# A Physicochemical Analysis of the Tibetan Drangsong Manuscript Collection from Mustang, Nepal

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The study of ancient material in terms of interdisciplinary cooperation of scientists representing various fields of science allows for a detailed study of the state of preservation of historical material and the development of effective ways to protect cultural heritage. One of the scientific research projects carried out within the framework of such cooperation is the project "Protecting the Kingdom with Tibetan Manuscripts: Codicological and Historical Analyses of the Royal Drangsong Collection From Mustang, Nepal" (No. 2018/30/M/HS3/00372, funded by the National Science Centre) led by Agnieszka Helman-Ważny (Department of Book and Media History, Faculty of Journalism, Information and Book Studies, University of Warsaw) and Charles Ramble (Ecole Pratique des Hautes Etudes, Paris).

The DRONG project (www.mustang.uw.edu.pl) was devoted to a codicological and historical analysis of a unique collection of manuscripts that are part of

the Tibetan Bön religious tradition, while the physicochemical examination of the manuscripts has been designed to identify the materials used. Detailed examination of the manuscripts' paper included identification of the raw materials using fibre analyses. In addition, the paper surface of the manuscript fragments was documented using the Reflectance Transformation Imaging technique, and the main elemental composition of selected samples was assessed using X-ray fluorescence spectrometry.

## Drangsong Collection

Mustang is a land that was once in Tibetan territory and currently forms one of the districts of Nepal. It is located in the Dhaulagiri Zone and part of Gandaki Province, in the Himalayan area, on the edge of the Tibetan plateau. In spite of the difficult historical and political situation in Tibet and many changes occurring in Nepal, the former Kingdom of Mustang remains one of the few regions in the Himalayan area where the language, paper-making and handwriting characteristic of the traditional Tibetan culture, religion – rites and rituals – as well as social relations have been preserved to this day. That is why Mustang is often called "the last bastion of Tibetan culture".

The royal Drangsong collection consists of 2,900 pages from 280 different items. It is a recording of the rituals of the Tibetan Bön religious tradition, practised by the priests of the kings of Mustang. The manuscript collection 'Drangsong' is named after the line of priests in whose house the manuscripts are stored. 'Drangsong' (*drang srong*) is a Tibetan term that translates the Sanskrit word *rishi* – that is a sage, but in the Bon religion the name has a special connotation as the equivalent of the Buddhist Gelong (*dge slong*), a fully-ordained monk. At present, there is no documentation that describes the origins of the priest family, but members of subsezquent generations appear in the literature of a later period. Based on the oral account of the house's current occupant, Wangdü, the building was inhabited in the mid-fifteenth century. According to the account, the ancestors of Drangsong line in Lo Monthang are the Bönpo

lamas of Jaragang, who were invited by King Agön Zangpo to settle in a house near the palace and become his private chaplains (*bla mchod*). Successive generations of the family of priests continued to maintain service to the royal family until the 1950s, when the last priest, Pema Trinle, died without a male descendant.

## Materials and Methods

### *Sample Characteristics*

From the Drangsong collection, 52 small loose paper fragments were selected from the most damaged pages identified within each volume[1]. For the selected samples, the major elemental composition was analysed by X-ray fluorescence spectrometry (XRF), Reflectance Transformation Imaging (RTI) were recorded, and paper fibre composition analysis was identified. Three selected fragments were additionally examined by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).

### *Examination of Samples Using the RTI Technique*

Reflectance Transformation Imaging (RTI), is also known as Polynomial Texture Mapping (PTM). RTI/PTM uses the ability to capture a sequence of digital images of a stationary object during snapshot time-forced spot illumination. The position of the light source changes, being placed at a different angle during each exposure. RTI/PTM images are created from reflective surface patterns – brightening and shadow, which are used to calculate surface normals – imaginary vectors perpendicular to a given point where light touches the surface of an object. By using algorithms of processing of the obtained images, appropriate

1 The results of the individual samples are included in the catalogue of the Drangsong manuscript collection on the project website: Mustang Manuscripts: Documentation and Preservation (http://mustang.uw.edu.pl/?page_id=9926&lang=pl). The following manuscripts were subject to detailed material examination: 5, 6, 8, 9, 10, 11, 17, 21, 32, 33, 36, 37, 38, 39, 41, 42, 53, 59, 60, 61, 62, 66, 72, 73, 79, 81, 112, 113, 121, 122, 123, 131, 143, 144, 194, 195, 229, 233, 234, 250, 251, 258.

selection of the angle of illumination of the examined object's surface, and contrast enhancement, sharpening masking and improvement of detail shading, it is possible to make texture details visible[2]. An appropriate software (*RTIProcessor*) identifies normals through a set of mathematical calculations (model functions, fourth degree polynomials)[3]. Each encoded normal corresponds to a given point on the object, so the whole set of them represents a complete and accurate "description" of its topography[4]. The digital map reproduces, pixel by pixel, the surface texture, colour and reflective properties. *RTIViewer* software makes it possible to move a virtual light and see the light reflecting off a real object on the screen and see it in three dimensions[5].

The RTI/PTM technique makes it possible to observe the extent to which the surface of the paper is sized, to look for the presence of traces of tools used to prepare the surface of manuscripts for writing, and to identify layers of ornamentation or text. Reflectance Transformation Imaging was used to assess the degree of ink penetration into the paper structure, indirectly providing information about paper properties. This technique also allows for better observation of the changes that the object has undergone under the influence of ageing

2 G. Palma, at al., *Dynamic Shading Enhancement for Reflectance Transformation Imaging*, "Journal on Computing and Cultural Heritage" 2010, Vol. 3, https://www.researchgate.net/publication/220451504_Dynamic_shading_enhancement_for_reflectance_transformation_imaging [date of access: 14.10.2019].

3 M. Mudge, at al., *Reflection Transformation Imaging and Virtual Representations of Coins from the Hospice of the Grand St. Bernard*, "The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, Pisa, Italy" 2005, p. 29–39, https://dl.acm.org/doi/abs/10.5555/2384344.2384348 [date of access: 14.10.2019].

4 M. Dellepiane, at al., *High Quality PTM Acquisition: Reflection Transformation Imaging for Large Objects*, "The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, Pisa, Italy" 2006, https://www.researchgate.net/publication/220955267_High_Quality_PTM_Acquisition_Reflection_Transformation_Imaging_for_Large_Objects [date of access: 14.10.2019].

5 Cultural Heritage Imaging a non-profit Corporation – Helping Humanity Save History: http://culturalheritageimaging.org/Technologies/RTI/.

processes, traces of damage caused by using it, or modifications made to the object as a result of conservation procedures carried out.

To create the photographic documentation, consisting of a series of 50 images for each manuscript sample, a Panasonic Lumix DMC-G80 camera with an Olympus M. Zuika Digital ED 60 mm f./2.8 Macro lens mounted was used. The camera and lens were connected to the multispectral illuminator in the form of a canopy using a reverse clamp ring. The multispectral illuminator has two modes of operation: RTI and PHOT, which allows for image capture in visible (465, 520, 638 nm), UV (375 nm), and IR (840, 930 nm) wavelengths as well as in broadband white light. Photographic documentation was created in RTI mode, in visible light, setting the interval between images to 1500 ms. The recording time for the series of 50 images was approximately 1 minute.

*Examination of Samples by XRF*

The XRF method is one of the most commonly used methods in the study of cultural heritage objects. Its popularity comes from the general acceptance for the use of non-invasive methods, with the added advantages of short time to record spectra and the availability of portable systems that allow items to be examined without having to transport them to the laboratory.

XRF captures the effects induced in atoms, involving forced transitions of electrons between internal energy levels. The incident primary X-ray radiation causes electrons to be knocked out of the shells closest to the atomic nucleus. The empty space left by the knocked-out electron is filled by an electron from a higher energy level – and the excess of energy during the transition is emitted as an X-ray photon – this is the phenomenon of X-ray fluorescence[6]. Each element, when excited, can emit characteristic radiation in the form of signals consisting of a series of lines named with consecutive letters of the alphabet: K, L, M. Using an energy dispersive spectrometer,

6 A. Cygański, *Metody spektroskopowe w chemii analitycznej (Spectroscopic Methods in Analytical Chemistry)*, Warszawa 1993.

qualitative analysis is performed by determining the location of peaks at the appropriate energy values. Relative comparison of the intensities of the recorded signals allows for estimation of the variability of the elemental composition of the analysed samples[7].

The portable X-ray fluorescence spectrometer (Bruker Tracer III-SD) was used in this study allowing the detection of elements from Mg to Pt. The source of excitation is an X-ray tube with Rh anode (max voltage = 45 kV, operating current from 2 to 25 μA). The spectrometer is equipped with a 10 mm2 XFlash® SDD silicon drift detector with thermoelectric cooling, allowing for 145 eV resolution at 100,000 cps. All measurements were performed using the operating voltage of 45 kV; beam current of 23.10 μA; spectrum recording time of 60 s. An additional continuous vacuum pump was also used, which maintained a constant pressure of < 2 Torr allowing an increase in sensitivity of measurements for lighter elements.

### *Testing the Fibre Composition of Paper*

Paper is a material made by pulping through a sieve the fibrous masses obtained from an aqueous suspension of plant fibres that have been previously mechanically processed. The raw materials from which a particular type of paper is made determine its characteristics. The identification of fibres is important to any examination of paper and can provide valuable information about the craftsmanship and history of manuscripts[8].

Fibre analysis is a destructive method because it requires proper sample preparation. For papers made from more than one raw material, it is also helpful

7 G. Stankiewicz, W. Stankiewicz, *Rentgenowska spektrometria fluorescencyjna (X-ray Fluorescence Spectrometry)*, [in:] *Metody analitycznej spektrometrii atomowej. Teoria i praktyka* (*Analytical Atomic Spectrometry Methods. Theory and Practice*), publ. MALAMUT, Warszawa 2010; M. Mantler, M. Schreiner, *X-ray analysis of objects of art and archaeology*, "Journal of Radioanalytical and Nuclear Chemistry" 2001, Vol. 247, No. 3, p. 635–644.

8 W. Sobucki, E. Jeżewska, *Wiedza o papierze dla konserwatorów zbiorów*, Biblioteka Narodowa, Warszawa 2015.

to dye the fibres with a suitable reagent[9]. The morphological structure of fibres is examined under an optical microscope, in polarised transmitted light. The findings may be of a qualitative nature, consisting in determination of the type of fibres present in the tested object, and of a quantitative nature (after qualitative analysis), providing information on their percentage share[10]. The size of the sample to be tested is usually small – even a few fibres are sufficient in certain cases.

A reliable analysis of fibrous composition requires proper preparation of the microscope specimen. To identify fibres, various reagents can be used[11], which colour the fibres with respect to their cellulose, hemicellulose and lignin content and reveal their morphological structure. Proper identification requires that morphological structure be observed and compared to appropriate atlases or clearly identified reference samples[12]. Fibres of the same plant species in historic material often differ from the fibres used to prepare model descriptions in atlases (as a consequence of preparation methodology). Aged papers rarely contain the fibre in its entirety. The most common changes in their structure are caused by previous mechanical treatment and degradation due to the passage of time (visual changes). When comparing ancient material and reference material, consideration should be given to possible length differences appearing between (fragments of) ancient fibres and their counterparts in the original plant material. During observations, length and width are usually not measured, whereas identification is supported by the determination of other distinctive features, such as:

- the regularity of the fibre structure (or lack thereof),
- the colour that the fibres develop in the reagents,

9 A. Helman-Ważny, *Asian Paper in Works of Art: A Comparative Fiber Analysis*, "Hand Papermaking" 2006, Vol. 21.

10 *Ibidem*.

11 *Ibidem*.

12 Ilvessalo-Pfäffli, Marja-Sisko, *Fibre Atlas: Identification of Papermaking Fibres*, Springer, Berlin 1995; Wang Juhua, *Papermaking raw materials of China: an atlas of micrographs and the characteristics of fibres (中国造纸原料纤维特性及显微图谱)*, China Light Industry Press (in Chinese), Beijing 1999.

- the shape of the fibre and its flexibility (the important thing is to observe the whole fibre and not only parts of it),
- the ratio of lumen width to the cell wall of the fibres,
- the characteristic cross-markings and dislocations,
- the shape of the natural fibre endings[13].

Fibre samples were prepared for analysis by boiling in distilled water for 20 minutes, which allowed for the removal of adhesive substances and more accurate observations of the morphological structure of the fibres. After removal from hot water bath, the samples were dried in conditions that assured no contact with other material containing foreign fibres. Two preparations were made for each sample: a permanent preparation in Canada balsam and a non-permanent preparation for analysis using Herzberg reagent.

To obtain a permanent preparation, the boiled sample was placed on a microscope slide, then a few drops of water were added, and it was finely dissected using preparation needles. It was then covered with a coverslip and checked under the microscope whether the state of dissection and distribution was sufficient. The resulting preparations were left to dry for a minimum of 7 days. The next step was to lift the coverslip and apply a drop of Canada balsam. The coverslip was repositioned with all air bubbles removed, and the preparation was allowed to rest for 7 days under a load.

The preparation with Herzberg reagent was always prepared immediately before the analysis. First, a previously boiled sample was placed on a microscope slide and a drop of Herzberg reagent was added. The sample was carefully dissected and a coverslip was gently placed so that no air bubbles were formed. The preparation thus prepared was carefully examined under the microscope, with documentation of the various morphological features of the fibres, and repeated observations for the Canadian balsam preparation of the same sample. The Olympus BX53 brightfield and polarization microscope with an Olympus UC30 digital camera integrated with STREAM 2.4 PRO image analysis software was used for the tests.

13 T. Tsuen-Hsuin, *Paper and Printing*, [in:] *Sciences and Civilization in China*, ed. J. Needham, Vol. 5: *Chemistry and Chemical Technology*, Cambridge University Press, Cambridge 1985.

## Results and Discussion

### *Examining the Surface of Paper Using the RTI Technique*

An example of the use of the RTI/PTM technique for imaging manuscript fragments is illustrated in the photos of sample 9 f.1. Photo 1A shows the effect of using *Specular Enhancement* mode to make the texture of the lettering visible, while Photo 1B shows the effect of using *Static Multi Light* mode to make paper fibres visible. The Specular Enhancement image processing mode, by adjusting the *Diffuse colour, Specularity* and *Highlight size* variables, improved the visual perception of the surface appearance, emphasizing the texture of the paper and especially the texture of the writing on it. By using the *Static Multi Light* mode – which does not allow the light source to change direction interactively, replicating the current view of the object – a static image with high contrast and adequate illumination was obtained, enhancing the visibility of the paper fibres.

52 tiny paper fragments[14] from the Drangsong manuscripts listed in footnote 1 were examined in detail for texture. The tests performed allowed us to develop the documentation methods using the RTI/PTM technique. Unfortunately, at

A) B)

**Photo 1.**
Images illustrating the texture of samples in different modes of RTIViewer. Photos – authors

14 Samples were catalogued according to the following format: the manuscript number first, followed by the card (folio) number, for example 5 f.1. A complete photographic documentation of the studied objects in the form of high-resolution snapshots taken for selected samples of Tibetan manuscripts from the Drangsong collection can be found on the project website: www.mustang.uw.edu.pl.

this stage it was not possible to apply it *in situ* to the entire surface of the pages, which limited the opportunity to examine tool marks or other structural features observable only on a larger surface.

*Analysis of the Elemental Composition of Paper by X-ray Fluorescence Spectrometry*

The samples examined are similar in terms of Si, S, K, Ca and Fe content (Fig. 1); Al, P, Ti, Mn, Zn and Sr signals of highly variable intensities were also observed in most of them. At first sight, however, it can be seen that the spectrum recorded for one of the samples (labelled 258a f.2) is characterised by exceptionally high AsKa1 and AsKb1 signals and distinguishes this fragment from all the samples examined.

Based on the recorded XRF spectra (Fig. 1), 13 elements were selected: Al, Si, P, S, K, Ca, Ti, Mn, Fe, Cu, Zn, As and Sr to characterise the studied set of objects. The use of different ways of data visualization allows for smooth viewing of the relationships between the intensities of individual elements and for showing their relative contents in the studied samples (Fig. 2). Intensities were calculated for each element separately relative to the highest recorded signal of the series for all samples. Their different contents are visible through the use of a colour scale that varies linearly in a three-colour system: – WHITE: lowest signal of the

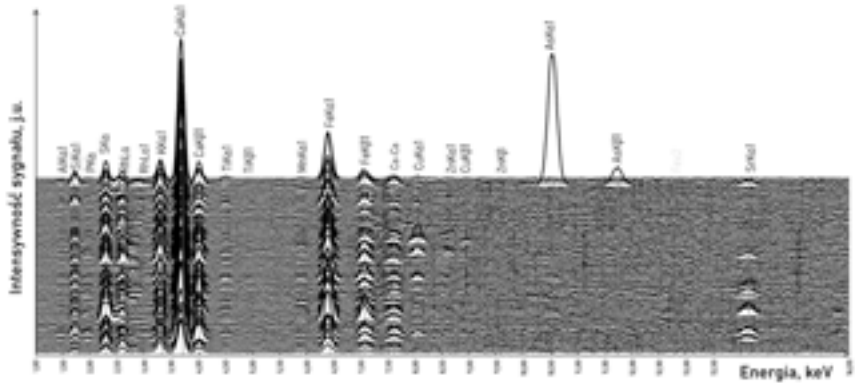


**Fig. 1.**
Diagram showing all recorded XRF spectra. Il. – authors

series; – GREEN: signals on the level of 50% of the highest intensity recorded for a given element; – RED: signals at and above 90% recalculated relative to the highest intensity for a given element.

Figure 2 contains some important information that makes it possible to read the data it contains: the columns are captioned with headings that refer to the individual sample numbers. In turn, the rows contain references to elements marked with chemical symbols and for each element the position of the signal (E, keV) included in the presented graph is also provided. This is a graph

A)

B)

**Fig. 2.**
Summary of relative intensities of recorded signals for selected 13 elements: AI, Si, P, S, K, Ca, Ti, Mn, Fe, Cu, Zn, As and Sr. (A) for the entire set of collection samples, and (B) after removal from the set of compared objects of the two samples labelled as: 5 f.1 fibre and 8a f.1. and signal As for the sample 258af.2. Il. – authors

created in Excel as a result of forcing the relative formatting of cells containing the calculated mean intensity values for the three readings of the spectrum in the vicinity of the maximum of a given peak. This simple step allows us to observe that the signal intensity for the Ca-Kα1 transition in most samples is comparable, with the exception of two samples – *5 f.1 fibre* and *8a f.1*. It is also evident (Fig. 2A) that the previously mentioned high arsenic content (As-Kα2) distinguishes the sample *258a f.2*. Selective removal of the results obtained for these samples (Fig. 2B) automatically changes the scaling of the colour ranges, providing further details of the comparison of elemental composition between the manuscript fragments examined.

The samples – *5 f.1 fibre* and *8a f.1* are fibre fragments probably from sewing thread – joining the pages of a volume and a fragment of a textile cover (Photo 2). Their XRF spectra contained Fe-Kα1 signals with the highest intensities. They are described here because they deserve special attention in the context of Tibetan book studies. The most typical format of books is pecha (*dpe cha*) consisting of rectangular, loose, unbound sheets of paper. Its prototype was a form of Indian Buddhist manuscripts written on palm leaves[15].

Figure 2B shows the data after removing the results obtained for the fibres seen in Photo 2 and one disproportionately high arsenic signal recorded for sample *258a f.2*. This further simple procedure allows us to observe the uniformity of elemental composition for the remaining fragments of the manuscript pages. The graphs presented (Fig. 2 A–B) only show a change in calcium (Ca) content relationship due to the removal of two samples with different characteristics. Other relationships did not change when only manuscript paper samples remained in the comparison group (Fig. 2B). The inks that were used to write Tibetan books and documents were made on the basis of various recipes; descriptions of their

15 A. Helman-Ważny, *Tybetańskie manuskrypty tradycji Bön w Nepalu na przykładzie kolekcji z jaskiń Mardzong w Górnym Mustangu (Tibetan Manuscripts of the Bön Tradition in Nepal on the Example of a Collection from the Mardzong Caves in Upper Mustang*), "Z Badań nad Książką i Księgozbiorami Historycznymi" 2018, Vol. 12, p. 21–38.

A) B)

**Photo 2.**
Photos of samples: A) of a fibre – 5 f.1 fibre and B) of a textile cover fragment– 8a f.1. Photos – authors

preparation and raw materials used can be found in the literature[16]. Tibetan black ink (*snag tsha*) is usually made from soot, obtained from burnt pine trees (*merang* or *thangshing, Pinus wallichiana*) mixed with animal glue[17]. The addition of other ingredients (such as sugar, lacquer, pepper, or cocoa) may change the colour or properties of the ink[18].

The inscriptions on the fragments partially written on one side were made with soot-based ink – this was confirmed by Raman spectroscopy. The presence of phosphorus (P) signal could then be taken as confirmation of the use of animal glue as a binder.

Among the fragments transcribed, the aforementioned sample *258 f.2* stands out with its high arsenic content. It was believed in the Himalayan region and Tibet that the coating of orpiment ($As_2S_3$) on the surface of the paper or the edges of the book protected the manuscripts from the destructive effects of insects[19]. In addition, this substance gives the paper its characteristic yellow colour.

16 Ch. Cüppers, *On the manufacture of ink*, "Ancient Nepal" 1989, No. 113, p. 8–9.

17 P. Ricciardi and A. Pallipurath, *Colours*, [in:] M. Elliott, H. Diemberger & M. Clemente (ed.) *Buddha's Word The Life of Books in Tibet and Beyond,* Museum of Archaeology and Anthropology University of Cambridge, Cambridge, UK 2014, p. 105.

18 *Ibidem.*

19 Orpiment is a compound of arsenic and sulphur (from the Latin term: *Auripigmentum*), resembling gold in its intense colour. From a mineralogical point of view, the orpiment is a yellow arsenic sulphide mineral with formula $As_2S_3$. It was known in China since the 2nd century BC and was commonly used in painting, and used in the production of manuscript books as

Mineral compounds were sometimes used in Tibetan manuscripts to make a base layer for the text. The paper was filled and polished with stone to reduce its absorptive properties and to obtain the desired hardness and gloss as well as a bright and smooth surface of the base[20]. Traditionally, a semi-precious stone, more typically found on the bottom of a river, or a shell, were used in the polishing process. For sizing animal glue was used – to allow writing with a pointed instrument[21], or starch obtained from barley or wheat flour in the form of water-soaked tsampa (*rtsam pa*) applied superficially or added to fibre mixed with water – to reduce tangling[22].

FTIR spectroscopy revealed the presence of a long-chain aliphatic compound, starch and calcium carbonate, which formed a coating on the paper surface. A comparison of the FTIR spectra recorded during surface examination

A) B)

**Photo 3.**
Images illustrating samples partially inscribed on one side – A) object 9 f.1, B) object 258 f.2. Photos – authors

an insect repellent and to increase the durability of paper. The authors thank the reviewers for drawing attention to information about the use of orpiment in China, including information provided in a Chinese treatise Qimin Yaoshu 齐民要术 (Essential Methods of the Common People) dating to the fifth century, written by Jia Sixie. Further information about preparing paper for writing using orpiment in Tibet can be found here: A. Helman-Ważny, *The Archaeology of Tibetan Books*, "Brill's Tibetan Studies Library" 2014.

20 *Ibidem.*

21 *Ibidem.*

22 *Ibidem.*

of the manuscript and the standards is shown in Figure 3. The bands at 1418, 873 and 712 $cm^{-1}$, characteristic of carbonate anion, indicate the presence of calcium carbonate, while the bands at ~925, 1076 and 1168 $cm^{-1}$ confirm the presence of starch.

The arrangement of bands in the CH stretching vibration range indicates the presence of organic compounds with a longer chain, while the two bands with maxima at 1577 and 1539 $cm^{-1}$ are characteristic of salts of carboxylic acids. It is likely that salt of a higher saturated fatty acid was used as an additive.

Mineral compounds were also used as paper fillers. Mineral fillers include aluminosilicates[23], which were given an appropriate degree of fineness, and their low solubility in water, chemical passivity and light colour were

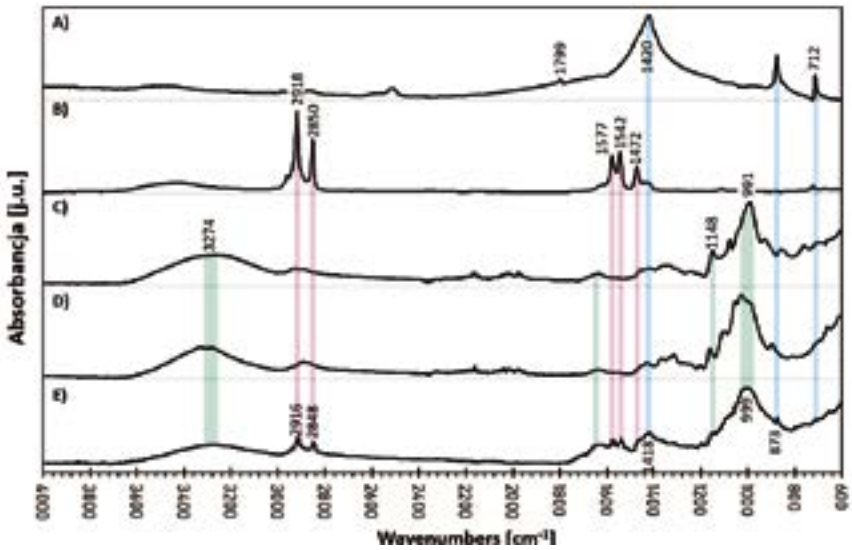


Fig. 3.
FTIR spectra: of the standards of A) calcium carbonate, B) calcium stearate, C) starch, D) cellulose, and E) manuscript sample 258.F2. Il. – authors

23 W. Sobucki, E. Jeżewska, *Wiedza o papierze dla konserwatorów zbiorów (Knowledge of Paper for Restorers of Collections)*, Warszawa 2015.

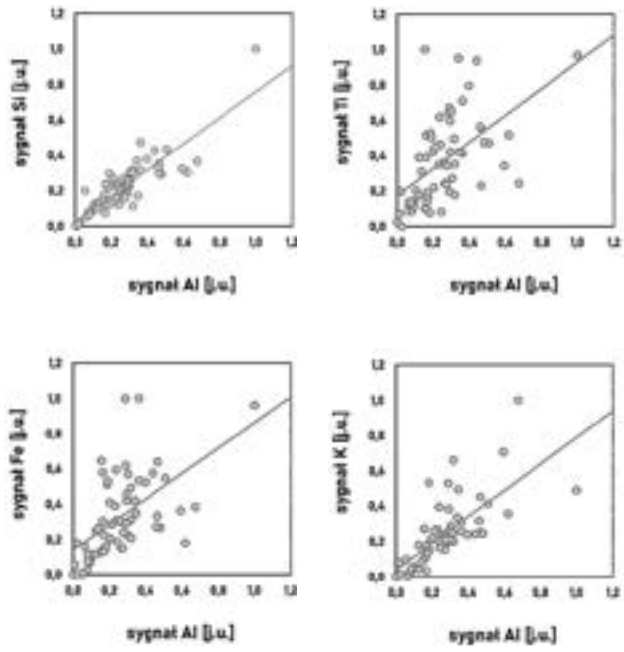


**Fig. 4.**
Graphs illustrating the co-occurrence of (A) Al and Si, (B) Al and Fe, (C) Al and Ti, (D) Al and K in a set of samples blank on both sides. Il. – authors

additional advantages. An example of such a commonly used filler is kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) – a mineral derived from natural deposits, containing a significant admixture of iron compounds[24]. The crystal structure of aluminosilicates may also contain elements such as Na, K, Ti, P, Si, Mn, Li, Ni, Zn or Zr[25]. Clay minerals, i.e. minerals composed of, in particular, hydrated aluminium aluminosilicates (plus magnesium and iron) may be present in sedimentary rocks, which also include chalk ($CaCO_3$) identified in the manuscript fragments examined. The co-occurrence of aluminium (Al) with other elements (Si, Fe, Ti, K...) in the set of blank samples is documented in the subsequent graphs (Fig. 4) indicating the high probability of the presence of aluminosilicates in the tested Tibetan paper samples.

24 *Ibidem.*

25 Website: https://www.pgi.gov.pl/muzeum/kopalnia-wiedzy-1/10596-krzemiany.html.

**Photo 4.**
Object 229 – an example of a manuscript from the royal Drangsong collection showing a layer of white ground beneath the text1. Photo – authors

Mineral compounds were used to refine the substrate layer for the text or as paper fillers added at the pulp formation stage[26]. Strontium may appear as an isomorphic admixture of aluminosilicates, most commonly of feldspars[27]. Sr content was noticeable even in the samples that had relatively low content of this element. An example of one of the manuscripts in which the ground layer is clearly visible in the central part of the page may be object numbered 229, shown in the following photograph (Photo 4).

*Fibre Composition Analysis*

In the analysed samples the most common occurrence of *Daphne* and *Stellera* fibres was found, therefore the main morphological features allowing to effectively

26 We were unable to conclusively determine whether the mineral compounds were used only as a primer to refine and level the surface of the paper prior to writing, or if they were also used as fillers added during the pulp-forming stage in an aqueous environment. The fact that studies indicate the presence of aluminosilicates or chalks also in manuscripts where the presence of soil is not apparent might suggest that these compounds may also be present in the structure of the paper, not just on its surface. Also, during interviews conducted by A. Helman-Ważny in 2013 in Tibet (Karki village in Tingri region), Tenzin Wangmo from a family of paper makers said that she adds to the pulp a white mineral substance extracted from the bottom of a nearby lake. However, we do not know if this was an isolated incident or a local tradition, which unfortunately no one else has been able to confirm.

27 W. Sobucki, E. Jeżewska, *Wiedza o papierze dla konserwatorów…*, *op. cit.*

distinguish between these two species are presented in Table 1. Although many of the characteristics that normally allow identification of fibres are similar in both species, the shape and flexibility of the fibres, as well as the width of the lumen relative to the fibres cell walls, remain differentiating.

**Table 1.**[28]

| Name | *Stellera chamaejasme* | *Daphne* |
|---|---|---|
| Fibre shape | tenuous | rigid |
| Colour (Herzberg) | grey and blue | grey and blue |
| Lumen | irregular, broad | irregular, narrow with widening |
| Cell walls | narrow, irregular | predominantly thicker |
| Shape of the fibre endings | rounded, with many bifurcations and irregularities | rounded with bifurcations and irregularities |
| Cross markings | present | present |
| Fibre length | 0.5–4 mm | 1.5–5 mm |
| Fibre width | 4–20 µm | 7–30 µm |
| Other | Numerous thickenings, callosities and branching | Numerous thickenings, callosities and branching |

The results of the fibre composition analyses allowed distinguishing two groups of paper. All samples contained mainly *Daphne* fibres, with the largest group of objects containing no admixtures of other plants. In the second group of objects, the presence of both *Daphne* and *Stellera* fibres were confirmed. A few samples also contained other individual fibres requiring further identification.

It has been confirmed that Tibetans have been making paper from the fibres of a group of plants in the laurel family (*Thymelaeaceae*) since at least the 9th century. Primarily, fibres of *Daphne* species, common in the Himalayan valleys (below 3600 m), were used. The plant that was used for the same purpose in the

28 Website: www.khartasia-crcc.mnhn.fr [date of access: 28.12.2020].

higher lands was the roots of the *Stellera chamaejasme*. The oldest manuscripts in which fibres of the *Stellera* species have been identified are dated to the 10th century[29]. From the 15th century onwards, these two species of plants were often mixed in the production of paper because of better properties of the paper that was produced, and this was also associated with the development of printing[30]. In the reagents used, the fibres of these two plants are dyed the same colour, which makes distinguishing between them problematic, although it should be noted that it is not entirely impossible. A number of specific characteristics, such as the ratio of lumen width to fibre wall, and fibre flexibility, allow these fibres to be correctly identified. Among the fibres of plants belonging to the Thymelaeaceae family, most difficult distinguishing seems to be between the species of *Daphne, Edgeworthia* and *Wikstroemia*.

## Conclusion

The research presented above points to the unique nature of the Drangsong royal collection. It was confirmed that it is possible to obtain detailed data on the studied samples using various testing techniques, including still relatively new method of Reflectance Transformation Imaging (RTI) – polynomial texture maps. This technique allows for very detailed photographic documentation, making it easier to collect data on how paper was made and its current state of preservation. X-ray fluorescence (XRF) spectrometry currently belongs to a group of instrumental methods of great popularity due to its universal nature and the possibility of conducting *in situ* studies. In the study described here, this method allowed for a relatively quick, non-invasive determination of the major elemental composition of the paper. It turned out that all paper objects

29 A. Helman-Ważny, *Overview of Tibetan Paper and Papermaking. History, Raw Materials, Techniques and Fibre Analysis*, [in:] *Tibetan Manuscript and Xylograph Traditions. The Written Word and Its Media within the Tibetan Culture Sphere*, red. O. Almogi, Hamburg 2016, p. 180.
30 *Ibidem*.

from the royal Drangsong collection had similar high calcium contents, but varying contents of other elements (Fe, Cu, Sr, Si, Ti, P, K). Aluminosilicates appear to have been used as paper filler. Interesting and worthy of further study is the distinction of two groups of objects in terms of strontium content, as well as the explanation of the source and nature of the arsenic compound in the sample distinguished by a significant content of this element. Analysis of the fibre composition of paper identified *Daphne* species as a major component of paper. Fibres of the *Stellera* species were also observed in some samples.

The aforementioned analyses are an important step in establishing a reference base for further physicochemical studies of paper from Tibetan areas. In the subsequent part of the project, the pigments and inks used will be analysed, and the codicological analysis will be compared to the physicochemical analysis described in the article above. All results of the research conducted and detailed information collected from the royal Drangsong collection can be found on the project website: www.mustang.uw.edu.pl.

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