Interim Report (The system asked for a White Paper, however, the project is still on-going.)
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Far from Home: Exploring the application of non-destructive pXRF clay analysis for the provenance study of cuneiform tablets
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Project Participants

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Far from Home: Exploring the application of non-destructive pXRF clay analysis for the provenance study of cuneiform tablets

The goal of this project was to test the application of non-destructive geochemical clay analysis for the provenance study of cuneiform tablets using portable X-ray fluorescence (pXRF). Clay composition can provide a clear indication of provenance for tablets by compositional analysis. From about 3300 BC until about 100 AD, literate societies in the lands of western Asia, from western Iran, over Syria, Iraq to the Mediterranean, made written documents on clay tablets in cuneiform script. Hundreds of thousands of these ancient documents survive in museums, academic, and private collections. Some cuneiform documents in the modern museum and academic collections come from legal archaeological excavations. Still, hundreds of thousands come from illicit excavations, and many are now coming from looting and pillaging of known sites. Unprovenanced cuneiform clay tablets present a legal, ethical, and scholarly challenge for scholars, curators, law enforcement, and all concerned with the cultural heritage of the ancient Near East.

1. Project Activities

a. Using the cuneiform tablets from the Oriental Institute, we identified and selected securely provenanced tablets for analysis. The Oriental Institute had excavated those tablets at six different sites: Bismaya and Nippur in Middle Iraq, Ishchali, Khafajeh, and Tell Asmar in the Diyala region, Nuzi in Northern Iraq. We selected tablets excavated at adjacent sites exploring whether we can distinguish the clay signature from the object created in similar geological environments. For each excavation, we choose objects from at least two antique periods where studied covering a timespan from 2050-1400 BCE or more than 1500 years.

b. For each tablet, we added detailed metadata, including findspot and circumstances, a period of writing, text genre, and a summary of the text content. We also added information about the dimensions, conservation status, and any observable abnormalities. The acquired metadata was comprehensive and proofed helpful in the analysis phase. At this stage, we excluded tablets where we expected that they might have been manufactured at a different site, including genres like letters but also tablets where our research on their provenance revealed issues.

c. For the geochemical analysis of the clay, we used a Bruker Titan 800 Analyzer (SMF2682) with a 4-watt Rhodium anode tube and a 20 mm2 SDD detector. Data was assayed in 3-6 different areas of the tablet for 60 seconds. Two beam configurations were used: a light assay of 9 kV, 70 μA with no filter and a trace assay of 50 kV, 35 μA, and a 100 μm Cu/25 μm Ti/300 μm Al filter.

d. A challenge in the analysis was the multi-dimensional nature of the elements traced in our tablets or to filter out which of the 31 elements we discovered are reliable and promising for clay sourcing. Chemical differentiation of clay can depend on most elements present. Therefore, Dr. Lee Drake introduced a Machine Learning Approach based on a neutral network and gradient boosting for the analysis of our data. 80 % of the data was used to train the model, while 20 % of the data was randomly withheld for validation.
We concluded the first three phases of the project successfully and were ready for phase 4a the application of our results to unprovenanced tablets in the OI Tablet Collection. However, this phase is delayed to the following challenges our project encounter:

- The one-year project started already with a delay of two months due to the government (January/February 2019).
- In August 2019, the Bruker Titan 800 broke beyond repair during normal usage. As a replacement the Oriental Institute assigned the project the only remaining tracer in the Oriental Institute’s Conservation Lab. However, this tracer returned broken from a fieldwork season in Turkey. The Oriental Institute started then a lengthy replacement process. As a pXRF tracer is an expensive piece of equipment, we had to go through a protracted procurement process, which included acquiring permission, interviewing different vendors, and testing models. Therefore, we applied for a six-month no-cost extension, which was granted. The purchase was approved on 1/9/2020. However, manufacturing and delivery was delayed, and the equipment arrived only in March 2020.
- The proper setup of the tracer was scheduled for 3/24/2020, and we were ready to assume data collection immediately. However, the University was then affected by the COVID-19 crisis. We had to work from home starting 3/13/2020, followed by an Illinois-wide stay-at-home order on 3/20/2020. While the University is currently slowly ramping up research, non-essential laboratory work is still not permitted as of 6/4/2020.

During this challenging period, we have worked on a peer-reviewed publication of the results obtained so far. We are preparing the dissemination of our results on an extended homepage of the Tablet Collection of the Oriental Institute.

2. Accomplishments

While the application phase of the project is still outstanding, we obtained proof that pXRF is a viable and up-and-coming method for the provenance study of cuneiform tablets. Scatter plots indicate distinct groupings of tablets, with elements such as chlorine (Cl) and copper (Cu) being particularly essential.
Fig. 1 Ratio plot of copper to chlorine and potassium to zinc.
Fig. 2 Ternary plot of copper, calcium, and chloride. Nearby sites like Adab and Nippur (fig. 1, 2), and Khafaje and Tell Asmar are distinguishable in the clustering. More significant sites like Nippur (168 ha) can have multiple clay signatures (Nippur I, II fig. 1). An analysis of the metadata showed that various clay signatures could correspond to individual find spots on the site and ancient archives/antique text clusters. Furthermore, a small group of results showed promise to solve contradictions between proposed find circumstance (Adab) and textually assigned provenance (Girsu/Umma), supporting that the tablets were likely produced at Adab. Those results are promising for application in the Humanities, especially in the field of Cuneiform Studies. So far, results support the idea that the clay signature does not vary over the timespan under investigation which is promising for tracing looted tablets back to their sites of origin. This application is essential for museum collections and law enforcement, likewise.

While scattered plots indicated grouping, overlaps between different groups occurred (fig. 1, 2). Machine learning approaches had better success with this variation. 1D convolutional neural network training occurred over 10,000 epochs with the best model reaching 90% accuracy on the withheld data set. Gradient boosting model training after Bayesian hyperparameter selection was run for 250 cross-validation iterations with five repeats; this model reached 96% accuracy on the test data set. Therefore, the combination of geochemical analysis and interpretation via machine learning seems to be the most promising approach.

3. Audiences

While the project is still not completed, we presented preliminary results to experts in conservation, scholars, diplomats, and members of the law enforcement during a conference on Cuneiform Tablets: Origins, trafficking, and best practices for the future at the Smithsonian Institution. Dr. Katharyn Hanson, our consultant, organized this successful after a stimulating brain-storming session in Washington, DC, in early 2019. During and after the conference, we received helpful, positive feedback from diverse stack-holders, and started conversations with several colleagues about future project applications. (https://www.si.edu/mci/english/professional_development/Cuneiform_Tablets_Conference_2019.html). Our work was also highlighted for a broader audience in a feature article by Mary A. Agner for Humanities. The Magazine of the National Endowment for the Humanities 41: 1 (2020). A – B

4. Evaluation

Throughout the project, we continuously evaluated our progress and discussed and implemented challenges. Changes made include significant aspects like involving machine learning and AI approaches outlined above and smaller changes initiated by our team members like reducing the number of readings per tablets to achieve better quality. Going through the lengthy procurement process for a new pXRF tracer allowed us to evaluate different options on the market and gain an insight in the strength and weaknesses of varying tracer models.

5. Continuation of the Project

If an extension is granted, we will conduct the last phase of the project. The goal of this phase is to apply the developed method to a case study of unprovenanced tablets to explore its potential further. The test material will be a selection from the 3,500+ Ur III tablets in the OI Tablet Collection. Other than the 924 tablets from Adab and Nippur, whose provenance is archaeologically secure,—many of which we tested in phases two—, the OI acquired all tablets through purchase or gift without secure origin. Comparing the
results from the textual analysis with the clustering obtained via chemical clay analysis will allow insights into the precision of both methods and further elucidate the potential of non-textual provenance study.

6. Long Term Impact

The results already illustrate the potential of the pXRF method for the field of Cuneiform Studies, collections with cuneiform tablets, and Cultural Heritage Protection and build the basis for a constitutive project currently in preparation.

7. Grant Products

A peer-reviewed paper is currently in preparation.