THE ARTEMIDORUS PAPYRUS: SOLVING AN ANCIENT PUZZLE WITH RADIOCARBON AND ION BEAM ANALYSIS MEASUREMENTS

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ABSTRACT. Ancient papyrus manuscripts are one of the most fascinating sources for reconstructing not only ancient life habits but also past literature. Recently, an amazing document has come to the fore due to the heated debates it raised: the so-called Artemidorus papyrus. It is a very long scroll (about 2.5 m) composed of several fragments of different sizes, with inscriptions and drawings on both sides. On the recto of the document, a text about geography and some drawings of heads, feet, and hands are present, while on the verso there are many sketches of animals, both real and fantastic. Its importance in classical studies comes from the fact that some scholars claim that it is the first known transcription of a relatively large fragment by the Greek geographer Artemidorus. However, other scholars think that the papyrus is a fake, drawn in the 19th century AD by a well-known forger. In order to overcome all possible ambiguities, the papyrus has been studied not only on the basis of historical and paleographic criteria but also by scientific techniques. We have contributed to the knowledge about the papyrus by radiocarbon dating the document and by analyzing the composition of the ink using ion beam analysis (IBA). Results are compatible with the scroll being an ancient manuscript: accelerator mass spectrometry (AMS) ^{14}C measurements have dated the papyrus to a period between the 1st century BC and 1st century AD, while IBA measurements have pointed out the use of an organic (carbon-based) ink, which was typical of ancient Roman and Greek times. Details of the measurements are presented to emphasize the importance of combining AMS and IBA results.

INTRODUCTION: THE ARTEMIDORUS PAPYRUS

Finding ancient documents, either written on papyrus, parchment, or paper, represents an excellent way for archaeologists to study past civilizations and literature. This is the case, for example, of the study of ancient Egypt, when most of the documents were written on papyrus. What is interesting in modern archaeological surveys is the fact that the discovery of these papyrus manuscripts can sometimes be totally unexpected; for example, they can be found in places identified as sort of scrapyards or on the floors of abandoned houses, like in the Fayum region in Egypt (van Minnen 1994). Among papyrologists, radiocarbon is not very widespread as a dating method; they are rather used to dating ancient documents on the basis of paleographic criteria. However, ^{14}C has been employed in some of the most controversial questions where papyri are involved: for example, the dating of the Dead Sea Scrolls (Bonani et al. 1992; Jull et al. 1995). The Artemidorus papyrus, the document we discuss in this paper, is not as famous as the Dead Sea Scrolls, but it has been at the center of a heated debate about its authenticity, especially in Italy, Germany, and throughout Europe.

The Artemidorus papyrus has huge and amazing dimensions: about 2.5 m long and 32 cm high (Gallazzi et al. 2008). It does not consist of a unique sheet but rather is composed of several fragments. This fragmentation is certainly a consequence of the history of the document. It was found in a private collection in the 1970s, appearing packed in a mass kept together by glue and gypsum. In this form, papyrologists have hypothesized that, after being thrown away as a writing support, it had been used as a filling for a little mummy. This kind of reuse has been well documented in some other cases (Salmenkivi 2002). The papyrus mass was disassembled and about 200 fragments were recovered. These fragments were classified in 2 separate groups. In the first one, the scholars collected fragments belonging to 25 documents that have been dated to AD 70–100 on the basis of paleographic studies or from chronological information written on some of them. The remaining frag-

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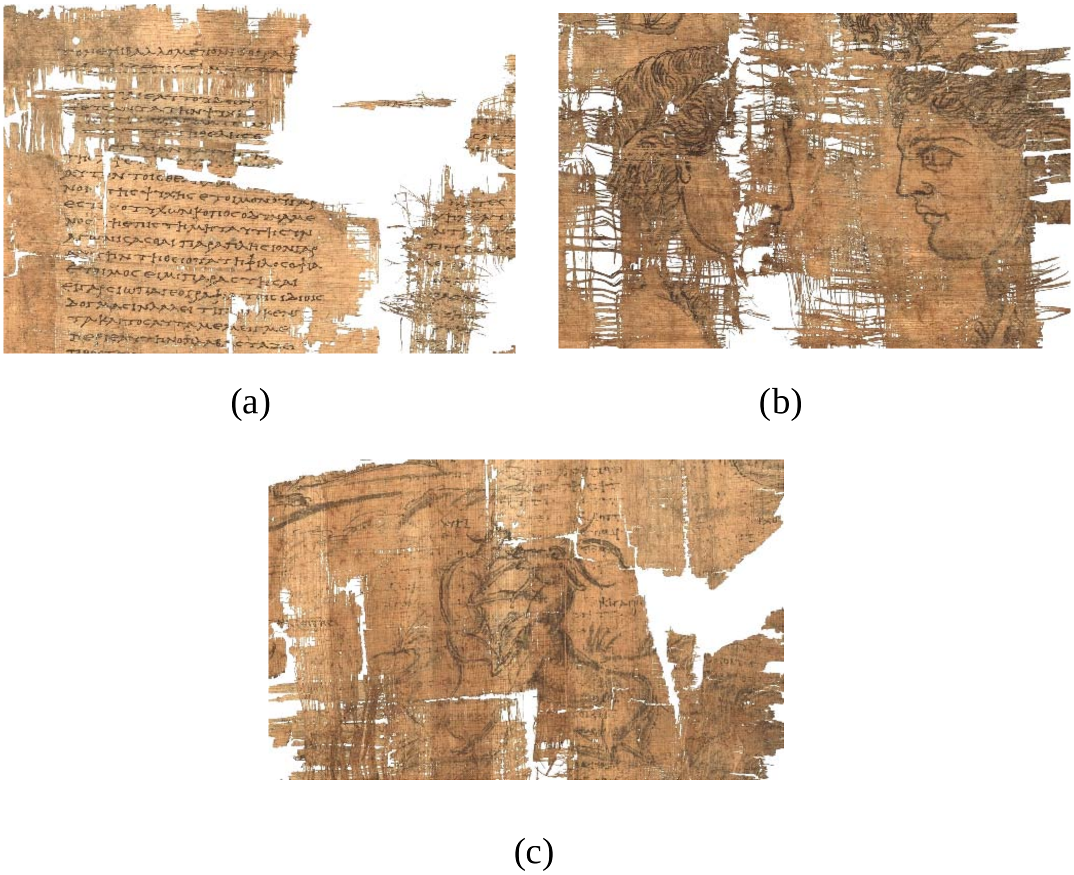
ments were found to be part of a unique document that has been reconstructed in the form we now call the Artemidorus papyrus. The name of this document is related to the topic of the text written on its recto: a dissertation on the meaning of geography and a description of what has been recognized as the Iberian Peninsula. A draft of a map, probably just the Iberian Peninsula, is also present (Kramer 2001). Some papyrologists have interpreted this text as the first known transcription of a work by the famous geographer of Hellenic times Artemidorus of Ephesus, who thus gave his name to the roll. The written text and the map are not the only inscriptions on the papyrus (see Figure 1). On the recto, besides the already mentioned text, there are also several drawings of heads, hands, and feet, while the verso is full of sketches of animals, both real (e.g a tiger, a giraffe and some fish) and fantastic (e.g. a griffin).



(a) (b)

(c)

Figure 1 Details from the Artemidorus papyrus: a portion of the written text (a) and the drawing of 2 heads (b) from the recto, and 2 fighting animals from the verso (c). Reproduced with permission from Gallazzi et al. (2008).

Given the richness of the inscriptions, some scholars claim that the papyrus is a very valuable document, one of the few ancient maps surviving to the present day. Others claim that it is simply a fake from the late 19th century, a time when collecting papyri was fashionable in Europe. Critics of the document’s authenticity even indicate the possible forger, the well-known Greek Costantinos Simonides.

Without entering into the details of the polemics, we present the results of our measurements on the papyrus. First, we dated the papyrus support using ^{14}C accelerator mass spectrometry (AMS). We also analyzed the composition of the ink by ion beam analysis (IBA). The composition of ink does not directly give a date. However, not all kinds of ink were used in each historical period; for example, iron gall inks were used routinely only starting in the late Middle Ages, while carbon black inks were commonly used since a few millennium BC (http://www.knaw.nl/ecpa/ink/; Zerdoun Bat-Yehouda 1983). In this sense, IBA measurements can constitute a further indication of the period when the document was written. Combining the results of ^{14}C dating and of the studies on ink composition is an approach already used in discussions on the authenticity of important documents: for example, the case of the Vinland Map is well known (Donahue et al. 2002; Harbottle 2008). In the present case of the Artemidorus papyrus, both AMS ^{14}C and IBA measurements were performed by the same research group at the LABEC (Laboratorio di tecniche nucleari per i Beni Culturali) in Florence, Italy. Meanwhile, AMS ^{14}C dating was performed also at the laboratory CIRCE (Center for Isotopic Research on the Cultural and Environmental Heritage) in Caserta, Italy.

MATERIALS AND METHODS

AMS Radiocarbon Measurements

Five papyrus samples were collected from 5 different areas of the scroll, both from the lower and upper sides, spanning its length, in order to avoid possible ambiguities due to the fact that the document consists of several different fragments. The collected samples are categorized:

- Arte1: close to the geographical map, about in the middle of the scroll;
- Arte2: close to the so-called exercises (i.e. sketches of hands and feet), at the bottom right;
- Arte3: close to the first column of text;
- Arte4: close to the first column of text;
- Arte5: a tiny fragment from the area of the map and another tiny sample close to the fifth column of text.

These samples, each with a mass <5 mg, were then shared between LABEC (Arte1, Arte2, and Arte3) and CIRCE (Arte4 and Arte5). Samples were pretreated following a typical ABA procedure (Cartocci et al. 2007; Passariello et al. 2007). For samples prepared and measured at LABEC, before ABA treatment, samples were washed in an ultrasonic bath with deionized water for 10 min and then dried in a vacuum oven at 100 °C for 2 hr to enhance the removal (by degassing) of any resin-like traces, following a procedure that is typical for cleaning vacuum components (Reid 1999).

Sample combustion to collect gaseous CO_2 is achieved by different methods in the 2 laboratories. At LABEC, samples were burnt in a CHN elemental analyzer (ThermoFinnigan Flash EA1112) and CO_2 was trapped after the gas chromatographic column; at CIRCE, samples were oxidized to CO_2 by combustion together with copper oxide and silver in sealed quartz tubes in a muffle furnace. Afterwards, in both laboratories, graphite cathodes to be measured by AMS were obtained by reaction of the carbon dioxide with hydrogen, using iron as catalyst (Vogel et al. 1984).

Arte1, Arte2, and Arte3 were measured at LABEC using the 3MV Tandetron accelerator (Fedi et al. 2007); Arte4 and Arte5 were measured at CIRCE by the 3MV Pelletron accelerator (Terrasi et al. 2008). In both laboratories, ^{14}C concentrations were calculated based on the measured $^{14}C/^{12}C$ isotopic ratios corrected for isotopic fractionation ($^{13}C/^{12}C$ isotopic ratio simultaneously measured in the accelerator beam line during each run) and background. The corrected values were normalized to the isotopic ratio measured for a set of NIST oxalic acid II standards (at LABEC) or IAEA C3 (at CIRCE).

IBA Measurements

Ion beam analysis (IBA) measurements were performed using the external scanning microbeam setup installed at one of the beam lines of the accelerator at LABEC (Giuntini et al. 2007). In the case of the Artemidorus papyrus, proton-induced X-ray emission (PIXE) and backscattering (BS) measurements were performed. Measurement conditions are summarized briefly here:

- The incident 2-MeV proton beam was focused on the target by a magnetic quadrupole doublet down to ~50 μm FWHM (although the minimum achievable spot size is 10 μm FWHM).
- The target, i.e. the papyrus, was not placed in vacuum: the proton beam was extracted into atmosphere through a 500-nm-thick Si_3N_4 window (2×2 mm^2 in size). As in our typical external setup, a helium flow was maintained in the volume defined by the exit window, the target, and the detectors in order to minimize energy straggling, energy loss, and spatial straggling of the incoming beam, and to optimize collection of the measured radiations.
- X-ray spectra were collected using a silicon drift detector and a Germanium detector, optimized respectively for soft and hard X-rays; backscattered particles were collected using a Hamamatsu silicon photodiode.
- Elemental maps were acquired by scanning the beam over the target surface using magnetic scanning coils, covering 2×2 mm^2 areas. Measuring time for each scanned area varied from 10 to 20 min, according to the required statistics.

Three different portions of the papyrus, each of them mounted in a glass frame, were analyzed: on the recto, an area with written text in the upper part of the second column, and an area with a sketch of hair in the upper right corner; on the verso, an area with irregular lines in an isolated fragment in the bottom part of the scroll. On the whole, 21 different 2×2 mm^2 areas were scanned.

Measurements Results

Table 1 summarizes the results of AMS measurements. ^{14}C ages were converted to calibrated ages by OxCal v 4.0 (Bronk Ramsey 1995, 2001), using the IntCal04 calibration curve (Reimer et al. 2004). Interestingly samples Arte1–Arte3, prepared and measured at LABEC, are consistent with samples Arte4 and Arte5 prepared and measured at CIRCE: a nice example of a “small” intercomparison between ^{14}C laboratories

Table 1 ^{14}C dating results. Uncertainties on measured ^{14}C ages are quoted as 1 σ.

Sample	^{14}C age (yr BP)	Calibrated age 1-σ range	Calibrated age 2-σ range
Arte1	1974 ± 80	87–79 BC (1.9%) 55 BC–AD 127 (66.3%)	176 BC–AD 225
Arte2	1906 ± 67	AD 24–142 (55.0%) AD 148–171 (7.4%) AD 193–211 (5.8%)	50 BC–AD 255 (95.1%) AD 306–312 (0.3%)
Arte3	1958 ± 33	AD 5–75	41 BC–AD 90 (88.9%) AD 100–124 (6.5%)
Arte4	1947 ± 34	AD 5–85	37–30 BC (1.5%) 22–11 BC (2.8%) 2 BC–AD 127 (91.1%)
Arte5	1903 ± 24	AD 76–126	AD 27–40 (1.7%) AD 49–140 (90.6%) AD 150–170 (1.6%) AD 195–209 (1.4%)

As far as the question of Artemidorus is concerned, we note (see Figure 2) that all papyrus samples can be dated to a period between the 1st century BC and the 1st century AD, thus being compatible with the hypothesis that the scroll, or the papyrus support at least, is an authentic document written in ancient times.

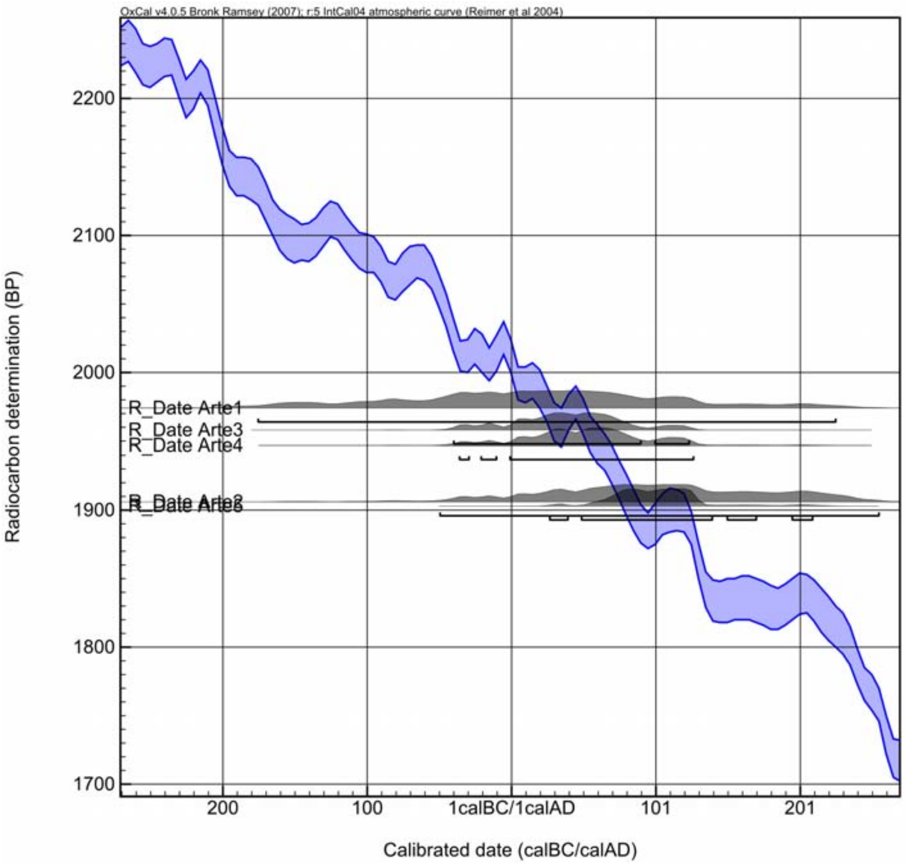


Figure 2 Calculated probability distributions of calibrated ages using OxCal v 4.0 (Bronk Ramsey 1995, 2001), represented on the IntCal04 calibration curve (Reimer et al. 2004).

Concerning the ink analysis, Figure 3 shows an example of the PIXE spectra obtained with the 2 dedicated detectors by bombarding an area (2 × 2 mm^2) of the papyrus (with a trace of ink drawn on it). We notice the presence of many elements, the most abundant being Si, Ca, Fe, and Zn. Of course, these spectra are related to the whole scanned area; thus, detected elements might be due either to the papyrus or the ink trace (or even partly to the glass support). Some remarks can be made already at this step of the analysis. For example, silicon can be reasonably attributed to the glass support; sodium and calcium both to the glass support and to the papyrus. More interesting (and less straightforward to explain) is the presence of other elements, such as iron or zinc (and also sulfur). In principle, they might be considered as markers for the use of an iron gall ink. Indeed, this kind of ink basically consists of iron sulfate, with traces of other metals (zinc, copper, or lead are actually quite common). Such an ambiguity can be solved by looking at the elemental maps. Figure 4 shows the spatial distributions of X-rays emitted from S, Fe, and Zn within the scanned region. It is evident that none of these elements, which might have been associated with the use of iron gall ink, can be associated to the written trace; they are instead spread almost uniformly all over the scanned area. Their distribution, uncorrelated with the ink trace, can be thus interpreted as a good indicator of the fact that an organic ink, probably carbon-based, should have been used for the scroll. This is only a sort of “negative” proof: it is well known that, in PIXE measurements with external setups, light elements like C, N, and O cannot be detected. However, it has been shown that, when an iron gall ink is used in a document, correlation between ink trace and elemental maps of S, Fe, and elements like Zn or Cu is definitely evident (Remazeilles at al. 2001; Grassi et al. 2007).

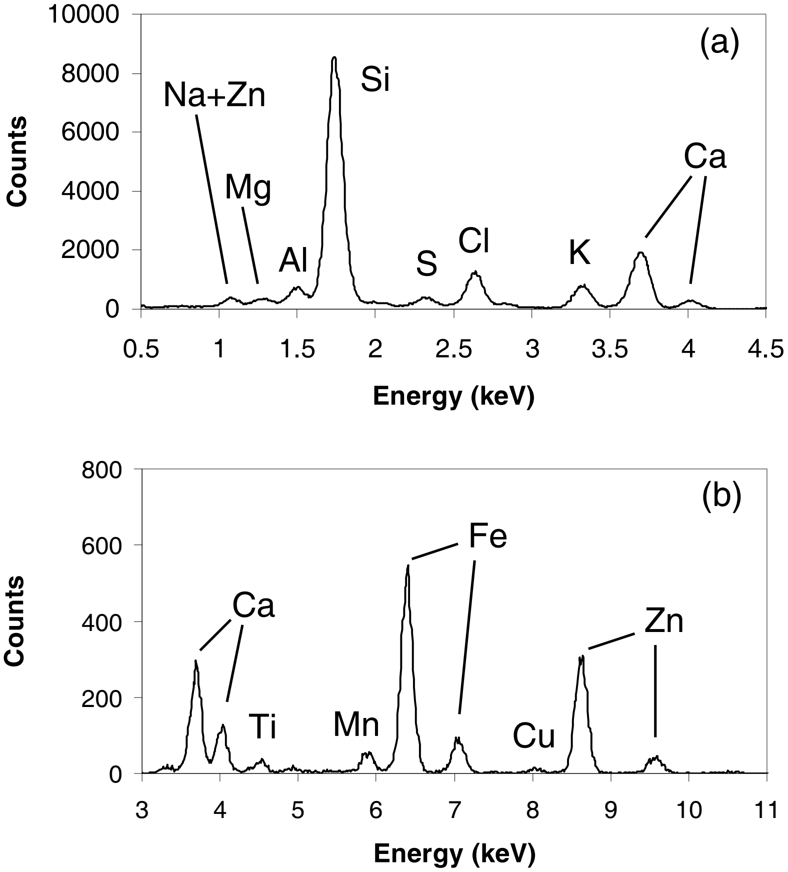


Figure 3 Spectra of low-energy (a) and high-energy (b) X-rays acquired via PIXE measurement by scanning a 2 × 2 mm^2 area in the upper right corner of the Artemidorus papyrus, where a sketch of hair is present.

A positive indicator of the presence of a carbon-based ink can, however, be given by BS measurements. Figure 5 shows an example of the comparison between 2 BS spectra acquired by bombarding an area with the ink trace or with the papyrus only. The shape of the spectrum obtained by bombarding only the papyrus area shows that the 2 detected organic elements (C and O) are essentially uniformly distributed over the probed target thickness. On the contrary, in the spectrum of the ink trace, the increase of counts in correspondence of the elements leading edges can be interpreted as a surface enrichment of carbon (and of oxygen, too). This suggests the idea that the ink used was carbon-based, just like the ink typically used in Greek and Roman times.

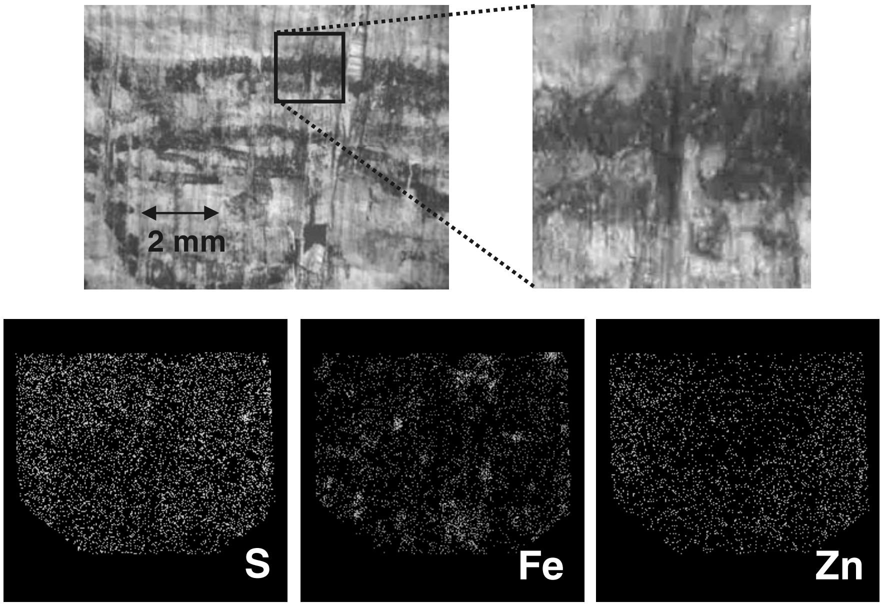


Figure 4 Photo of the scanned area whose PIXE spectra are shown in Figure 3, and corresponding elemental maps of S, Fe, and Zn. Lighter tones in the maps correspond to a higher number of counts.

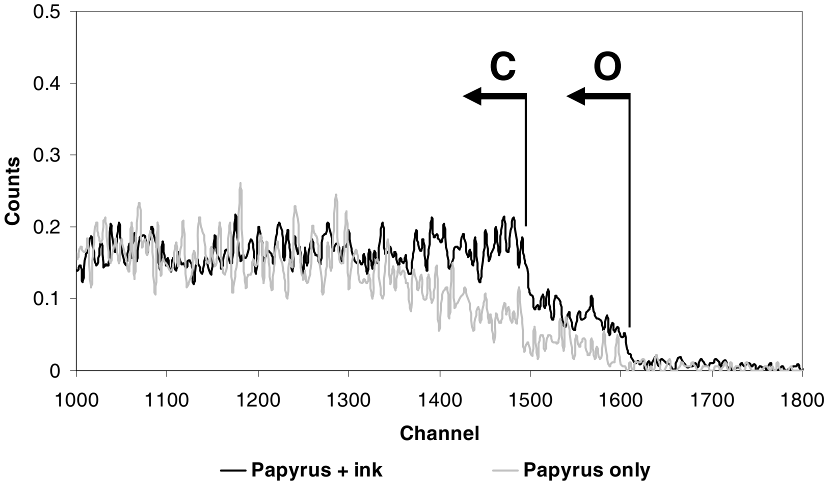


Figure 5 Comparison of backscattering (BS) spectra acquired on the ink trace (dark gray line) and on the papyrus only (light gray line). The 2 spectra are normalized to the total collected charge.

CONCLUSIONS

^{14}C measurements have dated the papyrus to a period that is compatible with the hypothesis of the papyrologists. However, this result alone cannot be conclusive proof of the document's authenticity. Some have already commented that a blank ancient papyrus might have been used to draw the inscriptions in the 19th century (even though it seems unlikely that a forger used such a great support). The ink analysis can add some important information: actually, all the results support the idea of the originality of the scroll. It is true that also in this case, someone has suggested that an expert forger might have simulated the composition of an ancient ink. In any case, in spite of and in addition to these results, discussion among the scholars is ongoing, mostly based on philological and linguistic issues. It will probably continue for a long time, at least until we are able to directly date the ink (perhaps in the future!).

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