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The Conservation of Plaster Casts in the Nineteenth Century

Abstract

Plaster casts of ancient sculpture were widely collected by universities and museums through the nineteenth century. One of the intended functions of these casts was to preserve accurate 3D records of the sculptures, many of which were in remote locations around the world, often vulnerable to damage from weathering and vandalism. Gypsum plaster makes excellent casts, capturing fine surface details; however, it is also soft, porous, and easily damaged. This paper draws upon historical archives and patents to reveal the considerable efforts made during this period to create new techniques, recipes, and equipment to try to protect the casts. Case studies are selected primarily from the collection of casts put together by Walter Copland Perry in the 1880s, originally for the South Kensington Museum but transferred in 1907 to the British Museum. Samples were taken from a number of these casts and examined using scanning electron microscopy with energy dispersive spectroscopy. These results, combined with archival evidence, demonstrate that protective coatings were carefully applied in thin coatings to many of the casts. Barium appears to have played an important part in these protective treatments and further testing is recommended to evaluate the precise nature of its role. These treatments successfully protected the delicate surfaces of the casts for many years. However, later neglect means that these casts now suffer from a range of other threats to their condition.

Key words

Plaster casts; conservation; surface coatings; nineteenth century; British Museum; South Kensington Museum; Walter Copland Perry

Introduction

Through the nineteenth century, many museums, galleries, and universities acquired large collections of plaster casts of ancient sculpture for display and study. The collections typically focused on specimens of Greek and Roman sculpture but casts from other societies and periods were also obtained, including casts of sculpture from ancient Egypt, Assyria, and Mesoamerica, as well as from Medieval and Renaissance Europe. The casts themselves were sourced from a mixture of in-house museum workshops (for instance at the Louvre, the British Museum, the National Museum of Naples, and the Gipsformerei of the Staatliche Museen, Berlin) and commercial establishments including Martinelli of Athens, Malpieri of

Rome, Geiler of Munich, Sturm of Vienna, and Hennecke of Wisconsin, supplying both institutions and private collectors.

Casts became popular archaeological tools. The first casts taken from a given piece of sculpture were often intended to provide a means by which the form of that ancient work might be recorded and transmitted. The British Museum, for instance, acquired casts supplied by Charles Fellows of the rock-cut tombs of the Lycians (Smith 1900, 57); these were remote and while some of the original sculptures were transported back to London, others were impossible to move. Creating casts taken in situ meant that they could be more accessibly viewed and studied. The collections of casts thus established meant that scholars and the interested public gained the chance to observe a curated group of important sculptures while the original works were scattered far and wide around the world. Casts were also considered a method of preservation. For instance, casts of the Parthenon sculptures taken in the nineteenth century were intended to form a record of the ancient works for posterity at a time when many of the originals remained outside where they were subject to weathering – worsened by pollution from the industrial revolution – and vandalism (Newton 1865, 18-19; St Clair 1967, 265).

The surface details captured by the casts were, therefore, of the utmost importance for scholars and museum curators. This paper explores the techniques invented and adopted by nineteenth century craftspeople and scientists to try to ensure that these objects were effectively conserved. I look first at the creation of the casts and their physical and chemical vulnerabilities and then reveal new evidence, drawn from the archives and through scientific analysis of the casts, demonstrating the efforts put into protecting them.

Making the Casts

Most of the nineteenth century casting workshops used similar production methods. The vast majority of full-sized casts were made from solid gypsum plaster (calcium sulphate) using the piece moulding technique. Books providing some instruction for this technique date back at least to the painter Cennino Cennini's fourteenth century *Il Libro dell'Arte*. He gave detailed descriptions of how to produce plaster casts and included an outline of plaster piece-moulding. While first experimented with by artists, casting in the eighteenth and nineteenth centuries had become a distinct specialism. Francesco Carradori's 1802 handbook gives more detailed instructions together with illustrations in the period just preceding the emergence of large-scale casting firms in the later nineteenth century.

Figure 1. Moulding a statue according to Carradori's *Istruzione elementare per gli studiosi della scultura* (1802, Plate VI).

Later instructions include those by Frank Forrest Frederick (1899), Victor Wager (1944), and William T. Brigham (1874, 26-30), which all describe the process in much the same way. Both the moulds and casts were constructed from gypsum plaster (calcium sulphate), which sets to form a rigid material. The brittle, inflexible nature of plaster necessitates the creation of a piece mould constructed from multiple interlocking sections (*tasselli*) to avoid the problem of undercuts. The *tasselli* are reconstructed within an outer shell (mother mould); plaster is poured into the assembled mould to create the finished cast. The steps can be reconstructed from these texts as follows:

1. Cover the original sculpture with oil or soap.
2. Decide how to divide the original into the sections that will form the *tasselli*. Ensure that undercuts will be avoided.
3. Apply plaster to the first section, working from the bottom of the sculpture up. Once partially set, trim the edges to be smooth and slightly inclined. Make joggles or small shallow holes/keys on the outer edges. Coat the edges with oil and then shellac.
4. Create all the required *tasselli* in the same way and number them to assist with reassembly. Once finished, the sculpture should be covered with these small, separable pieces of mould.
5. Oil the outer surfaces of the *tasselli* (and also coat with shellac, if desired).
6. Apply an outer shell of thick plaster on top of the *tasselli*. This forms the mother mould (designed to hold the *tasselli* in place) and is typically made in two parts: a front and a back. Once set, remove the mother mould and coat it with oil and shellac.
7. Remove the *tasselli* from the surface of the sculpture and reconstruct them within the two sections of the mother mould. Ensure the *tasselli* sit securely within the mould and fit tightly together: the joggles/keys will help to achieve this.
8. Oil the newly exposed inner surfaces of the *tasselli* (against which the plaster will be cast).
9. Tie the pieces of the mother mould together.

10. Pour in a fine, creamy mixture of plaster into the open base and run this around the mould to coat all surfaces. Then fill the mould completely with a coarser grade of plaster mixture.
11. Once the plaster has set but is still damp, take the mould apart to reveal the cast.

Separate moulds may be constructed for different parts of the statue: head, limbs, torso. Limbs may be cast around iron rods in order to strengthen them. The different portions of the cast can be attached using steel dowels and the application of fresh plaster. The joins may be completely sealed using plaster and paint, or left so that the different pieces remain detachable (useful for transport and storage).

When removed from the piece mould, the surface of the cast will display a mesh of seam lines. Frederick (1899, 83) notes that these '*become large and unsightly'* after repeated handling and use of the piece mould. Therefore, as indicated by Mitchell in *The New York Times* (1885), fine seam lines were generally left in place as a testament to the high-quality of the mould, rather than being gently chiseled and sand-papered away. As Brigham wrote:

> If the casting has been successful the cast will be marked with a network of fine lines made by the joints of the pieces of the mould. The fineness of these lines and the sharpness of their intersections indicate the condition of the mould and the consequent value of the cast. In old or carelessly used moulds the edges and corners get rubbed or broken, and then the fine raised line becomes a thick ridge. Hence it is better to purchase casts with these marks on them.
>
> Brigham (1874, 27)

The catalogues of the *formatori di gesso* typically indicate that casts will indeed be sent with seam lines unless specifically requested otherwise (e.g. Hennecke 1889, I; Castelvecchi 1906, 2). Brigham also testifies to various difficulties in the process. He notes that when the fresh cast is removed from the mould:

> … small portions with slender attachments are very apt to drop off, and must be replaced. The casts may also crack if dried too quickly, or be stained if the mould has been carelessly oiled… Another defect is where the pieces of the mould are not bound firmly together, and one or more yield to the pressure, and the corresponding portion of the cast is raised or sunk below the common surface… [Removal of seam lines] is too often left to unskilled or careless hands, and the cuts and gashes made are sand-papered over until the whole surface of the part is destroyed. This is the condition of the images for sale in the street, and not infrequently of those in cast-factories… Plaster is of various qualities, and only the superfine should be used for small casts or

> for lining the moulds for large ones. Frequently, the cheap French casts are made with so thin a skin of French plaster that it chips off from the inferior material beneath when subjected to the jars of transportation.
>
> Brigham (1874, 27-29)

Both Wager and Frederick also describe 'jelly' or 'flexible' moulds. These were most often made from gelatine. They were much more elastic than plaster. This reduced the issue of undercutting and meant that a mould could be constructed from only a few pieces. However, gelatine moulds shrink over time and cannot be reused indefinitely like plaster moulds. It was not until the introduction of silicone rubber that these flexible moulds became more popular: the longevity of silicone rubber is far superior to that of gelatine. Wager (1944, 67) mentions 'rubber jelly' moulds as a recent development and notes that this material is '*more expensive than gelatine, but lasts indefinitely*'.

A further notable exception to the piece moulding trend was the work of Leonard Alexander Desachy, a French modeller who patented fibrous plaster casting in 1856. The Desachy method produced hollow casts by applying plaster strengthened with layers of jute inside the mould (Millar 1905, 349; Salavessa et al. 2013, 859).[1] This formed a lighter, tougher cast than those constructed from solid plaster:

> … the plaster or cement in a sufficiently fluid state is applied to the interior surface of the mould, so as to produce a thin coating therein, and whilst the plaster or cement is still plastic or moist a coating of one or more pieces of canvas or suitable woven fabric is applied to the interior surface of the plaster or cement so as to adhere thereto, size, glue, or oil being used to aid the adhesion of the canvas or woven fabric to the plaster or cement when required. In cases where greater strength is required, two or more layers of canvas or woven fabric are cemented together, one on the other, in the mould, by the aid of size, glue, or suitable cementing material. To facilitate the fixing of such moulded surfaces to other surfaces, wires are, when required, laid into and retained beneath the two or more layers of canvas or woven fabric… By these means the cement or plaster employed is only for producing the exterior surfaces, whilst the requisite strength and stiffness are obtained by the canvas or woven fabric. The articles thus produced will be very light, and comparatively of small cost.
>
> Desachy (1856, 1-2. Patent No. 2494)

Both the British Museum and the V&A hold some casts made using the Desachy method. However, the majority of casts were made from piece moulds.

[1] Letters patent to Leonard Alexander Desachy of Great Marlborough Street for the Invention of 'Improvements in producing architectural mouldings, ornaments, and other works of art formed with surfaces of plaster or cement' (A. D. 1856. No. 2494).

The Material Qualities of Plaster

Plaster is a heterogenous substance that can differ quite fundamentally in chemical composition. The main chemical types are lime plaster and gypsum plaster. Lime plaster is produced by heating calcium carbonate (limestone) to produce calcium oxide (quicklime). Water is added to form calcium hydroxide (slaked lime), which forms the plaster mix. Lime plaster sets chemically by reacting with carbon dioxide (CO_2) present in the air (Carran et al. 2012, 118):

Calcination	calcium carbonate + heat → calcium oxide + carbon dioxide $CaCO_3$ CaO CO_2
Hydration	calcium oxide + water → calcium hydroxide CaO H_2O $Ca(OH)_2$ (aq)
Carbonation	calcium hydroxide + carbon dioxide → calcium carbonate + water (evaporates) $Ca(OH)_2$ (aq) CO_2 $CaCO_3$ H_2O

This forms a smooth, white plaster. Lime plaster, particularly when used as stucco[2], can be used for free working and will withstand tooling after it has set (Penny 1993, 194). However, pure lime plasters shrink significantly when drying and require extremely high temperatures of around 900°C during the initial calcination stage. Both types of plaster have been known for millennia (Penny 1993, 194; Carran et al. 2012, 118); certainly, their use dates back at least to the Neolithic period (Gourdin and Kingery 1975). However, gypsum plaster has slightly different properties; these make it more suitable for casting and it was this material used for the nineteenth century casts.[3] Gypsum plaster is commonly known as 'Plaster of Paris' because of the large gypsum deposit at Montmartre. Gypsum (calcium sulphate dihydrate) is heated to become dehydrated gypsum (Plaster of Paris). Water is mixed into the Plaster of Paris, providing a short working time for procedures like casting, before it hardens and reforms into gypsum:

Calcination	calcium sulphate dihydrate + heat → calcium sulphate hemihydrate + water

[2] A type of lime plaster traditionally produced by burning marble/Roman travertine rather than limestone at the initial calcination stage, and then mixing the slaked lime with pulverized marble.

[3] It is often impossible to distinguish between the types visually. However, if hydrochloric acid is added to a small sample then the acid should bubble/fizz as it reacts with lime plaster, but will not react with gypsum plaster. This test can, however, be complicated by the presence of contaminants (Gourdin and Kingery 1975, 134).

	(given off as steam) $CaSO_4.2H_2O$ $CaSO_4.0.5H_2O$ $1.5H_2O$
Hydration	calcium sulphate hemihydrate + water → calcium sulphate dihydrate $CaSO_4.0.5H_2O + 1.5H_2O \rightarrow CaSO_4.2H_2O$

Gypsum plaster is a soft material, measuring only 1.5-2.5 on Mohs' hardness scale of 1-10. It is easily scratched and highly porous; this makes it vulnerable to mechanical damage, discolouration by dirt penetration, and softening and disintegration caused by the presence of moisture. Plaster is partially soluble in water; thus, any water allowed to seep into plaster pores can cause softening and the solubilization of salts (Gourdin and Kingery 1975, 135). If salts crystallize (following evaporation of water) or water freezes within the pores, then these can break open and eventually result in spalling and surface loss. Strength and porosity are related to the crystalline structure of the plaster and vary according to the temperature at which the plaster is first calcined and the proportion of water added during manufacture (Gourdin and Kingery 1975, 135). The higher the temperature of calcination and the less water is added, the denser and less porous the crystal structure, meaning that the plaster is stronger and somewhat less absorbent. This soft, porous nature of plaster means that treatments to seal the surface are very important.

Like lime, gypsum also forms a smooth, white plaster. It is generally even softer, more brittle, and more absorbent than lime plaster (Gourdin and Kingery 1975, 135-137). However, it also sets more quickly, which makes it particularly suitable for moulding and casting. Gypsum plaster flows fast and is capable of recording very fine details. Gypsum plaster is also easier to produce than lime, requiring heating to only 100°C for the initial calcination (Penny 1993, 194; Carran et al. 2012, 118). Gypsum can contain a wide variety of natural impurities, including small amounts of calcium carbonate, clay (hydrous aluminium silicate), and iron oxide. These change the precise nature of plasters from different regions and batches, and other materials can be added to alter the working properties, setting time, mechanical characteristics, and appearance of the plaster. These include: (accelerators) alum, potassium, zinc sulphate, nitrate and chloride salts and acids, sugar, calcium, barium carbonate; (for mechanical properties) straw, hemp, sawdust, hair; (retarders) borax, glue, lime, stale beer, and ammonia (Megens et al. 2011, 2). Bulking agents like sand or pulverized marble might be mixed with the plaster to improve its strength and change its colour and texture.

The various cast-making treatises of the nineteenth and early twentieth centuries (including Frederick 1899, Millar 1905, and Wager 1944) include recipes for a multitude of coatings devised to alter surface appearance, for example, to achieve a high gloss or antique effect, involving the application of materials like beeswax, paraffin wax, glycerine, milk, and linseed oil, often followed by polishing with French chalk (Table 1). These frequently recommend 'sealing' plaster with materials like shellac, size, and dextrine to reduce its porosity. This would make the cast more durable and easier to clean. And increasingly during the nineteenth century, following the increased concern for the accuracy of casts, we see concerted efforts to protect the vulnerable surface of plaster and to ensure that its fine details are preserved.

Table 1. A Selection of Recipes for Surface Coatings

This was not a new phenomenon. The popular appetite for classical statuary in Britain had first been satiated via early eighteenth century mass-production of lead casts by John Nost (d. 1729) and Andrew Carpenter (1672-1737) at Hyde Park. In about 1738, John Cheere (1709-1787) took over this business and developed his own recipes for bronzing, gilding, and painting plaster casts such that they might resemble marble for commercial marketing (Clifford 1992, 40). Cheere quickly acquired competitors like Peter Vanina, who was also based in London and, among other subjects, produced moulds and casts in plaster of ancient sculptures, sometimes using bronzing finishing techniques (Roscoe et al. 2009, 1310). Other competitors included partners James Hoskins and Benjamin Grant (former employees of Cheere), and John Flaxman (1755-1826), who produced casts of relief work. These men started to acquire an international market, with William Cheere (son of John) supplying copies of ancient sculptures '*finisht neat & bronzd w'copper*' to George Washington for his estate at Mount Vernon in 1760 (Clifford 1992, 41). And so, the business of making classical casts exploded in Britain in the late eighteenth century. Craftspeople increasingly devised distinctive manufacturing methods, such as the recipes pioneered by John Cheere, in order to carve out niche areas of the market for themselves.

Nineteenth century commercial casting firms supplying both private collectors as well as museums and universities typically offered a similar range of surface finishes replicating materials including marble, bronze, and terracotta. For example, casts ordered from Hennecke's *Florentine Statuary* catalogue (1886, 8) were available in the following finishes:

No. 1. FLORENTINE	A rich, soft stone color. No. 1. is our standard color, and we have always a large stock ready in this finish for immediate shipment.
No. 2. METAL BRONZE	Dark antique.
No. 3. METAL BRONZE	Burnished gold.
No. 4. TERRA COTTA	
No. 5. WHITE	

But while these commercial workshops were keen to advertise their high quality and the range of finishes available, there is also a good deal of evidence for government support, particularly in Europe, for scientific research into the investigation of protective treatments for casts which did not alter their appearance. These were geared towards the study collections used by archaeologists rather than those acquired primarily for aesthetic display.

In the mid nineteenth century, the Prussian government awarded a prize to Dr. Reissig for his development of a method for treating casts such that they would become water-resistant. This involved converting the surface of the calcium sulphate cast into either barium sulphate or calcium silicate, both of which are insoluble compounds. It was stated that this '*was not only desirable to obtain a surface which should not wash away, but also to include a simple process for preventing dust entering the pores, and rendering them more easily cleansed*' (Brannt & Wahl 1919, 308-309). The process of converting the surfaces of the gypsum plaster casts into barium sulphate using baryta water (an aqueous solution of barium hydroxide) is described as follows:

> A large zinc vessel is required with a tight-fitting cover. In the vessel is a grating made of strips of zinc resting on feet 1 to 2 inches high. This vessel is two-thirds filled with soft water of 50° to 75° F., and to every 25 gallons of water are added 9 pounds of fused or 14½ pounds of crystallized pure hydrated oxide of barium, and 9½ ounces of lime previously slaked in water. As soon as the baryta water gets clear it is ready to receive the casts. They are wrapped in suitable places with cords, and, after removing the scum from the baryta bath, are dipped in as rapidly as possible, face first, and then allowed to rest upon the grating.

Hollow casts are first saturated by rapid motions in the bath, then filled with the solution and suspended in the bath with the open part upwards. After the cords are all secured above the surface of the liquid the zinc vessel is covered. The casts are left in the bath for 1 to 10 or more days according to the thickness of the water-proof stratum required. After taking off the cover and removing the scum the casts are drawn up by the strings, rinsed off with lime water, allowed to drain off, carefully wiped with cotton or linen rags, and left to dry, without being touched by the hands, in a warm place, free from dust. The same solution which has been used once can be used again by adding a little more baryta and lime.

Brannt & Wahl 1919, 309

The chemical reaction employed here can be described as follows:

calcium sulphate	+	barium hydroxide	→	barium sulphate	+	calcium hydroxide
$CaSO_4$ (s)		$Ba(OH)_2$ (aq)		$BaSO_4$ (s)		$Ca(OH)_2$ (aq)

This process using barium hydroxide is recommended as the '*easiest, simplest, and cheapest method*' (Brannt & Wahl 1919, 309). However, an alternative treatment applied to convert the surface of the calcium sulphate cast into calcium silicate is also described:

This process depends upon the conversion of the calcium sulphate into calcium silicate – an extremely hard, durable, insoluble compound – and is accomplished by the use of a dilute solution of silicate of potassium containing free potash. To prepare this solution make a 10 per cent solution of caustic potash in water, heat to boiling in a suitable vessel, and then add pure silicic acid, free from iron, as long as it continues to dissolve. On standing the sold solution usually throws down some highly silicate potash and alumina. It is left in well-stoppered glass vessels to settle. Just before using it, it is well to throw in a few small pieces of potash or to add 1 or 2 per cent of the potash solution. If the plaster articles are very bulky this solution can be diluted to one-half with pure water. The casts are silicated by dipping them in a cold state for a few minutes into the solution, or applying the solution by means of a well-cleaned sponge, or throwing it upon them as a fine spray. When the chemical reaction, which takes place almost instantly, is finished, the excess of the solution is best removed with some warm soap-water or a warm solution of stearine soap, and this finally removed with still warmer pure water.

Brannt & Wahl 1919, 309-310

This is not a precise recipe and slightly different compounds of calcium silicate may be formed depending on the conditions. However, a possible equation for this reaction may be:

calcium sulphate	+	potassium silicate	+	potash	→	calcium silicate	+	potassium sulphate	+	water

$CaSO_4$ (s) K_2SiO_3 (aq) $2KOH$ (aq) Ca_2SiO_4 (s) $2K_2SO_4$ (aq) H_2O (aq)

Following either recipe, once dry, a soap solution is applied to the casts for further water-resistance and durability:

> A pure, good, hard soap is cut into shavings, which are dried and then dissolved in 50 or 60 per cent of alcohol, 10 or 12 parts of alcohol to 1 of soap. A solution of Marseilles soap known as "*spiritus saponatus*" can be bought at any drug store. The finest appearance as well as a high degree of durability is obtained by using a solution of stearate of soda in strong alcohol. Both the solution and the cast should be warm, so that it may penetrate as perfectly and deeply as possible. It does no harm to repeat the operation several times as long as the liquid is absorbed by the cast. When dry the cast is finished.
>
> Brannt & Wahl 1919, 309

In the 1870s, the development of new casting materials and protective measures was further encouraged through the formation of the German Commission for Consultation on the Treatment and Conservation of Plaster Casts, created on the instigation of the Royal Ministry for Education in Berlin (Badde 2009, 12). Presumably in response to this, Dr. Von Dechend (1884) developed Reissig's work, designing a machine to treat and clean plaster casts. This comprised an adjustable atomizer nozzle attached to a flexible tube for the application of a fine spray of hardening and cleaning preparations onto plaster casts of different sizes and shapes, eliminating the need to submerge casts in chemical baths (**Fig. 2**). The machine could also produce a stream of air to remove dust from the casts without wiping, thus reducing the risk of staining. The liquid preparations recommended for application with the nozzle included the following substances in aqueous alcoholic solution: barium hydroxide; strontium hydroxide; salts of barium, strontium, calcium, magnesium, zinc, lead, and iron; boric acid and its derivatives; and soap. The primary emphasis of this patent is the atomizer nozzle and details are not given concerning the chemical reactions created by the application of these substances nor does the patent distinguish between those intended for hardening and those for cleaning. However, the mention of barium hydroxide and soap solutions indicates that processes very much like those developed by Reissig were intended.

Figure 2. Illustrations from Von Dechend's patent (Deutsches Patent- und Markenamt No. 31032)

By 1885, this apparatus had been installed by Herr Dielitz of the Royal Museum (now known as the Altes Museum: part of the Staatliche Museen), as well as at the Gewerbe Museum, and at the museum in Kassel (Mitchell 1885).[4] By 1890 it was also in use at the Boston Museum of Fine Arts (MFA), and had been ordered by museums in Chicago, New York, and Norwich (USA). A report (31st December 1890) written by Edward Robinson, the Curator of Classical Antiquities at the MFA noted that it had three purposes:

> First, by increasing the density of the surface of the plaster, to render casts capable of undergoing a thorough cleaning with fluids, when necessary; second, to provide the proper fluids and means of application for such a cleaning; and third, to serve as a machine for the ordinary dusting of casts.
>
> Robinson (1891, 22)

Robinson (1891, 22) also notes that the results of its use thus far at the MFA have been satisfactory and that the process is '*merely a practical one, and has no appreciable effect in altering the tone or color of the plaster*'. His decision to adopt this treatment was not taken lightly; he had also stated that it was important to avoid treatments leading to:

> One of four fatal objections. Some of them hide the subtleties of delicate modelling by covering them with a coating; others produce an effect which though picturesque is meretricious, and therefore out of place in a museum; others again, such as oiling are apt to produce false spots of light and shadow, which confuse the student; and there is a danger that all of them will in time turn black, and injure the casts.
>
> Robinson (1891, 23)

Clearly, Robinson was convinced that Von Dechend's protocol helped the casts to avoid these problems. They were common concerns, which are also reflected in the treatment of the casts in Britain, including those acquired by Walter Copland Perry in the 1880s. These were originally housed at the South Kensington Museum (later the V&A) but most were moved to the British Museum in 1907. Many of Perry's casts were ordered from Germany, where these surface treatments were being developed, and the V&A records indicate that they were applied to these casts.[5] In a Minute Paper of the 12th December 1881 (no. 6559) regarding an order of casts to be sent to Herr Schöne (Director General of the Royal Museum, Berlin), it is requested that the '*hardening process*' be applied to all of the casts. This refers specifically to the work of Von Dechend in '*preparing the casts for cleaning*', which was subsequently

[4] The Kassel casts were moved to the University of Marburg in the 1920s, where they remain today (Borbein 2000 [1997], 35).
[5] V&A Archives ED84/168/1, ED84/168/2 and ED84/169, Blythe House, London.

mentioned at the Meeting of the Committee of Advice and Reference on the Gallery of Casts held on the 24th March 1882 (no. 1807). Although his work was not patented until 1884, it is clear that his reputation was already well-established. It is stated that his process had been applied to certain casts at the British Museum and that Dr. Hodgkinson of the Science Museum was conducting experiments inspired by the work of Von Dechend. The issue was raised again on the 8th June 1882 (no. 3697) when the Advisory Council agreed to experiment with Hodgkinson's hardening process for the surfaces of the casts. These trials were reviewed on the 7th June and the 6th July 1883 (no. 3979) when, after inspecting the casts, they decided that the process should now be applied to the remaining casts. Furthermore, when a large order for casts was sent to Herr Dielitz (General Secretary, Royal Museum) on the 18th November 1883, instructions were included for '*all to be hardened*'.

Unlike Robinson's casts at the MFA, the V&A records reveal that the Perry casts had been given a coloured tint. When Hodgkinson's treatment was being tested, it was stated that:

> The Committee having inspected the casts already received, and especially those on which Dr. Hodgkinson's experiments in hardening the surface had been tried, recommended that the preparation used by Dr. Hogkinson should not be applied to any more casts until some time had elapsed, in order to afford means of judging if the colour remains unaltered when exposed to strong light. Three months would probably suffice for this trial. For the purpose of this comparison the present tints should be imitated in water colour, to be put aside for future inspection.
>
> Meeting of the Committee of Advice and Reference, 7th June 1883 (V&A Archive)

While the V&A archive indicates that there was also experimentation with surface treatments at the British Museum, no records relating to this have been found. However, when the Perry casts arrived at the British Museum from the V&A in 1907, there were complaints concerning the quality of the surfaces that had been so meticulously treated:

> Since their arrival Mr. Cecil Smith has examined the casts, and regrets to report that they are in an unsatisfactory condition. He finds that the surface has in almost every case been coated with a preparation about 1/30 in. thick which destroys the sharpness of detail and generally blunts the impression, besides imparting an unpleasant tone of colour.
>
> Report of 3rd October 1907, Department of Greek and Roman Antiquities, British Museum[6]

[6] I would like to acknowledge Ian Jenkins of the British Museum for showing me these records.

The origin of this coating is not clear from the V&A records. Robinson had stated that Von Dechend's hardening treatment caused no obvious visible changes. The specifics of Hodgkinson's treatment are unknown, but could have been rather different to those of Von Dechend. It is equally possible that this disfiguring 'coating' was simply an oily accumulation of dirt and grime, which would certainly cause discolouration. Nevertheless, the hardening treatment did its job. At the British Museum, cleaning was tested on the Centocelle Eros to good effect: '*the cast, which appeared to be of indifferent quality, turns out to be fresh and clear*'. However, it is also noted that:

> Unfortunately the process is costly and laborious, as it can only be done by a highly skilled formatore working very slowly… For removing the present surface, repairing and recolouring the whole of the 279 casts Messrs Brucciani estimate the cost at £710-4-0.
>
> Report of 3rd October 1907, Dept. Greek and Roman Antiquities, British Museum

The 'recolouring' was probably a light tint to 'warm up' the casts, given the fact that few now display any clear polychromy. The only casts known to have been routinely coated at the British Museum were the 'store casts'. These were those specifically allocated for storage rather than display in order to keep a spare set from which further moulds and casts could be produced if necessary. The store casts now appear a dark brown colour because of the shellac coating applied to protect their surfaces.[7]

Analysis of the Casts

Method

The British Museum permitted a limited number of samples to be taken from damaged casts originally in the Perry Collection. Eight cross-section samples were examined using scanning electron microscopy with energy dispersive spectroscopy (SEM-EDX). A Hitachi S-3400N scanning electron microscope with an Oxford Instruments energy dispersive detector was used for this analysis (calibrated with a cobalt standard), which took place at UCL's Institute of Archaeology. Samples of not more than 5 mm^2 were taken from existing areas of damage or retrieved from an already detached chip (the original location of which could be securely ascertained). The samples were vacuum impregnated with epoxy resin (Bisphenol A-

[7] '*It has long been the practice when one of the sculptures of the Museum is moulded, to retain the first and best casts as a 'store-cast', to be used when a new mould of the subject is called for… The natural colouring of the store casts is not pleasing, being various tints of brown…*' The British Museum during the War (I), Department of Greek and Roman Antiquities, unpublished notes.

Epichlorohydrin) and polished to a level of 1 micron. This allowed for better visualization of the layered structure of the samples and provided a planar surface for quantitative elemental analysis.

Results

All of the samples except for one were found to exhibit a coating rich in lead and barium in the layer closest to the gypsum plaster substrate; most then display at least one further lead-rich layer (often containing small quantities of zinc and iron, and sometimes further barium) on top of the lower coating (Table 2). The upper lead component is likely to be from either lead carbonate or lead oxide sulphate (Eastaugh et al. 2008, 228-237), both commonly used pigments for lead paint. The lead component in the layer next to the substrate may also be attributed to a pigment, or may be connected with the hardening process applied, since Von Dechend lists salts of lead as one of the possible treatments. The amount of lead (compound %) is typically rather less in this layer than in the upper layers. Barium also makes up a significant percentage of the layer next to the substrate; however, its function is similarly ambiguous. The archival evidence clearly indicates that these casts were treated with a hardening process and we would expect to see evidence of this in the upper substrate and/or the layer closest to this substrate. Barium is a known recommended component of the hardening treatments of both Reissig and Von Dechend. These were advanced for their time: barium hydroxide has more recently been employed for the consolidation of wall paintings (Giorgi et al. 2010). The hardening treatment prepared for these casts by Hodgkinson was inspired by the formula of Von Dechend; however, the specifics of its components are unknown. It is also possible that the barium could be attributed to barium sulphate, a white pigment developed in the late eighteenth century and made artificially in the nineteenth century (CAMEO). This would suggest that Hodgkinson's hardening preparation was based on a particular selection of pigments for a very thin protective paint layer, distinct from Von Dechend's treatment which changed the chemical composition of the surface of the plaster.

Visual analysis during SEM revealed that the barium and lead rich layer consists of much finer particles than paint layers subsequently applied. However, in most cases, it sits on the surface of the plaster in the manner of a paint layer, rather than penetrating the substrate (Figure 3: Sample from The Three Graces). Here the substrate appears as a consistent layer of calcium sulphate; yet in another case (Figure 4: Sample from the Eleusinian Relief) there is a denser layer towards the surface of the substrate. EDX did not indicate that this layer is chemically distinct from the rest of the substrate nor that it contained any significant quantity of barium. EDX provides information only on the elements present, and data on the lighter elements is limited. Other analytical techniques were not available for this phase of research but further microscopy combined with micro-Fourier transform infrared spectroscopy would, therefore, be highly valuable for improved characterisation of these layers and their molecular structure.

There is evidence for further 'refreshing' layers of paint in a number of the samples; several contain a third lead-rich layer. The sample from the cast of the Hestia Giustiniani displays two additional, more recent layers of paint containing significantly less lead. However, none of the samples examined display more than four layers of coating, and the combined width of the coatings is very thin, measuring between approximately 40 um (0.04 mm) and 280 um (0.280 mm). It is notable that the only sample found to contain just a small quantity of barium not clearly concentrated in the layer closest to the substrate is that from the cast of the Orchomenos Stele, commissioned from the Royal Foundry, Berlin in 1881. The archival evidence for this batch of casts includes specific instructions sent to Berlin's Royal Museum for their hardening – and yet this sample perhaps contains the least evidence of such a procedure. The exposed area on the small samples may not be representative of the surface across the whole cast, especially since sampling was restricted only to damaged sections. Moreover, it is possible that the procedure in Berlin involved less (or no) barium than that derived by Hodgkinson at the V&A, whose treatment may not have been applied to the Berlin casts, which were already considered to have been suitably treated.

Table 2. Results of SEM-EDX analysis.

Figure 3. One of the cross-section samples examined using SEM-EDX (Sample 2 from a cast of the Three Graces).

Figure 4. One of the cross-section samples examined using SEM-EDX (Sample 9 from a cast of the Eleusinian Relief).

These results, combined with the archival evidence, indicate that with some exceptions, such as those commissioned from the foundry of Berlin's Royal Museum (the Gipsformerei), the casts were treated at the V&A with a hardening preparation devised by Hodgkinson, probably based on lead and barium to improve their durability. The precise nature of this preparation is, however, unclear and further testing is required, particularly regarding the role of the barium. On top of this initial coating, a lead-based paint was applied, containing small quantities of other pigments, including iron oxide-based earth pigments to provide a warm tint. It is likely that this was applied prior to acquisition by the British Museum, since the V&A records include references to a tint. By the time the casts arrived at the British Museum, their cleaning had been neglected and they had become discoloured and coated with a layer of grime. The casts were cleaned, and in some cases provided with a further 'refreshing' layer of paint. Additional layers of paint are found in some instances, which may reflect further such treatments at a later date.

The coatings applied to these casts have, in general, been carefully considered and applied. The total thickness of coating found in the British Museum's casts is extremely thin: most display coatings with a sum of less than 100 um (0.1 mm). Even the sample from the cast of the Hestia Giustiniani, which has four surface coatings, exhibits a total thickness below 0.3 mm. This attests to the high quality of these casts and the efforts exerted to reflect and preserve their fine surface details.

Conclusions

The importance of work into the composition and coating of casts can be divided into two separate and sometimes contradictory strands. Identification and preservation of their historical coatings reflects the notion that casts can be important craft objects. Their composition and the paints, lacquers, oils, varnishes, and chemical treatments applied to them were carefully considered and, often, specifically and ingeniously formulated. This was sometimes for predominantly aesthetic purposes, as with the early products of John Cheere, but increasingly in the nineteenth century, was also a means through which to produce casts that would accurately reproduce original classical sculptures and preserve their fine surface details in perpetuity. At once these casts were carefully constructed objects, reflecting a historical craft tradition, but also utilitarian tools for research within the new discipline of archaeology.

The nineteenth and early twentieth century treatments of casts such as those at the British Museum appear to have been quite effective at preserving the plaster surfaces. However, they have not been able to protect them from other issues caused by the years of subsequent neglect suffered by many casts. Conservation concerns now typically afflicting casts include surface dirt, the corrosion of internal armatures and resulting stress fractures to the plaster, breakages to extremities, and surface abrasions and chips (and, in some cases, salt efflorescence). Conservators must be aware that any intervention made to disturb the morphology of a cast's surface will interfere with its capacity to retain details of the object from which it was moulded. This is particularly pertinent in the case of 'archaeological' casts of sculptures remaining in external contexts; such casts may well contain fine sculptural details since lost from the originals. Therefore, while broken, detached pieces of cast may be reattached if they can be securely located, the filling of damaged areas is more problematic.[8] The addition of material to smooth abrasions and fill losses can more accurately resemble the visual appearance of the original when moulded; however, this will not have been achieved via direct transmission of the original surface – it is a fabrication. Since the damaged surface also no longer correctly reflects the original when moulded, whether or not such interventions are considered desirable will depend on the history of the casts in question and the curatorial aims of the collection. A cautious approach should be favoured. For instance, during the recent conservation of casts of twelfth to sixteenth century sculptures from Polish castles and churches–where the originals have in some cases been lost–a considered decision was made not to restore serious losses. This was, in part, because there was some uncertainty over precisely which losses related to the casts and which to the originals from which they were moulded. However, for aesthetic purposes, small losses along the joins of attached fragments were filled (Klosowska & Obarzanowski 2010, 111-114). This remains a trade-off and it is arguable that even such small losses should be left to reduce meddling with the historical surface; this may include old surface coatings – none of the casts analysed in this study were left untreated.[9] In either case, it would be valuable, if possible, to conduct detailed 3D imaging of the casts to ensure that a record of their current form is preserved in digital, if not, material form. If interventive work, such as filling, is conducted then it is essential that this is comprehensively documented. This documentation (textual and visual) should include pre-treatment condition, post-treatment condition, and the techniques and materials used during

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8 For example, the conservation of plaster casts at the University of California, Berkeley, has involved the filling of channels caused by exposure to rainwater (Pearson 2015).

9 The filling of such losses can, however, also help to protect the object from decline: already damaged edges can be particularly vulnerable to further deterioration. This must be taken into account when determining appropriate conservation. For instance, if the casts are to be kept in a secure location with a stable environment then the filling of small losses may be unnecessary; however, filling may be beneficial if the casts are likely to be kept in a less than ideal environment or frequently subject to moving and handling.

conservation (Moore 2001). In essence, it is important that the casts are approached as artefacts, rather than as replicas, during conservation.

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References

Badde, A. 2009. *Dust on Busts. Dust on Plaster Surfaces: Focussing on the Portrait Busts in the Rococo Hall of the Duchess Anna Amalia Library in Weimar*. Unpublished MA dissertation, Department of Arts & Social Sciences, Northumbria University at Newcastle.

Brannt, W. T. & W. H. Wahl. 1919. *The Techno-Chemical Receipt Book*. USA: Henry Carey Baird.

Borbein, A. H. 2000. "Zur Geschichte der Werschätzung und Verwendung von Gisabgüssen antiker Skulpturen (insbesondere in Deutschland und in Berlin)." In Lavagne, H. & Queyrel, F. eds *Les moulages de sculptures antiques et l'histoire de l'archéologie. Actes du colloque international Paris, 24 Octobre 1997, Paris*. Geneva: Droz: 29-43. Available at: www.digitalsculpture.org/casts/borbein/index.html. Accessed 28th August 2018.

Brigham, W. 1874. *Cast Catalogue of Antique Sculpture*. Boston: Lee and Shepard.

CAMEO (Conservation and Art Materials Encyclopedia Online). "Barium sulfate." http://cameo.mfa.org/wiki/Barium_sulfate. Accessed 21 February 2019.

Carradori, F. (1802) 2002. *Elementary instructions for students of sculpture*. Translated by Auvinen, M. Los Angeles: J. Paul Getty Museum.

Carran, D., Hughes, J., Leslie, A., & C. Kennedy. 2012. "A short history of the use of lime as a building material beyond Europe and North America." *International Journal of Architectural Heritage* 6: 117-146.

Castelvecchi, L. C. 1906. *Catalogue of A. Castelvecchi & Co. Plastic Reproductions of Antique and Modern Masterpieces of Art*. New York: L. Castelvecchi.

Cennini, C. 1954. *The Craftsman's Handbook 'Il Libro dell' Arte'*. New York: Dover Publications.

Clifford, T. 1992. "The Plaster Shops of the Rococo and Neo-Classical Era in Britain." *Journal of the History of Collections* 4: 39-65.

Desachy, L. A. 1856. *Improvements in producing architectural mouldings, ornaments, and other works of art formed with surfaces of plaster or cement*. London: The Office of the Commissioners of Patents. Patent No. 2494.

Eastaugh, N., Walsh, V., Chaplin, T., & R. Siddall. eds. 2008. *Pigment Compendium: A Dictionary of Historical Pigments*. Oxford: Elsevier, Butterworth-Heinemann.

Frederick, F. F. 1899. *Plaster casts and how they are made*. New York: W. T. Comstock.

Giorgi, R., Ambrosi, M., Toccafondi, N., & P. Baglioni. 2010. "Nanoparticles for cultural heritage conservation: calcium and barium hydroxide nanoparticles for wall painting consolidation." *Chemistry – A European Journal* 16: 9374-9382.

Gourdin, W. H. & W. D. Kingery. 1975. "The beginnings of pyrotechnology: Neolithic and Egyptian lime plaster." *Journal of Field Archaeology* 2 (1-2): 133-150.

Hennecke. 1886. *Hennecke's Florentine Statuary*. Milwaukee: C. Hennecke.

Hennecke. 1889. *Hennecke's Art Studies*. Chicago and Milwaukee: C. Hennecke.

Klosowska, A. & M. Obarzanowski. 2010. "Plaster casts in the collection of the National Museum in Krakow. Conservation issues." In W. Marcinkowski & T. Zaucha eds. *Plaster Casts of the Works of Art: History of Collections, Conservation, Exhibition Practice: Materials from the Conference in the National Museum in Krakow*. Krakow: National Museum Krakow, Muzeum Naradowe w Krakowie: 103-115.

Megens, L., Joosten, I. De Tagle, A. & R. Dooijes. 2011. "The composition of plaster casts." *Preprints 16th ICOM-CC Triennial Conference*, Lisbon, Portugal: ICOM-CC: 1-9.

Millar, W. 1905. *Plastering, plain and decorative: a practical treatise on the art and craft of plastering and modelling*. London: Batsford.

Mitchell, L. M. 1885. "Plaster in sculpture. Its value as a medium for copying the old masters." *The New York Times*, 20th April 1885. New York.

Moore, M. 2001. "Conservation documentation and the implications of digitisation." *Journal of Conservation and Museum Studies* 7: 6-10.

Newton, C. T. (1865) 1989. *Travels and Discoveries in the Levant*. Hildesheim: G. Olms Verlag.

Penny, N. 1993. *The Materials of Sculpture*. New Haven and London: Yale University Press.

Salavessa, E., Jalali, S., Sousa, L. M. O., Fernandes, L. & A. M. Duarte. 2013. "Historical plasterwork techniques inspire new formulations. *Construction and Building Materials*." 48: 858-867.

Robinson, E. 1891. *Report of the curator of classical antiquities 1890*. Boston: Museum of Fine Arts Boston.

Smith, A. H. 1892, 1900, 1904. *A Catalogue of Sculpture in the Department of Greek and Roman Antiquities, in the British Museum, Volumes 1-3*. London: Trustees of the British Museum.

St. Clair, W. 1967. *Lord Elgin and the Marbles*. *The Controversial History of the Parthenon Sculptures*. Oxford: Oxford University Press.

Von Dechend, F. 1884. *Verfahren und Apparat, um Härtungs- und Conservirungsflüssigkeiten auf Gypsabgüsse etc*. *aufzutragen*. Kaiserliches Patentamt, Berlin, Germany. Deutsches Patent- und Markenamt No. 31032.

Wager, V. H. 1944. *Plaster casting for the student sculptor*. London: Tiranti.

A. A piece mould being made of a statue
B. First portion of the mould
C. A segment of the mould, made sequentially with plaster
D. Steel spatula for making segments
E. Small basin for wet plaster
F. A piece of the mould that is being refined with a knife
G. Tub for storing pulverized plaster
H. Sack for carrying plaster
I. Bench with a double top that swivels
A. Basin to mix the plaster for casting
B. Pitcher to have water available
C. Finished piece of the mould to be oiled before the casting process
D. Brush for applying the oil
E. Mould of an arm already cast, ready to be removed from the mould
F. Containers of oil
G. Coil of iron wire
H. Tongs, spatulas, and brushes
I. Mould where the plaster is being cast
J. Sawhorses that provide a mobile table
V. Mallet for various uses

Figure 1. Moulding a statue according to Carradori's *Istruzione elementare per gli studiosi della scultura* (1802, Plate VI).

Table 1. A Selection of Recipes for Surface Coatings

Treatment	Recipe Book	Method
For an antique effect	Frederick (1899, 111)	'Put a thin wash of very hot [linseed] oil upon the cast. When dry, polish the surface by rubbing with an old silk handkerchief. Into the second coat of oil touch a little raw or burnt umber, yellow ochre, raw sienna, or any desired colour, in the low places where a marble would be likely to be weather stained. Wipe the oil from the points of highest relief and from plane surfaces with a clean cloth.'
For a wax-like surface	Frederick (1899, 111)	Immerse 'the cast in warm oil for ten or twelve hours. When thoroughly saturated the cast should be so placed that the superfluous oil will run off, and when quite dry the surface can be polished with the silk as described above.'
For an ivory-like finish	Frederick (1899, 112-3)	Use candle wax or paraffin wax: 'Rubbed onto the surface of the cast and polished with a silk handkerchief. The cast should be slightly warmed. If it is small, it can be heated and immersed in melted wax and then polished. If the cast has first been oiled the effect is that of old ivory.'
'Old ivory' finish	Wager (1944, 88)	Two coats of linseed oil brushed on. To give an 'old ivory' finish, keep a week over a smoky fire then polish up.
	Millar (1905, 578-581)	'Plaster casts thoroughly dry and brushed with two coats of clear linseed oil, and kept for a while in a smoky room, will take a good polish, and acquire the appearance of old ivory. 'Ivory carving may be so closely imitated that only an expert can detect the difference. Ivory carvings, or rather castings, when mounted in metal, wood, or plush frames, have been sold in great numbers and at highly remunerative prices, at exhibitions and art dealers' sales. The

		process is simple, but requires a considerable amount of skill on the part of the craftsman. The moulds are generally taken from real ivory, carving wood, or art metal work. Superfine plaster is used. The water is tinted with fine yellow ochre. For the general colour of old ivory, add ½ oz. to each pound of plaster. When the casts are thoroughly dry, they are dipped into spermaceti [wax from sperm whale], and suspended until the excess of the spermaceti has run off, and when the cast is nearly dry, but still sticky, fine yellow ochre is sprinkled on. The prominent parts are wiped with fine rags or cotton wool. The success of the work greatly depends on the art displayed in laying and wiping the ochre. The ochre is dusted through a fine muslin bag. Sometimes the grain or spots (as seen in old ivory) is obtained by brushing, stippling, or dabbing with small tool brushes having the hair cut square, short, and wide apart. If the cast is too large to be dipped, it can be brushed over with warm spermaceti quickly and evenly, taking care that the spermaceti does not cake. In both methods the cast should be warm, and the ochre ground to a fine powder. To imitate new ivory, gauge with the tinted water, and when the cast is dry, dip it for 15 minutes into a solution of spermaceti, white wax, and stearine in equal parts, then polish with cotton wool.'
Recipe of Mr F. D. Millet: medium for wax painting which also makes an excellent surface for casts – "both in appearance and for protection"	Frederick (1899, 113)	'Melt 1 ounce of pure white glue and 2 ounces Venice turpentine in jar placed in boiling water. Add, stirring gradually, about one-half pint spirits of turpentine, or enough to make it flow freely. Brush on the cast while hot. Polish with silk. Tint can be obtained by adding dry colour to the mixture.'
For a delicate finish	Frederick (1899, 115)	Use: 'White shellac dissolved in alcohol. This surface is easily broken.'
For a marble-like surface	Frederick (1899, 115) Wager (1944, 88)	'Repeatedly saturate the cast with milk.' 'Coat (or immerse) cast with skimmed milk until saturated. Blow off superfluous milk and place in dust-free cupboard until dry. Polish with French chalk with pad of cotton wool to

		give appearance of marble.’
Bronzed surface	Wager (1944, 90)	‘Mix a little raw or burnt umber or green (depending on shade required) with gold size in a saucer (for a matte finish use methylated spirit instead of gold size). Float onto cast as quickly as possible. Avoid disturbed first coat (put on to close the pores). When colour coat is hard, mix a little bronze powder with cellulose lacquer and apply to projecting parts of the cast. Experiment also with red and gold bronze powders and the red and blue colours. The emerald green will provide the patinae of old bronze. Wax for protection by applying stearine or white paraffin wax dissolved in turpentine (as above). Apply hot with a large soft brush. Leave for a day and then polish with cotton wool. ‘Alternatively, apply the bronze coat before the colour coat. Apply the colours mainly to the hollows, leaving the bronze coat showing through the projections and high parts by shading the colour off with cotton wool. This is more pleasing but more expensive as more bronze powder is used.’

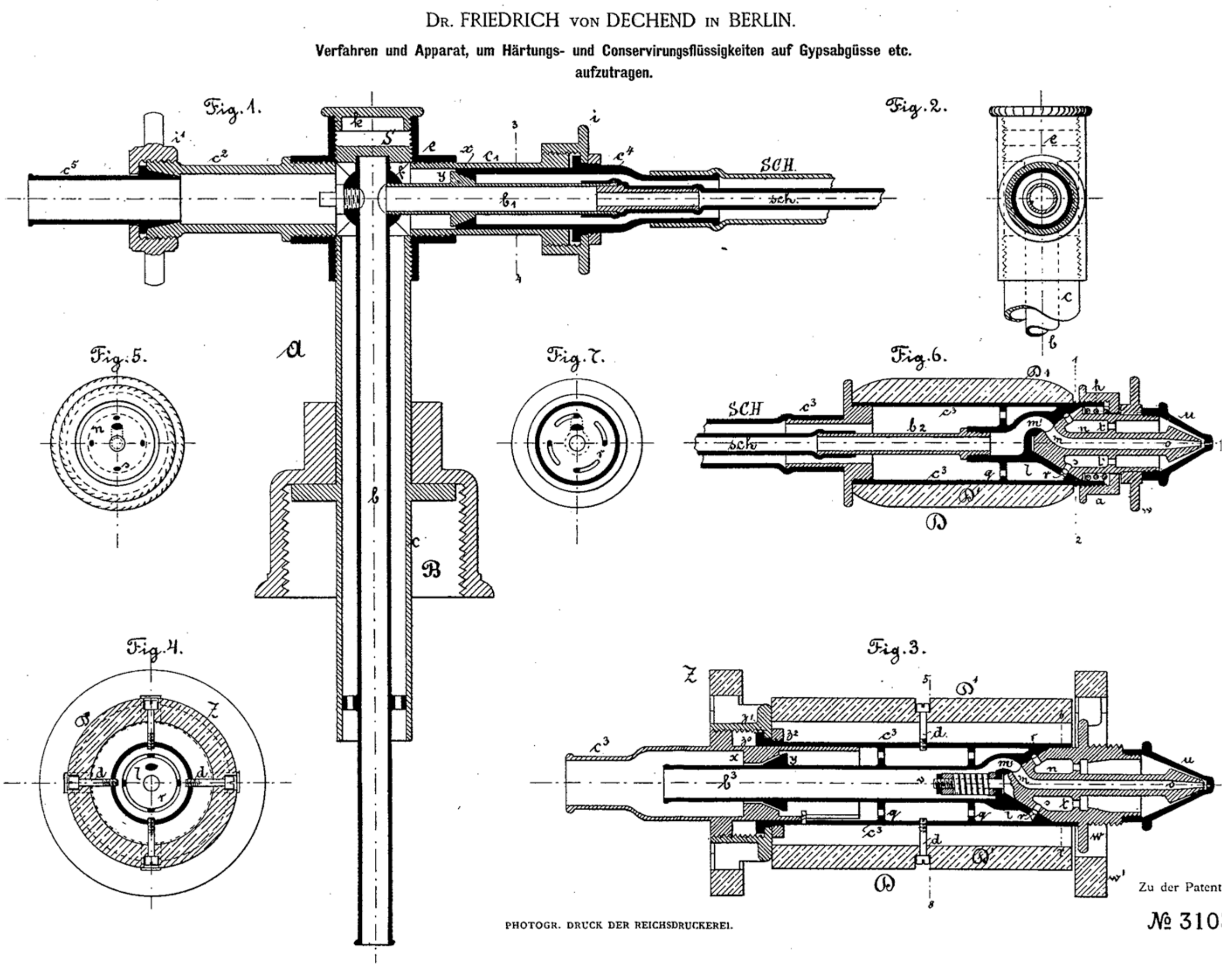


Figure 2. Illustrations from Von Dechend's patent (Deutsches Patent- und Markenamt No. 31032)

Table 2. Results of SEM-EDX analysis*

Sample No.	Cast	Maker	SEM-EDX Results			
			Barium concentrated in surface coating layer closest to substrate	Lead rich layer(s), sometimes containing zinc and/or iron	No. of layers in surface coating	Approximate total thickness of surface coating
1	Orchomenos Stele 2012,5024.17	Royal Foundry, Berlin		✓	3	76 um (0.076 mm)
2	The Three Graces 2012,5024.26	Malpieri, Rome	✓	✓	3	75.6 um (0.0756 mm)
3	Capitol Amazon 2012,5024.34	Louvre, Paris	Sample found to be too fragile for polishing			
4	Doryphoros 2012,5024.29	Naples Museum	✓	✓	3	111 um (0.111 mm)
5	Apollo Sauroktonos 2012,5024.39	Lehmann, Dresden	✓	✓	2	66.7-187 um (0.0667-0.187 mm)
6	Arrotino, 2012,5024.55	Brucciani, London	Sample found to be too fragile for polishing			
7	Hestia Giustiniani 2012,5024.27	Lehmann, Dresden	✓	✓	4	280 um (0.280 mm)
8	Eirene and Ploutos, 2012,5024.38	Geiler, Munich	Sample found to be too fragile for polishing			
9	Eleusinian relief 2012,5024.35	Desachy, London	✓	✓	2	64.4 um (0.0644 mm)
10	Kouros of Tenea 2012.5024.12	Brunn, Munich	✓	✓	3	91.3 um (0.0913 mm)
11	Stele of Dexileos 2012,5024.44	Martinelli, Athens	✓	✓	1	40.3 um (0.0403 mm)

*For full results, see Appendix I.

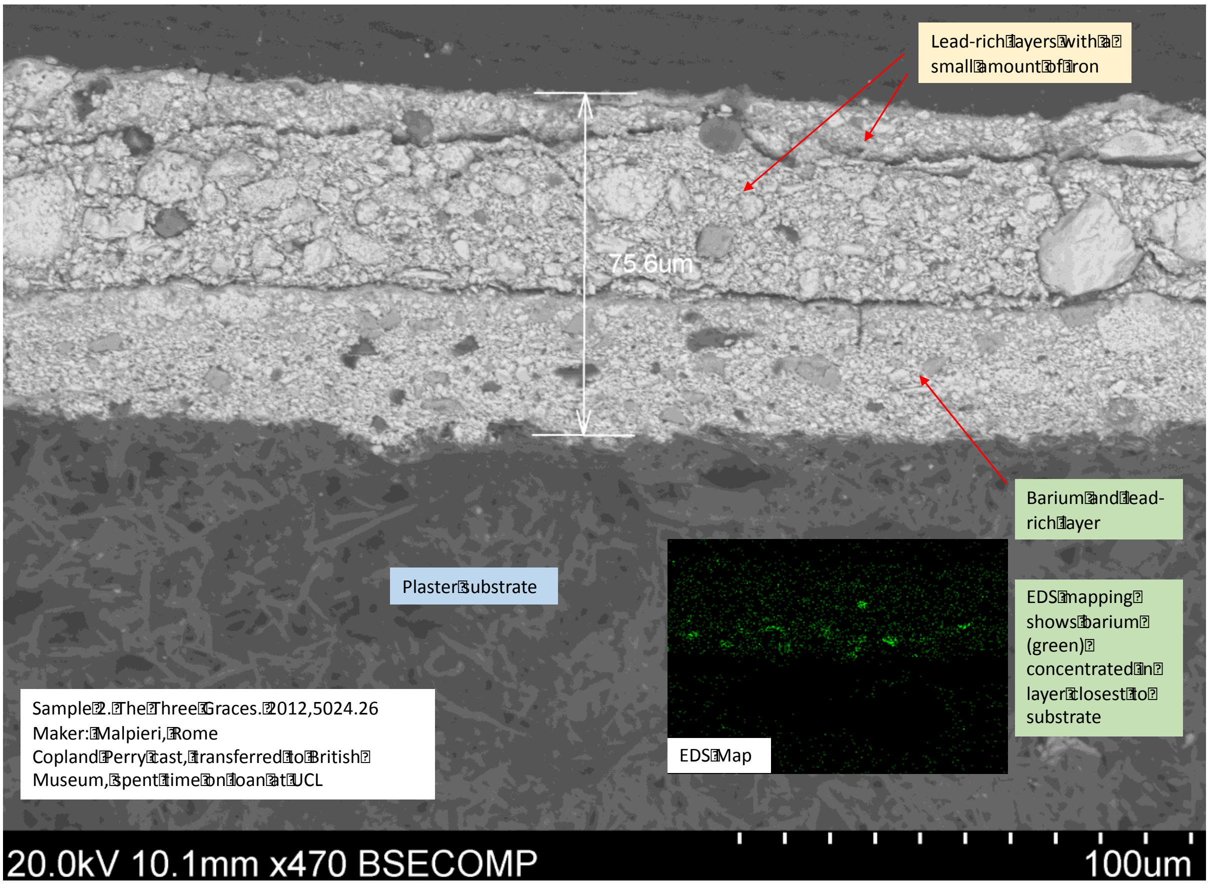


Figure 3. One of the cross-section samples examined using SEM-EDX (Sample 2 from a cast of the Three Graces)

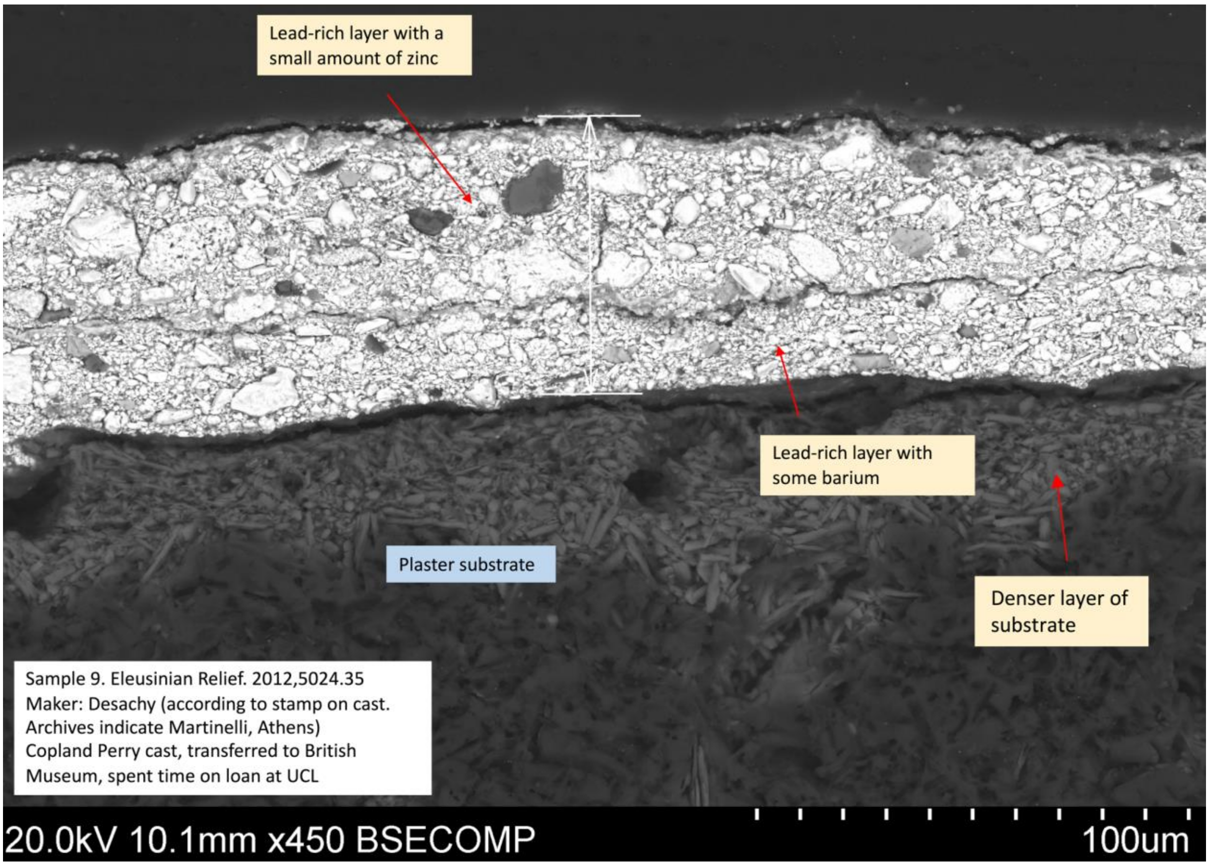


Figure 4. One of the cross-section samples examined using SEM-EDX (Sample 9 from a cast of the Eleusinian Relief).

Figure 1

Figure 2

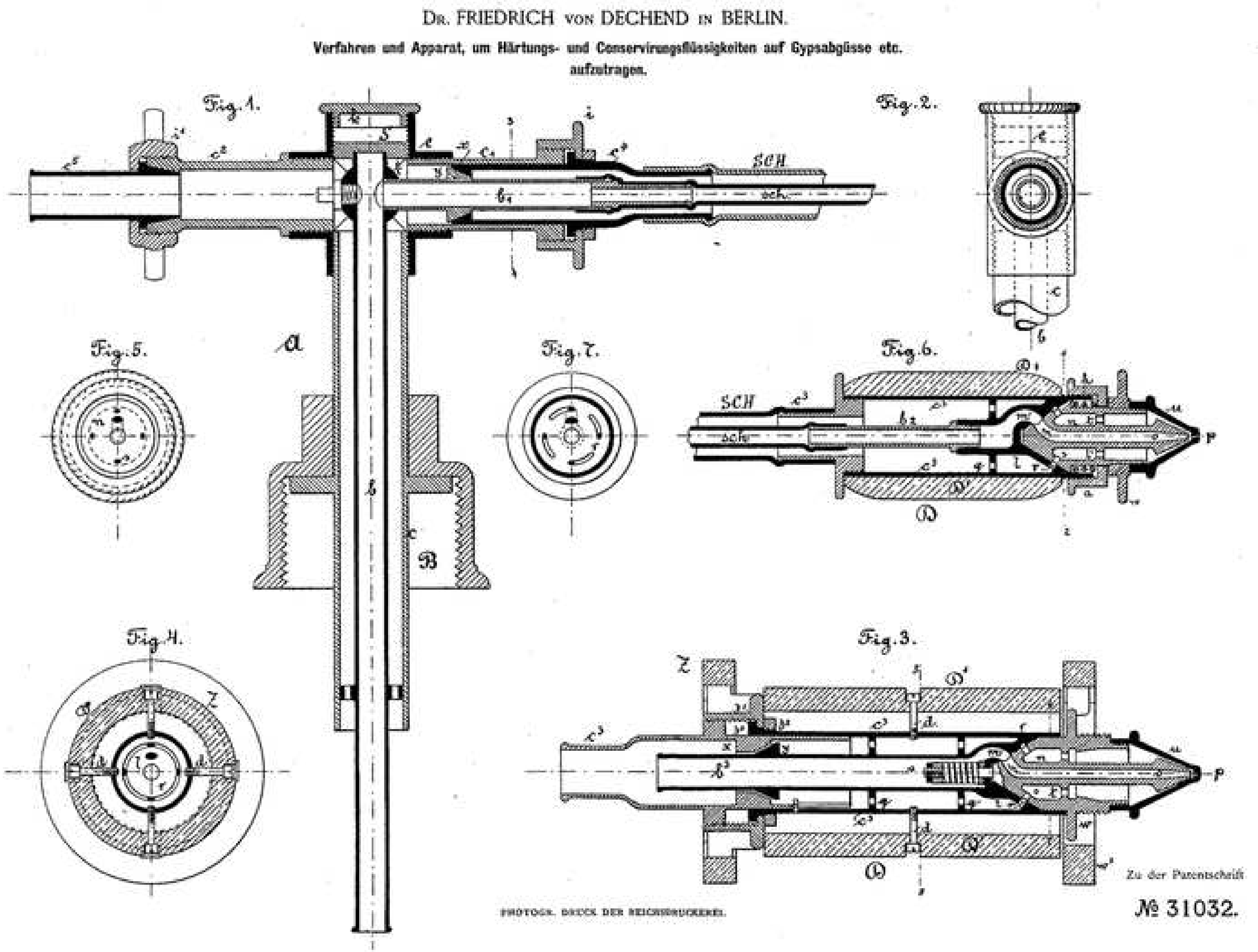

DR. FRIEDRICH VON DECHEND IN BERLIN.
Verfahren und Apparat, um Härtungs- und Conservirungsflüssigkeiten auf Gypsabgüsse etc. aufzutragen.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
SCH
PHOTOGR. DRUCK DER REICHSDRUCKEREI.
Zu der Patentschrift
№ 31032.

Figure 3

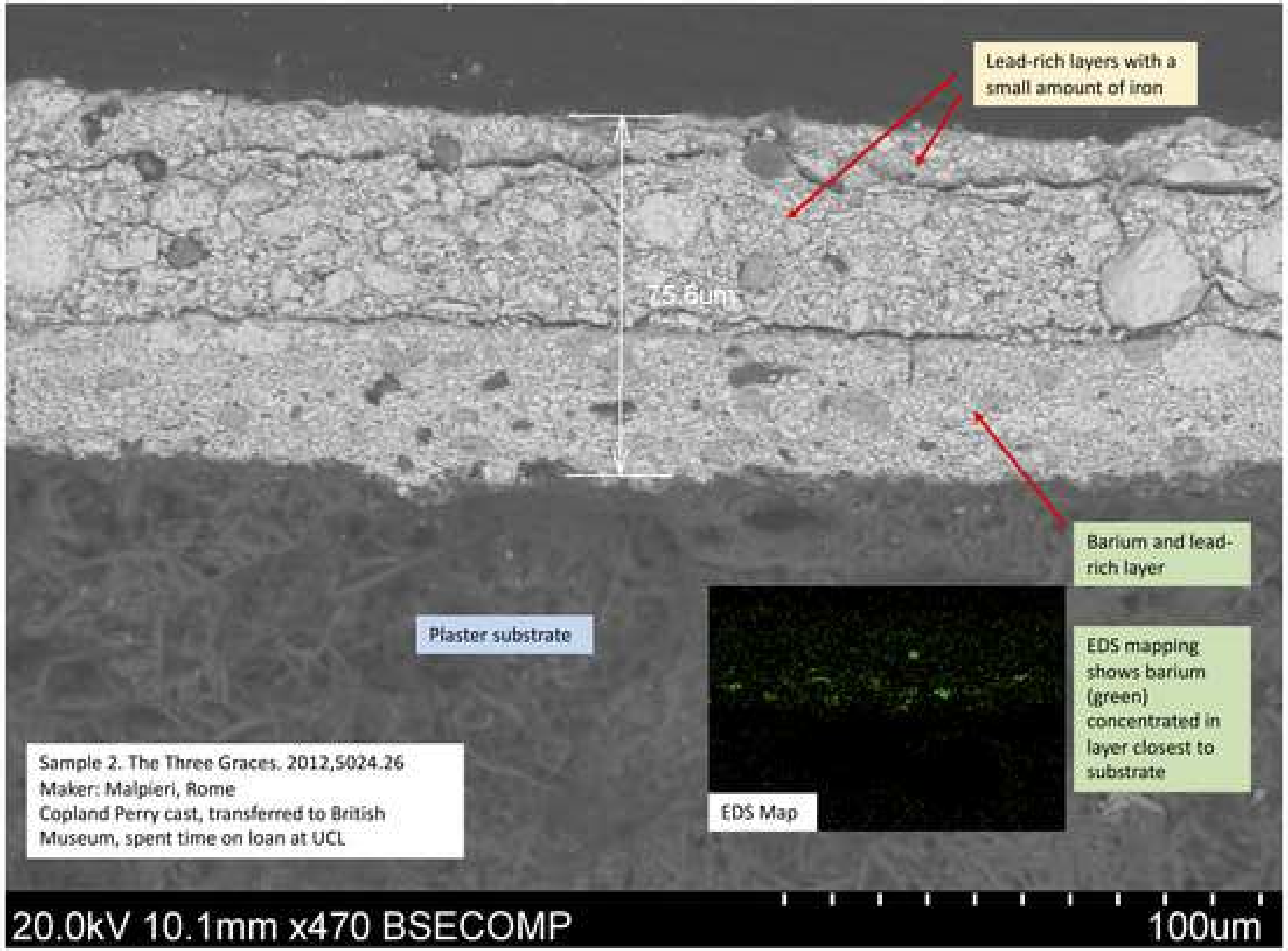
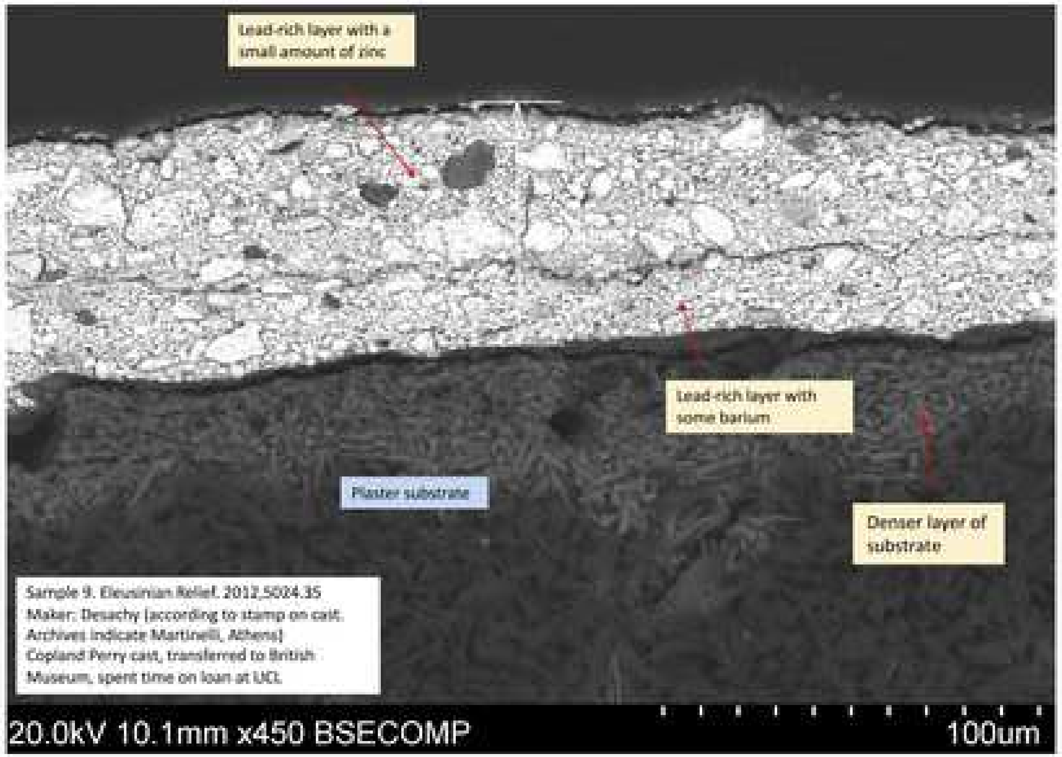

Lead-rich layers with a small amount of iron
75.6um
Barium and lead-rich layer
Plaster substrate
EDS mapping shows barium (green) concentrated in layer closest to substrate
EDS Map
Sample 2. The Three Graces. 2012,5024.26
Maker: Malpieri, Rome
Copland Perry cast, transferred to British Museum, spent time on loan at UCL
20.0kV 10.1mm x470 BSECOMP
100um

Figure 4

Click here to access/download;Colour figure;Fig 4.jpg



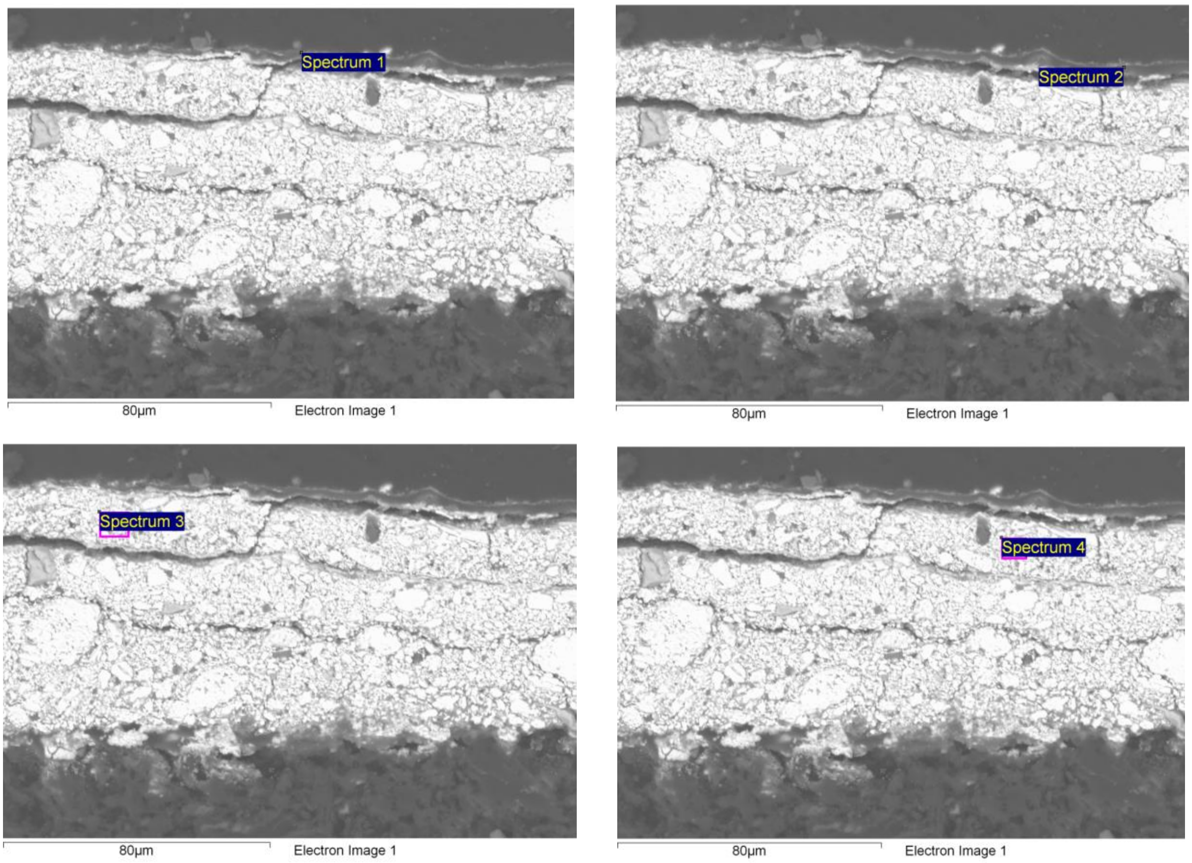
Appendix I: SEM-EDX Results

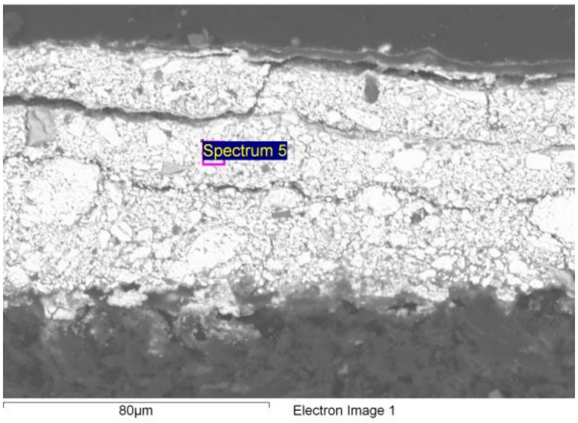
Sample 1: The Orchomenos Stele by Alxenor (man with dog) (2012,5024.17)

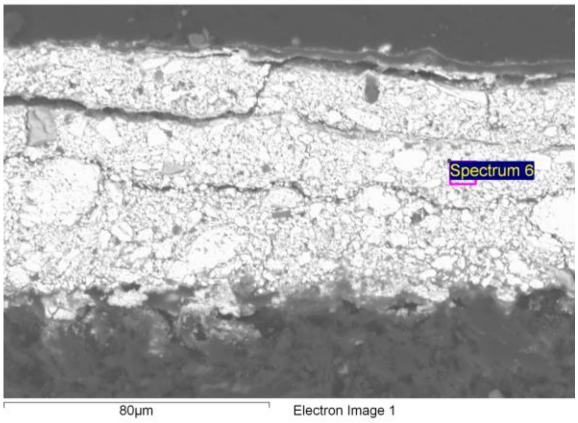
All results in compound %

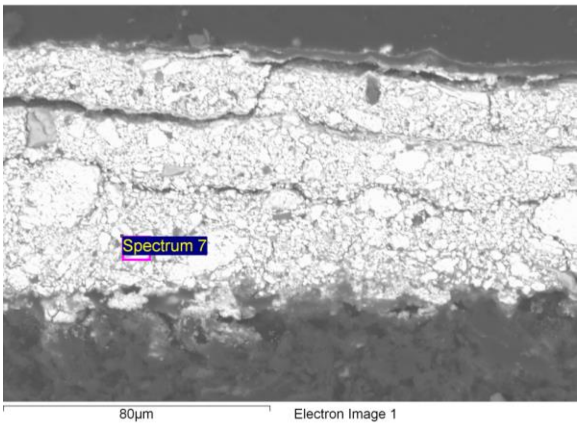
	Na	Mg	Al	Si	P	S	Cl	Ca	Ti	Zn	Ba	Pb	O	Total
1	3.08	0.69	3.39	1.86		6.43	3.18	4.40	1.60	2.03		51.21	22.80	100
2			0.79	1.50	0.54	4.15	2.00	28.61		1.05		37.45	23.91	100
3												92.83	7.17	100
4												92.83	7.17	100
5								0.42			0.91	91.34	7.33	100
6												92.83	7.17	100
7												92.83	7.17	100
8								0.61				92.04	7.35	100
9				1.84		17.78	3.39	27.92				8.56	40.51	100

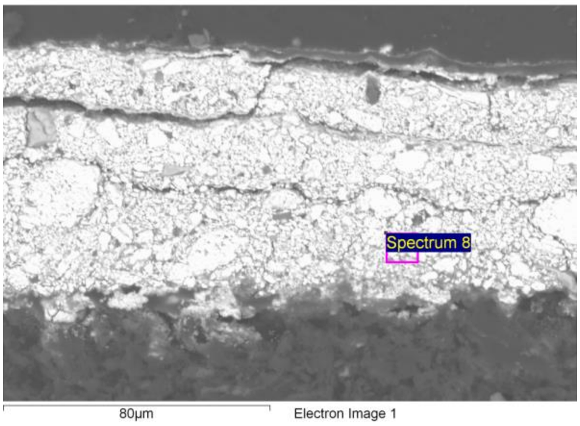
Sample 1: Spectra locations. Substrate in lower section of micrograph

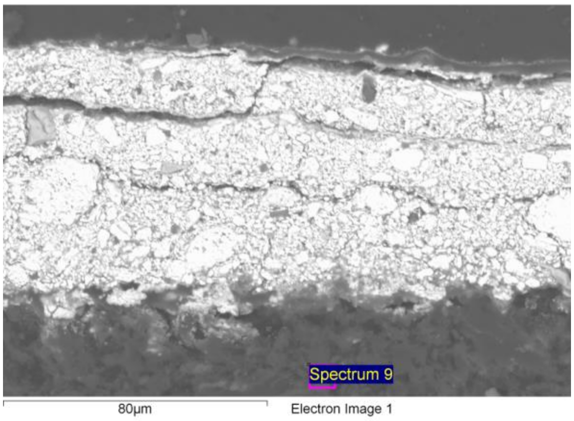



Spectrum 5
80µm
Electron Image 1


Spectrum 6
80µm
Electron Image 1


Spectrum 7
80µm
Electron Image 1

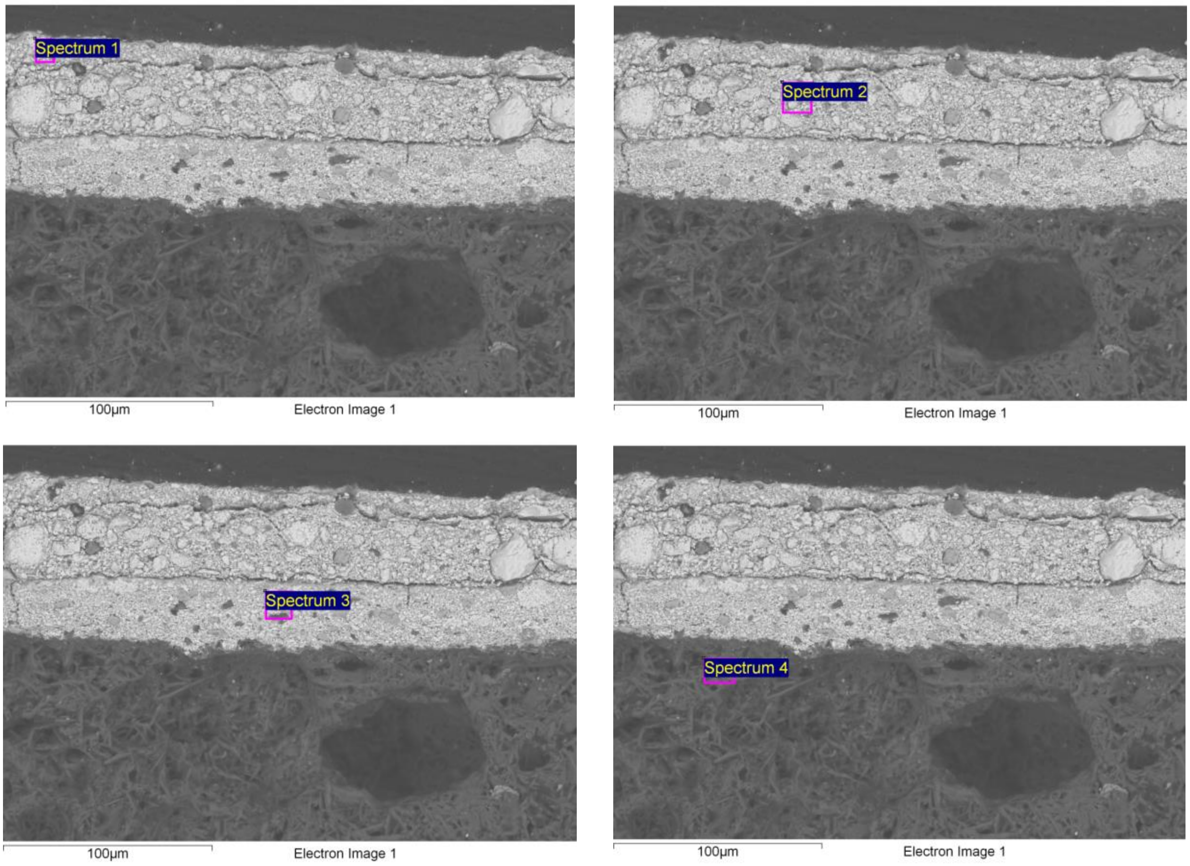

Spectrum 8
80µm
Electron Image 1

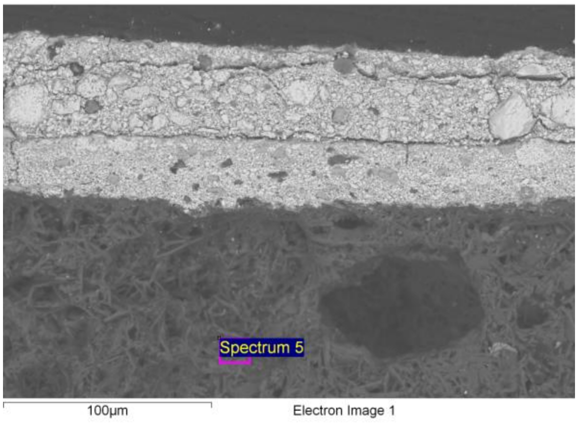

Spectrum 9
80µm
Electron Image 1

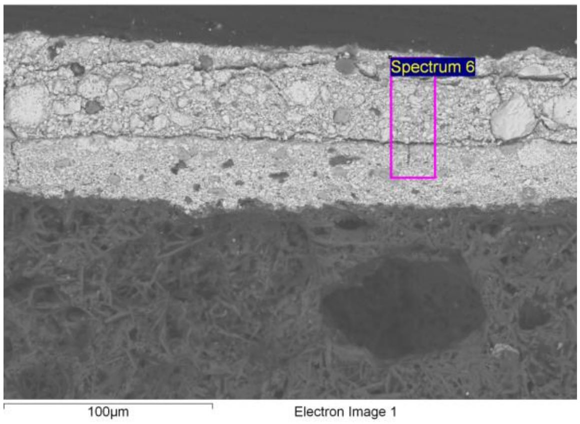
Sample 2: The three Graces (2012,5024.26)

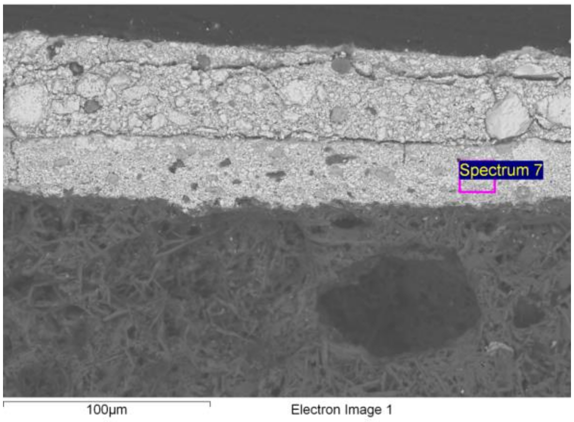
All results in compound %										
	Mg	Si	S	Cl	Ca	Ti	Fe	Ba	Pb	Total
1							0.85		99.15	100
2							0.72		99.28	100
3		4.71	12.55		0.50			24.13	57.54	99.45
4	1.12		55.15		43.74					100
5			58.59		41.41					100
6			2.80			0.93			96.28	100
7			3.36		0.95			4.57	91.12	100

Sample 2: Locations. Substrate in lower section of micrograph




Spectrum 5
100µm
Electron Image 1


Spectrum 6
100µm
Electron Image 1

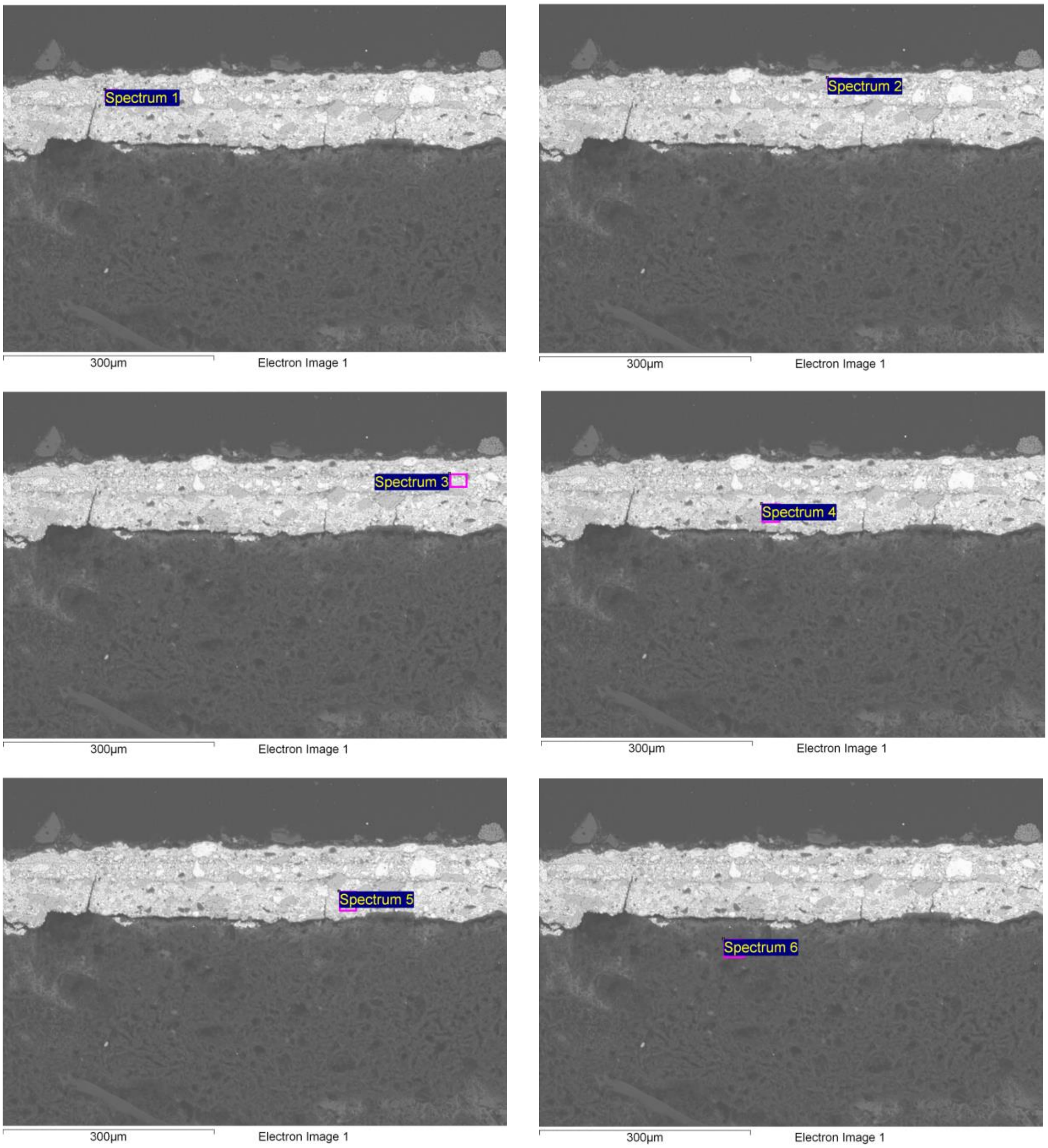

Spectrum 7
100µm
Electron Image 1

Sample 4: Doryphoros (2012,5024.29)

All results in compound %

	Si	S	Cl	K	Ca	Fe	Zn	Ba	Pb	O	Total
1		1.35				0.84	1.12	7.27	79.84	9.56	100
2	6.47	2.71	0.69	0.44	0.36		1.24		70.68	17.42	100
3							1.27	2.42	88.85	11.79	100
4		2.95			0.63			14.98	69.66	11.79	100
5		1.48			0.50			7.08	81.42	9.52	100
6		21.03	1.70		32.72					44.55	100

Sample 4: Locations. Substrate in lower section of micrograph

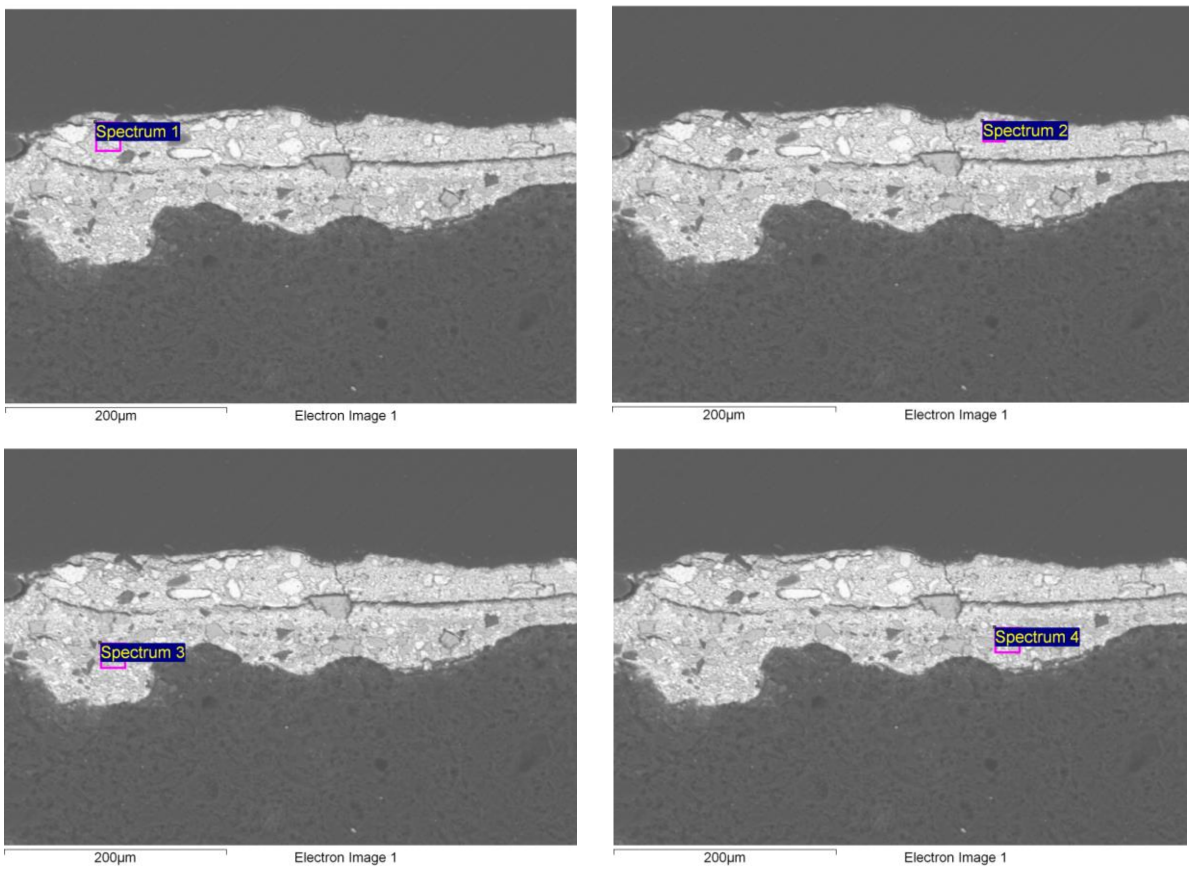


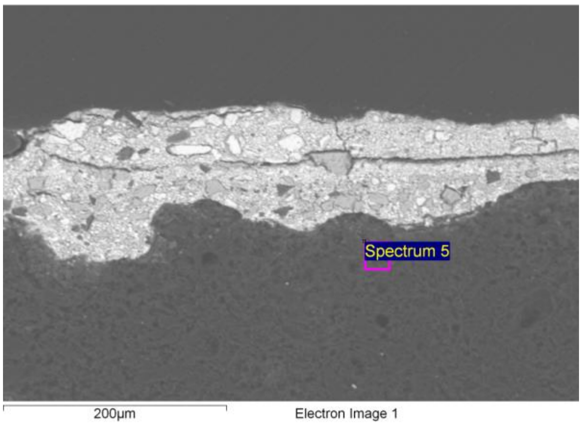
Sample 5: Apollo Sauroktonos (2012,5024.3)

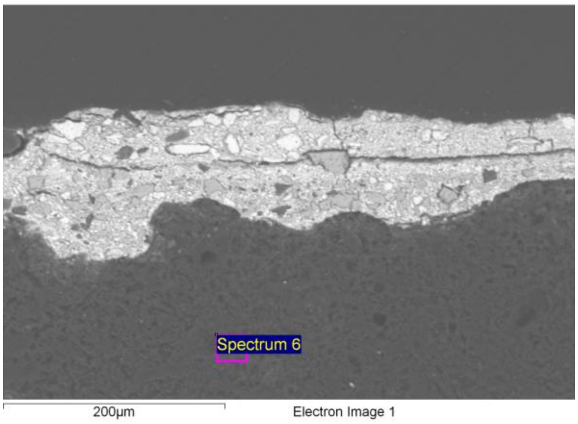
All results in compound %

	Si	S	Cl	Ca	Fe	Zn	Ba	Pb	O	Total
1			1.68		0.60	1.07		89.32	7.33	100
2			1.54			0.811		90.46	7.18	100
3		4.86					26.52	54.08	14.54	100
4		4.74		0.51			24.03	56.28	14.44	100
5	1.17	18.92	2.54	26.12					40.88	100
6		19.79	9.39	29.44					41.38	100

Sample 5: Locations. Substrate in lower section of micrograph



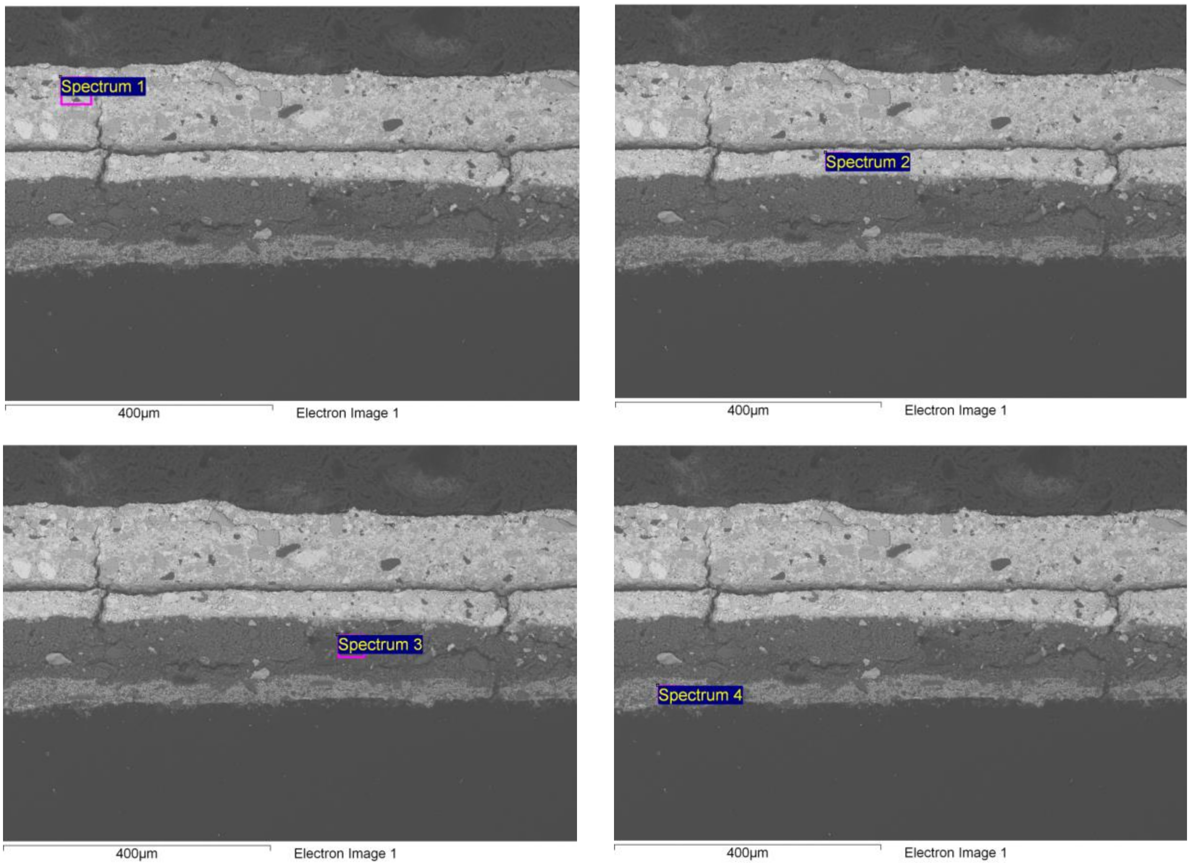

Spectrum 5
200µm
Electron Image 1

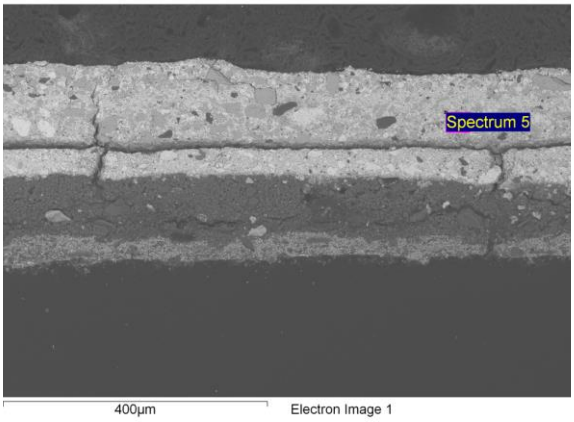

Spectrum 6
200µm
Electron Image 1

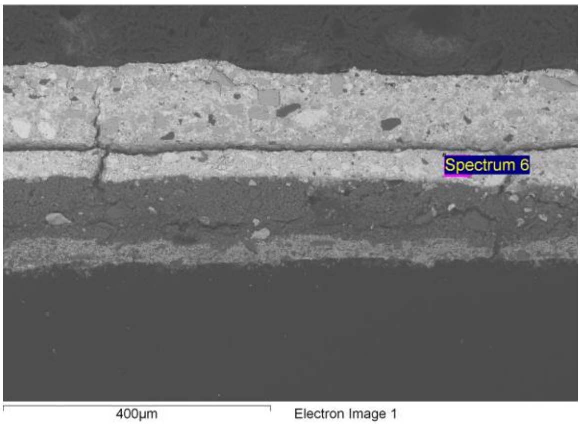
Sample 7: Hestia Giustiniani (2012,5024.27)

	Al	Si	S	K	Ca	Fe	Zn	Ba	Pb	Total
1		4.46	12.15		0.84			27.88	54.68	100
2									100	100
3		2.00	2.64		78.24	2.33	1.75	2.44	10.60	100
4	8.28	8.93	24.81	0.31	5.07	3.37	16.19	30.11	2.91	100
5		10.44	7.02					13.07	69.47	100
6	0.87								99.13	100

Sample 7: Locations. Substrate in upper section of micrograph




Spectrum 5
400µm
Electron Image 1

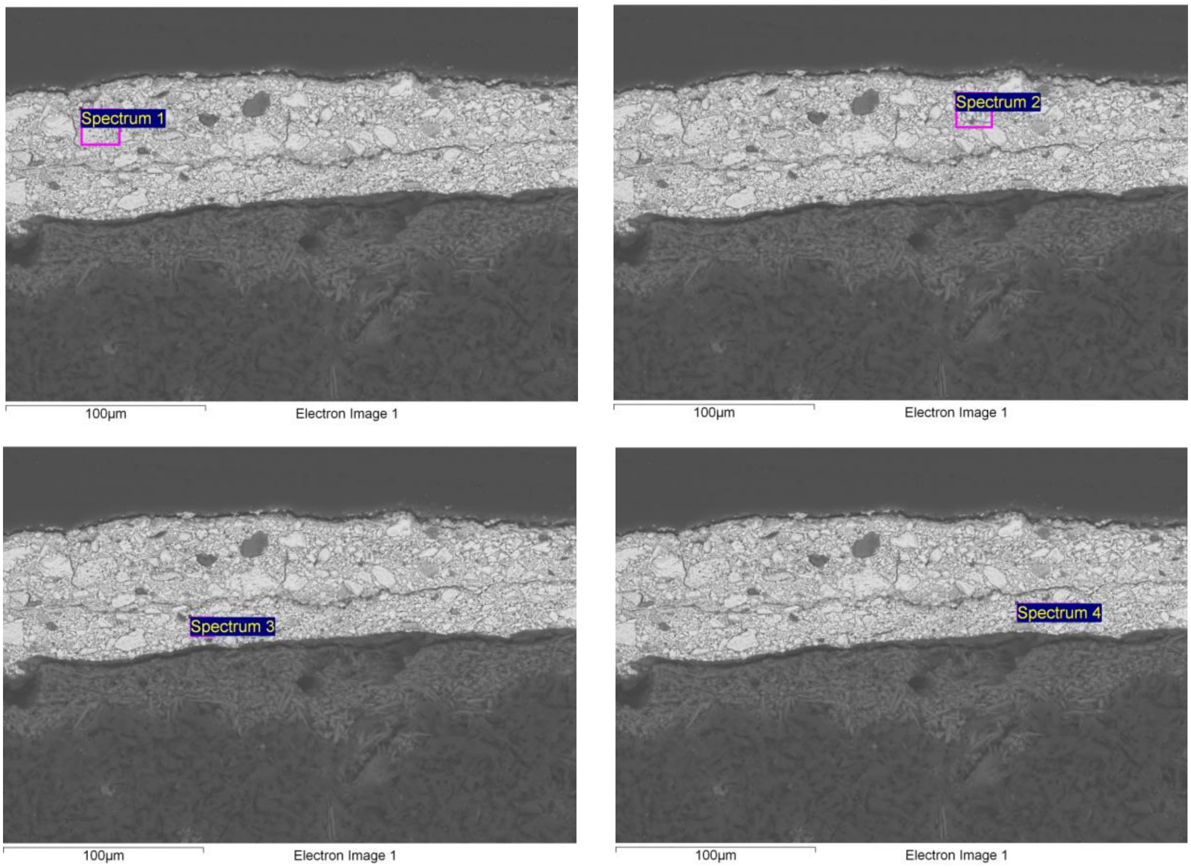

Spectrum 6
400µm
Electron Image 1

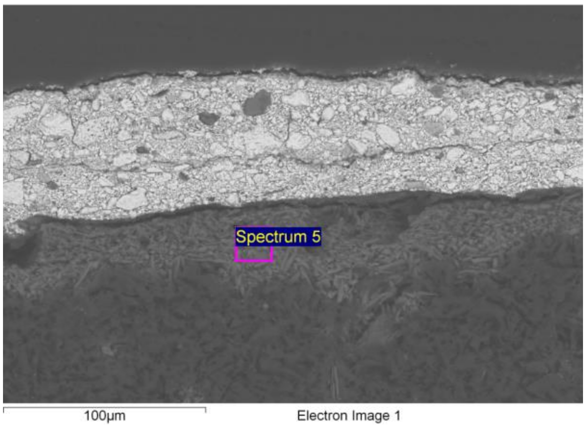
Sample 9: Eleusinian Relief (2012,5024.35)

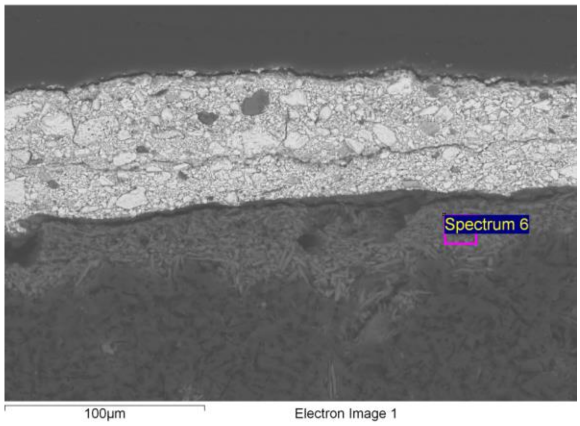
All results in compound %

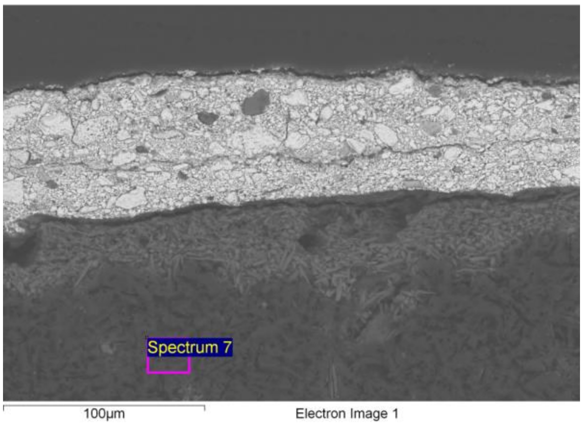
	Si	S	Cl	Ca	Fe	Zn	Ba	Pb	Total
1								100	100
2						1.21		98.79	100
3				0.52				99.48	100
4				0.53	5.73		3.23	90.51	100
5	0.57	57.34		42.08					100
6		58.21		41.79					100
7		56.76		41.49					98.25

Sample 9: Locations. Substrate in lower section of micrograph




Spectrum 5
100µm
Electron Image 1

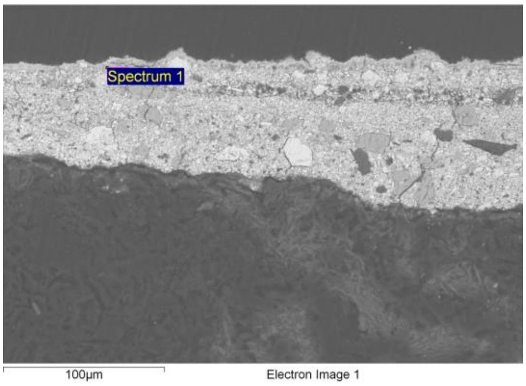

Spectrum 6
100µm
Electron Image 1

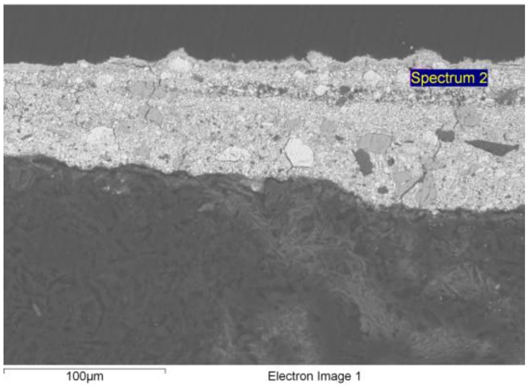

Spectrum 7
100µm
Electron Image 1

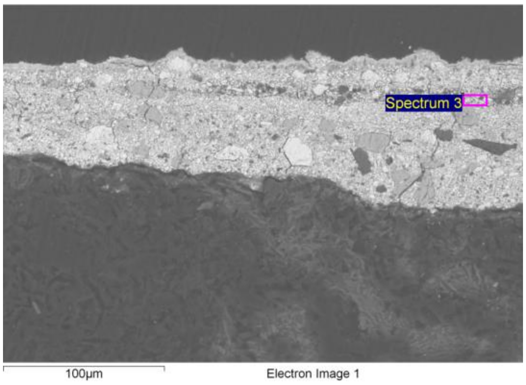
Sample 10: Kouros of Tenea (2012,5024.12)

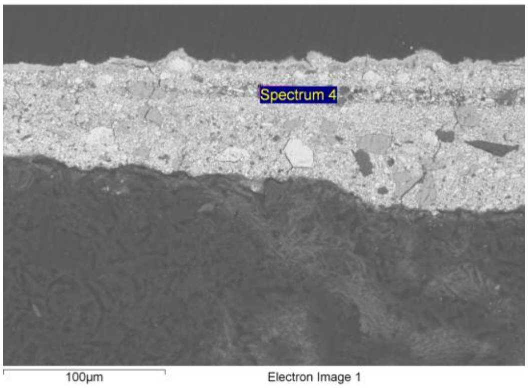
	Na	S	Cl	Ca	Fe	Zn	Ba	Pb	O	Total
1	0.74	2.45	1.22		0.54			84.44	10.60	100
2					1.40			91.16	7.44	100
3						2.13		90.37	7.50	100
4		1.04		1.25		4.80		83.25	9.66	100
5				0.81			3.05	88.62	7.52	100
6		2.34		1.30			9.91	75.44	11.01	100
7		22.84		30.72					46.45	100

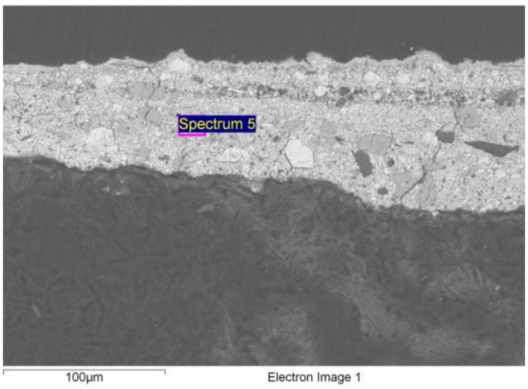
Sample 10: Locations. Substrate in lower section of micrograph

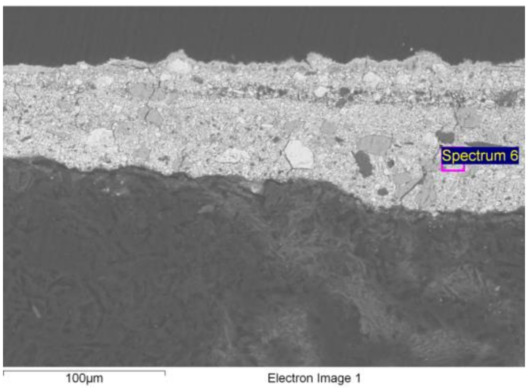


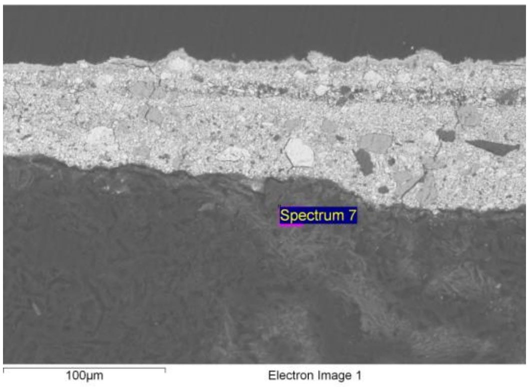











Spectrum 7
100µm
Electron Image 1

Sample 11: Stele of Dexileos (2012,5024.44)

	S	Cl	Ca	Ba	Pb	Total
1				1.68	98.32	100
2			0.71		99.29	100
3	54.93		40.23		4.42	99.57
4				2.65	97.35	100

Sample 11: Locations. Substrate in lower section of micrograph