Figure 1: The 11.62 ct Roman sapphire intaglio examined for this study is engraved on the back side with a hippocamp. Photo by E. Butini, IGN.

Gemmological Analysis of a Roman Sapphire Intaglio and Its Possible Origin

Michael S. Krzemnicki, Flavio Butini, Enrico Butini and Ernesto De Carolis

ABSTRACT: The gemmological analysis of a Roman intaglio engraved with a hippocamp (winged 'sea-horse') reveals that it was carved from a sapphire of basaltic origin. Its bluish grey appearance is due to Rayleigh scattering by sub-microscopic inclusions and is not related to an intervalence charge transfer process. In light of historically documented extensive trade relations between ancient Rome and Ethiopia (the kingdom of Aksum), we hypothesise that the recently documented basalt-related sapphire deposits in northern Ethiopia are a possible source of raw material for this Roman intaglio (as well as other basaltic sapphires used in Roman times), in addition to previously held views that ancient sapphires originate from deposits in Sri Lanka, France and perhaps Southeast Asia. This rare opportunity to characterise in detail one of the very few engraved sapphires from the Roman period permits a better understanding of gem materials used in classical antiquity.

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Antique jewels and gems have long fascinated scholars and the public alike, as they offer an intimate sight into human cultural history, unveiling aspects such as adornment, belief, social and political status, artistic style, fashion and craftsmanship in ancient cultures (Pinckernelle 2007; Spier 2007; Entwistle & Adams 2011; Papagiannaki 2013). This fascination is further based on their relevance to modern life in design and significance (Unger & Van Leeuwen 2017). Antique jewels are also valuable to archaeological science because they can unveil ancient trade routes (e.g. Maritime and Central Asian Silk Roads). Gems and jewels were traded extensively in ancient times together with other goods of value over long distances from their (remote) sources to historical marketplaces and political centres (Begley & Puma 1991; Borell *et al.* 2014; Borell 2017; Galli 2017; Sidebotham 2019).

Jewellery and gems of Roman age have been abundantly studied, but only in a few cases has it been possible to carry out a thorough gemmological analysis of such historical items (Giuliani *et al*. 2000; Calligaro 2005; Lüle-Whipp 2006; Entwistle & Adams 2011; Gast *et al*. 2011; Thoresen & Schmetzer 2013; Schmetzer *et al*. 2017; Thoresen 2017b; Gilg *et al*. 2018). This is mainly due to the fact that they are considered cultural heritage and often are not accessible for testing with laboratory analytical methods.

In this article we describe a glyptic masterpiece: a Roman sapphire intaglio (Figure 1) that was found in 1986 in Pompeii. In late 2017, the Museo Archeologico Nazionale di Napoli loaned the engraved sapphire to the authors for detailed examinations at the Istituto Gemmologico Nazionale (IGN; Rome, Italy) and at the Swiss Gemmological Institute SSEF (Basel, Switzerland). This article provides a description of the glyptic artwork and gemmological characteristics of the specimen, while also considering possible origins for the sapphire raw material and presenting a new hypothesis that could explain its provenance, as well as that other historical sapphires of Roman age (e.g. Butini *et al*. 2018).

HISTORICAL BACKGROUND OF POMPEII

Pompeii was an urban settlement with ancient origins (Figure 2), located on the southern slopes of Mount Vesuvius adjacent to the present city of Pompei in southern Italy. Due to its climate and location, Pompeii developed into an important commercial centre, and first attracted the Greeks and the Etruscans (7th–5th centuries BCE), and later the Samnites (4th century BCE). In the 3rd century BCE, although never conquered by military force, Pompeii became part of the economic

Figure 2: This drone photo of the excavated Roman city of Pompeii includes Mount Vesuvius on the skyline, which caused the sudden burial of the area during a major volcanic eruption in 79 CE. Photo courtesy of Wikimedia Commons.

and administrative circuit of the Roman Republic, and in 80 BCE it was transformed into a colony under Roman law (Cooley & Cooley 2013 and references therein).

In 62 CE, Pompeii suffered a devastating earthquake, which left it badly damaged and severely weakened economically. The Emperors Nero and Vespasian promoted the reconstruction of the city, which was quickly restored with luxurious governmental and religious buildings and private residences. However, the city had not yet been completely rebuilt when, between August and November 79 CE, an explosive eruption of Mount Vesuvius buried Pompeii under about 6 m of pumice and ash. Approximately 1,500 inhabitants died (the city's population was estimated between 6,000 and 20,000 people), among them the famous naturalist Pliny the Elder—author of the encyclopaedic *Naturalis Historia*, still today a fundamental reference for the ancient use and provenance of gems. Pompeii was not rebuilt again and by 120 CE vegetation began to cover the area that it once occupied until it disappeared completely (De Carolis & Patricelli 2003, Cooley & Cooley 2013).

In 1748 CE, more than 1,600 years later, the first archaeological excavations of Pompeii began at the behest of the Bourbon Dynasty (of Naples, Italy) following the discovery of Herculaneum (another inhabited centre destroyed by the same volcanic eruption). From the beginning of the 19th century the excavations went through various phases until the unification of Italy in 1861. Pompeii was almost entirely unearthed, although some areas later suffered considerable damage due to bombing during World War II. In 1997 the archaeological area was declared a UNESCO World Heritage Site, and in 2012 the Great Pompeii Project was established with the goal to restore and secure the site.

During the excavation of Pompeii a large number of jewels were discovered, consisting of approximately 800 pieces of jewellery and 94 gemstones. Eleven of these were found in 1986 in two wooden boxes at the House of Gemmarius in the south-eastern part of Pompeii (Figure 3), close to the Porta Nocera (Sodo 1988, 1992; Pannuti 1994; D'Ambrosio & De Carolis, 1997). The gems in these wooden boxes included the sapphire intaglio described here (Museo Archeologico Nazionale di Napoli, Inventario P 39597; see D'Ambrosio & De Carolis 1997), along with an object identified as a 'stone holder' work tool. In this sector of the ancient city, the houses were modest in size, as they were intended for middle-class members of Pompeiian society. The architecture of these buildings reconciled housing with commercial activities, so several workshops were located in this area.

The House of Gemmarius is thought to have been the private home and workshop of a gem cutter and jeweller (D'Ambrosio & De Carolis 1997). This hypothesis is supported by the Latin inscription *Prisco coelator campano gemmario feliciter* ('Prisco from Campania, successful gemstone engraver'; see Toynbee 1951) found on a wall near the house, which supposedly represents an antique billboard. Still, as there is no further written evidence, we cannot fully exclude the possibility that the two boxes just stored the gems of an unknown private owner who lived in the ancient city of Pompeii.

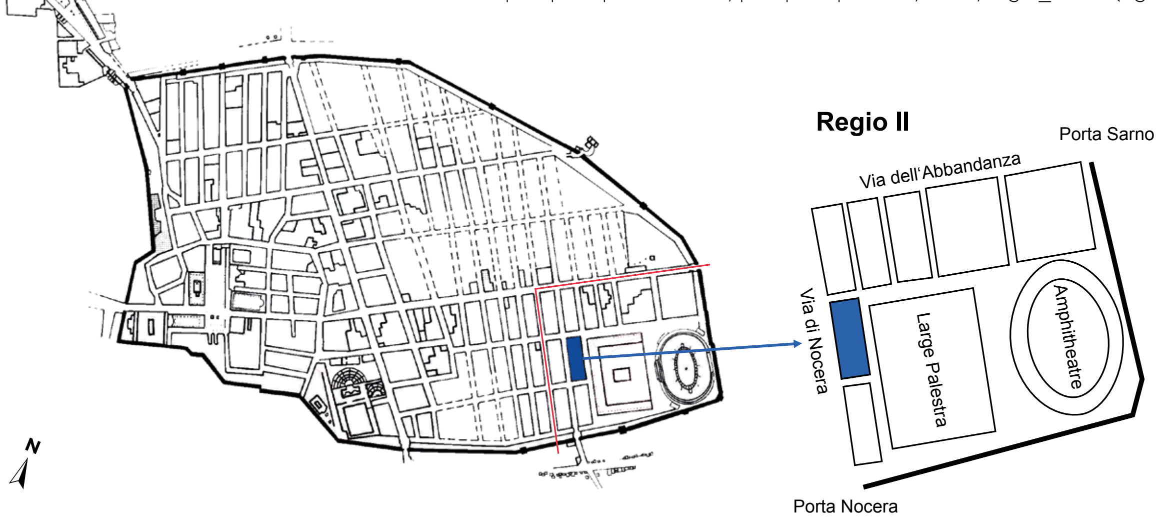

Figure 3: This map of the city of Pompeii indicates the position (blue rectangle) of the House of Gemmarius (regio II, insula 9.2), where a hoard of jewels containing the sapphire intaglio was excavated in 1986. Adapted from drawings courtesy of Wikimedia Commons (left) and https://pompeiiinpictures.com/pompeiiinpictures/Plans/regio_2.htm (right).

MATERIALS AND METHODS

The Roman sapphire intaglio is a flat, oval cabochon measuring 21.78 × 12.27 × 4.31 mm and weighing 11.62 ct.

The intaglio was examined with standard gemmological instruments such as a refractometer (spot method) and a hydrostatic balance (Mettler Toledo), and was also observed under long- and short-wave UV radiation. Detailed microscopic investigation was performed with an Eickhorst Gemmaster trinocular microscope equipped with a Nikon F7000 digital camera.

The intaglio was chemically analysed by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using a Thermo Scientific ARL Quant'X instrument. Also analysed for comparison were four other Roman sapphire cabochons (one light blue and three dark blue) from the collection of author EB. Raman microspectroscopy of inclusions in the intaglio was performed with a Renishaw inVia unit equipped with an argon-ion laser (514.5 nm). Fourier-transform infrared (FTIR) spectroscopy was accomplished with a Nicolet iS50 instrument. Polarised ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra were collected for the o-ray (parallel to the optic axis) in the range of 280–800 nm using a Varian Cary 500 spectrophotometer in transmission mode.

RESULTS AND DISCUSSION

Glyptic and Carving of the Intaglio

The Roman intaglio is a unique piece of cultural heritage, not only because it consists of sapphire—a gem known to the Romans but only rarely used in their jewellery (Spier 2012, Thoresen 2017a, b)—but also because it combines beauty and craftsmanship with a fully documented archaeological provenance. This is very much in contrast to other ancient sapphire intaglios and carvings described in the literature, most of which are from historical gem collections and thus have a more debatable and obscure geographical/historical provenance. Examples of such specimens include the sapphire seal of Alaric II, king of the Visigoths, in the Kunsthistorisches Museum Wien (see Kornbluth 2008; Thoresen 2017b), the Cambridge sapphire cameo depicting Aphrodite (Guy Ladrière Collection; see Ogden 1982; Thoresen 2017b) and other engraved sapphires of Roman age described previously (Spier 2007; Content 2016; Thoresen 2017b).

The sapphire intaglio examined here is a flat, oval cabochon that was masterfully carved (Figure 4) on the back surface. As the sapphire is nearly free of inclusions, the carving is very discernible through the stone, perfectly revealing the fine details of the engraving

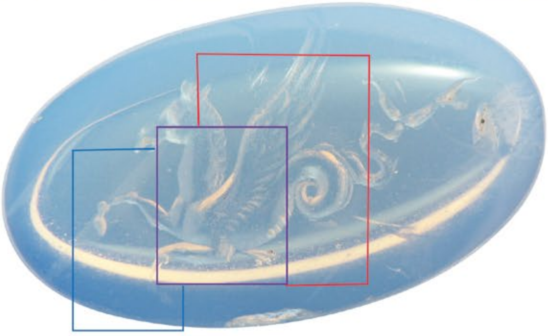

Figure 4: Details of the Roman sapphire intaglio reveal the craftsmanship involved in the creation of this gem. Photomicrographs by E. Butini, IGN; magnified 10×–20×.

Figure 5: This iron tool with a diamond tip for engraving gems was assembled by the authors based on descriptions in the literature. Photo by E. Butini, IGN.

and craftsmanship of the artist (again, see Figure 1). The carving depicts a mythological creature known as a hippocamp—*hippokampoi* or ἱππόκαμπος in Greek, derived from ἵππος (horse) and κάμπος (sea monster)—a winged 'sea-horse' that has the upper body of a horse and the lower body and the tail of a fish. Since ancient times, this motif has been one of the most common emblems of the marine world. Specifically, it appears as one of the symbols of Poseidon/Neptune, and is seen pulling his chariot or being ridden by him (Smith 1849; Charbonneau-Lassey 1994). In addition, the hippocamp is frequently depicted together with Tritons (sons of Poseidon) or Nereids (sea nymphs in Greek mythology), and because of their association with the ocean they are often engraved in 'sea-coloured' gem materials, notably aquamarine (L. Thoresen, pers. comm. 2019; see also Zwierlein-Diehl 2007 and specimen 732 in the Marlborough Gem Collection described in Boardman *et al*. 2009). Hippocamps may be depicted on Hellenistic, Roman and more recent engraved gems (see Richter 1920; Greifenhagen 1970; Zwierlein-Diehl 1991; Spier 1992; Pannuti 1994), as well as on coins (Calciati 1986), sarcophagi (Magni 2009), frescoes (Iacopi 1943) and mosaics in Roman bathing facilities (Di Nunno 2015).

Our study reveals that the hippocamp engraving on this sapphire was carried out with great detail and accuracy (Figure 4, again). Presumably, this was done using a lathe with pivots and rotating hand-drills of various sizes that were impregnated with oils, grease and abrasives. The engraving may have also been accomplished with the aid of iron tools containing diamond tips (e.g. Figure 5). These tools were well known in Roman times (Maaskant-Kleibrink 1978, 1989; Ogden 1982, 2018; Devoto 1985; Rosenfeld *et al*. 2003), and were used for engravings in stone and gems of high hardness (corundum is 9 on the Mohs scale).

The authors were especially intrigued by small carving traces close to the hippocamp's caudal fin (see arrows in Figure 6) that were visible with the microscope. Although possibly accidental notches caused by a rotating disk, the authors favour another interpretation: at least some of them were made intentionally by the artist to express dynamic movement of the hippocamp, similar to what we recognise today as kinetic markers to express movement and speed in cartoons and comics. The authors incline to this latter hypothesis after having examined numerous other ancient engraved gems that appear to us to show similar kinetic markers. For example, Figure 7a shows a glass 'paste' carving of Roman age reportedly originating from the Middle East (residing in a private collection) that depicts a mythological creature which exhibits five small notches near the end of its tail. These notches are very similar to those of the present sapphire intaglio and, when interpreted as kinetic markers, create a sensation of motion. An even more supportive example is shown by an early Roman green Cr-bearing chalcedony (from author EB's collection) that portrays a man operating a pedal lathe used to produce vases (Figure 7b). Several kinetic markers clearly represent his foot moving up and down on the pedal.

Figure 6: Small notches along the tail of the hippocamp might be kinetic markers added to suggest movement. Photomicrograph by F. Butini, IGN; magnified 15×.

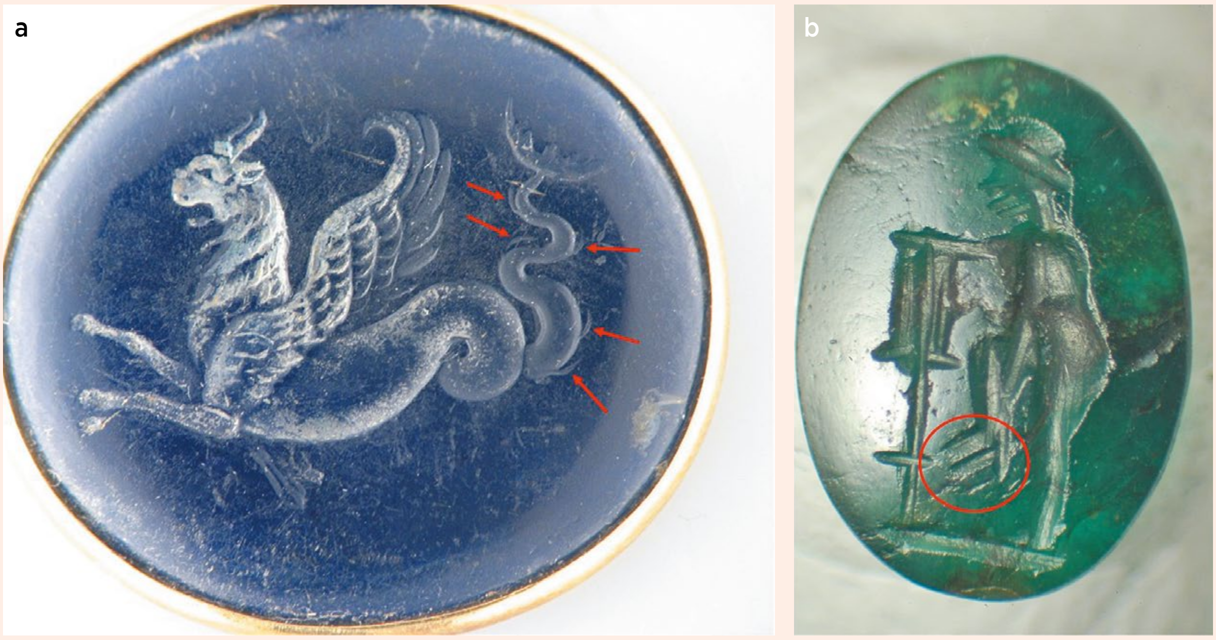

Figure 7: (**a**) This Middle Eastern glass paste intaglio (dating from around the time of the Roman Empire) measures approximately 35.0 × 25.0 mm and depicts a mythological creature. The red arrows point to kinetic markers similar to those inferred in Figure 6. (**b**) An early-Roman intaglio of chromium-bearing chalcedony (8.42 × 6.14 mm) depicts a man operating a pedal lathe. Kinetic markers (see red circle) represent the up-and-down movement of his foot. Photos by F. Butini, IGN.

Gemmological Properties

The sapphire intaglio is translucent and appears light bluish grey in most lighting situations, but it is greyish brown when viewed in transmitted light (Figure 8). The bluish grey appearance is the result of light scattering by sub-microscopic dispersed inclusions within the gem, as discussed in more detail below.

The sapphire had an average RI of about 1.77 (spot method) and an SG value of 4.0, both characteristic for corundum. It was inert to long- and short-wave UV radiation. Viewed with the microscope, the sapphire showed a slightly zoned 'velvety' turbidity due to fine sub-microscopic particles (Figure 9). In addition, the specimen contained a few partially healed fissures, characterised by dispersed and randomly structured fluid inclusions. Some of the larger fluid inclusions had expansion discs consisting of a mirror-like internal plane surrounded by a rather thick and structured whitish rim of fluid droplets (Figure 10). Interestingly, these expansion discs locally contained tiny prisms in radial arrangements (see arrow in Figure 10). Based on their visual appearance, they are assumed to be an Al-hydroxide (e.g. diaspore), typical of late-stage precipitates in fissures, partially healed fractures and fluid inclusions

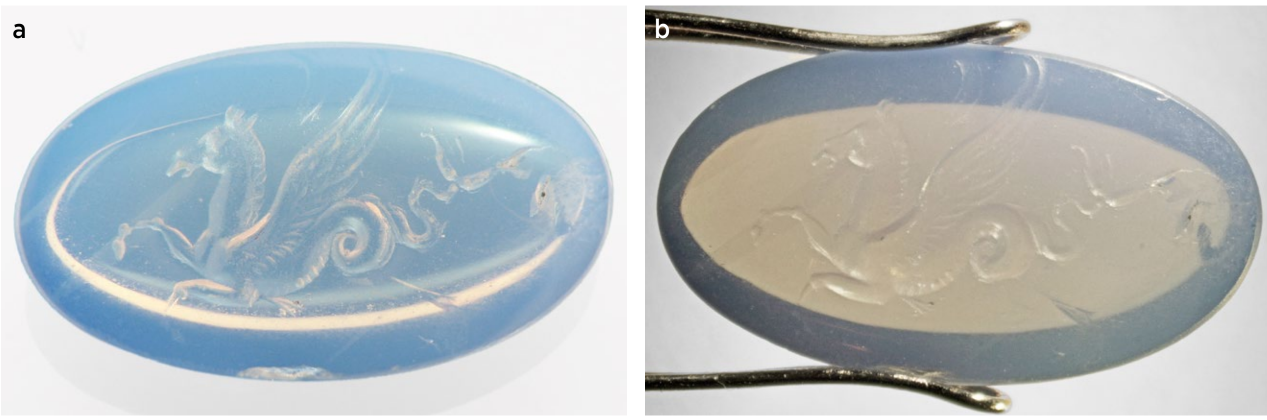

Figure 8: A comparison of the Roman intaglio in (**a**) reflected light and (**b**) transmitted light reveals the different colour appearances of the sapphire (bluish grey and greyish brown, respectively). Photos by M. S. Krzemnicki, SSEF.

Figure 9: Zoned turbidity is present throughout the Roman sapphire intaglio. Photomicrograph by M. S. Krzemnicki, SSEF; image width 10 mm.

Figure 10: Magnification reveals twin planes and a healing fissure with dotted fluid inclusions in the Roman sapphire intaglio. The larger fluid inclusions show structured expansion discs. The main expansion disc contains tiny, radially arranged needles interpreted as Al-hydroxide precipitates (red arrow). Photomicrograph by M.S. Krzemnicki, SSEF; image width 4 mm.

Figure 11: Small idiomorphic plagioclase (albite) inclusions, identified by Raman microspectroscopy, are also present in the sapphire intaglio. Photomicrograph by M. S. Krzemnicki, SSEF; image width 2 mm.

in unheated sapphires from various locations (e.g. Smith 1995; Hughes 1997). In addition, we found a few small twin planes, as well as colourless idiomorphic inclusions (Figure 11) that were identified by Raman microspectroscopy as Na-rich plagioclase (albite).

The observed microscopic features are consistent with those described in sapphires associated with alkali basalt (Guo *et al*. 1992; Smith *et al*. 1995; Krzemnicki *et al*. 1996; Gübelin & Koivula 2008; Pardieu *et al*. 2014). The specific nature of the mirror-like expansion discs with structured white rims indicates that a natural heating of the sapphire occurred (i.e. associated with its entrainment in alkali basalt). No indications of heat treatment were found in this sapphire, although heating of gemstones was known and practised in antiquity, as documented in ancient literature such as the *Papyrus Graecus Holmiensis* codex (also known as 'The Stockholm Papyrus'; Anonymous ca. 300 CE) that was compiled in the 3rd century CE (see also Caley 1927; Francis 1986; Hackens & Moucharte 1989; Sax 1996), and in Roman times by Pliny the Elder (23–79 CE) who mentioned gem treatments in a more general context in his *Historia Naturalis* (see, e.g., Hughes 1997, p. 103).

Chemical Composition and Spectroscopy

The trace-element analysis by EDXRF revealed that this sapphire of bluish grey appearance contained a relatively high amount of Fe (0.41 wt.% Fe_2O_3), traces of Ti (0.03 wt.% TiO_2) and Ga (0.02 wt.% Ga_2O_3), and almost no Cr (at the detection limit). This composition fits well with basaltic sapphires when plotted according to their trace-element ratios (Figure 12; as proposed by Abduriyim & Kitawaki 2006 and Giuliani *et al*. 2014). Because this Roman sapphire intaglio is an archaeological artefact and considered part of the historical heritage of Italy, it was not possible to analyse its trace-element composition further by laser ablation inductively coupled plasma mass spectrometry (e.g. GemTOF; Wang *et al*. 2016), as this method would have been slightly destructive (leaving a laser ablation spot). We also used EDXRF to analyse four other Roman sapphires, and three of them were found to be of basaltic origin while only one was of metamorphic origin (most probably Sri Lanka; see Figure 12). The abovementioned analytical limitation may explain why the data obtained by EDXRF on our samples mostly plots outside the indicated distribution fields for basaltic sapphires (which were defined using LA-ICP-MS data).

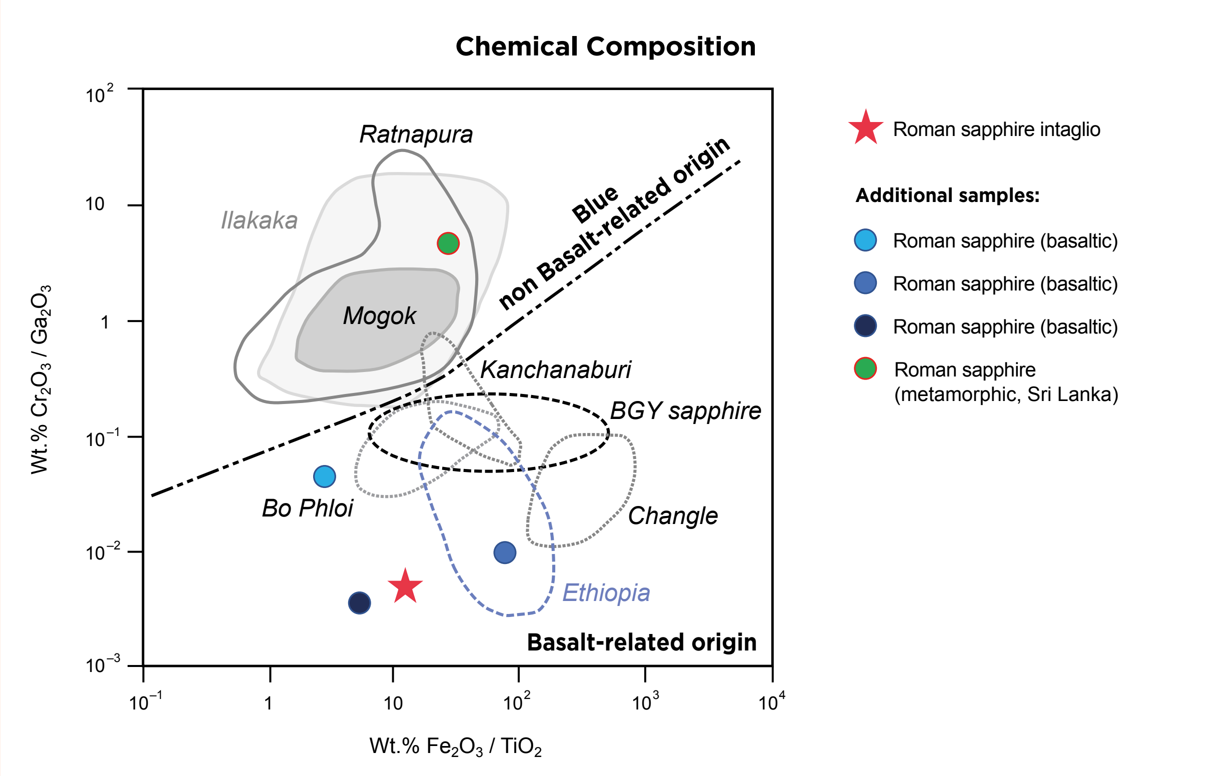

Figure 12: A trace-element ratio diagram reveals that the Roman sapphire intaglio is of basalt-related origin, similar to three other Roman sapphires. An additional Roman sample was found to be of metamorphic origin. The distribution field for Ethiopian sapphires is based on samples in the SSEF research collection. Diagram adapted from Abduriyim & Kitawaki (2006) and Giuliani *et al.* (2014).

FTIR spectroscopy of the sapphire intaglio revealed distinct hydroxide (OH^-) features, with a band at 3309 cm^{-1} dominating a series of lines at 3393, 3377, 3366, 3231 and 3183 cm^{-1} (Figure 13). Such a pattern has been attributed to intrinsic hydrous defects within the sapphire structure (Smith *et al.* 1995; Beran & Rossman 2006), and is commonly found in sapphires from basaltic deposits (unheated and heat treated) and also in metamorphic sapphires that have been heat treated. The features in the range of 2800–2950 cm^{-1} in Figure 13 are due to organic contamination (e.g. skin oils) and are not intrinsic to the sapphire.

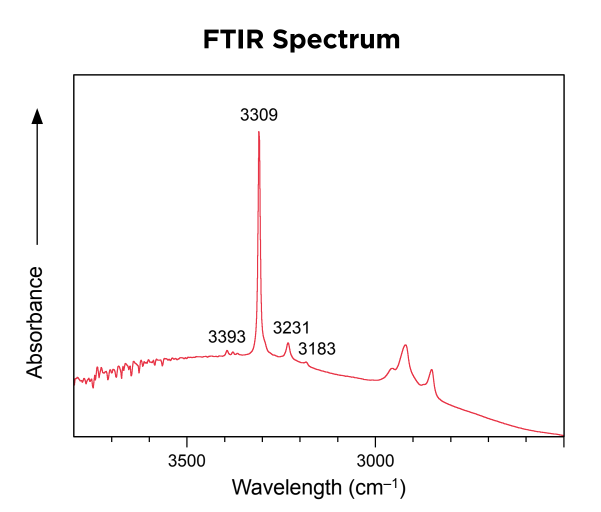

Figure 13: The FTIR spectrum of the Roman sapphire intaglio shows a characteristic pattern—band at 3309 cm^{-1} accompanied by a series of small features—for the presence of hydroxide (OH–) in sapphire.

UV-Vis-NIR spectroscopy of the intaglio obtained in transmission mode yielded an absorption curve related to the sapphire's greyish brown body colour (Figure 14). In detail, the spectrum was dominated by a steady increase in absorption from the near infrared towards the ultraviolet region, superposed only by small peaks related to Fe^{3+} at 450, 387 and 376 nm (Figure 14). The general absorption trend in combination with an absorption edge at about 340 nm is mainly due to the presence of numerous sub-microscopic particles that cause the slightly milky appearance of the stone.

The sapphire showed no absorption band centred at 560 nm related to Fe^{2+}–Ti^{4+} intervalence charge transfer (IVCT; Schmetzer & Bank 1981) nor at about 870 nm related to Fe^{2+}–Fe^{3+} IVCT (Ferguson & Fielding 1971;

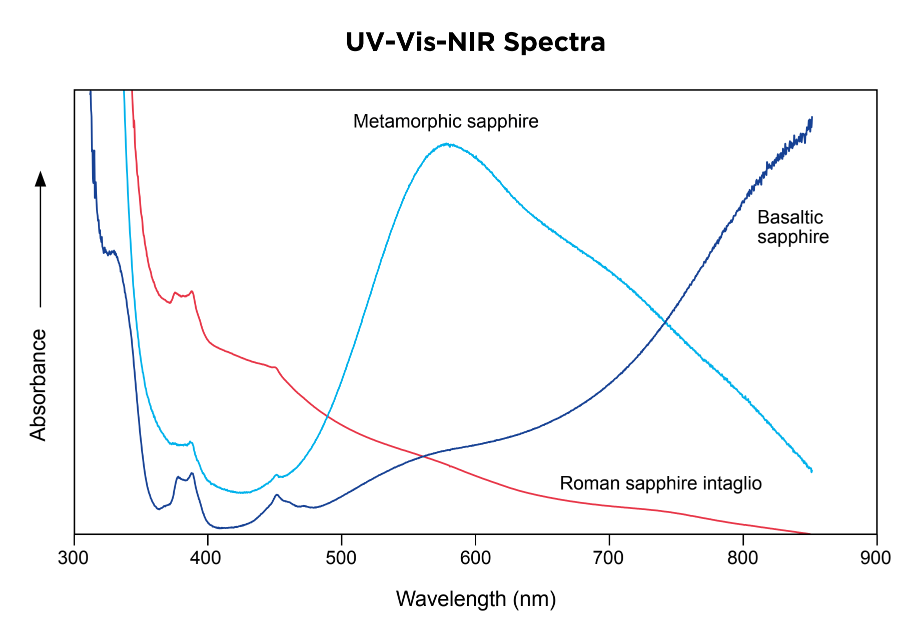

Figure 14: The polarised UV-Vis-NIR absorption spectrum of the Roman sapphire intaglio is very different from those of typical metamorphic and magmatic (basaltic) sapphires, which owe their blue colour to Fe^{2+}–Ti^{4+} and/or Fe^{2+}-Fe^{3+} intervalence charge transfer. The bluish grey appearance of the Roman sapphire is thus not related to absorption, but is the result of Rayleigh scattering by sub-microscopic inclusions. The turbidity caused by these inclusions induces a broad absorption band towards the UV region.

Schmetzer & Bank 1981). These two broad bands (either alone or in combination) are normally the main cause of blue colour in metamorphic and magmatic sapphires (see blue traces in Figure 14; Schmetzer & Bank 1981; Fritsch & Mercer 1993). Therefore, we conclude that the apparent bluish grey colour of this sapphire is not related to absorption but is only the result of Rayleigh scattering by the sub-microscopic particles within the sapphire. Similar scattering effects are well known in sapphires from both metamorphic and basaltic origins (Hänni 1990; Krzemnicki *et al.* 1996; Hughes 1997; Gübelin & Koivula 2008). In such sapphires, the scattering effect supports the blue colour that is mainly caused by IVCT absorption. By contrast, bluish colour caused mainly or only by Rayleigh scattering—as for the sapphire intaglio described here—is rather uncommon and has been described previously for basaltic sapphires from Nigeria (Pardieu *et al.* 2014). Nowadays, such stones are commonly heat treated to enhance their blue colour by creating Fe^{2+}–Fe^{3+} and Fe^{2+}–Ti^{4+} IVCT absorption bands.

POSSIBLE SAPPHIRE ORIGIN

The few sapphires found in jewellery from the Roman period can be divided into two groups: small, dark sapphires of basaltic origin (mostly lenticular beads) and paler sapphires presumably of Sri Lankan origin (Thoresen 2017a, b; J. Ogden, pers. comm. 2019). In the literature, most Roman sapphires have been attributed Sri Lanka—called Taprobanê in Greek and Roman times—which has been known since antiquity for its gem wealth (see also the ancient text *Periplus Maris Erthraei*; Casson 1989). Stones from this origin are commonly described as being imported into the Roman Empire from the East along the maritime silk route (Ogden 1982; Sevillano-López & Gonzalez 2011; Hughes 2017; Seland 2017). However, since Sri Lanka's secondary gem deposits contain only metamorphic sapphires (and no basaltic ones), it appears that there were other sapphire sources available to the Romans that provided basaltic sapphires for their jewels.

In considering a possible origin of the present intaglio—as well as other basalt-related Roman sapphires—a conclusive determination is presently not possible due to similarities in the characteristics of basaltic sapphires from various deposits. The inclusion features, trace-element concentrations, UV-Vis-NIR absorption and oxygen isotopic signatures of sapphires from alkali basalts are rather uniform, and this is very much in contrast to those from metamorphic deposits such as Ratnapura or Elahera in Sri Lanka, Mogok in Burma and Kashmir in India (Hänni 1994; Abduriyim & Kitawaki 2006; Giuliani *et al.* 2014; Wang *et al.* 2016), for which origin determination is more feasible.

Although sapphire deposits related to alkali basalts are known today from many localities (e.g. Cambodia, Laos, Vietnam, Ethiopia, Rwanda and Nigeria to name a few; see Giuliani *et al.* 2014 and references therein), it is not presently known which of these deposits were productive in the 1st millennium CE. One of the few historical basaltic sapphire deposits is located in the

Massif Central (Puy-en-Velay) in France. Although its initial discovery (first mentioned at the end of 13th century) is generally assigned to medieval times (Forestier 1994; Gaillou 2003; Médard *et al*. 2012), it is possible that these sapphires had been found much earlier in alluvial sediments of this area. Furthermore, Ogden (2015) suggested the Massif Central as a possible source of dark blue sapphires (typical for iron-rich sapphires from alkali basalts and related volcanic rocks) in the ancient Roman period. However, to our knowledge there are no historical accounts of Roman sapphires from the Massif Central, so this option is possible but remains hypothetical.

Sapphires related to alkali basalts have been known since the 19th century from Scotland (e.g. from Arran, Mull, Ardnamurchan and Aberdeenshire; see Smith *et al*. 2008), but there is no evidence that these localities were known by the mid-1st century CE, when the Roman Empire just started its conquest of northern Britain. In addition, these Scottish sapphires are commonly described as being small and mostly not of gem quality.

Another source of basaltic sapphires in Roman times might be alkali basalt-related deposits in Southeast Asia, such as those in Thailand (Gunawardene & Sing Chawala, 1984; Saeseaw *et al*. 2017), Cambodia (Jobbins & Berrangé 1981), southern Vietnam (Smith *et al*. 1995), Laos (Sutherland *et al*. 2002), or even China (Guo *et al*. 1992; Keller & Keller 1986; Wang 1988). We know that in Roman times the Mediterranean was connected to the Far East along the Maritime Silk Route (Borell *et al*. 2014; Dimucci 2015). This has led authors in the past to attribute antique sapphires of basaltic origin to such Southeast Asian deposits, although in our opinion the analytical data presented to support such claims (Butini *et al*. 2018) often do not stand up to critical scrutiny.

Current productive sources such as Australia (New South Wales and Queensland), Nigeria, Rwanda, northern Madagascar and Colombia, to name a few, can be excluded, as they were beyond reach in Roman times and no historical account has documented their discovery that early.

Although the authors have no scientific proof, we propose a new hypothesis for the origin of (some) basaltic sapphires used by the Romans: that they came from surface deposits in northern Ethiopia which were already known and productive in ancient times, but that were possibly abandoned later, forgotten, and only recently rediscovered. This hypothesis is supported by comments made by Pliny the Elder (23–79 CE) and Solinus (early 3rd century CE), both of whom referred to gems from Ethiopia (J. Ogden, pers. comm. 2019) and specifically mentioned *hyacinthos*, which is generally accepted in archaeology to be the ancient name for sapphire (Thoresen 2017a). Specifically, Pliny the Elder stated 'Ethiopia, which produces hyacinthos, produces chrysolithos also, a transparent stone with a refulgence like that of gold' (Eichholz 1962), and Solinus indicated 'Amongst those things of which we have spoken [in Ethiopia] is found the hyacinthos of a shining sky blue colour' (Apps 2011).

Basalt-related sapphire deposits in northern Ethiopia are located near the town Chila (Tigray region), about 25 km northwest and north of the town of Aksum (Bruce-Lockhart 2017; Vertriest *et al*. 2017). Structurally, this area is located at the northern end of Africa's Great Rift Valley dominated by geologically young extensional tectonics (Tertiary to Quaternary; Corti 2009), similar to sapphire deposits further south of this large-scale structure, such as near Lake Turkana in Kenya (Themelis 1989) and Cyangugu in southwestern Rwanda (Krzemnicki *et al*. 1996). This region is dominated by extensive igneous (magmatic and volcanic) rock suites, including alkali basalt and associated secondary gravels containing sapphires in large quantities, often showing strong turbidity or milkiness (Lucas *et al*. 2018) similar to the Roman intaglio of this study.

Near the northern border of modern Ethiopia, the city of Aksum and its surroundings were an important trading centre during the Aksumite Empire (early 1st century to 900 CE), which controlled northern Ethiopia and part of present-day Eritrea, including the ancient port of Adulis. This port was an important trading hub between the Roman Empire and the Middle East and India (Figure 15), as described by an anonymous merchant or sailor around the middle of the 1st century in *The Periplus Maris Erythraei* ('Voyage Around the Red Sea'; Casson 1989). Recent archaeological excavations of several ancient graves in Aksum revealed numerous artefacts, including jewellery and glass beads, thus offering evidence of intense trade between the kingdom of Aksum and the Roman Empire (Sidebotham 1986, 1996, 2019; Wendrich *et al*. 2003) since the early 1st century CE (Morrison 1989; Alberge 2015).

Although sapphires have not been found so far in any archaeological excavation at Aksum or its surroundings, the present-day deposits in Ethiopia might have been known in antiquity, as they are located within the realm of the ancient kingdom of Aksum. In addition, the deposits are readily accessible (in mining terms) on the surface and in shallow gravel layers, such that sapphires could be easily gathered from the ground (Vertriest *et al*. 2017, Lucas *et al*. 2018).

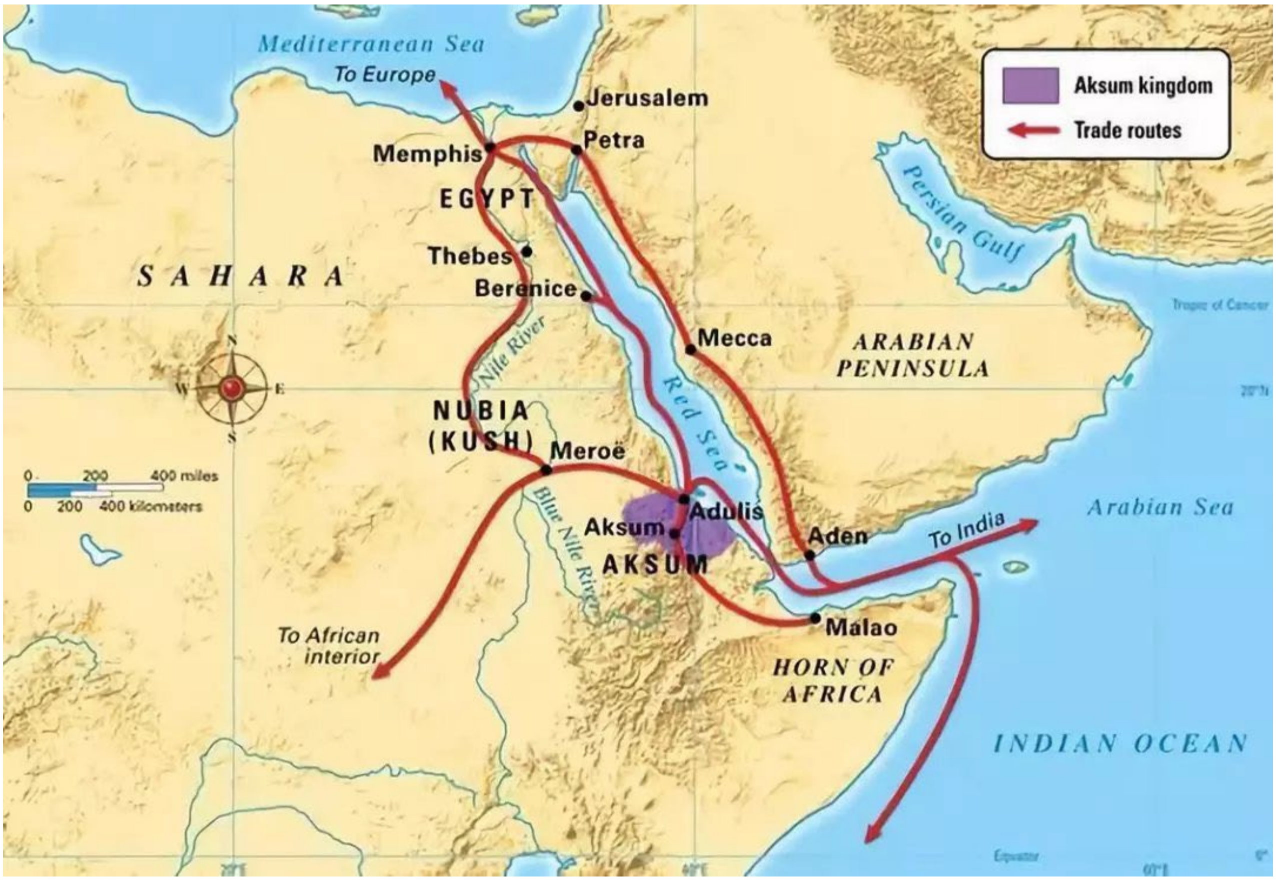

Figure 15: This map illustrates ancient trade routes from Aksum towards the Roman Empire and elsewhere.

CONCLUSIONS

This study provides a rare case where a gemstone of archaeological significance and documented provenance (1986 excavation of Pompeii, Italy) could be analysed in a laboratory setting with advanced analytical methods. Based on our analytical data and microscopic observations, we conclude that the studied Roman intaglio was made from an unheated basaltic sapphire. A possible origin from gem gravels of Sri Lanka—known since antiquity as a source of (metamorphic) sapphires and many other gems—can be definitively excluded, although the gem's hazy light bluish grey colour appearance might be considered reminiscent of some Sri Lankan sapphires. Due to its close similarity in trace-element composition to basaltic sapphires from various deposits, a clear geographic origin for this Roman sapphire intaglio cannot be determined based on the currently available data.

In addition to the existing literature, which commonly refers to the origin of ancient sapphires as Southeast Asia and the Far East, we propose an Ethiopian origin for the studied Roman intaglio as similarly plausible, although we have no direct evidence (by gemmological data, archaeological excavations or historical accounts) to support our hypothesis. Another option for such basalt-related sapphires might be the Massif Central in France. Although first mentioned only in the 13th century (Forestier 1994), they might have been known as early as the 1st century CE.

This study clearly shows that more detailed research on basalt-related ancient (Roman) sapphires is necessary. Especially with the recent progress in gem testing using chemical fingerprinting (e.g. GemTOF; Wang *et al*. 2016), statistical methodology (e.g. non-linear algorithms; see Wang *et al*. 2019) and stable isotopes (e.g. oxygen; see Giuliani *et al*. 2000, 2008, 2014) it might be possible to verify in the future whether the recently documented sapphire deposits near Aksum in northern Ethiopia were known in ancient times as a source of gem-quality basaltic sapphires showing milky bluish or dark blue colouration.

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