Alchemical procedures and their implications for the chronology of medieval *rasaśāstra*

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This paper examines those chronological conclusions that can be drawn from the distribution of procedures described in medieval alchemical texts. Applying cluster analysis to this data reveals a structure that supports the chronological results reached by Ray and later scholars without using traditional modes of philological argumentation.

In his work on the chemical and alchemical traditions of ancient India, P.C. Ray proposed a bipartition of medieval Indian alchemy (*rasaśāstra*) into a tantric and a iatrochemical period, which together range from about 700 A.D. to 1550 A.D. (Ray 1956, 113-164). Although later scholars such as White (1996) or Meulenbeld (2000, IIA) have corrected some of Ray's assumptions, most studies published in this field still rely on the appealingly simple model that Ray constructed from the general orientation of alchemical texts (Ray 1956, 158):[1]

> The prominent feature of the former [Tantric period] lay in the search after the *elixir vitae* and the powder of projection, . . . ; whereas in the latter [iatrochemical period] these fantastic and extravagant ideas, impossible of realization, had subsided into something more practical and tangible. The numerous preparations . . . were found to be helpful accessories in medicine.

The merits of Ray's historical analysis of this complicated, undated, and mostly anonymous literature are beyond question. However, grounding the chronology of a literary tradition mainly on only two features may yield

[1] See, for example, Biswas & Biswas (1996, II, 141ff.) and numerous articles published in the *Indian Journal of History of Science*. Similar networks of citations can be found in Western articles about Indian alchemy: e.g.,

Balbir (1990) ⟶ Roşu (1986) ⟶ Ray (1956) .

unreliable scientific results, especially since Ray frequently only touches on the reasons for assigning a text to one of the two main periods. While Ray and later scholars were concentrating upon the general and, especially, the religious orientation of these alchemical texts and upon historical hints hidden in them, much less attention has been paid to the actual (al-)chemical content of these works and its development over time. Meulenbeld (1989, 59) has raised the idea that plants may serve as philological "guide fossils" for dating medical texts. In this paper, we will examine which (statistical) methods are needed to detect such "guide fossils" in the content of alchemical texts and what they can tell us about the history of Indian alchemy.

Over the last four years, a database of Indian alchemy has been compiled, which now comprises the detailed descriptions of some 1,200 alchemical procedures coming from central texts of medieval Indian alchemy.[2] Hellwig (2009) reports that far-reaching chronological results can be deduced when the content of these alchemical procedures is compared by combining a modified phylogenetic model with statistical methods. In this paper, we will analyze the data contained in this database from another, more general point of view. Instead of comparing the content of alchemical procedures, we will examine which types of procedures are mentioned in which texts and what sort of chronological conclusions can be drawn from how they are distributed. Let us, therefore, specify what the term "procedure" refers to in this paper. Large parts of alchemical literature consist of detailed descriptions of how certain substances such as mercury, sulfur, and other minerals (e.g., realgar, orpiment, or mica) have to be prepared for their advanced alchemical or medical use. Among these descriptions, three types of "basic procedures" are especially frequent. The first procedure is called *śodhana* ("purification") and is obligatory for almost all substances.[3] The second procedure to be examined in this paper is *māraṇa* or "killing" (frequently translated by the obsolete term "calcination"), which is the formation of a new chemical compound: in most cases,

[2] The corpus from which the database is built contains the following texts: ĀNANDAKANDA (ĀK), BHĀVAPRAKĀŚA (BHPR), RASAKĀMADHENU (RKDH), RASAPRAKĀŚASUDHĀKARA (RPSUDH), RASAMAÑJARĪ (RMAÑJ), RASARATNASAMUCCAYA (RRS), RASARATNĀKARA (RRĀ), RASASAṂKETAKALIKĀ (RSK), RASAHṚDAYATANTRA (RHT), RASĀDHYĀYA (RADHY), RASĀRṆAVA (RARṆ), RASENDRACINTĀMAṆI (RCINT), RASENDRACŪḌĀMAṆI (RCŪM), RASENDRASĀRASAṂGRAHA (RSS), ŚĀRṄGADHARASAṂHITĀ (ŚDHSAṂH). Adding the RASOPANIṢAD to this database remains a desideratum. The RRĀ is taken as a single work, although Wujastyk (1984) has shown that parts of it are copied from other works; see below, page 62, for internal criteria supporting this conclusion.

[3] From a chemical perspective, most *śodhana* processes correspond to a removal of unwanted admixtures from a substance; see, e.g., Deshpande (1994) about the removal of tarnishes.

an oxide.[4] The third procedure is *sattvapātana* ("extraction of essence"), and is applied mainly to non-metallic substances. From a chemical perspective, *sattvapātana* can be interpreted as the splitting of a chemical compound in many cases.[5] Although many more procedures are described in alchemical texts, they are either not frequent enough to allow us to derive valid conclusions from their distribution, or they are "badly" distributed from a statistical point of view. If, for example, the metallurgical procedures mentioned prominently in the RHT, the RArṆ, and in parts of the RRĀ were included in our statistical analysis, we would base our investigation on an important subset of Ray's criteria. Since we intend to double check Ray's chronological conclusions, we have to resort to features that are different from the ones he used. The basic procedures are ideal candidates for this purpose, as they are mentioned in every alchemical text in the corpus, but have not yet been used consistently as time markers by Ray or later scholars.

In the following pages, we will show how alchemical texts become organized when the distribution of the three basic procedures is examined using a clustering algorithm. This abstract approach can be interpreted as a computational examination of the growth of alchemical knowledge, and it imitates a typical philological mode of reasoning: that the numbers and types of alchemical procedures record the alchemical knowledge codified in a text. Now, we assume that these procedures represent the general state of alchemical knowledge at the time the text was composed. Therefore, in this model, the alchemical procedures are clues indicating the time of origin for a text. Texts that the algorithm assigns to one cluster or group on the basis of the procedures they describe may thus have been written during the same period of Indian history. This approach is, of course, grounded on idealized ideas regarding text production and the (social) mobility of Brahmanical authors, as well as upon the idea of a widely uniform Indian cultural area: it assumes, for instance, that the procedures described in a text are representative of the alchemical knowledge of the time the text was produced. In addition, Witzel (1985) has, among others, sketched the highly dynamic social milieu of medieval Brahmins. If we really took into account such aspects of Indian social and cultural history, not only the present statistical approach would be made impossible. Even most of the usual philological techniques could not be applied any longer due to under-specificied historical parameters. This does not mean that the results of this study are necessarily invalid or unreliable. It only means that we could

[4] In most cases, a *bhasman* or "ash" is created from the basic substance. Some of these preparations are analyzed chemically in Patel (1963).

[5] See, for instance, the extraction of mercury from cinnabar (*hiṅgulākṛṣṭa*) or the *sattvapātana* from *rasaka*, which probably describes the extraction of zinc from zinc carbonate.

not use such a simple model if we knew more about the historical and social circumstances of text production. But as long as additional historical data is not available, we should not overcomplicate theoretical models.

To examine which groups of alchemical texts are accounted for if only the occurrence of the basic procedures is taken into consideration, we built a data structure that recorded how the procedures are distributed over the texts. Texts that contain too few procedures, as well as procedures that occur in too few texts, were thus removed from the data structure, since neither condition would contribute to a general picture; they may even obscure the structure underlying the data. Based on these frequent datasets, the texts were grouped using the Ward algorithm, a so-called hierarchic clustering method. The results of this procedure are displayed in figure 1.[6] This figure shows two types of information. First, it describes the order of the clustering process. Texts that are connected directly at a low point in this diagram are combined into groups during an early stage of the clustering process. The rightmost group 3, for example, is constituted by the core members RARṆ and RHT, to which RSK and RADHY were added later and in that order. The second type of information is indicated by the lengths of the branches connecting the texts and clusters. Long branches, as between the RSK and the next cluster {RARṆ, RHT}, for instance, indicate a large difference in the frequencies of the procedures described in {RSK} and {RARṆ, RHT}. The grouping structure and the difference values make it possible to distinguish three groups of texts. The first group consists of RPSUDH, RCŪM, and RRS. It is definitely not surprising that these three texts constitute one group, especially since the RRS and the RCŪM are identical over wide passages. However, what should be noted is the fact that they form such an isolated cluster without noticeable connections to other texts.[7] The second group (ŚDHSAṂH to RRĀ) is comprised of

[6] Using a slightly more technical terminology, the structure of Figure 1 can be described as follows. We distinguish three basic procedures P (*śodhana*, *māraṇa*, and *sattvapātana*) and the substances x (e.g., sulfur, iron) to which the procedures P are applied. If procedure P is applied to substance x, the specialized procedure is labeled P_x (e.g., $\textit{śodhana}_{\text{sulfur}}$ = "*śodhana* of sulfur"). While there are only three features per text that are derived from P, there are in theory $3 \cdot |x|$ values of P_x for the same text. If n_t is the number of texts that contain a sufficient number of procedures P_x and n_p is the number of procedures that occur in a sufficient number of texts, a $n_t \times n_p$ matrix M is created. Cell (i, j) of M is set to 1 if procedure j is mentioned in text i. Note that the matrix does not store how often procedure j is mentioned in text i, but only if it is mentioned at all (binary values; see also footnote 10). Next, the distances between all pairs of texts are calculated using the Jaccard coefficient. These distances are stored in an $n_t \times n_t$ matrix, and this matrix is evaluated using the Ward algorithm (see, e.g., Bortz (2005, 575-577)). The actual calculation is done with R (R Development Core Team 2007).

[7] To be exact, the branch leading upwards from the RPSUDH indicates that the group

texts that Ray assigns to the late iatrochemical period of alchemy. The third group consists of texts that are generally assumed to be the founding treatises of medieval alchemy (RARṆ, RHT), plus outliers such as the RADHY and the notorious RSK (see Hellwig (2009) and below). To find out which features influenced the organization displayed in Figure 1 we selected the procedures that are most typical for each of the three groups.[8] Table 1 reports these results, ordered as metallic and non-metallic substances. The third group shows the lowest number of internal correspondences, which is in accordance with the large distances between the members of the group (see the long branches in figure 1). Nevertheless, we find procedures from all three basic classes (*śodhana*, *māraṇa*, and *sattvapātana*) among the common stock of group 3 . Group 1 shows the most complete inventory of alchemical procedures, while the texts of the second and probably late group are marked by the almost complete absence of *sattvapātana* procedures from an otherwise comprehensive account.[9] When relative frequencies of the basic procedures are used instead of binary values (not displayed),[10] a similar organization is achieved, that yet differs in two important details. First, the RADHY is not connected with the third group (RARṆ, RHT), but is a complete outlier, located at the root of the tree. Second, the RRĀ now appears in the third group. If we accept Ray's bipartite chronology, this means that the RRĀ has been transferred from late to early alchemy. We will come back to this "chronological oscillation" of the RRĀ later in the paper.

As mentioned above, Table 1 reveals clear differences in the types of procedures that appear in each of the three text groups in Figure 1. This effect is corroborated when the simple frequencies of the three basic procedures are examined, which would constitute a further step of abstraction from the original content of the texts. For this purpose, we recorded how often procedures of the types *śodhana*, *māraṇa*, and *sattvapātana* are described without taking into ac-

{RPSUDH, {RCŪM, RRS}} was added last to the clustering tree.

[8] This means that a procedure P_x (cmp. footnote 6) must be skipped only in one of the texts of a group. There are more sophisticated methods to evaluate the influence of variables on a grouping process (e.g., linear discriminant analysis or factor analysis), but these methods require larger datasets.

[9] Note again that the absence of a procedure P_x in table 1 does not mean that it does not occur in any text of a given group. It is, however, not prominent enough to be distinctive for the group (see footnote 8).

[10] Instead of binary values as defined in footnote 6, we use the complete frequency information of P_x in this setting. Each cell (i, j) of the matrix M stores the absolute frequency of procedure j in text i. After the whole database has been parsed, the values in each cell (i, j) are divided by the sum of cell values from row i = text i which results in relative frequencies.

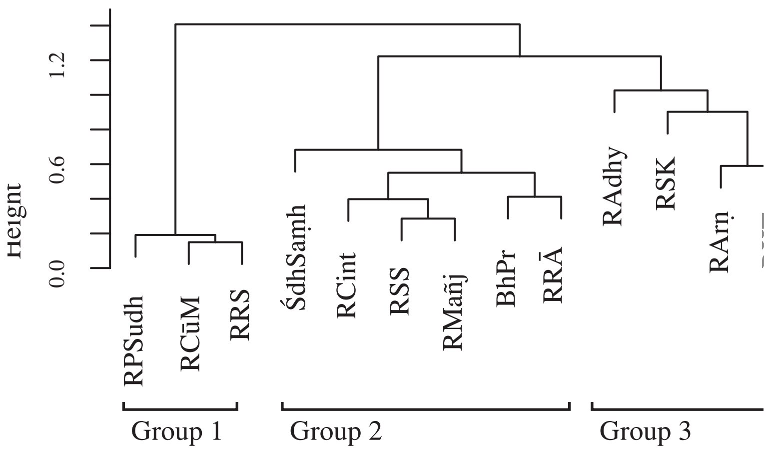

Figure 1: Clustering using all procedures mentioned in the corpus; binary data (cmp. footnote 6), Ward's algorithm

Group	*śodhana*	*māraṇa*	*sattvapātana*
RPSUDH, RCŪM, RRS	metals: bronze, Fe, brass, Ag, *vartaloha* non-metals: *abhra*, orpiment, *añjana*, *gairika*, cowries, *kaṅkuṣṭha*, *kāsīsa*, *rasaka*, realgar, *rājāvarta*, *sasyaka*, *saurāṣṭrā*, *sādhāraṇarasas*, *vaikrānta*, *vajra*, *vimala*, *śilājatu*	metals: Pb, bronze, Fe, Au, Cu, brass, Ag, *vartaloha*, Sn non-metals: *abhra*, jewels, *mākṣika*, *rasakasattva*, *rājāvarta*, *sasyaka*, *vaikrānta*, *vajra*, *vimala*, *śilājatu*	*abhra*, orpiment, *mākṣika*, *rasaka*, realgar, *rājāvarta*, *sasyaka*, *saurāṣṭrā*, *vaikrānta*, *vimala*
ŚDHSAṂH, BHPR, RCINT, RRĀ, RSS, RMAÑJ	metals: Pb, Fe, Au, Cu, Ag, Sn non-metals: orpiment, *rasaka*, realgar, S, *tuttha*, *vajra*, cinnabar, *śilājatu*	metals: Pb, Fe, Au, Cu, Hg, Ag, Sn non-metals: *abhra*, *vaikrānta*, *vajra*	cinnabar
RADHY, RSK, RHT, RARṆ	metals: Pb, Cu, Sn	metals: Pb, Hg	*rasaka*

Table 1: Procedures influencing the formation of groups in Figure 1

count the substances to which the procedures are applied. Table 2 reports the absolute and relative frequencies (in the left and right half, respectively) for each text. When cluster analysis is applied to the relative frequencies, we obtain the structure displayed in figure 2.[11] The clustering tree shows a bipartite structure. At the left side, we find texts that Ray has labeled as iatrochemical, while most of the earlier texts are collected at the right half of the tree (RARṆ to RRS). Note that the RSK is associated with the late texts in Figure 2, and that the RRĀ is again assigned to the earlier texts.

As collected thus far, this evidence may be interpreted according to chronology if the groupings are compared with philological theories about the history of Indian alchemy. To strengthen this interpretation, we will correlate the development that emerges in Table 2 with one probable chronological order in Indian alchemy. With the exception of the RSK, each text is assigned to one of three periods of Indian alchemy according to the results reported in Hellwig (2009).[12] These assignments are given in the last column of Table 2 ("time period"). The temporal distribution of the three basic procedures as recorded in columns 5-7 of Table 2 is displayed using nine box plots (see Figure 3: three time periods for each of the three procedures). The box indicates the range in which 50% of the data (from the 25th to the 75th percentile) are found, and the strong horizontal line marks the median of the data (= 50%). The first three box plots show the temporal distribution of the *śodhana* procedures. This distribution does not follow any clear trend, as the relative frequencies of this procedure vary around 50% in all three box plots or time periods. We may thus conclude that *śodhana* was equally important in all periods of Indian alchemy. On the other hand, *māraṇa* and *sattvapātana* show well discernible temporal patterns. While the importance of *māraṇa* increases over time (box plots 4-6), *sattvapātana* almost becomes obsolete in late Indian alchemy (box plots 7-9). This result can be corroborated using statistical tests of significance.[13]

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[11] We use the same binary values that are described in footnote 6, but do not consider to which substance *S* procedure *P* is applied. If, for example, the frequency 2 is given for *śodhana* in Table 2, this means that a text mentions two different kinds of *śodhana* procedures (e.g., "*śodhana* of sulfur" and "*śodhana* of realgar").

[12] When the content of alchemical basic procedures is compared using statistical methods, the texts contained in the corpus are assigned to three periods of medieval Indian alchemy: 1. early texts: RHT, RARṆ, RADHY, RRĀ; 2. middle texts: RCŪM, RRS, RPSUDH, RCINT; 3. late texts: RMAÑJ, RSS, BHPR, ŚDHSAṂH. The position of the RSK cannot be determined with this method. This relative chronology is largely in accordance with results given in Meulenbeld (2000, IIA).

[13] We use a Mann-Whitney test as described, for example, in Bortz & Lienert (2003, 138ff.) to decide whether the features in texts from two time periods come from the same population.

Text	abs. freq. *śodhana*	abs. freq. *māraṇa*	abs. freq. *sattvapātana*	rel. freq. *śodhana*	rel. freq. *māraṇa*	rel. freq. *sattvapātana*	Time period
ŚdhSaṃh	12	15	1	0.43	0.54	0.04	3
BhPr	18	15	1	0.53	0.44	0.03	3
RArṇ	20	5	11	0.56	0.14	0.31	1
RCūM	27	21	12	0.45	0.35	0.20	2
RPSudh	26	23	10	0.44	0.39	0.17	2
RRS	27	24	13	0.42	0.38	0.20	2
RRĀ	22	14	11	0.47	0.30	0.23	3 (?)
RSS	27	19	1	0.57	0.40	0.02	3
RAdhy	2	2	2	0.33	0.33	0.33	1 (?)
RCint	25	13	4	0.60	0.31	0.10	2
RHT	12	3	4	0.63	0.16	0.21	1
RMañj	19	16	2	0.51	0.43	0.05	3
RSK	5	8	0	0.38	0.62	0.00	

Table 2: Absolute (left) and relative (center) frequencies of the three basic procedures mentioned in the alchemical database and the times of origin of the texts (rightmost column; 1 = early, 2 = middle, 3 = late period of Indian alchemy)

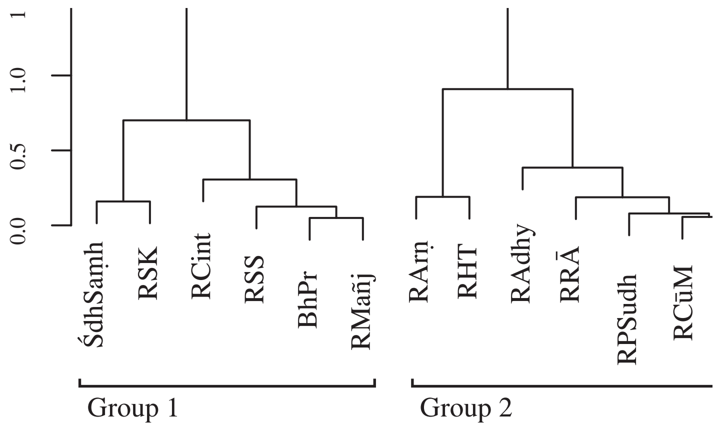

Figure 2: Grouping the alchemical texts by the relative frequencies of the three basic procedures (data in Table 2, right half)

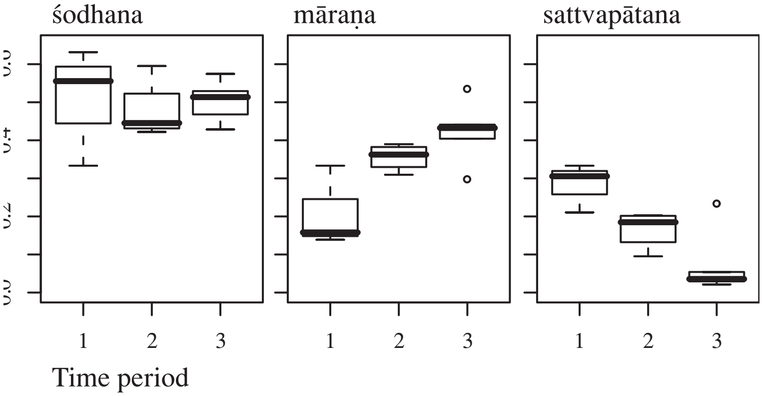

Figure 3: Temporal development of the three basic procedures (based on column 5-7 from Table 2)

Similar, though less clear temporal patterns are found when we investigate the "chemical" categories of substances that are used in the alchemical procedures. We can differentiate the data recorded in Table 2 by indicating whether a procedure is applied to a metal or to a non-metallic substance.[14] Table 3

We calculated the following significance values:

Procedure	Periods		p	test type
śodhana	1	2	0.857	two-sided
	1	3	0.786	two-sided
	2	3	0.556	two-sided
māraṇa	1	2	0.057.	$1 < 2$
	1	3	0.036∗	$1 < 3$
	2	3	0.095.	$2 < 3$
sattvapātana	1	2	0.029∗	$1 > 2$
	1	3	0.036∗	$1 > 3$
	2	3	0.095.	$2 > 3$

With significance assigned to 10% or above, *śodhana* does not show significant differences between the time periods, which confirms the visual impression gained from Figure 3, whereas *māraṇa* and *sattvapātana* show a significant increase and decrease, respectively.

[14] For this investigation, iron, gold, copper, bronze, brass, silver, *tīkṣṇaloha*, *kāntaloha*, tin, and lead are counted as metals. This group conforms with the ideas propounded in alchemical texts, since these materials are collected in groups of substances (*varga*s) as, for instance, the "Eight Metals" (*aṣṭaloha*), and since they share common modes of preparation (e.g., the conversion into a *bhasman* during *māraṇa*). Mercury is left out due to its special position in Indian alchemy, and the remaining substances are labeled as non-metals

reports how often *śodhana*, *māraṇa*, and *sattvapātana* are applied to metals and non-metals. The eighth column of this table gives the ratio r between procedures applied to metals and to non-metals.[15] High values of r indicate that more metals than non-metals are processed. The box plots of the ratios (Figure 4, left) show that the processing of metals gains in popularity in the late alchemical literature, and at least the increase from the second to the third time period is statistically significant.[16]
As the right box plot in Figure 4 shows, this increase in late alchemy is mainly due to numerous prescriptions in which metals are subjected to a *māraṇa*. On the whole, a somewhat astonishing trend in Indian alchemy is disclosed by these box plots: although texts labeled as early by Ray and later scholars discuss the transformation of metals and other metallurgical topics in greatest detail, standardized methods for processing metals only gain in importance in late alchemical treatises.

Let us summarize two important findings of this study. First, alchemical texts can be split into three groups when the texts are organized on the basis of the procedures described in them (Figure 1). The three groups represent, approximately, an early, middle, and late state of Indian alchemy. When clustering is repeated using different features, some of the texts "oscillate" between these groups.[17] While the cases of the RADHY and especially of the RSK remain unclear, the statistical approach may offer a solution for the RRĀ. Although Wujastyk (1984) has on good grounds assigned the whole RRĀ to a single author, it is noticeable that many basic procedures are described in both the RASAKHAṆḌA and the VĀDIKHAṆḌA of the RRĀ. If these chapters are

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in this paper. Numerical differences between Tables 2 and 3 are caused by the exclusion of mercury from Table 3. By defining groups (*varga*s) that only contain metallic substances Indian alchemy has sketched a rudimentary material science without, however, giving the rationale that motivated the compilation of these *varga*s.

15 If n_{met} is the sum of absolute frequencies of procedures applied to metals in a given text and $n_{\neg\text{met}}$ is the respective sum for non-metals, the ratio is calculated as $r = \frac{n_{\text{met}}}{n_{\neg\text{met}}}$. For the ŚDHSAṂH, for example, it is given as $r = \frac{1+8+1}{11+6+0} = 0.59$.

16 Using the same test as in footnote 13, we calculated the following results:

Periods		p	test type
1	2	0.686	$1 < 2$
1	3	0.125	$1 < 3$
2	3	0.016∗	$2 < 3$

17 Repeating clustering processes with different features and parameter settings is, by the way, a typical approach in computer science. Since single clustering solutions may represent a suboptimal partition of the data, the "oscillation" introduced by different settings is used to detect the unchanging core clusters and the unreliable candidates.

Text	*śodhana*		*māraṇa*		*sattvap.*		Ratio
	metals	non-met.	metals	non-met.	metals	non-met.	
ŚdhSaṃh	1	11	8	6	1	0	0.59
BhPr	9	8	11	3	1	0	1.91
RArṇ	6	13	3	1	1	10	0.42
RCūM	7	19	10	11	0	12	0.41
RPSudh	7	19	10	12	0	10	0.42
RRS	6	21	11	12	1	12	0.40
RRĀ	9	12	9	4	1	10	0.73
RSS	8	18	9	9	1	0	0.67
RAdhy	0	2	1	1	0	2	0.20
RCint	10	15	6	7	0	4	0.62
RHT	6	6	2	0	0	4	0.80
RMañj	8	10	9	6	1	1	1.06
RSK	5	0	5	2	0	0	5.00

Table 3: Absolute frequencies from Table 2, differentiated by metallic and non-metallic substances to which the procedures are applied

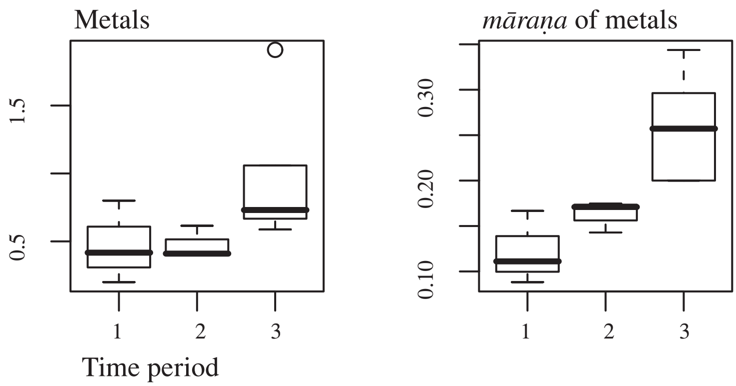
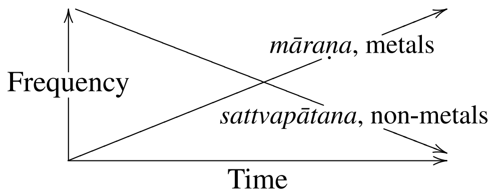


Figure 4: Box plots of ratio *r* between metals and non-metals (left) and of the rate of *māraṇa* of metals (right)

treated as different texts, the VĀDIKHAṆḌA is unanimously assigned to the early group of texts, while the RASAKHAṆḌA is associated with the late treatises. In my opinion, this result corresponds well with the rather disparate content of these Books of the RRĀ, which may be a compilation from different sources (cmp. footnote 2). Second, we were able to detect a correlation between the probable time of origin of a text and the basic procedures described in it, which may be sketched in this way:



Although *māraṇa* and *sattvapātana* may be candidates for the "guide fossil" of Indian alchemy, such a model, of course, oversimplifies the development of this tradition for three reasons. First, the temporal positions of some texts remain unclear. Basing statistical analysis on such data actually requires a more complicated framework than the one proposed in this paper. Second, we cannot exclude the possibility of vicious circles, since the dating of some texts may be based on the very criteria as those that were correlated with time in this paper. Third, we did only show that there are trends in Indian alchemy, but did (and could) not prove that these trends are linear (see, above all, the distribution of metals and non-metals in table 3). Even if we accept these restrictions, we were, on the whole, able to detect a grouping of alchemical texts that corresponds well with the chronology proposed by Ray and later scholars. The fact that the traditional chronology was corroborated without using Ray's dating criteria opens up encouraging perspectives for the further application of statistical methods to the anonymous literature of medieval India.

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