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LUZ RANGEL / AURELI ALABERT

Printing chronology of the 42-line Bible. An update

BETWEEN 1983 AND 1987, Richard N. Schwab, historian, and Thomas A. Cahill, physicist, along with other collaborators, studied the ink of the Gutenberg 42-line Bible (B42), with the aim of settling the order in which its pages were printed. The analysis was not intended to uncover the specific recipe used, but only to approximately quantify the chemical elements present in the compound. Among them, traces of sodium, silicon, sulfur, chlorine, potassium, titanium, manganese and iron were found, together with surprising amounts of calcium, lead and copper. While the calcium turned out to belong to the paper, the high concentrations of metals came from the ink.

For some reason, the quantities of copper and lead in the ink are not constant along the pages. There are significant variations among different intervals during the 46 months of printing work, as well as selective extreme values in very short periods. In particular, the observed fluctuations of the ratio copper / lead allow the conclusion that the ink was manufactured in small quantities and not following a fixed recipe, at least not strictly. These fluctuations are the key to obtaining a timeline that hopefully reflects what actually happened in the Gutenberg workshop.

The first chronological chart of the Gutenberg Bible was proposed by Paul Schwenke in the early twentieth century.[1] It was corrected by Paul Needham,[2] using the paper stocks and their different watermarks as primary tools. Almost simultaneously, Schwab, Cahill and collaborators started the series of papers in which chemical analyses are detailed and discussed.[3] In fact, they studied not only several copies of the B42, but also other printing works in which Gutenberg was involved. The last paper[4] contains the most complete table of data and the most updated version so far of the chronological chart.

The main goal of this article is twofold. First, we review the results by Schwab et al.,[5] pointing out some doubtful issues. We agree with some solutions, whereas we propose modifications for others. On the other hand, even since Schwenke's first version, some pauses in the work had to be postulated to adjust the whole table. These pauses have never been positioned in the chart with objective criteria. We have used a statistical technique, inspired by the methods of DNA alignment in bioinformatics, and based on the same ink data, to find the best locations to place the pauses. We have to say, though, that due to the poor accuracy of the data, we simplified the computational model with additional assumptions that may well be questioned.

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1 PAUL SCHWENKE: *Johannes Gutenbergs Zweiundvierzigzeilige Bibel: Ergänzungsband zur Faksimile-Ausgabe.* Leipzig 1923.

2 PAUL NEEDHAM: The Compositor Hand in the Gutenberg Bible: A Review of the Todd Thesis. In: *The Papers of the Bibliographical Society of America.* 77 (1983) 3, pp. 341–71.

3 RICHARD N. SCHWAB et al.: Cyclotron Analysis of the Ink in the 42-Line Bible. In: *The Papers of the Bibliographical Society of America.* 77 (1983) 3, pp. 285–315; BRUCE H. KUSKO et al.: Proton milliprobe analyses of the Gutenberg Bible. In: *Nuclear Instruments and Methods in Physics Research.* Amsterdam 1984, pp. 689–94; THOMAS A. CAHILL, BRUCE H. KUSKO and ROBERT A. ELDRED: Gutenberg's inks and papers: Non-destructive compositional analyses by proton milliprobe. In: *Archaeometry.* 26 (1984) 1, pp. 3–14; RICHARD N. SCHWAB et al.: New evidence on the Printing of the Gutenberg Bible: The Inks in the Doheny Copy. In: *The Papers of the Bibliographical Society of America.* 79 (1985) 3, pp. 375–410; RICHARD N. SCHWAB et al.: Ink Patterns in the Gutenberg New Testament: The Proton Milliprobe Analysis of the Lilly Library Copy. In: *The Papers of the Bibliographical Society of America.* 80 (1986) 3, pp. 305–31; RICHARD N. SCHWAB. The History of the Book and the Proton Milliprobe: An Application of the PIXE. Technique of Analysis. In: *Library Trends.* 36 (1987) 1, pp. 53–84; RICHARD N. SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, vol. II. In: *The Papers of the Bibliographical Society of America.* 81 (1987) 4, pp. 403–32.

4 SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, Volume II (see note 3) pp. 421–32.

5 Ibid.

We present an updated chart containing all or nearly all of the information known until today, including information regarding the paper watermark. Our final result is sketched in a chart [**fig. 1**]. Due to layout restrictions, this chart can be only approximate and has an unusual vertical orientation. For a more precise, complete, and colored table, please contact the authors directly. In Section 3, we explain the method used to analyze the ink in a non-destructive way. Section 4 delineates what is to be understood by composition line and concurrent pages in our context. These concepts are fundamental for the chronological chart. We devote Section 5 to discussing the printing order of the pages inside each quire; this is collateral to our main theme, but it is an issue to which little attention has been addressed so far, and we believe it is relevant to the study of early printing techniques. Section 6 reviews the knowledge that can be considered as well established before the chemical analyses. In Section 7, the most important deductions from the ink analyses are summarized, whereas Section 8 is devoted to details and the fine-tuning of our table. We conclude with some final remarks and open questions.

1 *Ink chemical analysis methodology*

The chemical analysis of the ink was performed by non-destructive methods. The general technique is known as Particle Induction X-ray Emission (PIXE) and has been used before in several applications, including air quality analysis in the presence of polluting substances.[6] The particular method applied for the ink analysis consists in focusing a ray of protons accelerated in a cyclotron towards the specific area of the incunabulum page with a precision that allows selection of areas smaller than a square millimeter. The proton ray neatly passes through the paper and the printed ink, except for a small number of protons. These collide with the atoms of the materials. The collision detaches an electron from the atom, which emits X-rays that can be detected by high sensitivity sensors. These X-rays have different levels of energy, depending on the chemical element of the atom. The counting of the different energy levels recorded establishes the proportion of each chemical element in the sample, provided they are not lighter than sodium. The whole process takes a few minutes and is called "proton milliprobe" due to its ability to analyze very small zones of the paper or vellum.

Of course, the non-destructive nature of this method is fundamental in order to obtain permission from the owners to analyze the documents. The energy that acts over these tiny areas of a page is equivalent to a 100-watt light bulb placed at a distance of 50 cm during a few seconds,[7] so there is no change visible to the naked eye or otherwise. It is important to note that this type of analysis detects the chemical elements present in the sample but cannot identify which are the specific compounds. Therefore the actual ingredients cannot be obtained and the recipe or recipes used to manufacture the ink cannot be reproduced.

6 For example: T. B. JOHANSSON / R. AKSELSSON, S. A. E. JOHANSSON: X-Ray Analysis: Elemental Trace Analysis at the 10–12 g level. In: *Nuclear Instruments and Methods*. 84 (1970), pp. 141–3; THOMAS A. CAHILL: Proton Microprobes and Particle-Induced X-ray Analytical Systems. In: *Annual Review of Nuclear Particle Science*. 30 (1980), pp. 211–52.

7 SCHWAB et al.: Cyclotron Analysis of the Ink in the 42-Line Bible (see note 3).

The proton emissions provide a reading of the chemical composition of all the scanned material, ink and paper (and ink, if any, in the opposing page). Thus, to obtain the values corresponding only to ink, scans of inked and inkless zones of the same page were performed and the values corresponding only to ink were obtained by subtraction. Since the ink composition may change between a recto and a verso, as we will see below, the inked zones of each scanned page were selected so that the counterpart in the opposing page was not printed, hence obtaining individual results for each page.

$$\bar{x} = \frac{1}{n} (x_1 + x_2 + \ldots + x_n)$$

[Formula 1]

$$\sigma = \sqrt{(x_1 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2}$$

[Formula 2]

Across different studies in the 1980s, R. Schwab, T. Cahill and other collaborators analyzed several copies of the B42, but not in its entirety. In fact, some pages were never studied and, to our knowledge, no new analyses have taken place since then. The copies used, contributing with more or less pages in each case, are those known today as Wells, Scribners', Doheny, Lilly and Harvard.[8] From a total of 1420 composed pages (we exclude blank pages but we count as two the pages that were composed twice), we have data from 1047 pages.[9]

The first PIXE analysis of a B42 page was performed on one particular page, owned by the University of California, in December 1980, and produced unexpected results, raising the interest in performing in-depth studies of more pages and from different copies.[10] The surprising point was the large amounts of copper (Cu) and lead (Pb) detected, which clearly contrasted with the absence of these elements in all other incunabula analyzed. This finding supports the hypothesis that Gutenberg based his work on an original formula from the pioneers of oil painting to produce a glossy ink that easily and uniformly adhered to the metallic types. His recipe was not used in later works, so it is a matter of speculation whether the formula was always kept secret, or whether it was simply dropped for other reasons.

To obtain a clue about the composition of the ink and its variations across the pages of the B42, it is better to use the Cu / Pb ratio (amount of copper divided by the amount of lead) than the absolute content values of Cu and Pb. The latter may depend on the amount of ink deposited in the zone being sampled, whereas the ratio is independent from the amount of ink. Moreover, this ratio cannot be perturbed by the irregular thickness of the paper or vellum, since neither of them contains a detectable amount of those metals.

According to Kusko et al., some variability exists in the measurements taken over the same page. Therefore, the ink was actually exposed to the proton emissions in several zones of each page, producing a mean value of Cu / Pb, taken as the Cu / Pb "value" for the page, along with an estimate of the precision of such value, by means of the standard deviation of the sample of measured ratios. Mathematically, if **formula 1** is the arithmetic mean of n ratios $x_1, \ldots, x_n$ in a page, then the standard deviation is given by **formula 2**. This is the customary evaluation in statistics for the dispersion of a dataset, measured in the same units as the original data.

Schwab, Cahill and collaborators published their results in the for-

8 The names correspond to the following entries in the mentioned Schwenke (see note 1) and Needham (see note 2) articles: ("Sch. 37", "Ned. 18") = Wells, ("Sch. 13", "Ned. 41") = Scribners', ("Sch. 34", "Ned. 39") = Doheny, ("Sch. 14", "Ned. 48") = Lilly and ("Sch. 45", "Ned. 24") = Harvard; SCHWENKE (see note 1); NEEDHAM (see note 2).

9 The complete results can be found in SCHWAB et al.: The Proton Milliprobe Ink Analyses of the Harvard B42, vol. II (see note 3), pp. 421–32.

10 KUSKO et al. (see note 3).

Increased edition

Pole Star

Data Tower

A

- i-1 001–010 *Gen.* Bull's Head ii [40, 41 and 42 lines per page]
- i-2 011–020 *Gen.* Bull's Head i + ii
- i-3 021–030 *Gen. / Exod.* Bull's Head i + ii
- i-4 031–040 *Exod.* Bull's Head i + ii
- i-5 041–050 Exod. / Lev. Bull's Head ii
- i-6 051–060 *Lev.* Bull's Head ii
- i-7 061–070 *Lev. / Num.* Bull's Head ii
- i-8 071–080 *Num.* Bull's Head i + ii
- i-9 081–090 *Num. / Deut.* Bull's Head ii; Grapes i + ii
- i-10 091–101 *Deut.* Bull's Head i + ii Grapes i + ii
- i-31 301–310 *Psalms* Bull's Head ii Grapes i + ii
- i-25b 242–246 *Ezra iii* Grapes i blank page: f. 246v
- ii-29 285–294 *Acts* Bull's Head ii Grapes i + ii
- ii-30 295–304 *Acts / James / I Pet.* Bull's Head ii Grapes i Ox
- ii-31 305–309 *2 Pet. / 1,2,3, John/Jude*; bh ii; Grapes i; f. 309v blank

B

- i-14 129–138 *I Sam.* Bull's Head i + ii [40 and 42 lines per page]
- i-15 139–148 *I, 2 Sam.* Bull's Head i + ii
- i-16 149–158 *2 Sam.* Bull's Head i + ii
- i-17 159–168 *2 Sam. / I Kgs.* Bull's Head i + ii
- i-18 169–178 *I, 2 Kgs.* Bull's Head ii
- i-19 179–188 *2 Kgs.* Bull's Head ii
- i-20 189–198 *2 Kgs.* Bull's Head ii
- i-21 199–208 *2 Kgs. / I Chr.* Bull's Head i + ii
- i-22 209–218 *2 Chr.* Bull's Head ii; Grapes i + ii
- i-23 219–228 *2 Chr. / Ezra I* Bull's Head i + ii Grapes i + ii
- i-24 229–238 *Ezra I, 2* Bull's Head ii Grapes i + ii
- i-25c 247–249 *Ezra 4*; bh i + ii; Grapes i
- i-26 250–260 *Ezra 4* Bull's Head ii Grapes i + ii blank page: f. 260v
- ii-32 310–319 *Rev.* Bull's Head ii; Grapes ii; Ox; blank pages: 318r–v, 319r–v

C

- ii-1 001–010 *Prov.* Bull's Head i + ii
- ii-2 011–016 *Eccles. / Songs* Bull's Head i + ii
- ii-2 017–020 *Wisd.*; Bull's Head i + ii
- ii-3 021–030 *Wisd. / Sir.* Bull's Head i + ii
- ii-4 031–040 *Sir.* Bull's Head i + ii
- ii-5 041–050 *Sir. / Isa.* Bull's Head i + ii
- ii-6 051–060 *Isa.* Bull's Head i + ii
- ii-7 061–070 *Isa. / Jer.* Bull's Head i
- ii-8 071–080 *Jer.* Bull's Head ii Grapes i + ii
- ii-9 081–090 *Jer.* Bull's Head i + ii Grapes i + ii
- ii-10 091–100 *Jer. / Lam.* Bull's Head ii Grapes i + ii
- ii-11 101–110 *Hab. / Ezek.* Bull's Head ii Grapes i + ii
- ii-12 111–120 *Ezek.* Bull's Head i Ox
- ii-13 121–130 *Ezek.* Bull's Head ii Ox

D

- ii-17 162 bh i + ii
- ii-17 163–171 *I Macc.* Bull's Head i + ii
- ii-18 172–181 *I, 2 Macc.* Bull's Head i + ii
- ii-19 182–191 *2 Macc. / Matt.* Bull's Head ii blank page: f. 189v
- ii-20 192–201 *Matt.* Bull's Head i + ii
- ii-21 202–211 *Matt. / Mark* Bull's Head i + ii
- ii-22 212–221 *Mark / Luke* Bull's Head i + ii
- ii-23 222–231 *Luke* Bull's Head i + ii Grapes i + ii
- ii-24 232–241 *Luke / John* Bull's Head ii Grapes i + ii
- ii-25 242–251 *John / Rom.* Bull's Head ii Grapes i
- ii-26 252–261 *Rom. / I Cor.* Ox

E

- i-11 102–111 *Josh.* Bull's Head ii
- i-12 112–121 *Josh. / Judg.* Bull's Head i + ii
- i-13 122–128 *Judg. / Ruth* Bull's Head i + ii
- ii-14 131–140 *Dan.* Bull's Head ii Grapes i
- i-15 141–150 *Dan. / Joel / Amos / Obad. / Jonah* Bull's Head ii Grapes i
- i-25a 239–241 *Ezra 3* Bull's Head ii
- ii-16 151–161 *Mic. / Nahum / Hab. / Hag. / Zeph. / Zech. / Mal.* Bull's Head ii Grapes i + ii
- ii-28 274–284 *I, 2 Thess. / I, 2 Tim. / Titus / Philem. / Heb.* Bull's Head ii Grapes i Ox

F

- i-27 261–270 *Tobit / Judith* Bull's Head ii
- i-28 271–280 *Judith / Rest. of Esth.* Bull's Head i + ii
- i-29 281–290 *Job* Bull's Head i + ii
- i-30 291–300 *Psalms* Bull's Head ii Grapes i + ii
- i-32 311–320 *Psalms* Bull's Head ii Grapes i + ii
- i-33 321–324 *Psalms* bh ii
- ii-27 262–273 *2 Cor. / Gal. / Eph. / Phil. / Col.* bh ii; Grapes i + ii blank page: f. 273v
- Tabula Rub. Bull's Head ii; Ox

Non-leaded ink

A

- i-1 001–010 *Gen.* 2nd printing Ox
- i-2 011–020 *Gen.* 2nd printing Ox
- i-3 021–030 *Gen. / Exod.* 2nd printing Ox
- i-4a 031–032r *Exod.* 2nd printing; Ox

B

- i-14 129–138 *I Sam.* 2nd printing Bull's Head ii Grapes ii; Ox
- i-15 139–148 *I, 2 Sam.* 2nd printing Ox
- i-16 149–158 *2 Sam.* 2nd printing Ox

C

- ii-1 001–010 *Prov.* 2nd printing Ox
- ii-2 011–016r *Eccles.* 2nd printing Ox

D

- ii-17 162r *I Macc.* 2nd printing; Ox

mat $x \pm \sigma$; for example: 0,65 ± 0,07. Here, the value 0,07 is precisely the standard deviation of the sample, which, in other words, means that the true value lies between 0,58 and 0,72 with an approximate probability of two thirds. Usually, the error margins are given with more / less two standard deviations; then, the same example would be stated as 0,65 ± 0,14, which means that the Cu / Pb value lies between 0,51 and 0,79 with a probability of approximately 95%. The numbers do not correspond to a single copy of the B42; they are a synthesis of the results obtained from the different copies mentioned above. According to Schwab et al.,[11] in the cases where the same page from different copies was analyzed, a reasonable concordance was observed within the error bounds. The authors do not rule out that some data may be the result of a measurement mistake; it seems that some pages which cast dubious results could not be analyzed again. It is unknown to us which pages this applies to. On the other hand, as already noted, there are pages which have never been analyzed.

The crucial fact that allows the ink analyses to contribute to the study of Gutenberg's Bible chronology is that the amounts of the relevant metals Cu and Pb are variable, leading to clearly varied Cu / Pb ratios. This proves that the ink was manufactured in small quantities as was needed, and that the proportions in which the compounds of the recipe were mixed were not followed with great care. We call the whole of the ink manufactured at once, thus having identical chemical composition, a batch. Hence, if several pages of the Bible have a similar measured Cu / Pb ratio, it may be assumed that they were printed with the same batch of ink and therefore at the same time or within a short time interval.

It is clear that the chemical data would not be useful if there were not already a "base chart" prepared with other criteria and suitable to be simply "adjusted" with the analyses. On the other hand, the numeric data of the Cu / Pb ratio are the most objective data available; therefore we wish to give them priority over other evidence that may be in conflict.

[← Fig. 1] Printing chronology of the 42-line Bible. The update includes data from the analysis of the ink and the paper watermarks. The red lines show discontinuities in the natural printing order

2 *Composition lines and concurrent pages*

It is natural to assume that to avoid mistakes when printing a work of this magnitude, everything was done with certain order and discipline. Starting with the first page and following a sequential order seems the most logical way to achieve this goal. However, if two pages could be worked upon simultaneously, thanks perhaps to the availability of tools and personnel (two composers working at the same time to feed one press or, more likely, a single composer feeding two presses at the same time, or even two composers working for two presses), then it is also natural to start from two very separate pages so that both lines can work independently as long as possible. It has been established that this happened at the beginning of the work, which started almost simultaneously on quires 1 and 14 of Volume I, giving rise to two lines of composition.

11 SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, vol. II (see note 3).

Note that we do not venture to define the specific circumstances that led to these two lines. There is no reliable data to establish such circumstances, although it is very likely that a workday included the tasks of composition and printing of one page. Furthermore, since the labor rules of the guild allowed daylight work only, the rhythm of work would have varied considerably from summer to winter.

For our purposes, we define composition line as a sequence of pages of the Bible that could have been produced physically by a single composition-printing team. Therefore, if two or more composition-printing teams worked simultaneously, we would be dealing with groups of pages being worked upon almost simultaneously. The chart elaborated by Schwenke[12] considers up to six composition lines during a long period of time. Schwenke's chart was based on considerations of the batches of paper used and the composition styles. The ink analysis allow to fine-tune the concurrence in time, if we accept the fact that two pages were printed with the same batch of ink, no matter if they were produced strictly on the same day or not. Hence we consider that two or more pages from the Bible are concurrent pages if they were produced with the same batch of ink, always on the base of the most natural possible order within each composition line.

In our chart [**fig. 1**], the concurrent pages are aligned vertically. For example, we affirm that the versos of pages 17 and 144 of Volume I and page 1 of Volume II were concurrent in time. Their Cu / Pb ratios were 0,84, 0,82 and 0,80, with error bounds of ± 0,05, 0,05 and 0,03 respectively, so it is perfectly possible that they were produced with the same batch of ink.

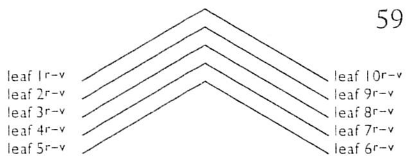
The variability in the ink composition among different batches leads us to speculate that several recipes were being tested consciously. This is certainly possible, especially in the initial stages of the work, but it is not necessarily inferred. The variability may be due to the impracticality of mixing or cooking the components with enough precision. Consider the following example: Assume that 10 units of a compound containing 5% of copper (and without lead) are to be mixed with 1 unit of pure lead and that the absolute quantities to mix are too small (just a few grams) to ensure that the amount of lead is precisely measured. For the recipe as indicated, the Cu / Pb ratio is 0,5; if we just add half a unit of lead, the ratio is 1; and if we add one quarter, the ratio increases to 2.

One must admit that there are some highly conflicting data in the chart. This may be due to accidents while cooking the ink or to the fact that a different person took responsibility or that another recipe was consciously used. It is precisely the pages with conflicting ink that allow us to establish the milestones that constitute the essential reference points for the chronology of the B42 (see Section 6).

During the printing of the B42, there were certainly some pauses in each one of the lines, for example, because of the maintenance of presses and tools, momentary lack of personnel, commitment to other work, etc. Moreover, there were interruptions concerning the entire

12 SCHWENKE (see note 1), p. 29.

atelier, such as holiday celebrations. Of course the latter cannot be detected by any means and are not represented in the chart. It can be said that the chart is the most compact representation possible, compatible with the established concurrence of pages. Note also that a particular pause of a line, reflected in the chart, may not be a "pause", strictly speaking; it could be due to their operators working more slowly.



[Fig. 2] 5-leafs quire

3 *The quires and the printing order*

The B42 consists of 65 quires in total. Each quire consists of a certain number of leaves (units of paper), each one comprising two sheets and therefore up to four printed pages. Some quires have additional separate sheets, but the more common type consists of five leaves, i.e. ten sheets [**fig. 2**]. The chronological chart [**fig. 1**] is made of a set of "boxes" that represent the quires. The widths of the boxes are proportional to the number of pages of the corresponding quire. Most of the boxes have the same width because the most common quire contains twenty pages.

The convention that we will follow (essentially the usual one) to denote the quires of the B42 is to write down first the number of the volume in Roman numerals and then the number of the quire within that volume, with a dash in between. For example, I-10 denotes the tenth quire of the first volume, whereas II-3 refers to the third quire of the second volume. In exceptional cases the number of the volume is omitted if it is contextually obvious. The numbering order of the quires is the natural order of reading. Within a specific quire, we may refer to sheets 1 to 10, each with its recto and verso pages, denoted by r and v respectively. For instance, 3^r and 6^v stand for the pages 3 recto and 6 verso of a quire. Nevertheless, most of the time we refer to the page of a specific quire by its absolute numbering and not its relative position within the quire. Thus, we refer to page 3^r of quire 4 of Volume I as page I-4-33^r and, analogously, the sheet to which it belongs as sheet I-4-33.

The printing order of the quires within each composition line seems currently well established. For a long time, the different lines worked on independent parts of the Bible and, within each part, they followed the natural order of reading or consecutive order.[13] When one of the lines reached a quire that has already been printed, this order is broken. Hence, towards the end of the work some doubts start to arise about the printing order of the quires and which composition line was responsible for them.

Regarding the printing order of the pages inside each quire, most authors seem to implicitly accept that it was also the consecutive order, that means: 1^r, 1^v, 2^r, 2^v, … , 9^r, 9^v, 10^r, 10^v. The acceptance of this hypothesis without any mention is somehow surprising to us; therefore we want to discuss some pro and con arguments of the assumption here. The following facts can be taken as certain, and they are deduced from observations regarding the increase of the edition size as analyzed in section 7:

13 LOTTE HELLINGA: *Impresores, editores, correctores y cajistas*. Instituto de Historia del Libro y de la Lectura. Salamanca 2006, pp. 137–73.

– Pages 1^r, 1^v, 2^r of quire I-4 were printed before the remaining pages of the quire.
– Pages 1^r, 1^v, 2^r, 2^v, 3^r, 3^v, 4^r, 4^v, 5^r, 5^v, 6^r of quire II-2 were similarly printed before the rest.
– Page 1^r of quire II-17 was also printed before the rest of the quire.

The natural order is clearly consistent with these three facts. Frequently it is argued in favor of the hypothesis that the beginning of the page depends on the point where the prior page ends, which cannot be established until such page is completed. However, at this point we must be careful not to confound the printing order and the composition order, which do not necessarily have to coincide.

Basically, the main problem for printing in consecutive order is that the ink printed in a leaf (first form) must dry completely before printing on the same leaf (reiteration form). Let us remark that pages were printed one by one and not in conjugate pairs, hence each leaf had to be moistened and passed through the press up to four times. The minimum amount of time for the B42 ink to dry completely is unknown. In the nineteenth century, twelve hours could be enough. Some older authors speak of "one day". The fact that the B42 recipes were inspired by oil painting suggests that the time could be even longer. The printing of all the copies of one page, after composing, could occupy a whole working day;[14] thus, if 24 hours were sufficient, then the pages could be printed in any desired order. If, on the other hand, more time was required for drying, then printing a composition line in consecutive order was no longer possible, because it would entail stopping the press for some time, between the recto and verso of the same sheet, and also between pages 5^v and 6^r of each quire. This seems absurd since the press is the bottleneck of the whole process.

In summary, printing in consecutive order without any break for the press was generally possible, if the time needed for a leaf to dry completely was not greater than the time necessary to print all the copies of the same page, including in the latter the whole night break if the printing concluded at the end of the working day or the following day after restarting.

Schwab et al.[15] consider this problem when trying to explain the "Roller Coaster" phenomenon: large zones of the numeric tables in which the Cu / Pb ratio of the recto pages is different from the verso pages. They propose a solution where a second press is employed in the same composition line [**fig. 3**]. However, this solution is not correct because it does not allocate drying time for the central leaf of the quire. Nevertheless, it is perfectly possible to print a full five-leaf quire without stopping the press and allowing each leaf to dry for 120 hours, at the rate of one printed page per day. An order satisfying this restriction is, for instance (cf. **fig. 2**):

– $1^r\ 2^r\ 3^r\ 4^r\ 5^r\ 1^v\ 2^v\ 3^v\ 4^v\ 5^v\ 10^r\ 9^r\ 8^r\ 7^r\ 6^r\ 10^v\ 9^v\ 8^v\ 7^v\ 6^v$. (A1)

Or, starting in the central leaf,

– $5^r\ 4^r\ 3^r\ 2^r\ 1^r\ 5^v\ 4^v\ 3^v\ 2^v\ 1^v\ 6^r\ 7^r\ 8^r\ 9^r\ 10^r\ 6^v\ 7^v\ 8^v\ 9^v\ 10^v$. (A2)

With any of these two schemes, up to four leaves of a quire would be

14 ENRIC TORMO I FREIXES: Gutenberg no fou impressor. Barcelona 1999 (*Memorias de la Real Academia de Ciencias y Artes de Barcelona.* 3a época, 958).

15 SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, vol. II (see note 3), pp. 409–12.

drying at the same time, which may imply, with an edition size of 200 copies, that up to 1000 leaves must be hanging up simultaneously. The feasibility of these schemes is therefore conditioned to the existence of enough space within the shop.[16]

Of course it is also possible to reduce the resting times of the leaves. The next order, while being as close as possible to the natural order, allows leaves to dry for 48 hours:

– $1^r\ 2^r\ 1^v\ 2^v\ 3^r\ 4^r\ 3^v\ 4^v\ 5^r\ 7^r\ 5^v\ 7^v\ 6^r\ 8^r\ 6^v\ 8^v\ 9^r\ 10^r\ 9^v\ 10^v$. (B1)

Observe the inevitable irregularity around the central leaf.

Order (A1) is consistent with the information above about quire II-17, but not with that of quires I-4 and II-2. Order (A2) is consistent with the information about II-2, but not with quires I-4 and II-17. Order (B1) is consistent with the information about I-4 and II-17, but not with II-2. However, a slight variation makes it consistent with everything: Notice that in (B1) the irregularity of the central leaf extends towards the end more than towards the beginning, but by symmetry we can make it appear in the initial part:

– $1^r\ 2^r\ 1^v\ 2^v\ 3^r\ 5^r\ 3^v\ 5^v\ 4^r\ 6^r\ 4^v\ 6^v\ 7^r\ 8^r\ 7^v\ 8^v\ 9^r\ 10^r\ 9^v\ 10^v$. (B2)

This is a possible printing order of a quire, which provides a 48 hours minimum drying time per leaf and it is not incompatible with the accepted facts.

The order of composition of the pages is a different matter altogether. If the printing is performed in consecutive order, then clearly the composition must follow the same order; if instead the printing follows a different order, then there are two alternatives: Either the composition follows the natural order and consequently there must be some forms prepared in reserve (which requires more cast types and work ahead of the press) or the so-called form composition is employed, which entails calculating the starting point of a page when its preceding page has not been yet composed, as was done a century later in the printing of *Don Quixote*.[17]

For example, if we print in the order (B2) and compose in the consecutive order, at some point five coexisting forms are required (pages $3^r\ 3^v\ 4^r\ 4^v\ 5^r$). In the rest of the quire only three simultaneous forms are required at most. If the composition follows the same order (B2), then the starting point of page 5^r has to be calculated from the ending of 3^r, skipping the three intermediate pages, whereas in the rest of the quire, only one intermediate page is skipped at most.

The second alternative above is clearly better, since computing the beginning of each page is not difficult if an exemplar is at hand. The existence of a manuscript model does not mean the identical copy of pages, lines and spaces of such a model. This is very unlikely, but the existence of a model or original manuscript[18] from which the textual structure is copied (order of the books, prologues and sentences), allowing the composition of a page without composing the preceding one, is a perfectly plausible conjecture.

Another possibility that would allow an intermediate day of drying for all leaves and, at the same time, allow for printing and composing

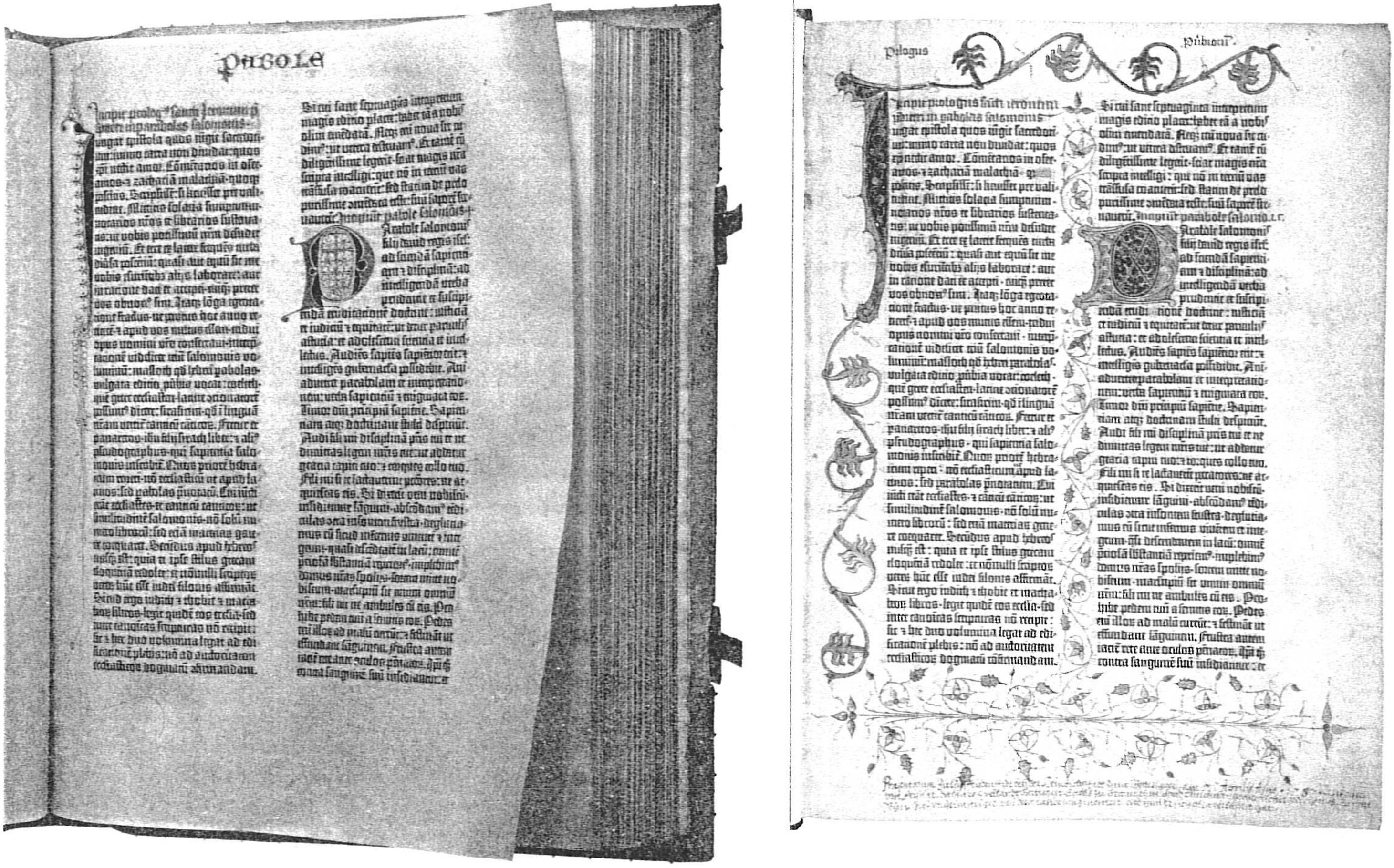
Day	Page printed		Page drying
	PRESS I	PRESS II	
1	1 / 1^r	—	—
2	1 / 2^r	—	1 / 1^r
3	1 / 3^r	1 / 1^v	1 / 2^r
4	1 / 4^r	1 / 2^v	1 / 3^r
5	1 / 5^r	1 / 3^v	1 / 4^r
6	1 / 6^r	1 / 4^v	1 / 5^r
7	1 / 7^r	1 / 5^v	1 / 6^r
8	1 / 8^r	1 / 6^v	1 / 7^r
9	1 / 9^r	1 / 7^v	1 / 8^r
10	1 / 10^r	1 / 8^v	1 / 9^r
11	2 / 1^r	1 / 9^v	1 / 10^r
12	2 / 2^r	1 / 10^v	2 / 1^r

[Fig. 3] Printing order of pages in a quire proposed by Schwab and his collaborators

16 There are other possible orders positioning each leaf rest during four intermediate printed pages. For example, for the following order each leaf is only unfolded once: $1^v\ 2^v\ 3^v\ 4^v\ 5^v$ / $10^r\ 9^r\ 8^r\ 7^r\ 6^r$ / $1^r\ 2^r\ 3^r\ 4^r\ 5^r$ / $10^v\ 9^v\ 8^v\ 7^v\ 6^v$.

17 FRANCISCO RICO: Don Quijote, Madrid, 1604. In: El *Quijote, biografía de un libro: 1605–2005*. Madrid 2005, p. 51–75.

18 «El primer paso en el siglo XVI para imprimir un libro era transcribir el texto del autor. Generalmente esta copia la hacía un amanuense profesional, rara vez la hacía el autor. La copia se concebía para uso exclusivo del taller como modelo para preparar la edición. El resultado debía ser un texto escrito con letra legible y a ser posible la misma que se utilizaría en la impresión, con un tamaño regular además de uniformidad en renglones y márgenes». LUZ RANGEL: *Del arte de imprimir o la Biblia de 42 líneas: aportaciones de un estudio crítico (2011)*. Diss. phil. U de Barcelona 2011.



[Fig. 4] The images show the differences between 1^{st} and 2^{nd} composition:

a LC, Bible, II-1^{r}-column 2, 1^{st} composition. Reproduced with permission from Octavo Corp. and LC, Special Collections Division

b NSUUB, Bible, II-1^{r}-column 2, 2^{nd} composition. Reproduced with permission from NSUUB, Göttingen, Digitalisierungszentrum

in the natural order, is that two lines of composition were feeding the same press. In such case, the printing of a leaf from one line can be alternated with a leaf from the second line. This would make sense if the composition was slower than the printing or, with comparable times, if the same composer worked on the two lines.

When preparing our chart we stuck to the assumption that, no matter the order of printing within a quire, the same order was followed in all quires similarly formed.

4 *Summary of the knowledge prior to the chemical analysis*

Before the study made with the PIXE technique, there were a number of facts already established which are not contradicted by the analyses. We recall them in this section. We refer the reader to our first chart [**fig. 1**] to follow the discussion.

1. Two lines of composition were started almost simultaneously: printing began on quires I-1 and I-14 at the same time. This means that two presses were available, each one fed by the work of one composer, located in the same workshop or perhaps at different physical locations. It is also possible that the composition work was very slow and two composers fed a single press. There are no definitive arguments in favor of one or the other option. Note that the composition, printing, drying and binding process was not completely linear. Indeed, a proof

of each page is printed and reviewed, errors are marked, the form corrected, and the final printing of all copies is done; the paper has to be moistened before passing through the press, brought and taken from the drying zone to complete the leaves, etc. We consider, as previously stated, that two pages from different lines of composition can be concurrent, whether they were produced by one or different composers or one or different presses. We believe that currently there is no scientific basis to delve into a greater level of detail.

2. The main reason to believe in two almost simultaneous lines is that pages I-1^r to I-5^r and I-129^r to I-132^r have 40 lines, I-5^v has 41 lines and all the others 42 lines. Also, there were bibles with all their pages composed at 42 lines, but they belong to the "second composition", related to the increase in the edition size, as explained in point 4 below. The reason to switch to 42 lines has never been clarified, but it is obvious that it was not to save paper, as it has been sometimes suggested; although there are more characters in the 42-line pages, the number of abbreviations was also reduced drastically. The type used in 40-line pages was never used afterwards or in any other work, a fact that has neither been satisfactorily explained.

3. Schwenke,[19] Zedler[20] and Ruppel[21] speculated about the existence of six different composition lines, which started at different moments in time, and were labelled with the letters A to F. This nomenclature persists today and we will employ it here. It is also speculated that there were only four composition lines[22] but the ink analyses give little credit this possibility.

4. Based on typographic, compositional and paper watermark differences, Schwenke observed that certain pages (I-1-1^r to I-4-32^r, I-14-129^r to I-16–158^v, II-1–1^r to II-2–16^r, and II-17–162^r) were composed twice. This fact is indisputable because the variations are evident when comparing pages from both compositions [see **fig. 4**]. The only reasonable explanation, also widely confirmed, is that at some moment a decision was taken to increase the edition size originally planned. Since the pages that were composed twice belong to four separate groups, one can deduce that at that moment there were four composition lines (the last one just started). It is also likely that the first four pages that were composed only once, i. e. I-4–32^v, I-17–159^r, II-2–16^v, and II-17–162^v, were concurrent. This permits location of the start of lines C and D in relation to lines A and B. The fact that the four pages do not appear completely aligned in our chronological chart will be explained below. They appear marked with a blue rectangle.

5 *Fundamental findings from the ink analyses*

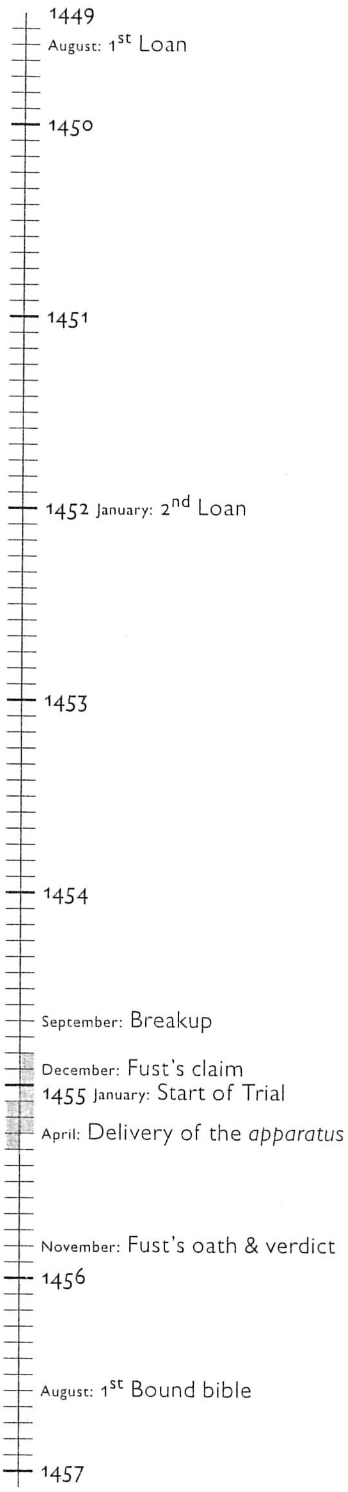
There are three milestones in the production of the B42 that are crucial for drawing the chronological chart. The first one is the increase in edition size, mentioned below. Based on the concurrency of the four cited pages, the starting of each of the four lines is fixed to certain points in time, and the quires are assigned to the lines, assuming the reasonable hypothesis that each line was following a natural order of quires.

19 SCHWENKE (see note 1), p. 41.

20 GOTTFRIED ZEDLER: Die Sogenannte Gutenbergbibel sowie die mit der 42zeiligen Bibeltype ausgeführten kleineren Drucke. Mainz 1929 (*Veröffentlichungen der Gutenberg-Gesellschaft*. 20), p. 97.

21 ALOYS RUPPEL: *Die Technik Gutenbergs und ihre Vorstufen*. Berlin 1940, p. 59.

22 SEVERIN CORSTEN: Die Drucklegung der zweiundvierzigzeiligen Bibel. In: *Johannes Gutenbergs zweiundvierzigzeilige Bibel: Kommentarband*. Munich 1979, pp. 46, 54/5; GEORGE D. PAINTER: Gutenberg and the B36 Group. A Reconsideration. In: *Essays in Honor of Victor Scholderer*. Ed. DENNIS E. RHODES. Mainz 1970, pp. 292–322, here p. 321.



[Fig. 5] Month-by-month timeline of the Gutenberg, Fust and Schöffer society during the printing of the B42. The "breakup" is the moment when Gutenberg quits

The other two milestones are revealed after the ink analysis. These are two moments where the composition of the ink, for a short time, undergoes a noticeable change in the measured index Cu / Pb. These two moments have been called the "Pole Star" and the "Data Tower".[23] The Pole Star is a huge increase of the Cu / Pb ratio that affects five pages of the Bible, specifically I-8–74^{v}, I-12–114^{v}, I-21–201^{v}, I-28–273^{v}, and II-21-202^{v}. The proportion of copper to lead in these pages is nearly tripled in comparison to the general trend of the surrounding pages (albeit the proportion itself is not unusual in other parts of the Bible). This seems to indicate that at that moment there were at least five composition lines at work. Furthermore, assuming again that the quires were printed in the natural order in each line, two pages of the Pole Star do not belong to lines A, B, C, or D, thus suggesting that there were a total of six composition lines at the occurrence of the Pole Star, and that one of those lines, line C, for some reason does not show this anomaly. The reason may be simply that this batch of ink was exhausted before line C began using it, and the new batch returned to the standard proportion. Indeed, its concurrent page II-6–57^{v} has a composition similar to the next pages of the rest of the lines.

The existence of two more lines, beginning more or less close to the Pole Star, had already been speculated by Schwenke and it is reflected in his original chart. The difference is that he placed the starting point of these lines at a moment which differs from what the ink indicates. The starting point of the lines is in fact simultaneous with quires I-11 and I-27, and coincides with pages I-7–62^{r} in line A and I-20–189^{r} in line B. This is deduced from the similarity of the ink of the new lines E and F between their starting point and the Pole Star.

The last milestone, the Data Tower, is a zone that spans six to eight pages in each of the six lines of composition, and where the Cu / Pb ratio again increases to unusual proportions, much bigger than those of the Pole Star, but similarly tripling the surrounding values. In our chart, the initial page of the Data Tower in all the lines has been marked with a black rectangle. We decided to align all those pages, disregarding the suggestions of Schwab et al.,[24] who concede some slight deviations without a convincing reason. Hence we set as concurrent pages I-31–303^{v}, I-24–232^{v}, II-9–88^{r}, II-24–234^{v}, II-15–147^{r}, I-32–314^{r}. Notice, however, that there is a page of line B that was never analyzed and produces some uncertainty in the starting point of the Tower in that line. The fact that the Tower appears in the six lines is a further confirmation that at least six lines were working simultaneously at some point in time.

In summary, our criterion is to consider the Pole Star and the beginning of the Data Tower as concurrent in all of the lines, following the consideration of the composition of the ink as the main temporal guide. As mentioned above, the increase in edition size should also make concurrent the pages where it is observed. However, we forward page I-17–159^{r} of line B, this time according to Schwab, because otherwise we would be forced to introduce a pause of one page on all the other lines before the Pole Star, plus a pause in line B before the increase in edition size, thus causing a great complication in the chart and a misalignment of concurrences that are well supported by the ink. On the other hand, it is not difficult to imagine that, at the moment it was decided to increase the edition size, page I-17–159^{r} might still have been in press when the other three lines A, C and D had already unmounted the form of the concurrent pages I-4–32^{r}, II-2–16^{r} and II-17–162^{r}.

6 *Details and fine adjustments of the chart*

In making the chart, it is assumed that each line follows a natural order of quires. This order breaks down when a line reaches the quire where other line has started, and thus is already printed. It happens in line A, after quire I-10, and in B and E after I-26 and II-6 respectively (apart from the fragmentation of I-25, to be discussed later). Besides, the necessary readjustments affect the continuity of line F after quire I-30.

From the moment the continuity is broken, it becomes much harder to establish the concurrency and assign quires to the lines, even with the ink analysis at hand. For example, assigning I-31 and I-32 to lines A and F, respectively, is in principle arbitrary; Schwab et al.,[25] unlike Schwenke, set them that way because the Data Tower fits more easily, without introducing more pauses, and despite the fact that it should have been the other way round, because line F was producing the previous quires and was available before line A. In fact, the coexistence of six lines (with the consequent consumption and constant preparation of ink) and the many possible ways of reassigning the remaining quires cause the part of the chart to the right of the Data Tower to be more tentative than the rest.

Lines C and D apparently do not have any discontinuity in their natural order of quires, II-13 being the last one printed before starting the second composition of the first quires. The formula of the ink in this second composition is radically different from some point of the first quire, with a much smaller metallic content than the rest of the work. Therefore, according to the definition of concurrent pages we have adopted, the majority of the second composition should have begun after the books of the original edition size were finished. For the sake of simplicity, we preferred to leave the whole second composition at the end of our chart [**fig. 1**], where it is marked with a different background colour. The assignment to lines and the concurrency between pages of the second composition, along with those of the Tabula Rubricarum, is completely arbitrary.

The ink chemical elements obtained for leaf I-129/138 of Doheny's copy showed that pages 1^{r}/1^{v} were printed before pages 10^{r}/10^{v}. This is consistent with both the natural order and the proposed orders A1, A2, B1, and B2 in Section 4. For example, with the order A1, the change in the recipe occurs when printing any one of the pages 2^{v} 3^{v} 4^{v} 5^{v} 10^{r}, and not before or after. Among the proposed orders, B2, produces more uncertainty of the precise moment of recipe change, which then

23 Pole Star and Data Tower were names given by Schwab and Cahill in their initial article CAHILL et al. (see note 3). The first refers to the fact that it was the main guide to align the six composition lines at a point sufficiently apart from the edition size increase; the second is due to the graphic representation in a bar plot of the ration Cu / Pb, which at that zone appeared as a very tall tower between the adjacent bars.

24 SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, vol. II (see note 3).

25 SCHWAB et al.: New evidence on the Printing of the Gutenberg Bible: The Inks in the Doheny Copy (see note 3), pp. 387/8.

would occur in any of the 14 pages 2^{v} 3^{r} 5^{r} 3^{v} 5^{v} 4^{r} 6^{r} 4^{v} 6^{v} 7^{r} 8^{r} 7^{v} 8^{v} 9^{r}. A new chemical analysis of this quire from a second composition copy may provide much information about the printing order of the pages, not only of this quire, but of the entire Bible.

The ink analysis shows another peculiarity, also lacking a clear explanation, but it is again helpful to establish the concurrency of pages. This peculiarity is the Roller Coaster, described in Section 4. The phenomenon appears in the following zones of line C, and some of their concurrent pages:[26]

- II-1–6^{v} to II-2–13^{r}
  (not noticeable in the other lines due to lack of analysis).
- II-2–17^{r} to II-3–22^{v}
  (not noticeable in A, B due to lack of analysis; noticeable in D).
- II-3–24^{v} to II-4–37^{r} (not noticeable in B due to lack of analysis; noticeable in A, D, with some anomaly).
- II-4–40^{r} to II-6–51^{r} (not noticeable in B due to the lack of analysis; noticeable in A, D, with some anomaly).
- Several zones in the six lines, from II-28–275^{r} in line E.

The Roller Coaster helps establish certain places where apparently there were pauses in lines C and D. By aligning the zones where the Roller Coaster is absent in C and D: II-3–23^{r} to II-3–24^{r} (C) with II-17–169^{r} to II-17–170^{r} (D), and II-4–37^{v} to II-4–39^{v} (C) with II-19–182^{v} to II-19–184^{v} (D), one can deduce a one sheet delay in D at some point between the two zones. Furthermore, the logical alignment with the ink of A and B implies that there was a pause of one sheet in C, before sheet II-2–17, and another pause of one sheet before II-17–163 in D. To fit the Pole Star, there should be another pause of one sheet in line D, and observing the Roller Coaster pattern, such a pause must be located between II-17–170^{r} and II-19–182^{v}. Schwab et al.[27] places it arbitrarily after sheet 171, finishing quire II-17. We placed it at the end of quire II-18, for reasons explained below.

Another noticeable difference between our proposal and that of Schwab et al.[28] is that these authors assign to line A the sheet II-21–210, that belongs to a quire that was being printed on line D. The explanation they offered, based on a slightly better fit of the ink, it is not strong enough, in our opinion, to justify this complication. The alternative, as we shall see, requires the addition of more pauses in all the lines, but we consider it is a less forced solution in order to fit the three basic milestones.

Accepting all of the above assumptions, the summary of the uncertainties left to be solved, prior to the Data Tower, is the following:

- Locate a four-page pause in A, between Pole Star and Data Tower.
- Locate a two-page pause in B, between Pole Star and Data Tower.
- Locate a three-page pause in C, between the increase of edition size and the Data Tower.
- Locate a two-page pause in D, between II-17–170^{r} and II-19–182^{v}.
- Locate a three-page pause in E, between Pole Star and Data Tower.
- Locate a three-page pause in F, between Pole Star and Data Tower.

26 To follow the rest of this section more easily we recommend consultation of the numeric table in SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, vol. II (see note 3), pp. 421–32 or the updated version in RANGEL (see note 18), chart 32 on pp. 468–71.

27 SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, vol. II (see note 3).

28 Ibid.

Our point of view here, in the absence of any other evidence, is that numerical data should guide us the optimum placement of the pauses. This can be done by searching those positions that make a better ink match between the resulting concurrent pages. On the other hand, there are certain elements that discourage from carrying out a very sophisticated analysis in this respect: Data uncertainty (quantified in the standard deviations, sometimes rather substantial), the lack of data from too many pages, and the fact that more precise analyses may possibly be performed with current 21st century technology. Hence we will simplify as follows: 1) We shall group all pause pages from each line into one single pause. 2) We shall assume that such a pause can only appear at the end of a quire. Under these two assumptions, one can see that:

- The four-page pause in line A must be placed at the end of quires I-8, I-9 or I-10.
- The two-page pause in line B must be placed at the end of quires II-21, II-22 or II-23.
- The three-page pause in line C must be placed at the end of any quire between II-2 and II-8.
- The two-page pause in line D must be placed at the end of quires II-17 or II-18.
- The three-page pause in line E must be placed at the end of quires II-12, II-13 or II-14.
- The three-page pause in line F must be placed at the end of quires II-28, II-29 or II-30.

By inspection, it is clear that the pause in line C, which has a priori more mobility, should not be placed before the Pole Star, because this causes a considerable mismatch of the ink concordance observed now with all the other lines. Therefore we will assume that the pause occurs also between Pole Star and Data Tower, that is, at the end of quires II-6, II-7 or II-8.

Thus we are left with 243 possible pause placement combinations in lines A, B, C, E, F (three in each line), a reasonable number for an exhaustive numerical search. We adopted a simple criterion to assess each combination: we will measure the standard deviation of each group of concurrent pages in the resulting table, ignoring missing data or pauses. Then we will compute the mean of these deviations for all the pages between the Pole Star and Data Tower. The best combination will produce the lowest mean. This optimal placement is as shown in our chart: The pauses occur in quires I-8 (line A), II-21, (B), II-6 (C), II-14 (E), I-30 (F). The mean standard deviation is 0,1185. The two next best combinations only move the pause in B to II-22 (0,1208) and to II-23 (0,1215). Accordingly, we might say that the position of the pause in line B is the most doubtful.

The reason for the last two-page pause, in line F, after the Data Tower, is the so-called Stuttgart error. In the Stuttgart copy (number 39, New York Theol. Sem., in Schwenke census), page II-28-279^{v} appears in the position corresponding to page II-27-272^{v}. This may indicate that both pages were being printed approximately at the same time and they are left as concurrent in Schwab et al.[29] The pause so generated in line F might be placed at the end of I-32 or I-33. Schwab chooses I-33, and a statistical analysis with the same procedure above confirms this is the correct position. The same statistical criterion compels us to place the pause in line D at the end of quire II-18, instead of its original position in quire II-17.

Quire I-25, distributed among three composition lines according to the chart published by Schwab et al.,[30] is an interesting novelty with respect to the position given by Schwenke. This distribution is not at all illogical, considering the situation of all the lines, either very close or already touching the discontinuity points in the order of quires, and the fact that I-25 consists of two books, Esdras III and Esdras IV, that could be conveniently split. As a side comment, note that these two books are rare and do not appear in many bibles at that age.

No analyses have been ever performed on the eight-page Tabula Rubricarum, thus we cannot place it in the chart with any certainty. We placed them arbitrarily at the end of line F because it was the first line that finished their previously assigned work.

Finally, we must deal with the non-trivial detail of the blank pages. As can be seen in **fig. 1**, the nine blank pages (I-25b–246^{v}, I-26–260^{v}, II-19–189^{v}, II-27–273^{v}, II-31–309^{v} and II-32–318^{r} to II-32–319^{v}) occupy a position in the chronological table, and therefore we are assigning them a production time similar to that of a printed page. Let us see why.

First, the blank pages correspond all of them to the end of books in cases where the first page of the next book had already been printed. This is true except for the Apocalypse (quire II-32), the last book of the Bible, which could have been printed without blank pages if a four-leaf quire had been used.

Of these nine blank pages, six of them occupy ends of line, thus they do not really occupy any execution time. For the remaining three, we see that deleting the space corresponding to II-19–189^{v}, the ink matching with the other lines is severely altered; for I-25b–246^{v} and I-26–260^{v}, we could optionally move a few pages, but a little beyond a pause needs to be inserted to reasonably accommodate again the ink readings between lines. For all these reasons, we let these three blank pages occupy their natural space, but we do not have a direct explanation of why it must be so.

7 *Final remarks*

In this paper we have studied the chronology of the B42, taking as a starting point the last article on the subject, which to our knowledge is Schwab et al.[31] That paper incorporates all the chemical analyses of the ink performed between 1983 and 1987 to introduce some important corrections to the chart published by Schwenke in 1923. We have made a few changes to their results: On the one hand, we suggest modifications in some of the conclusions presented in the different articles

29 SCHWAB et al.: Ink Patterns in the Gutenberg New Testament: The Proton Milliprobe Analysis of the Lilly Library Copy (see note 3), pp. 314/5.
30 SCHWAB et al.: The Proton Milliprobe Ink Analysis of the Harvard B42, vol. II (see note 3), pp. 421–32.
31 Ibid.

by Schwab and collaborators when in our opinion they are weakly justified; on the other hand, we have performed a statistical analysis of the concordance of the ink in the different composition lines to place the pauses in an optimal way.

The poor accuracy of the data does not allow us to build the chronological chart from scratch based only on the Cu / Pb ratio. The best arrangement would possibly lead to the introduction of many more pauses and also to incompatibilities with other widely accepted facts. We have abandoned the idea of applying statistical analysis to clarify some other doubtful issues, like the assignment of quires I-31 and I-32 to lines A and F, or the optional pause in line B that would cause the Data Tower to start in 232^r instead of 232^v. Regarding the former, let us mention that the argument offered in Schwab et al.[32] for the assignment of I-31 and I-32, simply relies on a better fit of the Data Tower. But Schwenke's solution meant only the introduction of a new one-sheet pause in line F and the suppression of a one-sheet pause in line A. So, from our point of view, the doubt persists.

In summary, the changes that we introduce to Schwab's chart are the following:

- A pause in line D is moved from quire II-17 to quire II-18.
- The pauses in lines B and C between the zones not showing the Roller Coaster are moved.
- The possible "aid" from line A to line D to make sheet II-21–210 is dismissed. The sheet is produced by line D, which is the natural one, and line A takes a four-page pause.
- Such a pause in line A is longer than strictly needed, in order to adjust the start of the Data Tower.
- The pauses in lines B and C between Pole Star and Data Tower are moved.
- New three-page pauses between Pole Star and Data Tower in lines E and F are inserted.
- The Data Tower is completely aligned at its start point in all lines.

We mentioned briefly in Section 4 that the number of composition lines and the number of working presses need not be the same. We believe that there is no enough evidence to asses how many presses were used. In the opinion of several authors (e. g. Zedler, Zazmeier, Ziesche, Schnitger), there could have been less presses than composition lines. This makes sense if we accept that the workload of composing a page was much larger than that of printing the 150 or 200 copies of that page, a fact we can neither confirm nor rebut. Perhaps one of the reasons for the increase of edition size was to adjust the work rate of composers and printers. Similarly, it is difficult to determine if each composition line was serviced by a dedicated composer, or if the same composer could serve two lines.

As in the studies of Schwab and his collaborators, we implicitly assume that the ink was manufactured in such a way that all composition lines essentially used the same provider. This assumption is fundamental in trying to adjust the chart by means of the Cu / Pb ratio.

32 Schwab et al.: Ink Patterns in the Gutenberg New Testament: The Proton Milliprobe Analysis of the Lilly Library Copy (see note 3), pp. 314/5.

Although it is likely that Gutenberg and Schöffer worked at different workshops, at least from some moment onwards, it is nevertheless perfectly possible that the ink was carried from one to the other, or that it was manufactured by a third party. Also, there seem to be periods in the chart where some lines are using a particular ink composition while all the others are using a different composition, but there is no consistent pattern detectable for a long enough period to deduce that the ink might be different or to infer which lines were working in each workshop.

To conclude, we refer to a curious fact that we found when trying to figure out the moment when Johannes Gutenberg had to abandon the project. According to the Helmasperger Notarial Instrument,[33] Gutenberg was committed to the "book business" from the beginning of the second loan by Johan Fust until the breakup, that is, during 32 of the approximate 46 months of total work (not counting the second composition of the first quires). This is shown in **fig. 5**.

Assuming a constant rate of production, so that, for instance, four composition lines are able to print four times faster than a single line, a simple computation locates Gutenberg's departure during the printing of the 85th page after the start of lines E and F. That is, one or two pages before one of the milestones, namely, the Data Tower. Therefore, it is possible that the radical change in the composition of the ink composition was related to this fact.

33 Model Book and Helmasperger's Notarial Instrument. In: *Gutenberg Digital: The Göttingen Gutenberg Bible.* Ed. ELMAR MITTLER and STEPHAN FÜSSEL. CD-ROM. Munich 2000.

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Anschrift des Herausgebers
Institut für Buchwissenschaft
Johannes Gutenberg-Universität
D 55099 Mainz
Telefon (+49) 61 31.3 92 25 80
Telefax (+49) 61 31.3 92 54 87
fuessel@uni-mainz.de

Internationale Gutenberg-Gesellschaft in Mainz e.V.
Liebfrauenplatz 5
D 55116 Mainz
Telefon (+49) 61 31.22 64 20
Telefax (+49) 61 31.23 35 30
info@gutenberg-gesellschaft.de

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