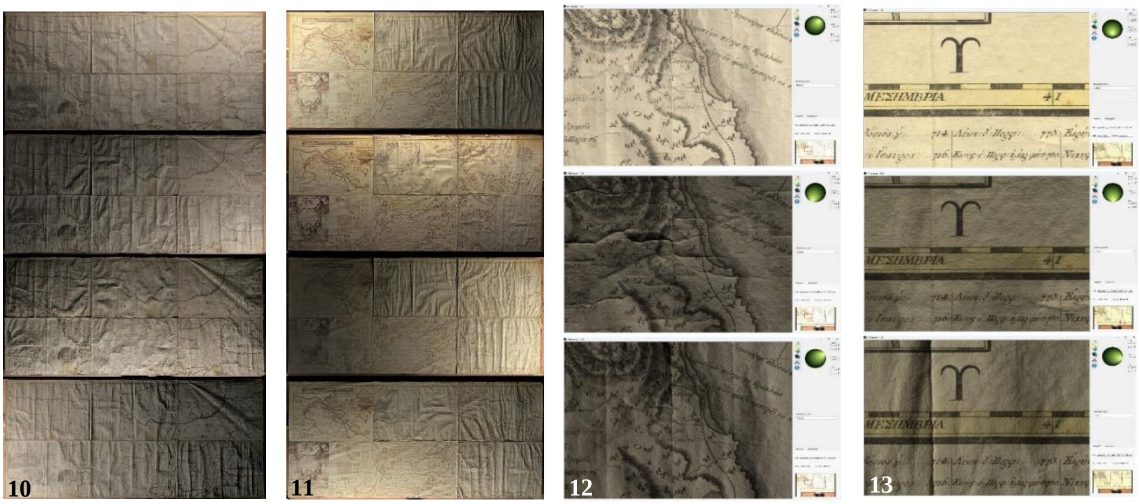


Figure 10, 11: RTI renderings under variable light directions expose diverse surface features of the Charta's upper and lower section, enhancing the differentiation of paper types and revealing condition-related irregularities. The surface relief of the Charta is depicted with enhanced visibility. Figure 12, 13: Screenshots from RTIViewer demonstrating the adjustment of the green sphere (top right) to simulate varying light directions for enhanced surface analysis.


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Figure 14, 15, 16: Comparative visualization using orthophotography (bottom) and Digital Elevation Models (top) of selected details from the Charta of Greece. The first two pairs of images illustrate surface undulations of the paper substrate, captured in DEM renderings through false-color elevation encoding. These variations reflect the differing hygroscopic behavior of laid paper types. The third pair reveals not only paper deformations but also traces of the printed matrix itself, offering additional insight into the mechanical aspects of the printing process. Elevation profiles along cross-sections defined in each area are metrically precise at a 1:1 scale, enabling the detailed assessment of topographic variations with high geometric accuracy.

Printing and Coloration

The intaglio printing process—most likely a combination of copperplate engraving and etching—was confirmed through raised ink lines visible under raking light and RTI enhancement. The printing ink appears oil-based, with spectroscopic data suggesting a carbon black pigment mixed with linseed oil (Alexopoulou et al. 2025).

Hand-applied coloration highlights select geographical, decorative, and symbolic features. Hyperspectral and UVL imaging identified the following pigment types:

- **Greens**: Likely verdigris, showing advanced degradation, discoloration, and support embrittlement.
- **Blues**: Possibly indigo or ultramarine, based on UV fluorescence and IR absorption patterns.
- **Reds**: Two varieties were noted—an organic lake (possibly carmine) and an inorganic red consistent with vermilion or red lead.
- **Yellows**: Indicative of organic lakes (e.g., *reseda*), showing characteristic greenish fluorescence under UV.

Manuscript Annotations

Several folios (e.g., A2, C3) feature graphite notations, circled numbers, and marginal inscriptions. RTI helped recover faded or partially erased entries by enhancing surface micro-topography and pencil stroke relief. These annotations may relate to cataloguing or curatorial handling (Fig 17, 18). Although full access to the verso sides was limited due to the fixed mounting, selective HSI scans of partially exposed areas revealed residual material, potentially associated with binder absorption from the paper support or residues of previous interventions. Further analytical work is necessary to verify these preliminary observations (Fig 19, 20).

17  18  19  20 

Figures 17-20: Circled graphite number notations appear on folios A2-C3 (Figs. 17-18). VIS and UVF imaging of a verso surface (Figs. 19-20) reveal binder absorption from the paper support or residues of previous interventions, or handling interventions.

5.3. Structural and Surface Condition Analysis

To assess the physical integrity of the Charta, DEMs and 2.5D surface models were generated via photogrammetry. These models exposed localized deformations, undulations, and mechanical stress patterns that had not been previously documented. Color-encoded elevation maps visualized folding lines, concavities, and areas where the paper lifts from the substrate.

Prominent findings include:

- **Aligned folds and creases** shared between vertically adjacent folios (e.g., A1 with B1, C3 with D3), suggesting the Charta had been historically folded along horizontal axes, likely for storage or transport. These folds are visible as ridges or depressions in the DEMs and corroborated by RTI-enhanced shading.
- **Warping and lifting** along folio borders, especially where adhesive failure is evident. DEM cross-sections show upward deviation from the mounting plane, suggesting mechanical tension and lack of structural support.
- **Surface disruptions** such as embedded creases, tears, and paper thinning, were clearly visible in both RTI specular enhancement and photogrammetric slope maps.
- **Accretions and stains**, including suspected waxy residues, aged adhesive remnants, and oxidized cellulose areas, were documented in high detail. UVL and RTI imaging emphasized these materials' differential reflectance and surface morphology.

The **hand-colored areas** exhibited the most severe deterioration, including cracking, flaking, and chromatic fading. Verdigris-rich green areas, particularly on the verso, demonstrated classic copper-induced degradation: darkening, brittleness, and support loss.

Overall, the integration of RTI and photogrammetry allowed for a high-resolution, non-contact condition assessment. These techniques provided complementary insights: **RTI** illuminated surface-level phenomena at the micron scale, while **photogrammetry** mapped broader geometric distortions and topographic anomalies. Together, they constitute a reproducible documentation archive of the Charta’s current state, offering a robust foundation for preventive conservation and future scholarly study.

5.4 Material Authentication through Imaging

A particularly significant outcome of this research was the identification of original versus later reprinted sheets of the Charta, achieved through the high-resolution surface imaging and material differentiation provided by RTI, close-range photogrammetry, and spectral methods.

Microscopic observation and spectral imaging revealed two distinct printing techniques among the segments. Sheets A1, A2, B1, B2, B3, C3, D2, and D3 were produced using intaglio techniques (Fig. 21)—etching and engraving—employing black lithographic ink likely composed of charred organic pigment mixed with boiled linseed oil (Alexopoulou et al. 2025). In contrast, sheets A3, C1, C2, and D1 exhibited the dot matrix pattern of halftone offset lithography (Fig. 22, 23)., confirmed by their lack of IR reflectance and their distinctive UV fluorescence

Equally important was the differentiation of paper substrates. The original folios were printed on antique laid handmade paper, easily identifiable in transmitted light by the presence of chain and laid lines. In three accessible cases (A1, B3, D3), a "C & I Honig" watermark was detected on the verso, corroborating the Dutch Provenance of the paper (Fig. 9). The offset-printed sheets, by contrast, were made on machine-made wove paper, which lacks such structuring and does not exhibit watermarks under transmitted light (Fig. 22, 23).

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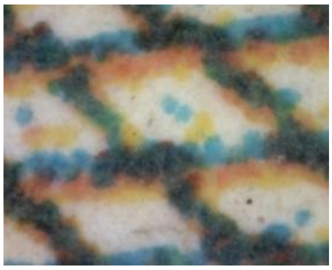

Figure 21: Photomicrograph of a printed letter produced using traditional intaglio (copperplate) printing. Figures 22, 23: Photomicrographs of blue, green, and red areas printed using offset lithography, displaying characteristic halftone dot patterns.

This distinction was most effectively demonstrated through three complementary imaging techniques:

- **Digital Elevation Models (DEMs)** generated via close-range photogrammetry clearly visualized variations in surface elevation related to the paper's dimensional stability and deformation behavior. These differences, caused by the contrasting hygroscopic characteristics of handmade rag and machine made wove papers, were mapped using a color gradient scale (Fig. 25, 28).
- **RTI datasets** allowed for enhanced visual analysis of the paper's surface grain and fiber morphology. Fine, linear impressions typical of handmade laid paper were clearly distinguished from the smooth, homogeneous texture of the machine-made wove sheets (Fig. 26, 29).
- **Ultraviolet luminescence (UVL) imaging** provided further material distinction by recording the fluorescence of the Charta's constituent materials. Differences in both paper type and ink composition resulted in divergent fluorescence behavior, reinforcing the material classifications derived from RTI and photogrammetry (Fig. 27). This technique also allowed for the visual separation of original and later-added elements in a single frame, using their differential luminescent response under UV excitation.

These integrated observations provided robust, reproducible indicators of authenticity, enabling the accurate classification of the *Charta*'s sheets and confirming the composite nature of the current artefact. Moreover, the methodology developed here offers a replicable model for material authentication in historical printed documents, applicable to a wide range of heritage objects.

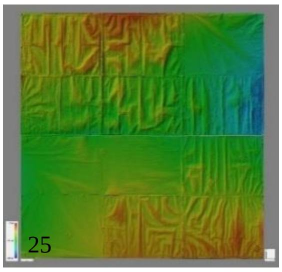

Figure 24: Orthophotographic reconstruction of the Charta of Greece: Full-scale (1:1) orthophoto produced via close-range photogrammetry, offering a geometrically accurate, high-resolution visualisation of the complete Charta. This image serves as the spatial baseline for comparative material analysis and facilitates the spatial correlation of structural and surface anomalies across different sheets.

Figure 25: Digital Elevation Model (DEM) with color-coded surface variation: Topographic rendering of the *Charta*'s surface, highlighting elevation fluctuations due to paper deformation. The pronounced undulations in the handmade laid paper (original sheets) contrast sharply with the minimal variation observed in the machine-made wove paper (reprinted sheets), enabling clear material differentiation. The image underscores the value of DEMs in detecting subtle structural behaviors linked to authenticity.

Figure 26: RTI rendering of the entire *Charta*, emphasizing surface texture and relief: Reflectance Transformation Imaging (RTI) enhanced with dynamic relighting reveals surface morphology and paper grain differences between original and reprinted sheets. The visibly stronger relief patterns and micro-topographic variations in the handmade sheets offer conclusive visual markers for material classification and further highlight the diagnostic potential of RTI in heritage authentication studies.

Figure 27: Ultraviolet luminescence (UVL) image of the full *Charta*. UVL imaging captures differential fluorescence responses across the *Charta*, reflecting variations in paper composition and printing inks. The divergent luminescence patterns between the laid and wove paper types further corroborate the results of RTI and photogrammetric analysis. This non-invasive technique provides complementary evidence for the surface inspection and material assessment of historical printed artefacts.

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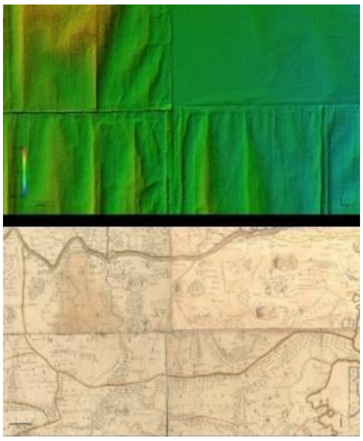

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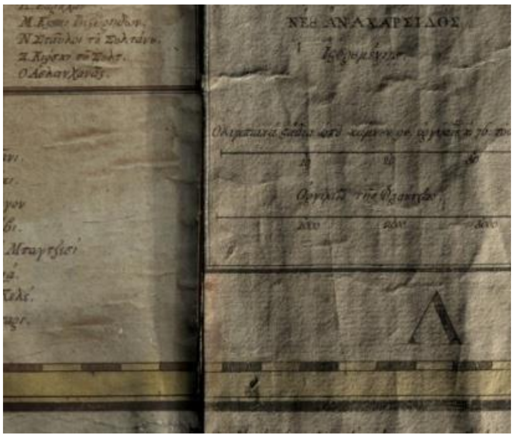

Figure 28: Comparative visualization using orthophotography (bottom) and Digital Elevation Models (top). The DEM rendering clearly highlights the contrast between the handmade paper and the later machine-made wove sheet (top right), providing a rapid and visually intuitive tool to assess dimensional stability and material behavior under environmental stress.

Figure 29: RTI rendering of two adjacent folios of reveals distinct surface textures: the left folio displays a smooth, homogeneous finish, while the right exhibits a pronounced relief characteristic of handmade laid paper with visible grid impressions. Surface undulations further emphasize the different hygroscopic responses of the two paper types.

6. Conclusions

The interdisciplinary approach adopted for the study of the *Charta of Greece* by Rigas Velestinlis, from the Onassis Foundation's collections, enabled a thorough investigation of its material composition, production techniques, and preservation state. At the core of this methodology was the integration of advanced imaging and analytical techniques, particularly Reflectance Transformation Imaging (RTI) and Close-Range Photogrammetry (CRP).

These two non-destructive methods proved especially effective in documenting surface morphology and material degradation, producing high-resolution, interactive visualizations of the *Charta's* physical condition. RTI enhanced the visibility of features such as incisions, creases, and deformations, while photogrammetry generated a metrically accurate 2.5D model capturing both geometric and visual characteristics. Together, they enabled the precise digital reconstruction of the *Charta*, offering critical insights into its fabrication, use, and historical storage.

Beyond this case, RTI and photogrammetry stand out as valuable tools for the documentation and preservation of archival cartographic materials, particularly those with significant cultural, historical, or emotional value. These techniques allow for the acquisition of objective, reproducible data that supports interdisciplinary research and informs conservation strategies—all without requiring physical contact. The resulting digital twin ensures long-term remote access for researchers, curators, and conservators, preserving the original's integrity while expanding its availability.

Combined with historical research, the analytical results clarified patterns of degradation, revealed details of production methods, and supported hypotheses regarding the *Charta's* handling over time—whether folded or rolled.

Importantly, this study highlights the broader role of multi-modal imaging in the authentication of complex cultural artefacts. In the case of the *Charta of Greece*, the integration of RTI, DEM, and UVL datasets did not merely document surface details but uncovered hidden material evidence crucial for distinguishing original 18th-century sheets from later reproductions. This underscores the potential of non-invasive imaging workflows to function as diagnostic tools in verifying authenticity, particularly in works composed of fragmented or heterogeneous components.

The systematic framework presented here establishes an analytical foundation for future research and conservation efforts in the field of historical cartography—and more broadly, in cultural heritage documentation.

The applied methodology demonstrates how the integration of imaging technologies, material analysis, and historical interpretation can significantly enhance our understanding of archival cartographic heritage. The *Charta of Greece* case study offers a model for documenting and conserving similar artefacts, promoting best practices that honour both tangible and intangible dimensions of cultural heritage. In doing so, it reinforces the critical intersection of science, history, and conservation, ensuring that fragile yet foundational objects can be studied, understood, and safeguarded for generations to come.

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