Article

Interdisciplinary Perspectives from Material and Computer Sciences on the Dead Sea Scrolls and Beyond

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Abstract

This paper will present the current state of the application of material and computer sciences to the Dead Sea Scrolls of Qumran and point out possible implications for other fields. It will also focus on the importance of working in interdisciplinary approaches to achieve further synergies.[1] After a brief introduction to the corpus, it will discuss present and future possibilities related to the four classical tasks of editing fragmentary papyri and will then address three further topics in which IT and material sciences could advance research.

1. The corpus

The Dead Sea Scrolls encompass about 2,000 manuscripts found during the second half of the last century, mostly in caves in the area near the western shore of the Dead Sea in Israel and the Palestinian territories.[2] The oldest manuscripts come from about the seventh century BC, the youngest from Islamic times. They were written in different forms of Aramaic, Hebrew, Greek, Latin and Arabic. These are the Dead Sea Scrolls in a broad sense.

When speaking of the Dead Sea Scrolls, many people refer to a specific group: the Qumran scrolls, doubtlessly the most important group, which consists of about 1,000 scrolls. They are actually the feeble remains of what was once a huge ancient Jewish religious library and were discovered between 1946/47 and 1956 in eleven caves about 12 km south of Jericho.[3] The Qumran scrolls date from roughly the third century BCE to the first century CE.[4] So far, it is the largest exclusively religious library known from the ancient Mediterranean world whose remains have been unearthed.[5] The scrolls have revolutionised scholarly perspectives in Biblical Studies, ancient Judaism, early Christianity, Hebrew palaeography, Hebrew language, Jewish book studies and many other fields.[6]

However, speaking of scrolls may create a false impression: 98% of the 'scrolls' consist of tiny fragments that can be as small as a fingernail (or smaller still). Altogether, there must be about 15,000 of them, but nobody has ever counted them. Furthermore, most parts of the majority of scrolls are now lost. Deciding which fragment once belonged to which scroll and where it used to be on that scroll has been one of the greatest puzzles in the history of human culture, not to mention the questions regarding genre, content, authorship and scribal origin of each reconstructed scroll.[7] Answering the questions posed by this extremely complex cultural puzzle will undoubtedly help solve analogous problems with fragmentary finds from many other cultures.

You may compare the task with the following parable. There are two versions of it. Here is the simple version: Your mother-in-law gives you a 'present': She takes eleven big boxes (the eleven caves) and 1,000 puzzles (the 1,000 texts) of 10 to 10,000 pieces each (the fragments). Each puzzle is put in one of the eleven boxes. She puts about 650 of them into the biggest one (Cave 4). Then the contents of each box

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[1] For previous surveys, see especially Tov (2011) and Broshi 2004. Many studies of varying quality have been published in Humbert, and Gunneweg 2003; Galor, Humbert, and Zangenberg 2006; Gunneweg, Greenblatt, and Adriaens 2006.

[2] See the catalogue by Tov 2010, *Revised Lists of the Texts from the Judaean Desert*.

[3] See Stökl Ben Ezra 2011.

[4] Paleographical dating schemes have been developed by F. Cross for the book scripts and by J. Milik and by A. Yardeni for the cursive scripts and for Nabatean; Cross, 1961 and 1998; Yardeni 2000. For the so-called Palaeo-Hebrew script of this period, see McLean 1982.

[5] See Stökl Ben Ezra 2009.

[6] See Stökl Ben Ezra, forthcoming.

[7] See Tigchelaar 2012.

are thoroughly stirred. Finally, she throws 95% of the pieces away. This is not the only challenge; many of the pieces are extremely darkened, so one often cannot distinguish ink from parchment with the unaided eye. Your task is to reconstruct the original puzzle for each piece, its size and artist, the image depicted and as many details as possible on it.

For some texts you have images (the known texts, such as the Bible), but for most you do not. Some puzzles show the same image as others, and you can use one partial image to reconstruct another one. This was the mission of a very select group of about eight scholars in the scriptorium.

2. The four classical tasks

The first part of this paper focuses on the four main tasks of the first two generations of scholars (which are in fact tasks of any publication project connected with a major discovery):

1. Transcription of fragments

2. Reconstruction of hypothetical manuscripts with the help of paleography, codicology (e.g., shape matching) and contents

3. Study of textual parallels to derive compositions and their recensions

4. Ideological provenance: study of contents of compositions to discern the author group and web of groups who authored, copied and/or transmitted the scrolls.

One can imagine this as a pyramid of increasing hypotheticality, as shown in fig. 1:[8] The smallest physical unit is a fragment. The next level consists of manuscripts tentatively reconstructed from a group of fragments that join directly or indirectly. Each manuscript is in fact a hypothesis, a construction rather than a reconstruction. Several manuscripts may have so many parallels that it becomes clear that they are different copies of more or less the same composition. Several compositions can in certain lucky cases be attributed by their ideology, rules and sociological descriptions to a specific group.

The task of making a preliminary transcription and establishing initial tentative associations that fragments have with one or another manuscript took researchers about ten years, as we know from the compilation of a handwritten concordance, but this did not result in the publication of most fragments.[9] Then, for several reasons, work slowed down
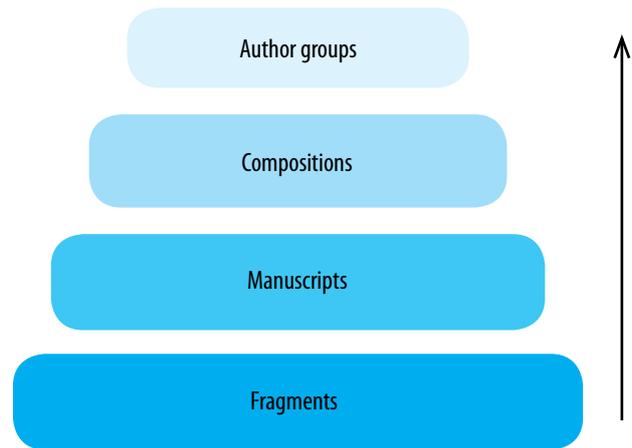

Fig. 1: Pyramid of increasing hypotheticality.

and came to a virtual halt for 30 years until the end of the eighties. Nobody apart from a very small team of about ten people had access to the fragments, photos, transcriptions or the concordance. Originally, this arrangement was probably a good idea for a quick and thorough publication, but it became increasingly problematic and eventually developed into what some people have called one of the biggest academic scandals of the twentieth century. Fanciful conspiracy theories about the Vatican trying to hide texts dangerous to Christian belief came into being. This is, of course, nonsense. Luckily, at this point, computers entered Qumran studies. Having laid their hands on one of the privately published and well-guarded concordances, of which only a handful existed at the time, and having entered the concordance into a computer, a small team around Ben Zion Wacholder and Martin Abegg simply reconstructed the complete fragments in a kind of reverse engineering and began to publish their work.[10] At about the same time, pictures had been made available in print in 'pirate editions'.[11] These were two of the factors in pushing the official editors forward with the publishing process that finally ended about five years ago with the final volume of the official edition. Everybody has access to many editions of all the texts today. In a limited number of cases, computer programs have assisted in the identification of some very small fragments containing only a few letters over several lines with large known texts.[12] However, some of these

[8] Eibert Tigchelaar's suggestion in an oral communication.

[9] Brown et al. 1988. For a history of discoveries and publications, see Fields 2009; Dimant, and Kottsieper 2012. See also Tov 2002.

[10] Wacholder, and Abegg 1991-1996.

[11] Eisenman, and Robinson 1991.

'identifications' or reconstructions can be shown to be highly hypothetical or even wrong.

Obviously, scholars differ – sometimes greatly – not only with regard to how they interpret a certain passage of writing, but also as to whether or not to ascribe a fragment to a particular scroll, or whether to differentiate a group of fragments into one or several scrolls. Designing a database that is capable of representing the different possibilities is quite a challenging task. The chain of philological problems is complex and resembles other complicated manuscript finds.

A) On a paleographical level, a chain of characters on a fragment can be interpreted by one scholar as N words with X characters, but by another one as M words with Y characters.

B) On a grammatical level, one scholar derives a word from root A linked to lemma B explained as form C with a syntactic function D. Other scholars will come up with other equally plausible explanations that are different.

C) On a level of textual criticism, one manuscript may represent a passage with 5 words in the order 1,2,3,4,5, while a clear parallel in another manuscript can consist of only 4 words in a different order and/or forms and/or lexemes and/or in a different language.

D) On a codicological level, one fragment can be linked by one scholar to a group of fragments I from place J, while other scholars will place it somewhere else and/or link it to a different group of fragments.

E) On an ideological level, one text may be interpreted as a copy of composition *Alpha*, while another scholar considers it a copy of composition *Beta*.

F) While some alternative suggestions can clearly be discarded as wrong, others may be judged as equally probable. One also needs a system that takes the hierarchization of proposed philological solutions into consideration.

Ingo Kottsieper from the Forschungsstelle Qumranwörter-buch (Qumran Dictionary Research Project) of the Academy of Sciences in Göttingen, a project directed by Annette Steudel and Reinhard Kratz, has succeeded in the complex task of constructing a database that can take all the problems mentioned above into account. Moreover, all parallels can be noted and texts interlinked. Different readings of a given

passage can be aligned and displayed. Critical editions of any passage can be produced on the fly. Many scrolls bear several names, revealing various levels of confidence with regard to our knowledge of contents and/or genre. This state-of-the-art database can handle all these tasks.

While still rather exceptional in manuscript studies of other languages in the late forties and early fifties, infrared photography helped in distinguishing the background from the ink from the very beginning.[13] Today, these PAM photos are extremely important not only for reconstructions of scrolls (because many of the fragments have deteriorated over the last 50 years), but also for recapitulating the reconstruction process of the fifties.

Shortly after its invention, radiocarbon dating was tested on materials from Qumran in 1950 and confirmed their dating to the turn of the era in a very general way.[14] Before the invention of Accelerated Mass Spectrometry (AMS), a great amount of material was needed – and destroyed – for such tests, so testing was almost exclusively done on peripherals of the scrolls: first and foremost on the wrapper, and later on palm wood. With the invention of AMS, the amounts needed for C14 tests decreased. Several tests have been undertaken on about 30 scrolls since the early nineties.[15] In a general way, these tests have confirmed the paleographical scheme suggested by the late Frank Cross, which was based on comparison with very few other finds, including ones in other related scripts, and on general typological observations (see below).[16] In some cases, we have to assume that the sampling was biased, probably due to the application of modern castor oil by the early paleographers, which they sometimes used to enhance the contrast between the ink and the blackened parchment.[17]

In manuscript studies, the classical papyrologists are arguably the most advanced with regard to shared and openly accessible catalogues, downloadable high-quality images and crowd-sourcing platforms for manuscript descriptions

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[12] See Pfann 2001, 213–225.

[13] Bearman, Pfann, and Spiro 1998; Zuckerman 2010.

[14] Libby 1951.

[15] The best explanation of the possibilities and limits of C14 dating is probably van Strydonck et al. 2000. For the first C14 analyses on Qumran scrolls, see Bonani et al. 1991 and 1992; Jull et al. 1995.

[16] Bibliography given above: fn 4.

[17] Doudna 1998. Rasmussen et al. 2006 and 2001; Atwill, and Braunheim 2004; van der Plicht 2007.

and transcriptions.[18] Qumran studies are not quite there yet, but the situation has considerably improved over the last decade. Today, all Qumran scholars work with one of two commercial databases on a daily basis: either *Accordance* or *DSSEL*, which include one transcription, one translation, grammatical analysis and one picture for most fragments, most of them as 300 or 900 dpi scans of the old infrared photos from the fifties.[19] Many related texts in different languages and from different periods, such as Bibles in various languages, Josephus, Philo, some pseudepigrapha and some Rabbinic literature complete the *Accordance* suite. Researchers using many other linguistic and cultural corpora, such as those available in Buddhist studies, can only dream of a similar infrastructure. Even so, a free online infrastructure usable by any group in any culture and to which different research institutes could provide plug-ins would still be a huge step forward.

Since September 2011, the Shrine of the Book website permits access to color photos of five of the almost complete scrolls, including some annotations for some 1QIsaa.[20] In December 2012, the Israel Antiquities Authority in collaboration with Google constructed the Leon Levy archive, a website that permits free internet access to scans of the historical infrared photos as well as some color photos[21] and, since February 2014, also to new high-resolution multispectral images of the scrolls. These photos have a 24-megapixel resolution in 1,215 ppi and were taken in 12 wavelengths from 445 nm to 924 nm. For some wavelengths, additional images with light coming from different angles were added. The images are freely viewable online, which is an immense step forward. They are not downloadable yet (a considerable deficit compared with the Greek papyrological world), but the IAA has kindly agreed to make them freely available to researchers upon request. Despite the fact that the state of preservation of many fragments has deteriorated

since the old IR images were made, the multispectral images of the current state will lead to the identification of some new letters that were unreadable using the old techniques.

There is as yet no collaborative platform for transcribing, translating, commenting or annotating the Scrolls. The International Image Interoperability Framework (IIIF) developed at Stanford University would be very interesting in this respect.[22] IIIF provides, on the one hand, a standard for selected regions on an image (a rectangle that can be turned around) or, more precisely, on a canvas that can be linked to a stack of several pictures of the same object, which is ideal for the multispectral images of the IAA. The Shared Canvas and Mirador viewers developed in collaboration between Stanford and the Bibilissima project in Paris are very promising steps in the direction of an infrastructure.[23]

Other IT tools that would be extremely practical should facilitate the very time-consuming reconstruction process of the Stegemann method, which is based on destruction patterns and the regularly decreasing size of the revolutions of a scroll from the outside to the inside.

Patch pictures of recto and verso of fragmentary opisthographs (scrolls written on both sides) could also be done automatically.[24] The Tel Aviv team (see below) is pursuing work in this direction in a very promising way. Computer pattern analysis has great potential for reconstruction work on highly fragmentary papyrus by matching the papyrus fiber pattern of non-contiguous fragments from the same papyrus sheet using 'join distances' at the same height (for the recto pattern) or width (for the verso pattern). Up to now, such work has largely and very painstakingly been done by hand, for example by the Egyptologist Kim Ryholt for the Tebtunis papyri and by Barns and Pfann for 4Q249.[25] Together with the team around Lior Wolf and Nahum Dershowitz from Tel Aviv and Jonathan Ben Dov from Haifa, we have started a research project that should (if successful) considerably alleviate the reconstruction task through a process that includes the relative distribution of the fiber pattern coupled with the height and distribution of the inscribed lines similar

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[18] One of the major projects is the shared platform www.papyri.info. The catalogue portal www.trismegistos.org is also useful, especially together with the *Leuven Database of Ancient Books* www.trismegistos.org/ldab, a catalogue of literary papyri; and finally there is the *Heidelberger Gesamtverzeichnis* for documentary papyri: http://www.rzuser.uni-heidelberg.de/~gv0/.

[19] Tov, and Parry 2005, *DSSEL*: *Dead Sea Scrolls Electronic Library*. Accordance: by Oaktree software: http://www.accordancebible.com/buzz/articles/dss_index.php.

[20] www.dss.collections.imj.org.il.

[21] www.deadseascrolls.org.il.

[22] www.iiif.io.

[23] Members of the Shared Canvas project at Stanford University and the Biblissima project at the Campus Condorcet in Paris are collaborating on creating an infrastructure.

[24] We are planning to construct such a macro at the EPHE.

[25] Barns 1977, 29 and Pfann 2000, 517–523; Ryholt 1999; 2006; 2013.

to the matching analysis of dendrochronological patterns. Of course, such an analysis would largely be independent of the type of script on the papyrus and could also be used by scholars working on completely different corpora. Promising preliminary results have already been obtained.

Perhaps computer pattern analysis can also be helpful in discerning the script of two fragments. However, as the fragments are often very small with only a few letters and are deformed three-dimensionally, a number of very complex issues will have to be solved before digital paleography can become a major factor in the reconstruction of tiny fragments. RTI (Reflectance Transformation Imagery)[26] coupled with 3D reconstruction could potentially help in overcoming these difficulties. It is particularly well suited for visualizing surface structures such as papyrus fibers and scratching.

In the long run, automatic paleography will arrive at OCR-like capabilities of a usable – albeit far from perfect – quality compared with human paleography. Since the Dead Sea Scrolls have been deciphered, this is important for other large corpora with unidentified and untranscribed texts, such as the cuneiform archives and libraries, Greek, Demotic and Coptic papyrology, Syriac and Geniza studies. Even before reaching an acceptable OCR level, these methods will enable computers to provide preliminary identifications of large collections of texts. Computer linguistics could also be of enormous help if joined to automatic paleography. The texts of the Qumran corpus have already been analyzed, so this is less relevant to them.

Material studies have enabled scholars to advance in ascribing fragments to specific manuscripts. Stephen Pfann has developed a hair-follicle pattern analysis, which examines the curve and distribution of hair follicles and compares them to the constant follicle pattern in the animal species that provided the skin to arrive at probable placements of a parchment fragment on a sheet.[27] I am not sure whether this method has been applied to or tested on manuscripts from other cultures. RTI could be helpful in hair follicle analysis. DNA could enable us to discern whether two fragments come from sheets that were cut from the hide of the same animal or not.[28] These hides of mainly goats, sheep and calves had

an average size of about 60 cm x 90 cm, enough for two or more sheets, depending on the height of each sheet.[29] While this does not necessarily allow the ascription of two fragments to the same sheet,[30] knowing that two compositions were written on material from the same animal would obviously be most interesting regarding the hide trade, scroll production ateliers and the proximity of various scrolls or scribes during production.[31] This is a piece of information at least as important as the ascription of this or that fragment to this or that scroll.

Whether two fragments do *not* belong to a sheet can also be examined by applying X-ray fluorescence spectroscopy (XRF). A number of studies have been undertaken by the group around Oliver Hahn and Ira Rabin at the Bundesanstalt für Materialforschung (BAM Federal Institute for Materials Research and Testing) in Berlin.[32] It is important to note that XRF can only disprove certain claims: If the profile of chemical elements of two given fragments can be shown to be very different, then the two fragments most likely did not belong to the same skin, as we have seen in the case of 4Q413/4Q413a.[33] If XRF shows a similar profile for both fragments, they could also come from the same scribal atelier, but not necessarily from the same sheet. In antiquity, some skins waited longer than others before being prepared as writing support. These skins had to be treated with salt that was then mostly, but not entirely, washed off in the process of preparing them for writing. In the 2,000 years since their production, the remaining salt has crystallized on the surface of these fragments. With methods capable of discerning salt crystals, one can distinguish between salted and unsalted skins, thus providing an additional hint for sorting fragments, as was shown by the Berlin team.[34]

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[26] See p. 25ff of the revised and updated version of Zuckerman's article quoted above, available online at: http://www.usc.edu/dept/LAS/wsrp/information/DynamicsDSS/.

[27] So far, only a brief summary has been published at http://orion.mscc.huji.ac.il/orion/programs/taskforce.shtml.

[28] On a new technique to arrive cheaply and quickly at a sample for DNA analysis with minimal involvement with the manuscript, see the contribution by XY in this volume. Also Woodward et al. 1996.

[29] According to Tov, most sheets had a length of about 30–40 cm (Tov 2011, 23); for 1QIsaa he gives a figure of 35–45 cm (2004, 80). For a scroll like 1QIsaa with a length of 28 cm, one could therefore produce about four to six sheets from one hide. For scrolls of greater length (e.g. 40–45 cm), the same hide size would only produce two long sheets.

[30] Tov 2011, 23–24.

[31] Tov 2011, 25.

[32] Rabin 2013.

[33] Hahn et al. 2007.

[34] Wolff et al. 2012.

3. Part Two

As other communications in this volume show as well, the physical remains of these texts obviously contain much more information about the owners than only the ideas expressed in the writing. Having pointed out some issues in which IT and material sciences and, especially, their combination could lead to progress in the classical tasks of editing fragmentary manuscript finds, let us now transit to three further complexes where material sciences have the potential to open alleys into largely untrodden fields. The fifth question of primary importance in the publication of the Scrolls or any other manuscript corpus is:

5. Scribal provenance: study of scribes and codicology to discern scroll production and networks or schools of scribes inside and outside of Qumran and the movement of the scrolls, scribes and/or owners of the library.

Of course, medievalists have addressed these questions for a long time. In Qumran's case, the main attempt has been Tov's controversial thesis of a special Qumran orthography.[35] Yet, provenance and clustering into schools is the first major question on which we can advance much further with the help of material studies and computer pattern analysis, especially if used in conjunction with each other, even though traditional paleography and codicology continue to be of fundamental importance.

DNA analysis could provide us with extremely valuable information regarding the kinship of the animals that provided the scribes with skins for making parchment. The more closely the DNA of the animal skins of two scrolls is related, the more probable it becomes that these skins came from the same production center or scribal school. Recent years have seen very few studies on DNA in the Qumran texts and none specifically for this purpose.

One of the biggest breakthroughs in the last decade has come from a different method in material sciences: In 2009, the team run by Oliver Hahn and Ira Rabin gave the definitive answer to the long-standing controversy as to whether the Scrolls came from a community that lived and worked locally at the site of Qumran or from a mixture of libraries in Jerusalem and elsewhere. The implications are huge. Local scrolls were certainly written (but not necessarily authored) by local Essenes, a splinter group of great intellectual but

little numerical importance. If the scrolls are not local, however, they more likely bear witness to wider Judaism.[36] In antiquity, ink was prepared by grinding a solid block of ink on a stone, thereby creating a powder that was subsequently mixed with water. An XRF analysis of the composition of the ink of one fragment has shown an unusually high bromine to chlorine ratio in the ink, *but not* in the parchment. Such a high ratio of bromine to chlorine only appears in water from the Dead Sea area. Therefore, the Berlin team was able to show that at least this fragment had been written with local water. Establishing water, ink, parchment and papyrus profiles for other areas could undoubtedly help in provenancing scribal activity in various cultures and periods. It could also serve as a fundamental point of departure for studying the history of the science of writing and the commerce in scribal materials. Let me add that the XRF results by no means imply that all scrolls come from Qumran. In fact, the philological studies of the last two decades have shown that the majority of compositions were not authored by the local Essenes, even though they may have copied some. Furthermore, there is now a consensus that there were several other Essene sites in Judaea (and perhaps beyond). Fragments from at least a number of other scrolls have been investigated by the same team using XRF analysis and some other techniques such as Raman and FTIR.[37] The results point to a non-Qumranic origin for some of these scrolls. Additional studies of a similar nature are of the utmost importance to our understanding of the collection and the socio-intellectual network behind them. Which scrolls are local, which are not? These questions are, obviously, of the greatest interest to anybody working on material coming from a circumscribed collection.

Another task is establishing a palaeographical typology that would permit scrolls to be dated, almost all of which are in an undated book script. In the almost complete absence of fixed pegs, this dating has had to rely on the typological development of the Judean script and developments among its cousins, such as Nabatean.[38] After the fall of the Persian Empire, the once homogenous Aramaic chancellery script split up into local types in the various parts of the political successor entities until about the first century CE. Luckily, we are speaking of a 'hot' period of scribal development

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[35] See the discussions in his *Scribal Practices and Approaches*. The most thorough critique has been that of Tigchelaar 2010.

[36] Rabin, Hahn, Wolff, and Masic 2009.

[37] Rabin, forthcoming.

[38] See above, fn. 4.

C20	4QSamª	4QJerª	1QIsaª	1QM	1QHª	Mur Gen

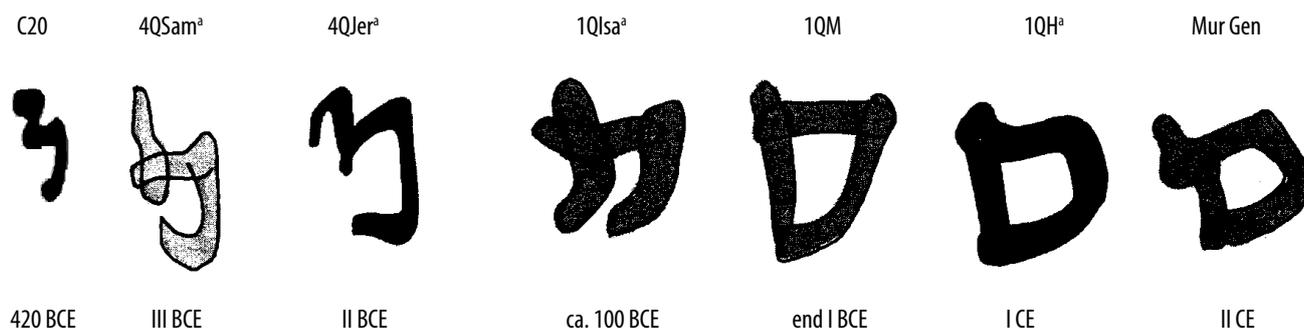| 420 BCE	III BCE	II BCE	ca. 100 BCE	end I BCE	I CE	II CE

Fig. 2: Typological development of the *samekh* over time.

with a fast pace, when relative typologies of what is closer to Aramaic and what is closer to later square script can be established with more confidence compared with 'cold' periods such as the Middle Ages, when the different regional types used for Hebrew script changed much less.[39] This can be illustrated with the typological development of the *samekh*, which gradually lost its head on the left side and became a closed entity, as fig. 2 shows.

Still, the palaeography of early Judean scripts is an area that is needs to be revisited. I see the greatest potential for pattern analysis in providing 'big data' that is numerical and, therefore, can be analyzed and evaluated with statistics and lead to scribal clustering (hands, styles, schools, geographical and/or chronological distribution).

One idea would be an evaluation of the proposed paleographical evolution scheme for dating manuscripts. Can we actually derive a logical sequence from the proximity that puts the different stages of Judean script on a timeline between the Aramaic and the square script? When does the neat scheme become too noisy? Do we have to, or rather, can we ascribe certain features to differences between contemporaneous schools? Can we describe the transition between cursive and formal styles and their intermediaries mathematically? Can we arrive at the level of distinction between scribes for texts as fragmentary as the Qumran scrolls? Another result could be some kind of check system that tells us where the current attribution of fragments to hypothetical manuscripts makes sense or whether one should reconsider comparisons with another group of fragments.

Bernd Neumann, Rainer Herzog and Arved Solth at CSMC, University of Hamburg, have done some very promising work on stroke extraction, automatic recognition of lines and automatic recognition of inscribed areas of interest in manuscripts.[40] Their method seems to be particularly well adapted to the nature of Hebrew, which (similar to Chinese) is written in mostly rather well separated characters or sometimes short chains of characters connected by a nexus.

The Friedberg Genizah project team, whose highly impressive and innovative IT component is being developed by the group around Lior Wolf and Nahum Dershowitz, has been able to provide scholars with tools of stunning effectiveness for join matching by means of automatic codicological and palaeographical analysis and for automatic classification of scripts such as Ashkenazi, Italian and Oriental.[41] The Tel Aviv team has also done automatic alignment of existing transcriptions of Hebrew manuscripts with ink traces on images using algorithms developed by Tamar Lavee.[42] Of course, this has great potential not only for training the pattern recognition algorithms but also for updating classical digital editions for the purpose of quickly publishing previously transcribed texts directly linked to photos of these manuscripts.

Another objective that could be achievable with the help of a large database and computer paleography would be to study the development of one scribe's hand over a short time (from the first to the last column of a scroll) and over the long period of his lifetime. This is of the greatest interest to anybody working on scribal attribution, archives or biographies. Again, a triangle involving material studies and IT would vastly surpass studies that only employ one

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[39] The drawings are taken from Yardeni 2003.

[40] Solth, Neumann, Stelldinger 2009; Herzog, Neumann, Solth 2010.

[41] www.genizah.org. Wolf 2010; Shweka et al. 2011.

[42] Lavee 2013 (available at: http://www.cs.tau.ac.il/thesis/thesis/Lavee.Tamar-MSc.Thesis.pdf).

methodology without the other. Computer-supported studies of the development of the script of one scribe would naturally benefit significantly from a network that assembles the greatest amount of data possible from precisely dated and/or provenanced sources in other scripts whose scribe is known and then extrapolates general variation algorithms for the less well known.

The GIWIS and *Monk* projects led by Lambert Schomaker in Groningen, Holland, have already assembled a vast amount of data on Latin scripts and are a hugely important step in this direction. According to Schomaker, GIWIS is able to *typologically* date medieval Latin manuscripts within periods of 25 years.[43] This does not mean that the manuscript actually comes from such a short time span, only that it is typologically in between two points that have been established with the help of a huge amount of paleographically analyzed manuscripts. It goes without saying that such a database should be openly accessible to everyone.

Another objective could be the question of whether a scribe wrote manuscripts in different scripts or even alphabets. This is a very challenging problem currently unsolved in the world of classical paleography. To establish a ground truth, it might be a good idea to assemble a large database of modern manuscripts written by the same scribes, but in different alphabets (e.g. Greek, Latin) or scripts (e.g., cursive, book script).

Beyond a doubt, philology, pattern analysis and material studies need to be applied to these questions in a combined approach to methodology. Coupling the results of material studies with traditional paleography and IT cluster analysis, one could establish a chronological profile that could provide insights into the history of activity of the site and possible waves of imports of outside manuscripts. This strategy is, of course, transferable to any manuscript collection whose production is linked to a particular place, no matter whether it is Ugarit, Elephantine, Herculaneum, Nag Hammadi, Athos, St. Gall, Timbuktu or the monastery of the Dharmaguptaka sect in Nagarāhāra (where the Gandhari manuscripts presumably came from). How many recipes for ink or parchment preparations are attested? How many scribes can we discern? When did local manuscript production start, peak or decline? Which ingroup manuscripts do *not* come from the center studied and point to the existence of further centers?

Which outgroup manuscripts come from the center? What proportion of ingroup and outgroup compositions did the scribes at the center write and when? Did local ingroup scribes write in all scripts, languages, styles and genres?

For the analysis of local schools, a triangle that combines philology with a database and the analyses generated by both material studies and IT has great potential for reinforcing any argument, e.g., if the pattern analysis data matches the chemical element profile. If it does not match, this poses further questions and could result in some interesting conclusions with regard to scribal migration or networks of scribal schools. Similarly, for the transmission of techniques and the development of writing styles, a combination of IT and material sciences could open up new avenues of investigation. Are specific text groups, distinguished by ideology, genre, dialect, orthography etc. linked to specific ink or parchment recipes, scribal schools or scribes? Of course, such a working program would imply substantial financial support, but the general idea is transferable to any project of major complexity with great historical implications.[44]

Let me move on to a rather more complex version of the parable mentioned at the beginning of this paper for which material studies are indispensable. The situation of the Qumran data is, in fact, more complicated than pointed out at the beginning: Let's say your mother-in-law did not actually give you the eleven boxes, but only six of them (all minor ones). Instead, she transferred most of the boxes – and all of the important ones – to a group of smugglers (the Bedouin). Furthermore, she also gave the same group of smugglers additional boxes with other puzzles that she had prepared, not for you but for your brother-in-law (other sites from the Judaean desert). When you buy the pieces from the smugglers one by one, *they* are your sole source of information regarding which box they found a piece in. Sometimes the smugglers lie. At least, you are lucky enough to strike a deal with the smugglers so that 99% of the pieces

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[43] Oral information by L. Schomaker. For some of his publications, see Schomaker et al. 2010; Schomaker et al. 2007.

[44] The École Pratique des Hautes Études in Paris has forged a cross-cultural and interdisciplinary working group of palaeographers skilled in the scripts of many major human cultures (cuneiform, Chinese, Japanese, Arabic, Hebrew, Greek, Latin, Tibetan, Coptic, Syriac, Central Asian scripts). Our first workshop was held on June 3, 2014 in Paris and concerned the theory and practice of dating methods. Throughout its history, the École Pratique has always had a tradition of quality and quantity with regard to scholars with this somewhat old-fashioned expertise in Europe and beyond. Often, giving chronological or geographical indications about the provenance of a manuscript is unjustifiably belittled as a *Hilfsdisziplin* (ancillary discipline). We are looking forward to suggestions for collaboration with experts from other universities in the coming years, be they experts in traditional palaeography, computer-supported pattern analysis, image treatment or material studies.

end up in your collection; other people (tourists and private collections) only get 1%. So, to the fragmentary state of the findings, we also have to add the difficulty of the black-market intermediary and unprovenanced data.

6. Transmission provenance: attribution of fragment to manuscript collection – origin in one or another specific cave – ancient, medieval and modern interventions.

In order to understand the collections in the caves and their relationships to the inhabitants of Qumran, proof of the authenticity of the provenance in this or that cave is crucial. We are certain that for some fragments the Bedouin have given us wrong information about the provenance, however, since some fragments purportedly from Qumran can physically be shown to belong to fragments from Murabbaat and Nahal Hever, sites of great importance further to the South. They contained Jewish archives from the Second Revolt and even personal letters by the leader of that uprising, Bar Kokhba, from about a century after the destruction of Qumran.

Scholars of the first generation (i.e., Strugnell) claimed to be able to recognize fragments from Cave 11, a major cave containing some very important scrolls. The fragments had a bitter taste (!) and a strong odor. Ira Rabin claims to have found the chemical compounds responsible for these features.[45] The large mass of bat guano accumulated over millennia marked the scrolls. Many scrolls were inevitably in contact with bat guano, which left microscopic but detectable traces on the fragments. The mass of guano was so large, in fact, that the resulting ammonia gas even penetrated into jars and under textiles and contaminated the outmost layers of otherwise protected scrolls such as the Temple Scroll. Was Cave 11 the only cave with bats in it? We need further chemical fingerprints to confirm the origin of fragments from other caves, especially for Cave 4. We may even eventually arrive at the conclusion that one of the so-called Qumran cave manuscript assemblies does *not* in fact belong together with the others. One challenge we face is that these methods will have to distinguish traces that are informative about ancient deposits from deposits that belong to either (1) modern conservation, (2) deterioration or (3) scroll production. Rather like policemen at the scene of a crime, archaeologists should always leave some of their material uncleaned and preserve the earth at the excavation site as it is so their finds remain in their original context.

If we transpose this possibility to other cultures, it would be trying to find traces of whether a manuscript was once in a specific city or library (e.g., St. Catherine's) or belonged to a specific scholar. I think it is possible in certain — but probably rare — cases to obtain fingerprints for the history of transmission, for example through ink analysis of marginal annotations, restored letters or bindings. Special places, their meteorological, biological (parasites!) or physical conditions and the techniques of their workers may leave special deposits behind.

7. Modern Conservation: Preservation.

Knowing more about the effects of transmission will obviously also lead to progress in modern preservation techniques.

4. Conclusions

The readable text is only a chapter in this history that remains to be written. The material features, many of them invisible to the human eye, are a chapter of at least the same importance in disentangling the complex history of the Dead Sea Scrolls. Bringing these issues together will only be possible by employing a combination of techniques consisting of classical philological analysis, material studies and image pattern analysis. One could also add complex data management to this (as in the example of the Göttingen database) and, of course, a true willingness to collaborate and share data in an infrastructure open to everyone.[46] The Tel Aviv team's algorithms for finding joins are so successful because they combine the results of several automatic analyses with paleographical, codicological and content information. Analogously, combing the results of XRF analyses of ink and parchment with automated paleography and DNA testing based on new imaging methods will undoubtedly lead not only to greater accuracy, but, through geographical, chronological and stylistic clustering, will also enable us to ask completely new questions regarding production techniques, transmission and interdependence between scribal schools.

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[45] Rabin et al. 2010.

[46] A database assembling all the results of examinations of inks, parchment, papyrus and paper would be of great importance here, especially if it also contained details about pottery gained with the help of material sciences (e.g., XRF, DNA, NAA), similar to what exists in dendrochronology, C14 dating and DNA sequencing.
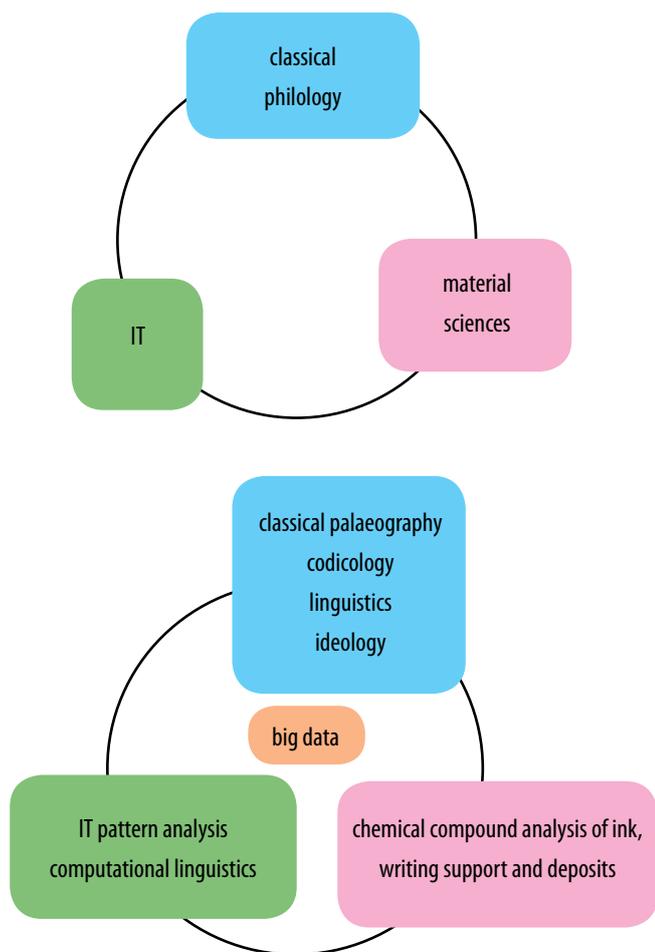
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