Appl. Phys. A (2015) 121:891–901
DOI 10.1007/s00339-015-9360-4

Applied Physics A
Materials Science & Processing

INVITED PAPER

Non-invasive identification of traditional red lake pigments in fourteenth to sixteenth centuries paintings through the use of hyperspectral imaging technique

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Received: 1 March 2015 / Accepted: 14 July 2015 / Published online: 21 July 2015

Abstract The present paper, which focuses on the identification of red lake pigments, in particular madder, brazilwood, and cochineal, addresses the advantages and drawbacks of using reflectance hyperspectral imaging in the visible and near-infrared ranges as a non-invasive method of discrimination between different red organic pigments in cultural heritage objects. Based on reconstructions of paints used in the period extending from the fourteenth to the sixteenth century, prepared with as far as possible historical accuracy, the analyses by means of visible/near-infrared reflectance hyperspectral imaging were carried out with the objective of understanding the most significant differences between these vegetal- and animal-based red lake pigments. The paper discusses the results that were obtained on four original Italian and North European paintings and compared with those from the paint reconstructions, in order to demonstrate how the hyperspectral imaging technique can be usefully and effectively applied to the identification and mapping of red lake pigments in painted surfaces of interest in the conservation field.

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1 Introduction

Interest in the scientific examination of cultural heritage objects, their materials and how they were created, for the purposes of art history and documentation, of contextualisation and authentication, and of conservation and restoration, has been increasing over recent decades. In particular, since colour is an art in itself, identifying what materials were used by artists to give colour to their works can greatly expand our comprehension not only of the objects and the artists' techniques, but also of the technological skills and economic, social, and cultural aspects of the past. Not only that, the study of the state of degradation of the colourants can provide information on how the appearance of artworks has changed over time, and can enhance our interpretation of what we see.

In recent years, non-invasive reflectance spectroscopy in the ultraviolet (UV), visible (Vis), and near-infrared (NIR) regions has played an increasingly important role in the scientific study of objects related to the cultural heritage [1–17]. It is a well-established technique for the identification of coloured artists' materials, even though its low fingerprinting ability—when compared with molecular spectroscopic techniques such as Fourier transform infrared and Raman spectroscopies—prevents its reliable use as a self-consistent tool [18]. On the other hand, due to considerable improvements in technology, current interest has been focused on the development of imaging spectroscopy, which by now is becoming accepted as a powerful technique for the scientific examination of cultural heritage objects, that makes it possible to obtain a large amount of spectroscopic information, as well as an accurate digital record of the object [18–22]. In its most advanced approach, by using hyperspectral imaging devices, imaging spectroscopy involves the acquisition of spatially co-registered images in hundreds of spectral bands in order to extract a spectrum at each point in the spectral image set. In the case of reflectance hyperspectral imaging in the UV–Vis–NIR regions, the spectral features collected relate to the electronic transitions and vibrational modes of the materials [23]. However, UV–Vis–NIR reflectance spectroscopy may suffer from poor specificity and the spectra obtained for different colourants may be similar and lack the degree of detail necessary for fingerprinting unknown materials. This is true, for example, with dark and opaque paints that present strong absorption with uncharacteristic spectral features, which limits the success of the spectroscopic technique as an analytical method for identification of coloured materials [24]. Thus, in the majority of cases an unambiguous identification is possible only by comparing their spectral features to the features of spectra in a reference database. Since the materials used in the past are no longer available for comparison, such database should ideally be created with historically accurate references.

References of pigments and paints reconstructed with historically accurate materials and methods should be made based on representative written sources that shed light on the colourants history and of the technology of their production, and should also be based on information obtained through a scientific examination of original artworks. This approach makes it possible, on the one hand, to create reference samples for comparison with what was obtained through analyses, and on the other hand, to support a better interpretation of the analytical results acquired from the artwork and thus to reach a better understanding of it [25]. Indeed, a thorough knowledge of the materials and techniques of the artists used to create their objects can be obtained only through the use of both approaches: i.e. descriptions of the past and data from contemporary scientific analysis [26].

Among the colourants used in the past, red lake pigments are a class of artists' materials that requires particular focus within the technical art history field. They are some of the most light-sensitive materials in artworks, and their fading leads to undesirable changes in the visual appearance of objects, which may be differently interpreted from the artists' original intention [27]. Therefore, their identification and characterisation in artworks, as well as an understanding of their degradation processes, are of outmost importance. This remains a big challenge, and the creation of a generally accessible, comprehensive reference database built with well-characterised historically accurate reconstructions of red lakes and paints, together with the development of an effective non-invasive analytical methodology, is crucial. For this reason, the authors of the present paper are devoting their efforts to the creation of such database and exploring the use of hyperspectral imaging for the study of these materials.

In a recent preliminary contribution, historically accurate paint reconstructions of brazilwood and cochineal lakes were characterised with Vis–NIR hyperspectral imaging [28]. In the present work instead, the first results of an ongoing research project on the possible differentiation between those two colourants and madder lakes are reported. Firstly, reconstructions of the pigments and paints were prepared according to historical documentary sources and the literature, and analysed by means of Vis–NIR hyperspectral imaging in order to characterise the reflectance characteristics of the materials and to assess whether or not the different dyes can be distinguished. Secondly, the results obtained with the reference samples were compared with those from Italian and North European paintings from the fourteenth to sixteenth centuries in which red organic pigments are present. This comparison will help to confirm the usefulness of the references prepared and to explore the potentialities of hyperspectral imaging for identifying the red lake pigments used in artworks, as well as to provide further information about these artists' materials directly from the case study paintings.

2 Red lake pigments in artworks

Natural organic materials of either plant or animal origin have been important traditional sources of red colours since earliest antiquity [29]. Red lake pigments, which are based on dyes that can be extracted from these materials, have long been widely used for painting on canvas, manuscripts, panels, and walls, and were extensively used by medieval artists [30]. Some of the most common and widely used dyes in medieval Europe, with hues ranging from pink to red and purple, were as follows: dyer's madder from the *Rubia tinctorum* plant (the coloured molecules of which are mainly alizarin, purpurin, and pseudopurpurin, in different proportions); brazilwood from the *Caesalpinia sappan* and *C. echinata* trees (essentially, brazilein); dyer's kermes from *Kermes vermilio* insects (mainly kermesic acid, with a small proportion of flavokermesic acid); domestic cochineal from *Dactylopius coccus* insects, and Polish and Armenian cochineal from *Porphyrophora polonica* and *P. hamelii* insects, respectively (mainly carminic acid, also with kermesic acid and flavokermesic acid); and Indian lac from the insects *Kerria lacca* (essentially, laccaic acids)

[31–35]. In general, the availability of these materials varied according to the geographical areas and, in the course of time, new sources were introduced on the market and gradually supplanted the previously used ones [36]. The artists' choice of dyes and the techniques employed for preparing the lakes were closely related to what was available and therefore to the economic, social, and cultural context in which artworks were produced, not to mention the practical knowledge that the artists themselves had of the materials' properties.

Red lake pigments were usually prepared by extracting the dye from its natural source in acid, neutral, or basic aqueous solutions, and by precipitating it in solution with an inorganic salt (commonly, alum, a source for aluminium ions). The coloured molecules would bind to the aluminium ion, forming a metal-dye complex that precipitates as a form of hydrated alumina at a neutral or weakly acidic pH. Other substances could be added to help during the process by changing the pH to optimal precipitation values, or as extenders to create a pigment with more body and opacity. A range of different hues could be obtained for the same dye depending on the preparation of the lakes using different recipes and ingredients [34]. During medieval times, red lake pigments were also prepared by extracting the dye from textile shearings that had been previously coloured, and not from the raw material itself [37]. This was especially the case of pigments made from madder, cochineal, and kermes (as opposed to brazilwood and lac), the production of which is very little documented in the written sources from the period [38].

The identification of red lakes in artworks is a challenging and seldom successful task due to: the complexity of their chemical composition, the frequent presence of different chromophores, degradation products and other pigments, the nature of their application, and the effects of natural ageing. When non-invasive UV–Vis–NIR reflectance spectroscopy is used, in some cases the spectra present one or more absorption bands that are useful for identification. Anthraquinone-based lakes show an absorption band structured into two sub-bands at approximately 510–515 and 540–545 nm for those of vegetal origin (e.g. madder), and approximately at 520–525 and 550–565 nm for those of animal origin (kermes, cochineal and lac) [39]. Brazilwood, on the other hand, shows a single absorption band centred at around 560 nm [32, 37]. However, several factors can influence the spectra, which make the identification of the compounds difficult or impossible [40–42]. For example, different preparations of the same dye may produce very different hues, depending on the complexing ion used or on the pH value at which extraction of the colour occurs. Also, the way in which the pigments are applied as paints can be responsible for the appearance of different absorption features. In particular, dark paints applied as complete hiding can exhibit flat low-reflectance curves (where it is generally possible to see the characteristic absorption bands) helping little in identification [28, 40]. A number of papers have been published in which red organic pigments present in artworks are simply described as red lake, or broadly classified as being of animal or vegetal origin [41, 43–47]. Clearly, then, discrimination of these coloured artists' materials by UV–Vis–NIR reflectance spectroscopy is dependent on the existence of a complete reference database built with historically accurate reconstructions that cover as many variants as possible. The variants should be related to the preparation (production materials and techniques), application, and ageing of these coloured artists' materials, in order to systematically study their effects on the respective reflectance spectral characteristics.

3 Experimental

3.1 Materials

For reconstructions of lake pigments, brazilwood (36150, Kremer Pigmente), madder roots (37199, Kremer Pigmente), and cochineal insects (36040, Kremer Pigmente), aluminium potassium sulphate dodecahydrate ($AlK(SO_4)_2 \cdot 12H_2O$, Riedel-de Haën), sodium carbonate (Na_2CO_3, Riedel-de Haën) and potassium carbonate (K_2CO_3, Riedel-de Haën), basic lead carbonate ($2PbCO_3 \cdot Pb(OH)_2$, Sigma-Aldrich), and calcium carbonate ($CaCO_3$, Roig Farma) were used. Lye and lime solutions with pH values between 11 and 12 were prepared, respectively, with wood ashes and calcium oxide (CaO) from Acrilar. Fresh urine with a pH around 7 and Millipore filtered water were used. A calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$) bowl was also used. Gum arabic (Bizzarri) and fresh eggs were the raw materials used to prepare the paint binders. Glass recipients and tools were used during all reconstructions in an effort to minimise contamination. For the grinding of pigments and the preparation of paints, agate mortars and pestles from Nahita were used.

3.2 Red lake paints reconstructions

Although the objective of this work was to use as far as possible historical madder (M) and cochineal (C) reconstructions, they were prepared by following information obtained from the literature, and not by following instructions from historical medieval recipes since the latter could not be found. In particular, for the reconstruction of madder lakes, the information reported by Jana Sanyova was followed [48]. Brazilwood lakes (B), on the other hand, were successfully prepared according to four different fifteenth century recipes [49]. As regarding the general process of historical accuracy, compromises had to be made during the preparation of the reconstructions because modern materials are unlikely to have the same chemical identity and characteristics as those used in the past. Reconstructions were prepared starting from the dyes' raw sources: brazilwood scrapings, madder roots, and cochineal insects. In the case of brazilwood, the dye was extracted using urine, alum and lead white (B1), urine and alum (B2), or lime (B3) and lye (B4 and B5). In B1, the extracted solution was filtrated over a gypsum bowl. Chalk (B2), alum (B3), and alum and chalk (B4 and B5) were added to the rest of the extracted solutions in order for precipitation to occur. In the case of madder, water was used for extracting the dye and precipitation occurred with the addition of alum and potassium carbonate (M1, M2, M3, M6) in different proportions. In the case of cochineal, the dye was extracted in the presence of potassium carbonate (C4 and C5), or with water (C1). Alum (C1 and C4), and alum and calcium carbonate (C5) were added to the extracted solutions. In M5 and C3, extraction was carried out in the presence of alum, and calcium carbonate was added to the extracted solution. In B6, M4, and C2, extraction was carried out in the presence of alum, and sodium carbonate was added to the extracted solution.

Seventeen pigments (six brazilwood, six madder and five cochineal lakes), ranging from light pink to reddish orange and purple, were used to prepare the paints. Each pigment was painted with two different binders, egg white and a 10 % solution of gum arabic in distilled water. All pigments were also mixed with lead white (basic lead carbonate) in different proportions (1:1 and 1:3), and painted with gum arabic. Paints were prepared by first grinding the pigment(s) with a mortar and pestle, then by grinding it with the addition of water, and finally by adding the binder. Afterwards, they were painted on filter paper sheets (290 mm × 210 mm) using artists' brushes. The goal was to obtain homogeneous paint films containing the same number of layers (2/3). Each individual paint was applied as 20 mm × 30 mm rectangles. A total of 66 paints were analysed (Fig. 1).

3.3 Case studies

The four case studies include Italian, French, and German artworks that belong to the permanent collections of Florentine museums. From the Museo Nazionale del Bargello, the *Dittico Carrand* (Fig. 2a), which is dated late fourteenth century (c. 1400), was selected as representative of the French school. From the Galleria degli Uffizi, two panel paintings were investigated. The first was the *Polittico di Ognissanti* (c. 1360, egg tempera) by Giovanni da Milano (c. 1325–1330—c. 1370), which is now dismembered and scattered. In the present work, only one of the lateral panels, representing San Giacomo Maggiore and San Gregorio, and with dimensions 131.7 cm × 38.7 cm, has been analysed (Fig. 2b). The second panel was the oil painting the *Adoration of the Magi* (1504, 100 cm × 114 cm) by Albrecht Dürer (1471–1528), Fig. 3a. Lastly, from the Museo Nazionale di San Marco, the *Madonna della Stella* (Fig. 3b), painted with tempera and gold on wood panel, by Beato Angelico (1400–1455), and with dimensions 84 cm × 51 cm, is dated to around 1424.

3.4 Instrumentation. Hyperspectral imaging in the 400–900 nm range was performed using an instrument that was designed and assembled at IFAC-CNR [2, 46, 50]. The system is based on a prism-grating-prism line spectrograph ImSpector^{TM} V10E (SpecIm Ltd, Oulu, Finland), with a 30-μm slit. The spectrograph is connected to a high-sensitivity CCD camera (Hamamatsu ORCA-ERG, Hamamatsu, Japan). The line segment analysed is usually focused on the entrance slit of the spectrograph by means of a telecentric lens Opto-Engineering Srl (Mantova, Italy), which is normally used to limit distortion due to effects when the surface is not perfectly planar. The line segment is illuminated by two Schott-Fostec fibre optic line lights equipped with focusing lenses that are fixed to the scan head and symmetrically project their beams at angles of 45° with respect to the normal direction of the imaged surface (0°/2 × 45° observation/illumination geometry). Light is supplied by a 3200-K 150-watt QTH lamp. The mechanical system can scan a maximum area of about 100 cm × 100 cm. The system provides a spatial sampling of ~11 points/mm (~279 ppi) and a resolution of better than 2 lines/mm at 50 % of contrast reduction. The system's spectral sampling is about ~1.2 nm, and resolution is ~2.5 nm at half maximum. The system is calibrated with a certified Spectralon® white standard. The hyperspectral scanner is equipped with customised software, developed at IFAC-CNR, for the management of the cube file acquired and the visualisation and interpretation of data.

The data set obtained (cube file), acquired with IFAC-CNR's imaging system, is constituted by 400 reflectance images within the 400–900 nm range and contains all the information needed to reconstruct high-quality image reproductions and to accomplish a spectral analysis of every point of the imaged surface. It can be properly elaborated to reconstruct the reflectance spectrum over the investigated spectral range for every pixel of the imaged picture. Moreover, by means of mathematic and statistic processing methods, elaborated thematic maps can be obtained, which allow a straightforward visualisation of the distribution of the different materials identified on the investigated area and of the hidden characteristics of the painted surface. In this context, besides the discrimination

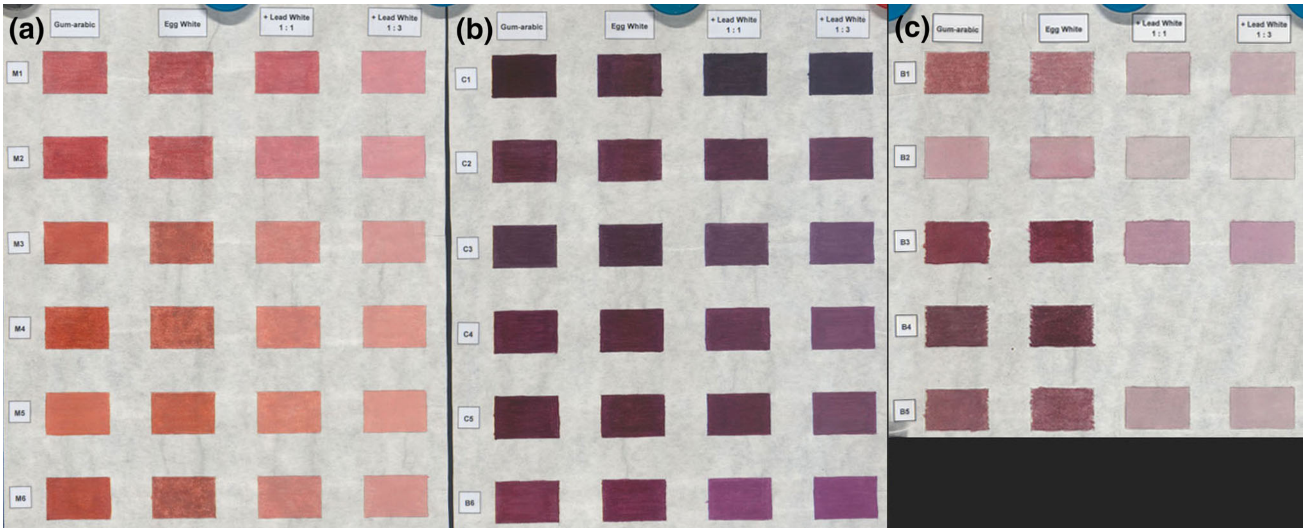

Fig. 1 RGB colour images of the filter paper sheets with madder (**a**), cochineal (**b**), and brazilwood (**c**) paints, reconstructed from the cube files

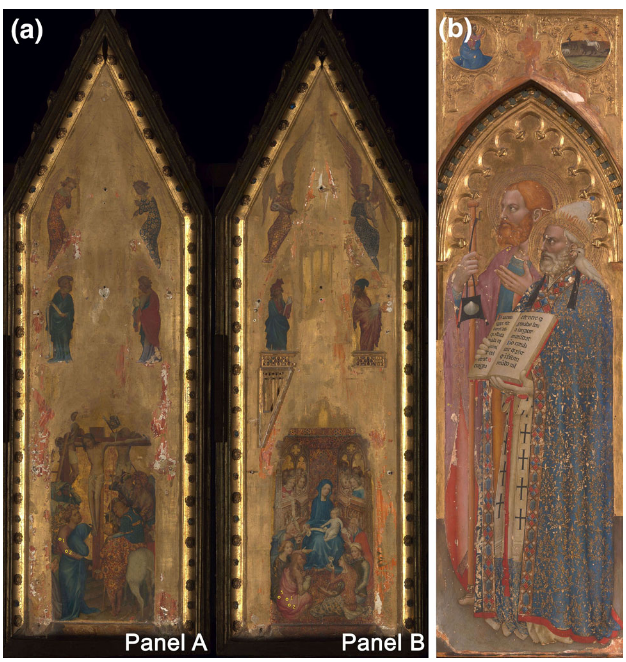

Fig. 2 RGB colour images of the *Dittico Carrand* (**a**) and the panel depicting San Giacomo Maggiore and San Gregorio of the *Polittico di Ognissanti* (**b**), reconstructed from the cube files

of artists' materials, the elaborated images are also an effective tool for visualising inpainting, *pentimenti*, and underdrawings. The comparison of these images with the RGB images makes easier the interpretation of the spectroscopic data and greatly enriches the readability of the artwork. Indeed, the cube file can also be used to extract, as "side-products", the information which is usually provided by more conventional techniques, such as infrared reflectography, infrared false colour images, and high-resolution RGB pictures.

4 Results and discussion

4.1 Analysis of red lake paints reconstructions

The hyperspectral data were acquired by imaging the red lake paints samples. Reflectance spectra with a spectral resolution of 2.5 nm were extracted from averaged 3 mm $\times$ 3 mm areas in the middle of the painted rectangles. The comparison between the spectra acquired on the three colourants and the different recipes showed negligible interferences from the binding media (Fig. 4a). On the other hand, the addition of lead white to the different pigments caused, as expected, a change in the reflectance features of the spectra, although the wavelength positions of the absorption features remained constant (Fig. 4a). In general, when considering the pure paints without the addition of lead white, the reflectance spectra obtained showed absorption characteristics that could be used to discriminate between the three colourants: madder (Fig. 4b), brazilwood (Fig. 4c), and cochineal (Fig. 4d). In the case of brazilwood, the absorption behaviour in the visible region is related to the extended mesomeric π-system formed as a consequence of the conjugation in the brazilein molecule between the quinonoid chromophore and the aromatic one [51, 52]. Spectra of the pinkish brazilwood paints were characterised by a strong absorbance band with a maximum at 557 $\pm$ 3 nm. For the darker brazilwood hues, the absorbance band is broader and centred at higher wavelengths (around 570 nm). On the

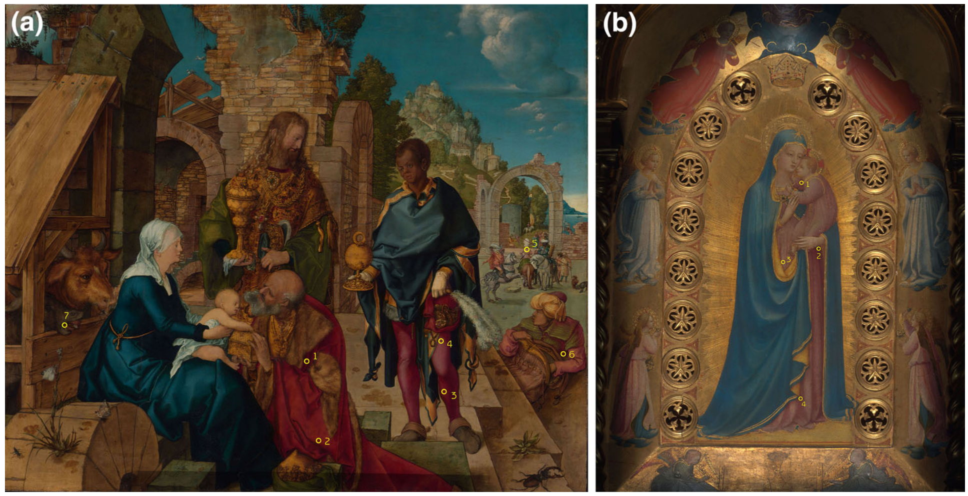

Fig. 3 RGB colour images of the *Adoration of the Magi* (**a**) and the *Madonna della Stella* (**b**), reconstructed from the cube files

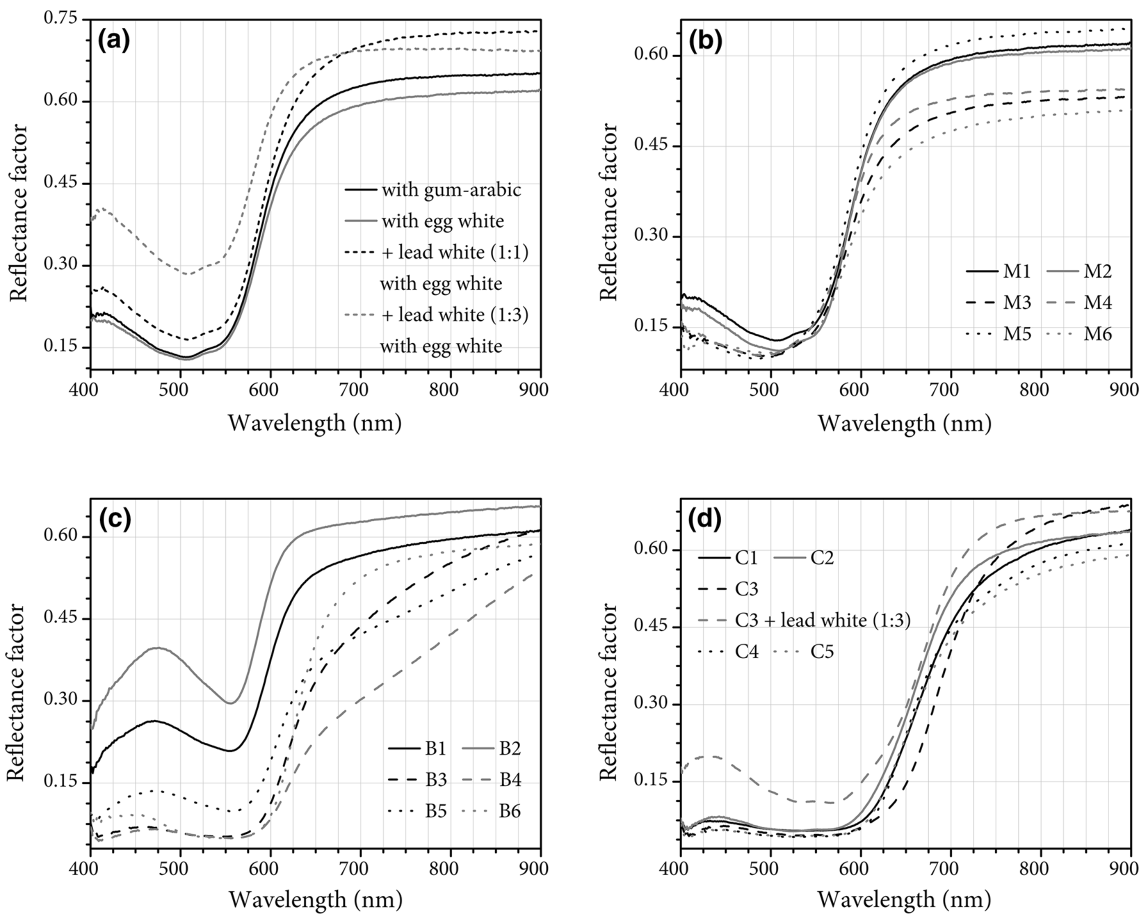

Fig. 4 Reflectance spectra of the red lake paints reconstructions, extracted from the cube files: **a**, **b** madder (M); **c** brazilwood (B); **d** cochineal (C)

other hand, madder and cochineal present more similar spectra since their chromophores are anthraquinone molecules, in which absorption behaviour in the visible region is related to the lowest energy π,π^* electronic transition, attributed to the conjugated double bounds and characterised by a significant charge-transfer contribution, and the n,π^* electronic transitions of the carbonyl groups [40, 53, 54]. In the case of madder, M1 and M2 had spectra with the characteristic absorption band structured into two sub-bands at 507 ± 2 and 545 ± 3 nm. The more orange hues produced by this same dye (M3–M6) had spectra with an unstructured band that was shifted to lower wavelengths, and a shoulder at 538 ± 2 nm. M4 and M5, in which the extraction of colour was carried out with alum (at acidic pH), present the absorption band centred at 488 ± 4 nm. For M3 and M6, in which the extraction was carried out with water, the absorption band is centred at 500 ± 3 nm. Lastly, in the case of cochineal, the spectra showed a strong absorption without the characteristic sub-bands and centred at higher wavelengths (around 600–610 nm). On the other hand, the spectra of cochineal paints C2–C5 with lead white, which were not so saturated, made it possible to identify the absorption band structured into two sub-bands at 530 ± 5 and 567 ± 3 nm.

4.2 Comparison with case studies

The hyperspectral data acquired on the four paintings were used to extract accurate high-resolution RGB images. In addition, from these data spectra with a spectral resolution of approximately 2.5 nm were extracted from small areas (3 mm × 3 mm) of pink and reddish colours (Figs. 5, 6). The *Polittico di Ognissanti*, the *Dittico Carrand* (panel A and B), and the *Madonna della Stella* paintings had spectra with similar absorption features that resembled those of anthraquinone-based lakes of animal origin: an absorption band structured into two sub-bands at 535 ± 5 and 572 ± 4 nm. In the darker area analysed (point 2 in Fig. 5b), the spectrum presented a strong absorption without the characteristic sub-bands and centred at higher wavelengths (around 590–600 nm). Although the reflectance features were variable, the spectra obtained from these three artworks very closely matched those of cochineal paint reconstruction C5 in terms of absorption characteristics (Fig. 7a). Visually, however, colours from the *Dittico Carrand* and the *Madonna della Stella* appeared to be lighter and more pink than those obtained with the cochineal reconstruction.

The painting *Adoration of the Magi* presented two types of reflectance spectra: one similar to the anthraquinone-based lakes of animal origin (with sub-bands at 530 ± 2 and 570 ± 3 nm), and the other with one broad absorption

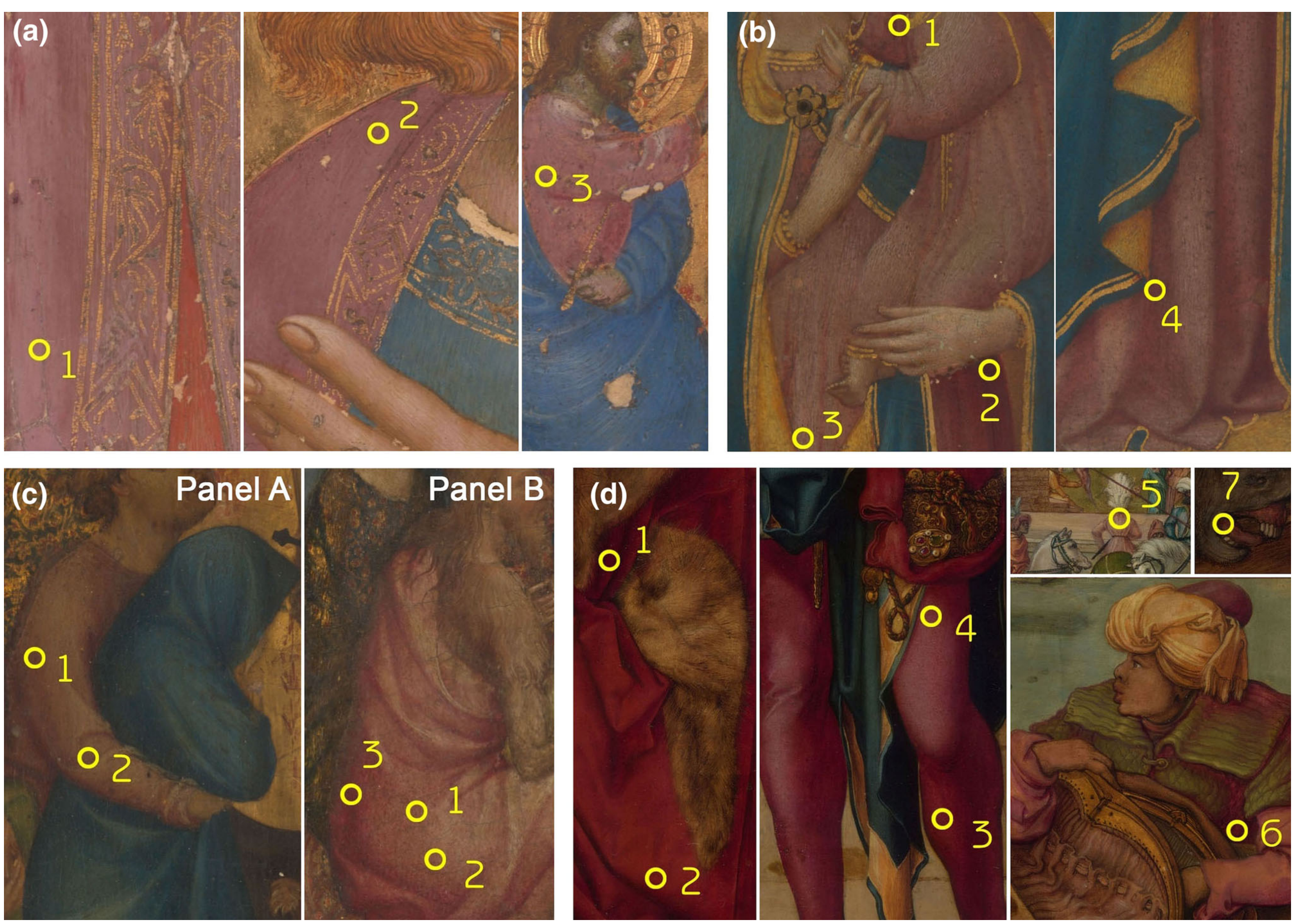

Fig. 5 RGB colour images of the *Polittico di Ognissanti* (**a**), *Madonna della Stella* (**b**), *Dittico Carrand* (**c**), and *Adoration of the Magi* (**d**), reconstructed from the cube files: details of the *pink* and *red colours* from the which the reflectance spectra were extracted

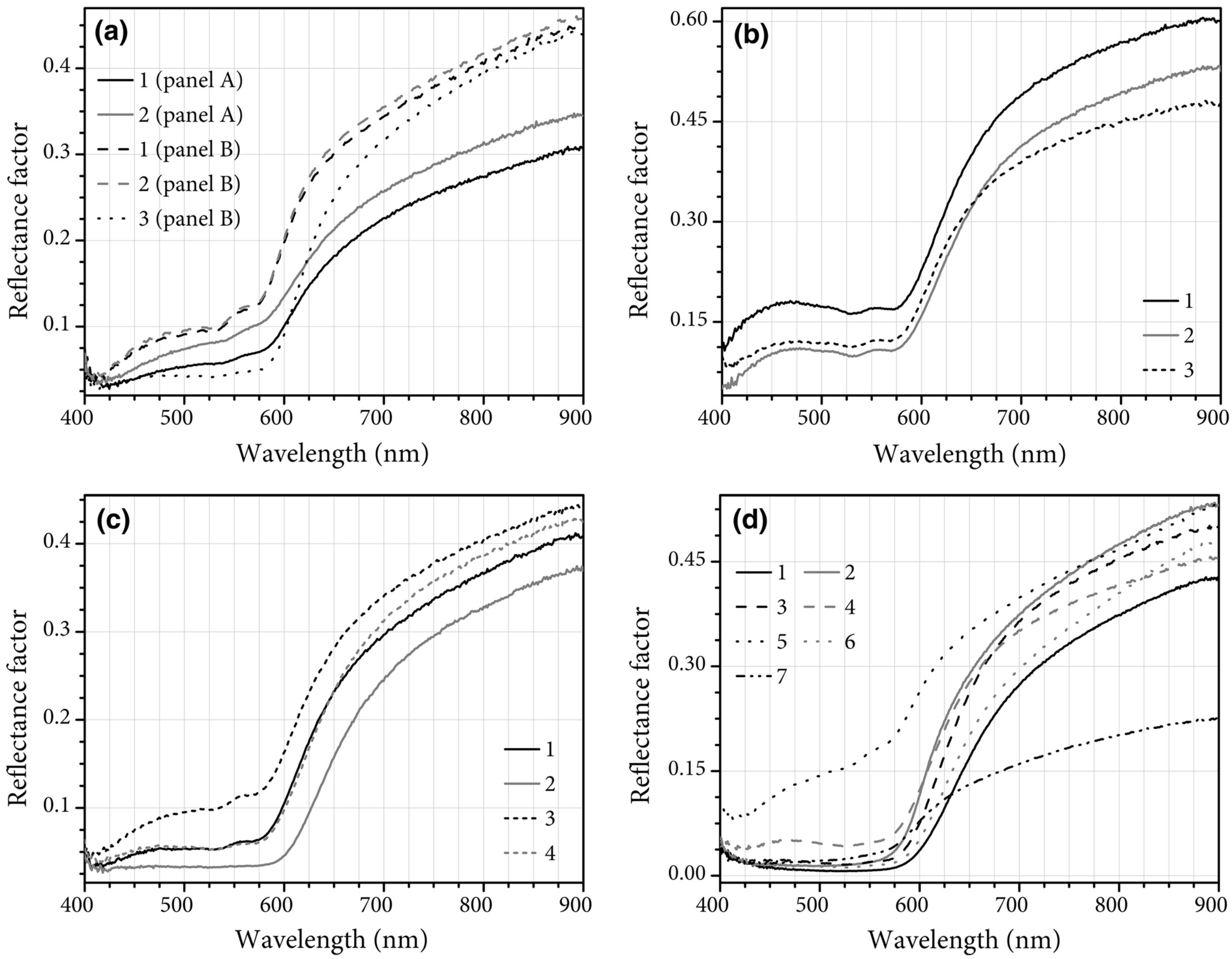

Fig. 6 Reflectance spectra of the case studies pink and red colours, extracted from the cube files: **a** *Dittico Carrand*; **b** *Polittico di Ognissanti*; **c** *Madonna della Stella*; **d** *Adoration of the Magi* (numbers in spectra correspond to numbers in Fig. 5)

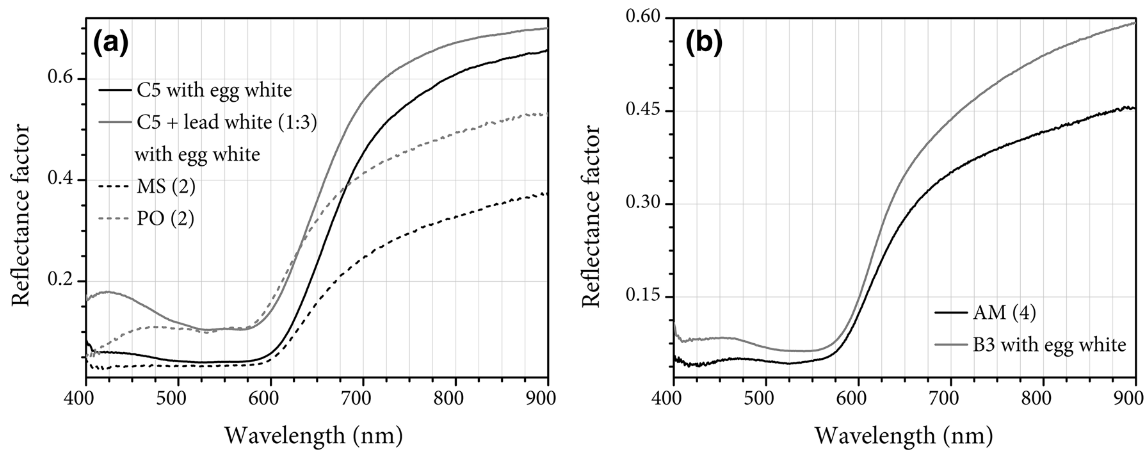

Fig. 7 Comparison between reflectance spectra of red lake paints reconstructions and pink and red colours from the case studies: **a** cochineal (C), *Madonna della Stella* (MS) and *Polittico di Ognissanti* (PO); **b** brazilwood (B) and *Adoration of the Magi* (AM)

band centred around 570–580 nm, which shape resembled the spectra of the more saturated anthraquinone colours or of the darker brazilwood hues (Fig. 7b). This result might suggest that Dürer used two different lake pigments, an anthraquinone-based one of animal origin and possibly brazilwood, or that he used the same colourant applied in different ways. To map on the painting the regions painted with the red lake that has the same spectral features of the area represented by spectrum 5 (Fig. 6d), the hyperspectral data were processed in order to extract all the pixels that showed the presence of the characteristic sub-bands at approximately 530 and 570 nm. To detect the simultaneous presence of those two absorption sub-bands, it was decided to create two separate maps using a parabolic curve in the first place. The estimates of the curvatures were given by the second-order coefficient of the polynomial used, which had to fit the spectral curve of each pixel in the 519–544 and 558–580 nm ranges, respectively. Subsequently, another map was built considering for each pixel the value of the second-degree coefficient of the parabolic equation in the previously described maps, and setting the threshold values of this coefficient above zero. Lastly, the final map was obtained by multiplying the values formerly obtained and, as a final result, the pixels having values above the 0.01 threshold were reported in red (Fig. 8b). This final map made it possible to discriminate between the areas marked as 3, 4, and 5, which are highlighted in red and present the same spectral features of spectrum 5, and the areas 1, 2, and 6 that have different spectra.

Instead of the heuristic procedure reported above, more complex algorithms could have been used, for example the multi-range version of SFF (spectral feature fitting), which can be found as a tool in software packages for the analysis of hyperspectral geospatial data [55]. SFF is a least squares fitting algorithm that measures the similarity within definite wavelength intervals between each spectrum, usually after removal of its continuum component, and a reference spectrum, either chosen from a library or obtained from the cube data. Nonetheless, when the wavelength ranges are narrow and the shapes of the absorption bands are close to Gaussian functions, SFF results are close to those of the above curvature approach used.

The case studies presented have shown that through the use of different mathematical tools, it could be possible to map the distribution of areas painted with red lakes with different spectral features (as well as of areas painted with other colourants). However, no accurate identification could be made for the four paintings without first comparing the results from the artworks with reflectance spectra obtained from historically accurate paint reconstructions of the other anthraquinone-based lakes of animal origin (kermes and lac), the spectral features of which should be similar to those of cochineal. Also, pigment reconstructions should be painted with an oil binding media in order to assess whether such binders have an influence on the reflectance spectra of the lakes.

5 Conclusion

The authors are exploring the study of red lake pigments through the creation of a database of well-characterised reference materials, and the use of hyperspectral imaging with the aim of developing an effective analytical methodology that will allow the non-invasive identification and mapping of these colourants in artworks. In this paper,

Fig. 8 RGB colour image of the *Adoration of the Magi* (**a**) and map of the painting considering a parabolic fit in the 519–544 and 558–580 nm ranges (**b**), reconstructed from the cube files

brazilwood, cochineal, and madder paint reconstructions were prepared with historical accuracy, as far as it was possible, and analysed by means of Vis–NIR hyperspectral imaging. In general, the reflectance spectra obtained showed absorption characteristics that could be used to discriminate between the three colourants. However, the preparation and application of these coloured materials had effects on the respective reflectance spectral characteristics, which causes ambiguous identifications. The spectra of reference materials were compared with those from four Italian and North European paintings from the fourteenth to sixteenth centuries in which red organic pigments are present. Although this comparison made possible to provide some level of discrimination, since analytical results point to the use of anthraquinone-based lakes of animal origin, a more complete reference data set has to be created. In this specific case, for example, a comparison with the reflectance spectra of historically accurate reconstructions of kermes and lac has to be made before any conclusions can be drawn. This work will be carried out during the ongoing project, which will also keep exploring the potentialities of hyperspectral imaging for identifying the red lake pigments used in artworks.

Acknowledgments The authors would like to thank Cristina Acidini (former head of the Soprintendenza Speciale per il Patrimonio Storico, Artistico ed Etnoantropologico e per il Polo Museale della città di Firenze), as well as the directors and the curators of the Galleria degli Uffizi, Museo del Bargello and Museo di San Marco in Florence, who kindly gave permission for the analysis of the paintings and for their useful discussions. The authors are also grateful to the conservators who were involved in the maintenance and restoration of the investigated paintings for their invaluable support in understanding the composition of the materials constituting the artworks, and for exchange of information. In addition, part of this work was supported by the European Cooperation in Science and Technology, COST Action TD1201 Colour and Space in Cultural Heritage (COSCH, www.cosch.info). Tatiana Vitorino is sincerely grateful to the COST Action TD1201 Management Committee for approving the short-term mission COSTSTSM-ECOST-STSM-TD1201-141013-036659, and to the Portuguese Science Foundation, FCT-MEC, for funding the PhD Grant PD/BD/105902/2014.

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